Ashraf Mozayani
Carla Noziglia
Editors

The Forensic Laboratory Handbook Procedures and Practice

Second Edition

Humana Press

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Preface

It takes two for the truth – one to speak and another to hear
–Thoreau

Mention a forensic science laboratory and Abby of NCIS might spring to mind. Nice, but not exactly a reality. Perhaps you think of writers such as Sir Arthur Conan Doyle (closer) or Kathy Reichs (reality). Whatever your persuasion, forensic science is and has been interesting to the public for many years.

In this *Forensic Handbook*, 21 of the best of the best, the cream of the crop, the "Energizer bunnies of forensic science" (to quote Abby) have written of their specialties in the careers they love. These are real world heroes and heroines who fight crime not with a cape, but a lab coat.

Just as forensic science has become more in depth and broader in scope, so, too, has this second edition. This edition contains 21 chapters to the first edition's eight chapters, giving the reader a better insight into more uses of forensic science.

There are more issues in, more challenges to, and more applications of the principles of forensic science than ever before. The information gleaned from the testing of evidence yields much more information. The procedures, analytical instruments, and interpretation of results in forensic science require the scientists to have higher and broader levels of knowledge, skill sets to encompass the tiny micro to the vast macro levels of evidence, and a myriad of abilities both in the laboratory and in the courtroom. Thus, they who perform the testing must have more and more education and career-long continuing education. The practices have also reached into areas unheard of a mere ten years ago, such as anything digital. This has resulted in scrutiny of procedures, practices, laboratories, and people. Accreditation of laboratories and certification of scientists are now the accepted norm. From the first collection of evidence through analysis and interpretation to the final presentation to courts and other official bodies, ethics must be the guiding principle. The myriad legal issues of evidence and testimony are presented.

The well-appointed and well-equipped laboratories of today are a far cry from the closets (literally) where scientists were relegated. Safety procedures, contamination abatement, and ergonomic modules now allow the scientists to work in comfortable areas, with the latest in technology, following strict standards. Thus, one chapter discusses planning and design of a laboratory.

And not to forget the animal kingdom, the reader will learn how insects and bugs can assist in determining many things including a margin of time of death. You will read about the Fur, Fin, and Feather Lab, where scientists practice forensic protocols as applied to animals and their products.

In reading this handbook, you will find that, in many chapters, authors have discussed similar areas: accreditation, certification, ethics, the National Academy of Science report, and quality. These important facets of forensic science apply to varied disciplines.

No forensic handbook would be complete without the tried and true forensic disciplines: fingerprints, trace evidence, chemistry, biology, explosives and arson, forensic anthropology, forensic pathology, forensic documents, and firearms and toolmarks. However, even here, there are new and modern practices.

New to this edition are questions at the end of each chapter that can be used by the reader or, if used as a text, by the instructor. Also, at the end of each chapter is a brief biography of the author.

If these chapters tweak your interest, you will find information about educational requirements. To assist you, the Appendices contain resources such as national and international degree programs, forensic societies and websites, and granting organizations. With the advent of technology, old evidence has been tested successfully, and, indeed, the truth has set some free.

There is but one goal to which all of this progress is directed: truth. Enjoy your reading and may the truth be with you.

Houston, TX — Ashraf Mozayani
Aiken, SC — Carla Noziglia

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Chapter 1
Forensic Laboratory Accreditation

Anja Einseln, BA, MEM

Contents

1.1 Purpose of Accreditation

There are multiple reasons why a laboratory may elect to become accredited. One may be because it is mandated to become accredited. These mandates can include legislative, organizational, and in response to specific critiques received by the laboratory. Another reason may be that the laboratory director sees the intrinsic value accreditation provides to a laboratory's operations via a peer-review process

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as well as providing external recognition. A third possible reason to pursue accreditation may be the perceived requirement of work needing to be performed in an accredited forensic laboratory that occurs during the court qualification of a forensic expert. Regardless of the reason *why* a laboratory seeks accreditation, the true value of the accreditation process are the activities involved in developing a sound quality system and then being committed to continually improving the laboratory's practices and procedures. All of these activities are done to ensure the ongoing quality of work being performed in the laboratory.

When a person first hears the phrase "accreditation," several ideas may come to mind. A new forensic scientist may not seem deeply concerned or interested in accreditation, as "it's something management should take care of." There could also be inclusion or confusion with the concept of individual certification (see keywords). The primary focus of this chapter will be accreditation, but it is also important to recognize how accreditation and quality assurance are closely related, therefore the organizational acceptance of operational review and commitment to continuous improvement will impact both quality assurance and accreditation. One essential element of success will be commitment to the quality process. Without a solid foundation of structure and commitment to continuous improvement throughout the organization, the process is little more than empty gestures and a waste of time and resources.

1.2 Why Accreditation?

Laboratories that commit their management practices and organizational culture to quality practices will be rewarded with high-functioning personnel, reduced costs (after an initial time and effort investment in the process), quality work output, clear channels of communication (internally and externally), and an external recognition process that can be demonstrated to both stakeholders and parent organizations. While some may see quality control and accreditation as burdens of working in a forensic laboratory, the true benefit is often articulated best by former opponents of the process. As we move through this chapter, several examples will be provided to help demonstrate that when the process is embedded in a laboratory and then woven into the culture of our day-to-day practices, the result benefits all levels of the organization.

1.3 Employee Responsibilities

When you become an employee of a forensic laboratory, several things will be expected of you. First, you will need to become familiar with the practices of the laboratory. Some labs may call this their "quality system." These practices may include building security, access to operational areas of the lab, completion of training programs, operational instructions for analysis, directions regarding recording technical notes, annual proficiency testing, handling evidence, maintaining chain of custody, quality control steps during evidence examinations, and report writing

requirements. While this level of detail may be overwhelming at the beginning, the structure provided by these requirements will provide assurance of consistent practices and agreed upon methods of operation. Some of you may welcome the structure: "just tell me what to do, and I'll do it." Others may see the structure as restrictive and suppressing creativity. What is essential to be aware of is that the laboratory has defined its operations based upon the needs of the science and the stakeholders within the judicial system. I would ask you to reflect upon the idea of each person being allowed to maintain their own version of a chain of custody – would this be a quality practice? Would having a defined process where evidence is handled, tracked, and secured in a similar manner be seen as a burden by the justice community? The concept I would like for you to start considering is that defining boundaries of quality and then electing to accept them as part of the working environment is an essential part of your forensic science practice.

An example of resistance to structure can be provided by Jackie. Jackie sighs again as he looks up the initialing requirements for examinations records. "Why does this have to be so complicated?" he asks himself and his computer screen. After finding the requirement for initialing each dated entry in his notes, he applies his handwritten initials in pen to the fourth entry he made on the same page. "Why can't someone see that this is my handwriting?"

A few weeks later Jackie goes to trial and is asked to identify the notes he made in a particular case. When looking at the notes handed to him, he sees that John also had notes on this case, and John's handwriting is very similar to his own. After taking a moment to sort through all the forensic notes that attorney handed him, Jackie is able to sort out his own from John's and then proceed with his testimony. Remembering his previous thoughts of the "waste of time" associated with initialing his exam records, he is now very thankful that the lab had this procedure in place.

1.4 Quality System

Once a laboratory has gone through the process of documenting their operational practices, they may then elect to go through a process of accreditation. As you read previously, accreditation is a process of external review. In most states, within the United States, accreditation is voluntary. At the time of writing of this book, four states do have various versions of legislatively mandated accreditation: New York, Texas, Oklahoma, and Missouri. If you work in a forensic laboratory in one of these four states, you should make yourself aware of the specific legislation that will affect your forensic work. Someone new to the accreditation discussion may assume that forensic labs should all work identically and follow all of the same procedures. An important "larger picture" idea is to become aware of the operational variability of state governments, the law enforcement community, and judicial community and how this same variability is mirrored in the forensic community. You should be very careful in making assumptions about operational practices from one laboratory to the next. Each laboratory is a product of the needs of the community it serves, the parent organization, the judicial system, and the requestors of

forensic services. After becoming aware of this variability, you will begin to see why accreditation and the process of preparing a laboratory for accreditation allow each laboratory to develop its own quality system. In the United States, we have an individualistic approach to our lives and our work. With this type of culture, we are very hesitant to mandate or dictate uniformity in our lives. It seems to go against the grain of our cultural fabric. Other countries have a more pluralistic approach – where the benefit of the whole society outweighs the needs of the individual. This individualism lends itself to an innate perceived "right" to be able to choose our own way. This perceived "right" may occasionally get in the way of a successful accreditation effort. If I manage a forensic laboratory with fourteen employees, each wanting to do things their own way, and I do not define a quality system, I then have no process of ensuring quality and consistency. How do I know that the analysis done by one person is of equal quality when compared with the next person? By defining and then requiring the same practices within the laboratory, I can be assured of consistent quality of the results.

There is a fine line between rote analysis and enabling the creativity of the forensic practitioner. I would like to bring to mind the physician that you may go to for your routine care. When it comes to a cough or cold, a broken leg bone or appendicitis, having a consistent process for treatment is favored, because it has been validated and practiced, but allowing the doctor to make adjustments based on what they encounter during the procedure ensures quality of care. This same process can be seen when flying a commercial airliner from New York to Los Angeles. Although having procedures for take-off and landing, flight plans, and safety are excellent, having the variability of modifying the flight plan based on weather encountered or turbulence is a way of ensuring a safe and hopefully calm flight. An effective quality system will provide a structured environment, but will also have a mechanism to both adapt to variables and a way of modifying or improving procedures when necessary for the quality of the work.

Now you can begin to consider the process of continuous improvement. This whole idea ties back to accreditation via the process of "plan > do > check > act." This concept is one that can be found in the ISO website (www.iso.org), and serves as the foundation of all quality practices. Without feedback into the process, all the audits, assessment, reviews and checklist would amount to a volume of dead trees, rather than a treasure chest of opportunities to improve a laboratory's quality system and the practices within the laboratory.

The Internal Audit

Mike looks at his Blackberry and sees that Pam has sent another e-mail reminder about the audit that will begin tomorrow as well as a revised audit worksheet. He quickly looks at the attached audit form and then deletes the e-mail, because the worksheet he printed out three days ago looks almost identical, plus he already took notes on his printouts. He's sure the changes are minor and won't impact his work. He's so familiar with the quality requirements, he could do it without all these checklists Pam is constantly creating. She's still mad at him for not sitting through the three hour training meeting she held on Tuesday. She'll realize soon enough that he's a lot smarter than the other folks on the audit team.

Pam sees Mike walking into the conference room where the case files have been collected and stacked for each of her auditors. She sees Mike pulling out some worksheets. She's relieved that he seems to have prepared for this audit. She has some misgivings about asking him to be on the internal audit team, but he had worked for the state crime lab for twenty years and seemed to be a nice enough guy. After the first two hours of file review, Pam walks over to Mike to check on his progress. She takes a quick glance at the worksheet he's using and sees that he's missing a complete section of checklist items. "Mike, did you get my e-mail yesterday?" "Yes, Pam, I did." "Well, I see that your notes haven't recorded the three clause requirements I added in the latest version of the checklist." "What three clause requirements?" "Sections 5.6.3, 5.6.3.1, and 5.6.3.2 about the noting of photographs section." Mike sighs – he looks at the stack of case files he's already reviewed and remembers that each one of them had at least a few photos in each of them. "I'm sorry Pam. The checklist you sent last night looked so similar, I just used the one's I had already printed out." Pam looks at him, the files he's already completed and walks over to her section of the table to pick up some copies of corrected checklists. "No worries Mike. I had a chance to review the reports from last year's internal audit and recognized that this was an area that we didn't catch during our last round of internal audits. I realize now that I should have highlighted this in my e-mail, so I'll review the files you've already done." "Thanks Pam, but you shouldn't need to do that. I should have used the checklist you sent. The catch you made in last year's internal audit was an astute one. I don't think we would have noticed that in our section, and considering our next assessment will be next year, I'd rather be in a position where we catch it, rather than the assessment team." "Thanks Mike. Care to help me comb through our procedures for evidence handling next month to help fine tune that audit checklist? Your experience at the state lab may give us some good ideas for things to consider." "Sure Pam. Thanks for asking. I'll start reviewing through these files again so we can finish on time today."

1.5 The Process of Accreditation

1.5.1 The Choice

The first step in the process of accreditation would be the laboratory management, typically the laboratory director, making the active choice of pursuing accreditation. As mentioned previously, this may be mandatory or it may be elective. The next step would be to become familiar with the specific requirements of the accrediting body. This may require purchasing or acquiring copies of various accreditation manuals and documents, and then beginning an in-depth review of the steps required to make an application. If a laboratory is pursuing accreditation for the first time, adequate time and resources should be planned to address the scope of the application project. It is highly recommended that this process not be undertaken by only one person in a laboratory, as the quality system within a

laboratory affects many individuals. Ensuring sufficient time for planning, review, feedback, and modification will allow laboratory management to thoughtfully prepare and acclimate all personnel to the process of accreditation. By taking a single-person approach to the process of preparing a quality system and an accreditation application, opportunities for gaps and misconceptions creep in. One of the important parts of the on-site assessment is the review of staff and operations, and if only one person "has the answers" then it becomes clear that the laboratory is not functioning as one organization, but more of a one-person-show where everyone else is kept in the dark.

1.5.2 Applying

The application for accreditation will most likely require a laboratory to submit copies of all of its operational policies, procedures, manuals, and documents. This will give the assessment team an opportunity to prepare checklists for the on-site review. Documents that may be requested by the accrediting body may include, but are not limited to: laboratory quality manual, casework analysis procedures, training programs and competency testing practices, proficiency testing program, evidence handling procedures, laboratory security requirements, report writing and note taking procedures, testimony monitoring program, statements of qualification for all case working personnel, organizational charts, job descriptions, and calibration and maintenance procedures. The task of pulling together all of the application materials takes time, and a laboratory shouldn't try to slap things together and hope that they are buying some time until the team arrives at the laboratory. It will become very apparent to the person reviewing the application, and the team leader will typically have many years of experience when it comes to accreditation and quality assurance, and this will signal that the laboratory is not taking this process seriously. The laboratory should approach the process of finalizing and submitting an application as a major milestone in the accreditation process – this usually takes a few weeks or months, rather than hours. Once an application is completed, the laboratory management needs to focus on ensuring that the employees are prepared and that they are continuing to work in compliance with their laboratory quality system. Changes to the quality system should be avoided after making an application, as these changes would need to be communicated to the accreditation body for incorporation to the laboratory's application.

1.5.3 The Assessment Team

Once the application has been received and reviewed by the accreditation body, an assessment team will be organized by the accreditation body. The team size will be based on the size of the laboratory, the forensic disciplines that the laboratory offers services in, and the total number of case working staff in each discipline. A conversation

will take place between the assessment team leader and the laboratory designated point of contact (typically either the laboratory director or the laboratory quality manager) and part of that discussion will include identifying any gaps in the application package. If the gaps are major, the on-site assessment may not be scheduled until sufficient remediation and resubmission of materials is completed by the laboratory. A date for the on-site assessment will be negotiated between the assessment team leader and the laboratory point of contact. The number of days required for the on-site assessment will depend upon the number of case working staff, the number of and types of disciplines being accredited, and the number of laboratory locations under review. Some accrediting bodies may provide accreditation in a single discipline, where others may require the entire laboratory to undergo accreditation at the same time. A laboratory that is part of a state system of crime labs may be part of a larger assessment process, and therefore additional variables come into play from a planning perspective.

1.5.4 Assessment Team Preparation

After a date has been set and a team is assembled by the accrediting body, the team will begin its preparation for the on-site review. These activities can include: review of procedures, policies and forms, development of checklists and interview questions, review of training programs and records, and working with the team leader to prepare for any adjustments or modifications to the quality system. Again, it is highly recommended that no major changes be made to the laboratory quality system after the application is submitted to the accreditation body, because the assessment team will be preparing their checklists and notes based on the policies, procedures, and instructions that were submitted with the application. If any changes are made, they should be communicated the assessment team leader as soon as possible.

1.5.5 Laboratory Preparation

As the assessment team prepares itself, the laboratory management and personnel should also be preparing themselves. Becoming familiar with the planned daily assessment schedule and team logistics may help everyone understand the process and be prepared. Providing a meeting room and all requested records in one location is highly desirable. The time the team has on site is typically limited to regular working hours, so efficient use of time by all is a sound idea. Little details such as lunch and breaks, escort duties and security, transportation, and communication channels should all be sorted out early so that everyone can help out while the assessment team is on site. Most laboratories take an “all hands on deck” approach when the assessment team is on site, so everyone may be asked to help support the process. Communication processes should be defined for laboratory staff by the laboratory management. When a request is made by the assessment team (for example, requesting a particular record or to access a particular area), that

laboratory staff should know what the assessment team can access without prior management approval or notification, and what limitations or boundaries are in place to protect the laboratory work and evidence (for example, not providing security access codes to the assessment team). Another purpose for open channels of communication is so that the laboratory point of contact can be advised either before or soon after such a request is made so that they can monitor, participate, and maybe even anticipate the future needs of the assessment team. Clear channels of communication will help everyone during this process.

1.5.6 On-Site Assessment

The on-site assessment process can be both very interesting and stressful for all parties involved. The on-site process begins with an opening meeting where the assessment team is introduced to the laboratory. The laboratory director decides who may attend this meeting. Some laboratories may elect to have a very small opening meeting, and other choose to invite all of the laboratory staff. After the opening meeting, the assessment team will get to work. The first day may seem very quiet from the laboratory's perspective. Often times the first thing an assessment team will do is to review case files and quality records. Based on the information gleaned during this review, the assessment team members are better prepared to ask relevant and pertinent questions during staff interviews. Some assessment teams interview all of the laboratory staff, others may only interview a portion of the staff. You may be asked to demonstrate a procedure or asked to explain what you may do in a particular scenario. The best answer would be to know the requirements of your quality system and then follow the instructions. Trying to "wing it" or impress the assessor would not be appropriate. If you would normally look at the procedure, do this. If you need to look something up on a computer, or ask someone, do this. Part of the assessment process determine if you know where the laboratory instructions and procedures are, how to access them, how to find out if it is the current version you should be using for casework. The laboratory management is responsible for ensuring that you have the tools and support to do the work. Your job will be to know how to access and follow the requirements of the laboratory quality system. The assessment process is not a time for sniping or venting about management, unless you truly believe that it is affecting the quality of the work. Personality conflicts and infighting should not become part of the assessment process. Dealing with personnel matters is the responsibility of the laboratory management. The primary focus of the assessment process and accreditation is determining if the laboratory has a quality system that has been effectively implemented and maintained.

Whining, Sniveling Malcontent (also Known as WSM).

Malfoy sat down at his desk to review his index cards. He knew his interview was coming up next. He was going to share all of the injustices he's had to suffer since the new section supervisor was promoted. He'd show them. Malfoy walks into the

conference room to meet with Tracy and she invites him to sit at the head of the table. Well, at least she knows how smart he is. He has his Master's degree in forensic science and has been working cases diligently for the last 6 months. He had a few issues during training, but other than having to do his moot court twice, he was able to fly through the training program. The questions from Tracy seemed to focus on the training program and the case files she had reviewed. She asked some questions about the positive and negative controls that were run during analysis, but she never got around to asking his opinion about his supervisor. He started getting concerned that he wouldn't be able to share all of his issues with her. After answering one more question about security, he plunged forward with his complaints. Tracy listened to him as he talked for five minutes straight. She took a few notes, as she had been doing during the entire interview. After he finished, she thanked him for his time and he walked out of the conference room feeling pretty smug.

Tracy sat down with John, her team leader, and shared what had happened earlier with Malfoy. John shook his head and shared "Well, we seem to get one of them in every lab: someone who sees the assessment process as a time to tattle on their supervisor or coworker. I'm hoping that you listened to him for a short while and then tried to put an end to that line of discussion. Did you finish all of the interview questions?" "Yes, I did. He seemed to just need to vent about all of these personal concerns. None of them were related to the work in the lab, so I didn't have any concerns about the quality of the lab work. Should I say something to his supervisor?" "Oh, no, at least not directly. I'll mention to the quality manager this evening that we finished our interviews and see if any questions come up."

1.5.7 The Report

After the records have been reviewed, the reports read, the interviews completed, and the assessment report is prepared by the assessment team, the laboratory will be presented with the "findings" of the assessment team. Remember that the word "finding" should not be seen as negative, rather what the team "found" during the review. If the laboratory has been sincere in its preparation activities, they will find that they will have a high level of conformance with a large number if not a majority of the requirements. The focus will narrow in on the areas of non-conformance and the corrective actions that will need to take place in order for the laboratory to become accredited. It should be remembered that many of the requirements will have been met, therefore will not require remediation.

1.5.8 Corrective Actions

The next step in the accreditation process will be the laboratory addressing the corrective action items. Some of the corrective actions may be straightforward and require little time to complete. Other corrective actions may ask the laboratory

management to review operations or procedures and make modifications after receiving a better understanding of how to understand or apply a requirement. If a procedure is modified to address a corrective action, the assessment team may request a demonstration of compliance with the new procedure for a defined period of time (thirty, sixty or ninety days, depending on the type of modification). After the laboratory prepares the corrective action and the assessment team review and agrees that the corrective action is correct and appropriate, the corrective action can be closed. Once all the non-conformances have been addressed via the corrective action procedure, a decision to accredit the laboratory can be made. The accreditation decision is typically a formal presentation from the assessment team to the decision-making accreditation body recommending that the laboratory be accredited.

1.5.9 Accreditation Maintenance

Once a laboratory is accredited, the process does not end there. It must be recognized that there is a maintenance process associated with accreditation. This process can vary from accrediting body to accrediting body, but most include some type of self-monitoring, self-reporting, and annual review. Some may require surveillance visits or on-site reviews. Regardless of the monitoring activity, the main message is that accreditation should not be seen as a one-time project, but rather as a process of continuous improvement. To provide you with an example of a project, reflect on how you approached your academic career, there were certain classes you took, exams you had to complete, papers you had to write, and once you had completed all of these tasks, you received your degree, or, viewed another way, you reached the end of your project. In contrast to this example, consider process of working in an accredited laboratory similar to maintaining your car, from the perspective of continuous monitoring and improvement. When you purchased your car, it had some fuel in the tank, and it was clean and ran well. Being committed to the process of owning a car you will need to refuel the car, change the oil, buy new tires, have it periodically inspected, and provide repairs depending on usage, much in the same way that a laboratory needs to maintain its operations and be committed to the process of running a quality organization. The initial accreditation can be equated to that original car purchase, but there will be continual monitoring and improvements required based on the needs of the laboratory. Most often, we will not encounter major maintenance, but when we do, we diagnose the non-conformance and correct the situation. Monitoring of all aspect of the vehicle will ensure ongoing positive performance, but ignoring problems will only cause what may have been a minor issue at one time to blossom into a major trip to the repair shop. Having everyone become part of the success of a laboratory will ensure that when even the smallest thing is noticed, it becomes a chance to catch an issue before it becomes a major corrective action.

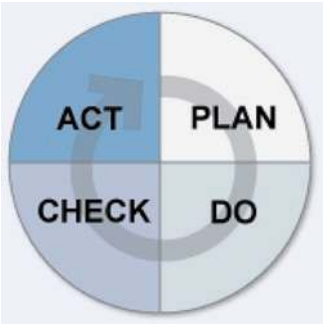

Fig. 1.1 Continuous Improvement Process

1.6 Continuous Improvement

As you have read during the course of this chapter, a laboratory must be committed to continuous improvement. The essence of this idea is captured in the four elements of Plan > Do > Check > Act.

1.6.1 Plan

The first element of this cycle is "plan." Plan can be identified as the activity taken by the laboratory management to develop its quality system. Planning or defining the policies, procedures, and instructions creates the foundation or structure in which all work needs to be done.

1.6.2 Do

The second element is "do." Do is defined as the activity done by the employees when they follow policies, procedures, and instructions. An assumption is often made that, if procedures are written, they will be followed. ISO sees these two activities as two separate steps that must be identified and be seen as elements of an effective quality system.

1.6.3 Check

The third element is "check." Check can be interpreted as either internal audits or external assessments. Incredibly important data is collected during this review activity. Having an effective audit will help a laboratory or any other organization successfully identify and then correct any possibly misinterpretations or defects in the quality system.

1.6.4 Act

The data collected during the check step needs to then feed into the "act" element of the cycle. It would be ineffective to go through all of the trouble of collecting the audit information and then just file it away where no one can learn from it. The essence of ISO is the feedback loop, identified in the graphic, that takes the data from "check" and then "acts" by incorporating back into "planning." Sometimes the "act" comes in the form of recognizing that laboratory staff didn't understand a new policy or procedure, then training may be appropriate. Another possible "act" would be realizing that a set of instructions or a new form is confusing, contradictory, or just not helpful. An "act" in this case may be the revision of a set of instructions or the deletion of a form that doesn't fit into the quality processes in place. Seeing this "act" element as having many possible functions or solutions will help the laboratory management recognize that the laboratory is not a static two-dimensional diagram, but rather a dynamic, continually adapting organization. All of the data coming out of the assessment process, the internal audits, and the other quality practices can be very useful tools in ensuring the laboratory recognizes and then pursues opportunities to improve. This is where the phrase "continuous improvement" comes from.

Having this foundation concept embedded in the laboratory's organizational culture helps ensure the quality of the work being done in the forensic laboratory.

1.7 Glossary

Accreditation Accreditation is a process whereby an external review is performed on interrelated processes and products of a laboratory in comparison with a set of defined or established requirements.

Accrediting body An accrediting body is an organization that provides accreditation services. Examples within the forensic community include: American Society of Crime Laboratory Directors, Laboratory Accreditation Board (ASCLD/LAB) www.ascld-lab.org, National Association of Medical Examiners (NAME) www.thename.org, The American Board of Forensic Toxicologists (ABFT) www.abft.org, The National Association of Testing Authorities, Australia (NATA) www.nata.asn.au, and Standards Council of Canada (SCC) www.scc.ca.

Assessment An assessment is the external review of a laboratory's operations both through review of records and practices/work. Typically, an assessment begins with a thorough review of a prepared application and is then followed by an on-site review of supporting activities. The result of an assessment could be either a compiled assessment report or issuance of corrective actions. If similar review activities are done internally (by laboratory personnel), it is defined as an *audit*.

Certification Certification within the United States is used to define an *individual* who has met the academic, knowledge, skills, and abilities as defined by the requirements of a certifying body. Examples of certifying bodies within the forensic community include: The International Association for Identification (IAI) www.theiai.org, American Board of Criminalistics (ABC) www.criminalistics.com/cert_ovw.cfm, American Board of Forensic Document Examiners (ABFDE) www.abfde.org, The American Board of Forensic Toxicologists (ABFT) www.abft.org, and the Association of Firearms and Toolmark Examiners (AFTE), www.afte.org.

Compliance Compliance indicates that a requirement has been met. Compliance with accreditation program requirements may be either mandatory or voluntary. Another word to describe compliance would be conformance. The antonym would be non-compliance or non-conformance.

Corrective actions Corrective actions are items or activities of remediation in order to achieve accreditation.

Finding Finding, while oftentimes having an incorrect negative connotation, should be correctly defined as the result of a comparison of a requirement with what was shown to meet the requirement or an absence of compliance – or in other words "what was found" during the assessment process.

Requirements Requirements may be defined either by international, governmental, community developed, or professional bodies. Other words used in place of requirements include: criteria, clauses, and standards. A requirement defines or identifies an element (program, procedure, practice, activity, record, etc.) that must be accomplished or achieved in order to obtain accreditation. Typically, a series of requirements make up an accreditation program.

1.8 Questions

1. Is forensic laboratory accreditation mandatory in the United States?
2. Who typically initiates the accreditation process? Why?
3. What are some of the variables that define the size of the assessment team and the length of the on-site assessment?
4. Why should there be some flexibility integrated into the laboratory quality system?
5. Who is responsible for responding to corrective actions?
6. Does a laboratory need to do anything after it receives its accreditation?
7. Name some of the records that are reviewed by the team during the on-site assessment?
8. Name the four elements of the cycle of quality, as defined by ISO.
9. Are the policies, procedures, and instructions of the forensic laboratory optional for you to follow?
10. When you have questions about your laboratory policies, procedures, and instructions, who would be the best person to ask?

1.9 About the Author

Anja Einseln joined ASCLD/LAB in October 2006 to become the first Training Manager. She provides instruction for Assessor Training and the ASCLD/LAB-International Preparation Course. Prior to joining ASCLD/LAB, Ms. Einseln worked for the FBI Laboratory as Training Officer. At the FBI Laboratory, she also held the positions of Acting Unit Chief of the Quality Assurance and Training Unit, Proficiency Testing Program Manager, and Quality Assurance Specialist. She has served as the FBI Ex-Officio member to the ASCLD Board and served on the ASCLD Training and Education Committee. Ms. Einseln served on the Scientific Working Group on Microbial Genetics and Forensics (SWGMGF), and the Scientific Working Group on Forensic Analysis of Chemical Terrorism (SWGFACT).

In 2000 she was asked by ASCLD/LAB to serve on the ISO 17025 committee where she assisted in preparing the ASCLD/LAB International assessment requirements and provided presentations to the regional and national forensic community regarding this program. Ms. Einseln has assisted in providing FBI Laboratory DNA auditor training to over 300 forensic laboratory personnel across the country.

Prior to joining the FBI Laboratory in 1996, Ms. Einseln worked in private industry providing technical support and testing services for an ISO 9001-certified manufacturing company. She served as the Editor for Mid-Atlantic Association of Forensic Scientists (MAAFS) from 1999 to 2004. Ms. Einseln holds a Bachelor's degree in Chemistry from the University of Buffalo and a Master's degree in Engineering Management from the George Washington University. She lives with her husband Matt in Alexandria, Virginia.

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Chapter 2
Forensic Biology: Serology and DNA

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Contents

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2.1 Introduction

In the forensic community, serology and DNA analyses are closely related. In fact, in many laboratories they are included within the same unit, collectively titled Forensic Biology. In the forensic laboratory, serology analysis refers to the screening of evidence for body fluids while DNA analysis refers to the efforts to individualize body fluids to a specific person. In most cases, body fluid identification is performed on evidentiary items before DNA analysis is attempted. Depending on the qualifications of laboratory personnel, analysts can be trained to perform either serology or DNA analysis or can be trained in both disciplines. While serology procedures have been employed for most of the twentieth century and the techniques have essentially remained unchanged, DNA has emerged in the forensic realm within the last two decades and its applications and technology are continuously developing.

2.2 Types of Evidence Examined

The types of evidence submitted to crime laboratories for serology/DNA analysis are those items on which body fluids are thought to be present. A large majority of DNA/serology cases involve sexual assaults. Evidence from these types of cases commonly includes sexual assault kits, complainant clothing, bedding, and, sometimes, suspect clothing. Other common case submissions include potential blood evidence from homicides, aggravated assaults, and burglaries. Items commonly submitted for blood testing include swabbings from crime scenes, clothing, weapons, or any number of other items that may possess bloodstains. If an item is small, it can be submitted to

the laboratory in its entirety. For larger items, stains can either be collected on a sterile cotton swab or a cutting from the item can be taken for submission.

It is also possible to collect items that have been in contact with an individual's mouth, such as cigarette butts, drinking cans, cups, bottles, gum, candy, toothbrushes, or ski masks. These items usually provide enough DNA for a profile to be established. Objects that have been touched or handled, such as a steering wheel, gun, phone, or even a fingerprint, may also contain biological evidence, which can be collected for analysis but may not always produce a DNA profile. Generally, these pieces of evidence do not contain a substantial amount of biological material and are processed for DNA without going through any type of serological screening to maximize the amount of sample available for DNA testing.

While the majority of cases processed for DNA testing involve violent crimes, more and more law enforcement agencies are tapping into the potential of DNA to assist in solving property crimes. Biological evidence is often left at burglary and theft scenes by the perpetrator. For example, a burglar may be injured breaking a window and leave blood at the crime scene, which can then be processed for DNA. In addition, DNA can be obtained from fingerprints or clothing left behind by a suspect. Historically, evidence from property crimes was not collected or processed by the laboratory due to the significant backlogs of violent crime cases, which take precedence. In recent years, the increased sensitivity of DNA testing and the decrease of violent crime backlogs has prompted some jurisdictions to focus efforts on using DNA to help solve these property crimes. Results of a recent study conducted by the National Institute of Justice indicate that twice as many property crime suspects were identified and arrested when DNA evidence was collected as when it was not [1].

Cases involving kinship determination do not require serology screening and can be sent immediately for DNA analysis. Most often, DNA profile comparisons to determine kinship are used for cases of criminal paternity, child abandonment, or remains identification. All of these cases rely on the comparison of known DNA profiles from individuals to determine whether two people are related, instead of the comparison of evidence to a known profile to determine the source of the biological fluid on a piece of evidence.

Reference samples from known individuals are used for kinship determination and also for comparison with evidentiary samples. Many types of reference samples are available to the forensic biologist. Typically, blood or saliva is collected from a living individual to serve as a reference sample. Blood is collected intravenously and stored in a purple- or lavender-top blood tube, which contains EDTA, an additive to prevent DNA from becoming degraded. The blood is then placed onto a filter paper card, dried, and stored. Blood samples dried in this manner are stable for many years even at room temperature. Saliva samples can be collected either by chewing sterile gauze, depositing saliva onto a collection card, or epithelial cells can be collected by swabbing the inside of a person's cheeks (buccal [buck' ul] swabs). Pulled hairs can also be used as a reference sample but are not as abundant a source of DNA and so are not preferred. Reference samples can also be collected from deceased individuals in the form of blood, tissue samples, or bone samples, depending on the state of decomposition of the remains.

2.3 Planning the Examination

The real challenge in evidence screening is determining which items of evidence should be processed and the most effective way in which to process them. In general, probative samples are those in which a transfer of body fluids, and therefore DNA, has occurred. Generally, a suspect's body fluid on a complainant's body or clothing, or a complainant's body fluid present on clothing or items belonging to a suspect are the objects that hold the most evidentiary, or probative, value. For some cases, the most logical course of evidence examination is rather obvious. For example, in most cases of sexual assault, the identification of semen is central to supporting a claim of sexual assault. Furthermore, semen found on swabs in a sexual assault kit may have more probative value than semen found on clothing or bedding because, along with demonstrating the presence of semen on the complainant, semen can only survive inside a victim for a finite amount of time, whereas semen stains on clothing or bedding can have a much longer duration depending on whether the evidence is washed. For these cases, a determination can be readily made for the type of testing to perform and the most efficient order in which to process the items. Other cases are less obvious. If a sexual assault is oral, digital, or utilizing a foreign object, then it is useful to determine the details associated with the alleged assault to process the evidence most effectively. In these sexual assault cases, examining an item for the presence of semen may have no evidentiary value. All cases may be affected by any post-assault activity by the victim such as washing, wiping, eating, drinking, etc. The time between the assault and the examination can be a critical factor in the successful identification of body fluids because the longer the time span, the more evidence that may be lost. In any forensic case, the order of analysis for each test should be planned in advance to lessen the chance of losing evidence for the next test.

Homicide cases are more time-consuming to process than other types of cases because the victim cannot verbally relate any details of the assault. Homicides generally involve many items of evidence that must be analyzed because a determination cannot always be made regarding which evidence has the most value. Thorough crime scene investigation is essential to ensure that probative items in a case are collected and submitted to the laboratory. In cases such as these, communication with law enforcement is necessary to convey important case details to ensure that evidentiary items are processed in the most logical manner.

When evidence is submitted, a determination must be made as to whether that evidence must go through serology screening or whether the evidence can be sent directly for DNA analysis. Generally, all evidence goes through serology screening first. However, cases involving samples with trace amounts of DNA may not benefit from serology screening. Paternity and remains identification cases also do not require any type of serology screening because only reference samples are processed.

Criminal paternity cases involve a sexual assault in which conception occurs. For these sexual assault cases, serology analysis is rarely performed. Instead, DNA analysis can be performed on the conceptus (living or aborted) and the alleged

father to establish or disprove parentage (paternity testing). While it is not necessary to have a reference sample from the mother/complainant for paternity testing, having the DNA profiles of the offspring and both parents facilitates the DNA interpretation. Maternity/paternity testing can also be used in cases of child abandonment to establish whether a suspected individual is a parent by comparing the profiles obtained from the child and alleged parent(s).

Comparing DNA profiles to test for kinship is also useful for remains identification and missing person cases. DNA can be collected from the blood or tissue of a decedent or from skeletal remains and compared with the blood or saliva from a potential relative. In cases where there is a suspected identity for a set of remains, the profile of the deceased can be directly compared with a family member for confirmation. In some cases, investigators may have no idea of the identity of the deceased individual. Unidentified remains can be analyzed and DNA profiles placed into a database of missing persons. Relatives of individuals who are missing can also be placed into this database to be searched against unidentified remains with the hope of establishing a relationship. Depending on the type of DNA analysis performed, kinship can be established from immediate family members to aunts, uncles, cousins, or possibly even more distant relatives.

2.4 Evidence Processing, Note Taking, and Report Writing

Most of the evidence processing and note taking occurs during serology analysis because this is usually the first time evidence is opened in the laboratory. Serologists are responsible for documenting the type, quantity, and packaging of the evidence received. In addition, a description of the evidence with notes and diagrams or pictures regarding the types of stains present and their location on each item is placed into the case file. Serologists also take detailed notes of their testing and outcomes, and this documentation is referenced during an analyst's testimony during criminal proceedings. Thorough and precise note taking is essential because there may be a substantial amount of time between the completion of case analysis and an analyst's testimony in court. It is also important in circumstances in which a different analyst must interpret the case notes.

Reports are written copies of an analyst's findings and should be an accurate representation of the results as the analyst would testify during criminal proceedings. Results should be conservatively stated and should take into account guidelines established by the forensic community and accrediting agencies. Reporting statements should also take into account the individuals who will be receiving the results. Police officers, attorneys for both parties, and jurors may find the scientific principles behind serology and DNA analyses difficult to interpret. For this reason, reporting statements should be clearly written and in laymen's terms whenever possible.

The paperwork associated with an individual case, such as the analyst's case notes, photographs, data, results, and reports are maintained in a case file. Historically,

case files contain hard copies of all documents associated with a case. Electronic Laboratory Information Management Systems (LIMS) may also be used to store case information. Electronic LIMS systems provide for the electronic input and storage of case data so that paper copies do not need to be maintained except for court purposes. Most LIMS systems can also track the chain of custody of evidence items through a system of barcodes. Each evidence item is assigned a separate barcode and each evidence transfer to a person or a storage location can be tracked by scanning the barcode thus replacing manual written copies of chain of custody on paper. Electronic systems are helping laboratories maintain paperless case files in order to ease overcrowded file rooms. Analysts have the option of printing hard copies of any document to take to court or to provide to attorneys upon request.

2.5 Serology Testing

Serology methods are relatively simple and straightforward. Forensic serology is not to be confused with conventional serology, which deals solely with serum and its properties. Instead, forensic serology involves the identification of different types of body fluids. The identification of biological fluids during serology analysis is accomplished through presumptive and confirmatory testing. Presumptive testing refers to testing that is sensitive, fairly specific to the body fluid in question, and can be performed quickly. It allows an analyst to narrow down the number of items or areas of an item to focus on for further testing. Presumptive testing can only indicate that a body fluid *might* be present on an item. It is not considered specific enough to state that a particular body fluid is unequivocally present on an item because other substances may also produce a positive test result, known as a "false positive." The limitations and types of false-positive reactions will be discussed for each particular presumptive test in the following sections.

Confirmatory testing is specific to the body fluid in question and sometimes also to a particular species. Confirmatory testing is still sensitive, but the time required for the testing can be much longer than that required for presumptive testing. In some instances, DNA analysis can be considered a type of confirmatory test because it is species, although not body fluid, specific for human DNA. Confirmatory testing is discussed in more detail in Sects. 2.5.4 and 2.5.5.

2.5.1 Identification of Semen

The identification of semen is important in many cases of alleged sexual assault. Semen is a body fluid produced by male individuals for fertilization. For forensic purposes, the composition of semen can be simplified into two components: seminal fluid and spermatozoa. Seminal fluid is a protein-rich body fluid originating primarily from the prostate and seminal vesicles.

Spermatozoa, commonly referred to as "sperm," are the male gametes, or sex cells, produced in the testis. Not all men produce spermatozoa. In men who have had a vasectomy, certain birth defects, or as the result of some diseases, seminal fluid will either not contain spermatozoa or contain very few. Therefore, it is useful to be able to forensically test for the presence of both seminal fluid and spermatozoa.

2.5.2 Acid Phosphatase Screening

The most commonly used presumptive test for the detection of seminal fluid relies on the identification of an enzyme known as acid phosphatase (AP). The acid phosphatase that is present in seminal fluid originates in the prostate. Body fluids such as blood, saliva, urine, vaginal secretions, and other fluids also contain acid phosphatase. However, the amount of AP in seminal fluid is greater than that found in other tissues. This property makes AP important for the screening of seminal fluid. The detection of acid phosphatase is only considered a presumptive identification of seminal fluid because other body fluids might also give a positive reaction; therefore, a positive test result indicates the possible presence of seminal fluid but its actual presence must be confirmed by other testing methods.

Acid phosphatase is identified in most forensic laboratories by using the Brentamine spot test, which commonly employs the chemicals -napthyl phosphate and diazo blue dye in a buffered solution. When these chemicals are placed onto an item where seminal fluid is present, the tested area quickly changes to a purple color. It is not advisable to test evidentiary items directly because of the possibility of contamination and also because the chemicals used in AP detection may interfere with subsequent analysis. Instead, a small portion of the stain is either cut from the item or some of the stain is transferred to sterile filter paper or a sterile cotton swab for testing. The speed and intensity of the color change reaction can be used to determine if the stain in question is seminal fluid. A rapid color change with intense coloration strongly indicates that a stain is seminal fluid. A slow and weak color change may indicate either a small amount of seminal fluid or the presence of a different body fluid containing acid phosphatase. Because the test for acid phosphatase is very sensitive, a lack of color change may indicate that no seminal fluid is present; however, it may also indicate that the level of AP is below the detection limit of the test. There have been instances in which spermatozoa were found from a stain negative for AP. For this reason, both negative and positive results must be interpreted with caution. Further testing may be required to confirm the presence or absence of semen.

2.5.3 Alternate Light Source or Ultraviolet (UV) Light

It would be time consuming, costly, and tedious to test large items in their entirety for the presence of AP using the Brentamine test. Instead, large items are visually examined and stained areas are identified and tested. Unfortunately, not all semen

stains are visible to the naked eye, depending on the amount of semen deposited and the fabric on which the deposition was made. To enable the laboratory analyst to identify these non-visible stained areas, a method utilizing an alternate light source is applied to pre-screen evidence in an effort to identify discrete areas for AP testing. Many body fluids fluoresce when excited with light at 450-nm wavelength. Semen stains have the tendency to fluoresce more intensely than most other body fluids. In this way, fluorescing areas of an item can be identified and tested for AP. Alternate light screening works well on light-colored fabrics but dark-colored and coarse fabrics are notoriously difficult to examine under visible or alternate light.

2.5.4 Microscopic Identification of Spermatozoa

Items that have tested presumptively positive for seminal fluid using the AP test can be confirmed either by microscopic detection of spermatozoa or chemical detection of a semen-specific protein (Sect. 2.5.2). Positive swabs or a small cutting from a positive stain can be smeared onto a microscope slide and then stained for visualization. Two common stains used for visualization of spermatozoa are nuclear fast red (red stain) and picroindigocarmine (green stain) and are sometimes referred to as the Christmas tree stain because of the red–green color combination. Once stained, epithelial cells (a group of cells such as skin cells and cells that line body orifices) and spermatozoa have a specific appearance (refer to Fig. 2.1).

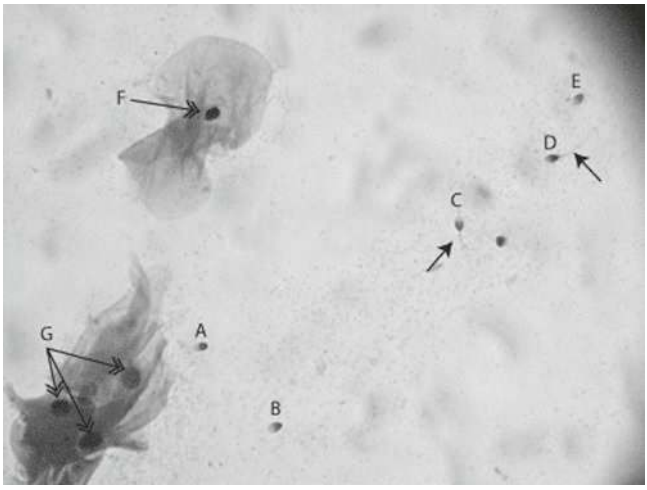

Fig. 2.1 A laboratory analyst can identify spermatozoa (A–E) to confirm the presence of semen on an item. The presence of spermatozoa (C–D) with tails (*arrows*) indicates that the semen may be of relatively recent deposition. Nuclear DNA resides in the spermatozoa heads (A–E) and the nuclei of the epithelial cells (F and G). Leica DM LS2 Microscope at 400×

The nucleus of an epithelial cell will turn red while the cytoplasm takes on a light green or blue appearance. The heads of spermatozoa will turn red with a lighter or white tip while the tail, if present, will turn blue-green.

Microscopically identifying spermatozoa is an absolute indicator that semen is present on an item. It is also useful because the relative quantity of spermatozoa and epithelial cells can be assessed. This determination becomes important during subsequent DNA analysis because spermatozoa contain male DNA while most epithelial cells in a male–female sexual assault will contain female DNA from the complainant. The drawbacks to using microscopy for spermatozoa identification are that it can be more time consuming than the protein confirmation method described below and that it is not necessarily specific to human spermatozoa. Automatic sperm detection is one way to decrease the amount of time analysts spend searching for sperm under the microscope. Automated imaging systems scan a microscope slide using specific search algorithms and recognize sperm cells based on their morphology. At this time, the use of such systems still requires human confirmation that the recognized cells are actually sperm cells.

2.5.5 Protein Confirmation of Semen

Not all cases where seminal fluid is identified can be confirmed with microscopy. If the semen belongs to a male who is vasectomized, or a male with a congenital or other defect of the male reproductive system, spermatozoa may not be present in the semen. In cases such as these, it is useful to have another method to confirm the presence of seminal fluid. It is possible to test for the presence of a protein specific to semen known as prostate-specific antigen (PSA), also referred to as p30 in forensic terminology.

Several different methods can be used to confirm the presence of p30 on an item. Traditional p30 detection tests utilize electrophoretic or diffusion methods such as crossover electrophoresis and Ouchterlony double diffusion, or ELISA. Commercial test kits for p30 are also available and have become prevalent in forensic laboratories because of their sensitivity and ease of use. All of these methods require a small cutting of an AP-positive stain to be incubated in water or saline until rehydrated. Afterwards, the liquid is separated from the cutting by centrifugation so that the stain will be retained in a liquid form instead of dried to the cutting. At this point, a portion of the extracted stain can be used to test for the presence of p30.

All of the methods that detect p30 rely on the formation of an antibody–antigen complex. If semen is present in a stain, the binding of p30 to the test antibody produces a visual result. The lack of a result in any of the tests would indicate that the stain does not contain semen or that not enough is present to facilitate a visible reaction. This test can be used alone to confirm semen, or it can be used in conjunction with the microscopic method described in the previous section.

2.6 Identification of Blood

The identification of blood is important in many cases submitted to the crime laboratory for analysis. Blood identification is central to many homicide investigations and is also useful in cases involving aggravated assault, sexual assault, and burglary. The evaluation of blood evidence can be crucial to substantiate a complainant's or suspect's account of alleged events. The presence of blood on evidentiary items can be critical in establishing guilt or innocence during criminal proceedings. The analysis of blood evidence can be important not only in establishing which individual might have been bleeding, but also in the manner in which blood was deposited. Blood spatter interpretation can be valuable in determining how blood was deposited on an item or at a scene, thus making it useful in crime scene reconstruction (Chapter 4). All of these factors can be taken into account during the investigation and prosecution of a crime and may corroborate or refute an individual's account of an assault.

2.6.1 Presumptive Testing for Blood

The presumptive identification of blood relies on the peroxidase activity of the heme group in hemoglobin. Phenolphthalein (PH), tetramethylbenzidine (TMB), leucomalachite green (LMG), and other indicators work by oxidation of the test sample in the presence of hemoglobin to produce a color change reaction. Phenolphthalein is the most commonly used presumptive test for blood and may be used by itself or in concert with other presumptive tests. A positive phenolphthalein result is indicated by a bright pink color that appears typically within ten to fifteen seconds after the test chemicals are added. This test is very sensitive and positive results can be obtained from stains that are barely visible or invisible to the naked eye. One drawback to this presumptive test is the number of substances that can produce false-positive results. Rust, copper and metal salts, salt-treated lumber, potatoes, and horseradish may all cause a positive result with PH. Usually, if one of these substances is present, the reaction time is slower and the color change takes longer to appear. Some laboratories use PH together with TMB in a double presumptive test. TMB, which works in the same manner as PH, turns a blue-green color in the presence of blood. Although TMB is more specific than PH, meaning fewer false-positive results are indicated, it is less sensitive than PH and does not work as well on highly diluted blood stains.

In any case where blood is suspected, the analyst must first determine what areas of an item of evidence may possibly contain blood. While the color change presumptive tests are good indicators for the presence of blood, they are not practical for testing whole items on which no stains are visible. Porous materials that have been stained with blood may absorb some of the blood even if the object has been washed and appears clean. For this reason, the luminol and fluorescein tests are used to indicate nonvisible blood stains. Luminol is a chemical presumptive test

that, instead of producing a color change reaction, causes stained areas to emit light which must be observed under 'black' light. Fluorescein also causes a light reaction but the fluorescence must be observed using an alternate light source. Either luminol or fluorescein can be sprayed onto large surfaces such as walls or floors and the positive areas marked for further testing. Both tests are very sensitive and will indicate bloodstains that may not be visible. Positive areas should be marked and photographed immediately because the light reaction is not permanent and will fade. One disadvantage to these tests is that both can have false-positive reactions. Luminol and fluorescein will react with the same false positives as PH and also with bleach and other cleaning fluids, which may interfere with blood detection on surfaces that have been cleaned. For this reason, fluorescein- or luminol-positive areas should be retested with one of the color change presumptive tests. Another problem with the light-based tests is that they are typically used on very faint stains. Spraying a chemical onto an already weak stain may dilute the stain even further, which could then lessen the chances of obtaining DNA from the sample.

2.6.2 Species Testing of Blood

Species testing of blood is typically accomplished through an antigen–antibody reaction. The Ouchterlony method works by diffusion, where an extract of the suspected blood stain and an antibody are placed opposite each other in a gel medium. As they migrate toward each other, the blood antigens and antibodies attach together to form a precipitate band that is visualized in the gel. Commercially available kits work in the same manner; however, in these, the stain extract is placed on a test card and the result is indicated by a visible band in the test area. The kits are less time consuming than the Ouchterlony test, but some may show cross reactivity with other species besides human and upper primate blood. Ouchterlony can be more widely applied because it can be used to determine whether a stain may have come from a variety of different species, as long as an antiserum has been made to that species. In a typical forensic case, it is only necessary to determine whether a stain is of probable human origin, unless there are indications that animal blood may be present on a sample.

2.6.3 ABO Blood Typing

Prior to the advent of DNA analysis for forensic science, other methods were developed for the comparison of biological fluid stains to individuals. The most common of these is ABO blood group typing. ABO blood typing identifies specific antigens present on the surface of blood cells. Within the population, individuals may have different forms of these antigens producing what is commonly referred to as a person's "blood type." Comparing the blood type obtained from an evidence stain to that of a known individual allows for the determination of whether the individual

could have contributed to the stain. A proportion of individuals known as "secretors" produce similar substances in other body fluids in addition to blood, which enables ABO typing to be performed on all body fluids in such individuals. The main drawback to ABO blood typing is that there are relatively few different ABO blood types throughout the population, making it difficult to individualize crime stains. Nearly 40% of the population has blood type A and another 40% type O. In addition to being much less informative than DNA analysis, ABO typing requires a fairly large amount of sample for accurate testing, much more than is required for current DNA testing procedures. With the development of faster and more accurate DNA methods, most forensic laboratories have given up ABO testing.

2.6.4 Blood Spatter Interpretation

Blood spatter interpretation can be a useful tool during the investigation of a crime. Interpreting bloodstain patterns can yield information on the manner that a bloodstain was deposited. The distance from the impact origin, the object that may have been responsible for the impact, the direction of the impact, the number of impacts (shots, blows, etc.), or the movement of an individual after injury may be determined by studying blood deposition [2]. All of this information can help investigators establish events that may have occurred at a crime scene and also whether an individual's account of an offense can be corroborated.

2.7 Identification of Saliva

The detection of saliva can be a useful tool in many types of criminal cases, although saliva testing is not requested as often as testing for semen or blood. While presumptive tests are available that can be used to indicate saliva, they have many limitations. Of the forensic laboratories that perform presumptive testing for saliva, the detection of amylase, an enzyme found at high levels in saliva, is currently the most widely utilized method.

Amylase is found in a variety of body fluids, saliva, blood, urine, sweat, tears, semen, breast milk, feces, and vaginal secretions [3, 4], but is more concentrated in saliva than in other body fluids. It should be noted that amylase is also found in plants and in some bacteria. In the body, amylase functions to break down starch into smaller molecules. A number of presumptive tests for amylase are available. While some of the presumptive tests are very sensitive for the presence of amylase, none can actually confirm the presence of salivary amylase [5]; as a result, many laboratories forego screening of evidence for saliva when the amount of test sample is limited. Instead, depending on the circumstances surrounding a case, some laboratories opt to save these samples for DNA testing.

Alternate light can also be used to pre-screen clothing and other evidence to identify possible saliva stains. Like seminal fluid, saliva will fluoresce when excited with alternate light. In these instances, it is important for a laboratory analyst to

know the details of an alleged assault so that a determination can be made on the most likely area where saliva might be present. Because many body fluids and other substances can fluoresce, this screening method only identifies areas for further examination using presumptive, confirmatory, or DNA testing.

DNA testing can be thought of as a type of confirmatory test for the presence of saliva and other body fluids on an item because DNA testing is specific to human DNA. However, DNA analysis without initial presumptive or confirmatory testing only indicates that human DNA is present on an item, not from which body fluid the DNA came. Nevertheless, on items that are suspected of having been in contact with a person's mouth (drink containers, bitemark swabbings, cigarettes, envelopes, toothbrushes, partially ingested food), it is logical to expect that saliva might be present and that any DNA obtained from these items might be from that saliva.

2.8 DNA Testing

After evidentiary items have been screened and positive samples identified, DNA analysis can begin. DNA, or deoxyribonucleic acid, is the inherited cellular material that is the blueprint for human development. DNA molecules are found in almost every cell in a person's body, inside each cell's nucleus where it is packaged into 23 pairs of chromosomes. One chromosome from each pair is contributed by an individual's mother and the other by an individual's father. Each person's DNA is unique, except in the case of identical twins. Identical twins will have exactly the same DNA sequence. Fraternal twins'DNA, on the other hand, will not be any more similar than that of regular siblings. Another property of DNA that is important to forensic analysis is that a person's DNA is the same in every cell in that person's body throughout life. While there are rare instances related to cancer, aging, and other cellular events when this statement might not be true, these occurrences rarely affect forensic examinations.

Although each person's DNA is unique, most of the sequence of the DNA molecule is the same for all individuals. Forensic DNA analysis is interested in the small percentage of DNA sequence that is different between people. Because forensic DNA analysis attempts to individualize DNA to a specific person, it would not be useful to look at segments of DNA that are the same across the population. Instead, polymorphic, or highly variable, regions of DNA are targeted for analysis. The various methods by which this is accomplished are discussed in Sects. 2.8.3–2.8.9.

2.8.1 DNA Extraction

The first step in any forensic DNA analysis is the purification of DNA from an item, also called a substrate, on which the DNA is deposited. This process is commonly referred to as DNA extraction. There are a wide variety of DNA extraction techniques, all of which function to (a) separate the cells containing DNA away from the substrate on which they are embedded, (b) lyse, or break open, the cells to release

DNA and other cellular material, and (c) separate the DNA from these cellular components and any inhibitors that might be present in a sample. (Inhibitors are chemicals or other compounds in a sample that might interfere with subsequent DNA analysis.) The goal of DNA extraction is to yield purified DNA in an aqueous, or liquid, solution that can be used in other applications.

Some of the methods used for DNA extraction are better at purifying DNA, increasing maximum DNA yield, decreasing processing times, or a combination of these, depending on which method is used. Different extraction techniques may work better for different types of samples. It is the forensic laboratory's responsibility to find the best DNA extraction technique for each sample type. New techniques are being developed all the time in attempt to make DNA extraction more streamlined with a higher DNA yield (quantity).

Regardless of which type of DNA extraction is being performed, or which type of chemicals are used, all DNA extractions attempted in forensic laboratories must be processed concurrently with an extraction negative control, also known as a reagent blank. A reagent blank is a sample that goes through the extraction process without a substrate being added to it. Its purpose is to monitor for contamination. In this sense, "contamination" refers to the presence of foreign DNA in a sample. Ideally, reagent blanks should never give any DNA result. If DNA is detected in a reagent blank, it can either mean that DNA contamination is present in the chemicals or plastic consumables used for the extraction process or that an event occurred during the extraction process to introduce foreign DNA into the extracts. If this happens, the DNA extraction for all the samples processed with that reagent blank should be repeated from the beginning unless the laboratory can show that the contamination event was isolated to the blank sample only. It is very important that reagent blanks are treated just like every other sample in the reaction process so that they can monitor for contamination most effectively.

In forensic casework, it is not good laboratory practice to consume an entire sample during DNA extraction. Typically, only half of a sample should be processed for each extraction in order to leave enough specimen for retesting. Retesting is important in several instances. First, if the original extraction becomes compromised, either by contamination of the extraction reagents or another event, or the results are inconclusive, then the extraction may need to be repeated by the laboratory. For items for which no DNA profile is obtained, saving a portion of the sample can be important so it can be processed in the future when new technology becomes available. Finally, a portion of each sample should be saved so that the evidence can be retested by another laboratory to confirm findings if requested by the defense.

2.8.2 Differential DNA Extraction

One distinctive type of DNA extraction used in forensic laboratories is commonly referred to as "differential extraction." Semen-positive sexual assault samples are usually swabs from a sexual assault kit, sometimes referred to as intimate samples,

or cuttings from a complainant's clothing or bedding. These types of samples generally involve a mixture of DNA from the perpetrator, in the form of spermatozoa, and the complainant, in the form of epithelial cells. Because these samples contain DNA from more than one source, it is useful to attempt to separate DNA derived from spermatozoa from all other sources of DNA.

Differential extraction relies on the distinction in the physical properties of spermatozoa from other, usually epithelial, cells. Spermatozoa are more robust than other cell types when it comes to the process of DNA extraction. They can withstand higher incubation temperatures for longer periods and remain intact. Using this property, it is possible to perform a two-step incubation in attempt to separate epithelial DNA from spermatozoa DNA. In the first step, the entire sample is incubated for a short period of time under less stringent conditions. Afterwards, the sample is centrifuged to separate lysed epithelial cells, which remain in the aqueous solution, from unlysed spermatozoa, which pellet at the bottom of the tube. The aqueous solution, now called the non-sperm or epithelial fraction, can then be removed to another tube for further processing while the spermatozoa pellet can be resuspended and digested under more stringent conditions to release the spermatozoas' DNA.

Differential extractions are by no means exact. In a perfect world, differential extraction results in a pure non-sperm or epithelial cell fraction and a pure sperm cell fraction. Ideally, during subsequent DNA analysis, the non-sperm cell fraction would yield a single DNA profile consistent with the complainant, while the sperm cell fraction would yield a single DNA profile consistent with a male perpetrator. While this sometimes happens, it is not always the case. One of the variables that influences the success of a differential extraction is the amount of spermatozoa in relation to other cells. This distinction is usually made during the microscopic examination of spermatozoa either during semen confirmation or by preparing a slide from the differential extraction products themselves (see Fig. 2.1). This determination can produce valuable information on the best way to process the sample during DNA extraction. Large quantities of the complainant's epithelial DNA may not all be lysed in the first incubation step and the unlysed cells may pellet with the spermatozoa to introduce complainant DNA into the sperm cell fraction. Another factor that may influence a differential extraction is the presence of perpetrator DNA in a form other than spermatozoa. It is possible for a perpetrator's blood cells or epithelial cells (from skin, saliva, or seminal fluid) to be present in a sample. These cells would become a part of the epithelial cell fraction and may cause the perpetrator's profile to be observed in the non-sperm cell fraction.

Even though differential extraction is not always precise, it is still worth performing because it allows at least a partial separation of spermatozoa from other cells. Researchers are currently working on other methods to more reliably separate spermatozoa from other cells. Some of these techniques involve passing the DNA through a filter to separate spermatozoa from other cells based on cell size (epithelial cells are large in relation to spermatozoa), or binding the spermatozoa to a membrane using antibodies. Also, a new method of DNA analysis has been developed in the last few years that is specific to male DNA, called Y-STR analysis (see Sect. 2.8.7)

that can give additional information on samples with small amounts of male DNA or samples that are a mixture of male and female DNA.

2.8.3 DNA Quantification

After evidentiary samples and comparison reference samples have been extracted, the amount of DNA in each sample must be measured in a process known as DNA quantification. It is important for subsequent steps to determine the amount of DNA in each sample. The DNA analysis techniques currently being used in most laboratories, such as short tandem repeat (STR) analysis, mitochondrial DNA (mtDNA) sequencing, and Y-STR, all require very precise amounts of DNA for processing.

The most popular technique available in forensic laboratories for DNA quantification involves a process known as real-time polymerase chain reaction (PCR). The polymerase chain reaction (PCR) is a way to amplify (copy) specific regions on the DNA strand. Real-time PCR is a way to monitor the amplification process as it occurs. Commercially available kits use real-time PCR to quantify the *amplifiable* human DNA in a sample [6–8]. The probes used in the real-time procedure are human specific, but some may also react to upper-primate DNA if present in a sample. Except in cases where a biological fluid of an upper-primate may be present in a sample, these quantification methods can be considered a reliable estimate of human DNA in a sample.

Real-time PCR, when applied to DNA quantification, is useful because instead of only determining the amount of DNA in a sample, this method can also predict how the DNA will respond during subsequent PCR analysis conditions. In this way, the real-time PCR technique identifies potential inhibitors of the PCR reaction (substances in the DNA extract that prevent amplification). Newer quantification kits offer the ability to determine the total amount of human DNA and male-specific DNA in a sample at the same time. Quantifying the amount of male specific DNA in a sample is useful for Y-STR analysis (see Sect. 2.8.7).

2.8.4 Restriction Fragment Length Polymorphism (RFLP) and Early PCR-Based Methods

In the mid to late 1980s, the technique known as Restriction Fragment Length Polymorphism (RFLP) was introduced to forensic science and became the first assay used for forensic DNA analysis. The DNA molecule contains sequences known as variable number of tandem repeat (VNTR) sequences, which are pieces of DNA whose sequence repeats over and over a different number of times in different individuals. These repeating sequences, each up to several hundred bases in length, can be cut out of the DNA strand using restriction enzymes and then isolated and their size determined using the Southern blotting technique. The VNTR

sequences were shown to be highly variable in the population and revolutionized DNA typing in forensic science. RFLP was eventually supplanted by STR analysis as the leading DNA technology in forensic crime laboratories because RFLP requires a large amount of sample to obtain enough DNA for detection and is not suitable for processing very small or degraded samples. It is also very time consuming to perform. A typical case from start to finish could take approximately 8 weeks to complete. In contrast, current STR-DNA analysis can be completed in days.

The PCR-based methods for DNA typing were developed to handle the many crime scene stains that are of limited DNA quantity. PCR is a process that amplifies, or copies, specific regions on the DNA strand to produce enough DNA to examine. This process is accomplished by combining the sample DNA with the enzyme Taq polymerase and human-specific DNA primers, which are short segments of DNA that indicate which area of the DNA should be copied, in a buffered chemical solution. Each sample, including reagent blanks, is placed into a separate tube for analysis. In addition, for each set of amplification reactions, a positive and negative amplification control is processed. A positive control is a DNA sample for which a profile is already established. A negative control is set up just like any other sample but does not contain DNA; instead, the water or buffer used for sample dilutions is added to the amplification reaction. Once all of the samples and controls are prepared, they are placed into a machine known as a thermal cycler. The thermal cycler facilitates PCR by incubating the samples in repetitive cycles of denaturation (unwinding and separating the DNA strands at high temperature), annealing (laying down primers in the target region at the primer specific temperature), and elongation (addition of bases to create a copy at the enzyme-specific temperature). Each cycle increases the amount of target DNA inside the sample tube. The amplification process generally continues for 25 to 40 amplification cycles depending on the manufacturer's established procedure and internal laboratory validation.

The AmpliType HLA DQ Forensic DNA and the AmpliType7 PM PCR Amplification and Typing Kits (formerly supplied by Perkin-Elmer, Foster City, CA) used sequence-based polymorphisms at specific DNA locations instead of the size-based polymorphisms used in RFLP analysis. These PCR-based methods were preferable to RFLP because DNA from very limited sources could be amplified to detectable levels and the time required for processing was greatly reduced. The biggest disadvantage to these PCR-based methods was that the sequential differences at DQ and the polymarker loci showed less variability in populations than the repeating sequences in RFLP, making statistical analysis less discriminating.

2.8.5 Short Tandem Repeat (STR) Analysis

The most widespread method of DNA analysis currently used in crime laboratories is Short Tandem Repeat (STR) analysis. STRs are repetitive sequences of DNA, usually 2–5 base pairs in length. Forensic STR analysis determines the number of

tetranucleotide (four base) or pentanucleotide (five base) repeats at specific locations (loci) on the DNA strand. The numbers of repeats observed at these locations are compiled into what is known as a DNA profile. Profiles from evidence can be compared with profiles from known individuals and conclusions can be drawn regarding whether specific individuals may have contributed to the DNA on evidentiary items.

The STR procedure is similar to RFLP in that it examines repetitive units on the DNA strand, although the repeat units in STR are significantly smaller in size than the VNTR units analyzed in RFLP. STR analysis is also a PCR-based procedure, making it much more sensitive than RFLP. STR analysis has become popular in crime laboratories because of its sensitivity, reduced processing time, and increased statistical discrimination over previous forensic DNA methods. Although each location examined for STR shows less variability than those examined in RFLP typing, the increased number of DNA sites examined during the STR procedure makes it more discerning than RFLP.

After DNA samples have been extracted and quantified, a small amount, approximately 1ng of DNA, is used for the PCR portion of the STR procedure. The PCR procedure is as described in Sect. 2.8.4, except that during each cycle of amplification a fluorescent tag is attached to each new copy of DNA. After the DNA is amplified, the amount and size of the DNA must be determined. This process is accomplished by detecting the fluorescently labeled tags attached to the amplified DNA. First, the DNA is separated by size using electrical current. The amplified DNA is applied either to a polyacrylamide slab gel (gel media sandwiched between two large glass plates) or to a polymer-filled capillary (gel-like medium contained in a long, thin glass capillary). When electrical current is applied to either the slab gel or capillary, the shorter DNA fragments migrate through the gel medium faster than the longer fragments. In this way, DNA fragments can be resolved down to a one base difference in size. After the amplified DNA has been separated by size, each fragment is detected by its fluorescent label. Detection is accomplished either by using the electrophoretic instrument's laser and CCD camera or by using a flatbed scanner with fluorescent detection capability. After the fluorescence has been read, computer software converts the fluorescent information into a format that can be analyzed.

STR systems detect DNA at several different locations on the DNA strand. At each of these locations (loci) a person will have up to two different fragment sizes (alleles) (see Fig. 2.2). Because DNA is packaged into pairs of chromosomes, the occurrence of two alleles is caused when the fragment size at one locus on one chromosome differs from the fragment size of that same locus on the other chromosome (heterozygous). If the sizes of the detected fragments are the same on both chromosomes, then a person will only have one allele at that locus (homozygous).

Once fragment sizes are determined for all of the loci under examination, then a DNA profile can be generated. A DNA profile is a listing of all observed allele sizes at each locus (see Tables 2.1 and 2.2). The DNA profile of an evidentiary sample can then be compared with the DNA profile of a known reference sample (complainant, suspect, witness, or relative). If the evidentiary sample is from a single

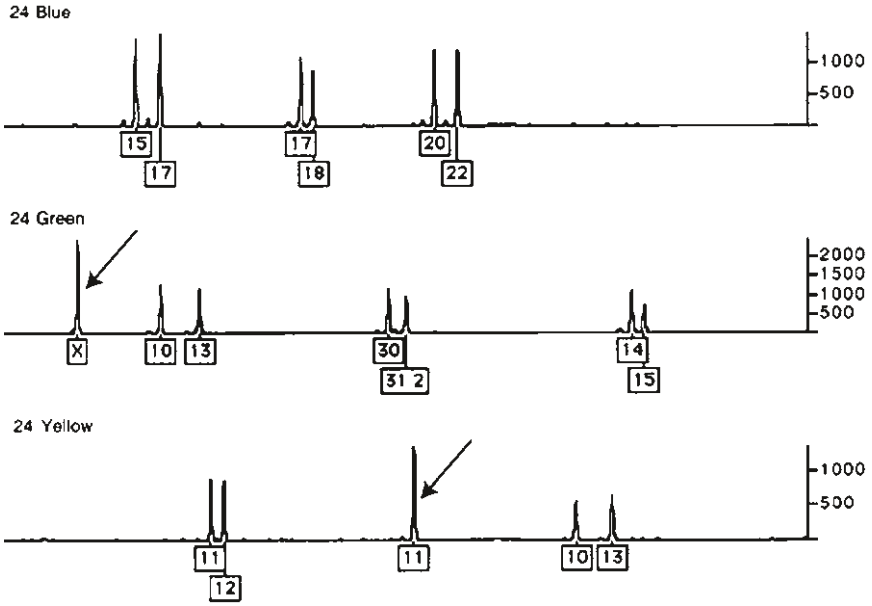

Fig. 2.2 A DNA profile from a single female individual. Loci where only one peak is present are homozygous (arrows). Loci where two peaks are present are heterozygous. The presence of an "X" allele without a "Y" allele indicates that this profile is from a female individual. The numbers indicated below the peaks are the number of repetitive fragments observed at each locus. These numbers are listed as a person's DNA profile

Table 2.1 CODIS case data

Locus	White styrofoam cup	Plastic drinking straw
D3S1358	16	15, 16
VWA	15, 16	15, 16, 18
FGA	22, 23	20, 25
Amelogenin	X, Y	X, Y
D8S1179	11, 12	11, 14, 15
D21S11	27, 28	28, 29
D18S51	14, 20	16, 19
D5S818	11, 12	11
D13S317	12, 13	11, 13
D7S820	8, 11	8, 11
D16S539	10, 13	9, 12
THO1	6, 9	7, 9
TPOX	8, 10	10, 11
CSF1PO	10, 12	8, 11

source and the DNA profiles are the same between an evidence sample and a reference sample, then that individual cannot be excluded as the individual to whom the body fluid belongs.

Table 2.2 Aggravated sexual assault data

Locus	C	S1	S2	V-SP	A-SP
D3S1358	15, 18	16	15	15	15
VWA	18	15, 16	16, 18	16, 18	16, 18
FGA	24, 25	22, 23	20, 25	20, 25	20, 24, 25
Amelogenin	X	X, Y	X, Y	X, Y	X, Y
D8S1179	12, 13	11, 12	14, 15	14, 15	12, 13, 14, 15
D21S11	29, 33.2	27, 28	28, 29	28, 29	28, 29, 33.2
D18S51	15	14, 20	16, 19	16, 19	15, 16, 19
D5S818	10, 13	11, 12	11	11	10, 11, 13
D13S317	11, 14	12, 13	11, 13	11, 13	11, 13, 14
D7S820	8, 10	8, 11	8, 11	8, 11	8, 10, 11
D16S539	11	10, 13	9, 12	9, 12	9, 11, 12
THO1	9.3	6, 9	7, 9	7, 9	7, 9, 9.3
TPOX	8	8, 10	10, 11	10, 11	8, 10, 11
CSF1PO	10, 11	10, 12	8, 11	8, 11	8, 10, 11

C complainant; *S1* suspect 1; *S2* suspect 2; *V* vaginal; *A* anal; *SP* sperm fraction

In forensic science, reporting statements for profiles that are the same between a piece of evidence and an individual rarely use the word “match.” Because only representative areas of the DNA molecule are tested in STR analysis, the possibility still exists that if other locations on the DNA strand were tested, the results might be different between the evidence’s and individual’s DNA profiles. Statistics can be calculated to determine how common the DNA profile of the evidence is in a given population. There are databases for the frequency of alleles at each locus in different populations. The statistical rarity of a profile will be influenced by the number of loci tested and the rarity of the observed alleles at those loci [9]. If the statistics generated for a certain profile meet a specified threshold, then some laboratories may make a reporting statement indicating that a certain individual is the source of an evidentiary stain or body fluid [10].

More than two alleles observed at one or more loci is indicative of a mixture of DNA from more than one individual (Fig. 2.3). Mixtures can arise if body fluids from more than one person are present on a sample, or when more than one individual contributes the same type of body fluid to a stain. Mixtures are observed frequently on sexual assault evidence because the DNA of the complainant in the form of skin cells, sweat, or vaginal secretions and DNA from semen may be present on the same item. Likewise, during homicides or assaults it is possible for more than one person to deposit blood on an item. A profile with more than two alleles at only one locus must be interpreted with caution. In rare instances, it is possible for an individual to have more than two alleles at a single locus, but this exception is identified when a profile is established from an individual’s known saliva or blood. When this tri-allelic pattern does occur, it is typically only observed at one locus, where a true mixture will be observed at two or more loci.

Mixture profiles can be difficult to interpret. If there are only two contributors to a DNA mixture and all of their alleles are present at equal intensity with no

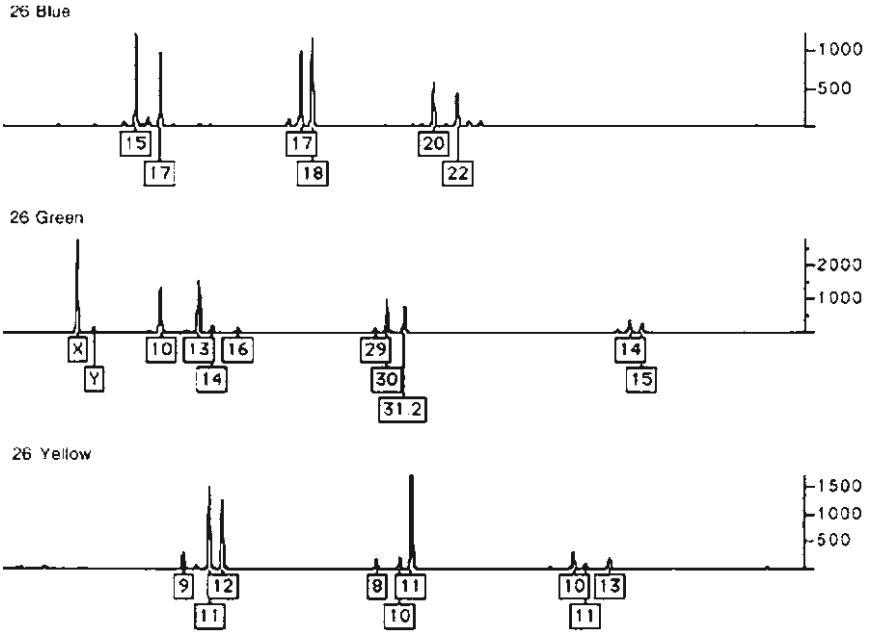

Fig. 2.3 A mixture of DNA from the individuals from Figs. 2.2 and 2.4. The taller peaks at each locus are consistent with the female individual from Fig. 2.2, indicating that more of her DNA is present in the mixture. Not all of the alleles from the male individual from Fig. 2.4 are observed in this profile above the threshold. When not all of the alleles from an individual are evident in a mixture, it makes interpreting the mixture difficult

additional alleles observed, then the interpretation is fairly straightforward. However, if a mixture is from more than two individuals, or if the amounts of DNA from different individuals vary in intensity so that not all of the alleles are observed (Fig. 2.3), mixture interpretation becomes more difficult. In any event, it is not possible to determine with absolute certainty that a specific individual is present in a mixture; instead, it is only possible to conclude that a specific individual might be a contributor. Because mixtures are a combination of alleles from more than one person, it is possible to have more than one combination of profiles that would explain the mixture on an item. As a result, it is difficult to state that a person is represented in a mixture absolutely. Using allelic frequencies, mixture statistics can be calculated to determine the number of unrelated individuals in the population who might be expected to contribute to a certain mixture profile.

While it is helpful to have a reference sample from a developed suspect to be used for DNA comparison, it is not always necessary. The advent of the CODIS database (see Sect. 2.9) makes it possible to process cases without a known suspect. If a presumed perpetrator profile is developed, the profile can be entered into the CODIS database and compared with evidentiary samples from other cases and with convicted offender samples. In some cases, even mixture profiles can be entered into the CODIS database. Success in using the CODIS database to help

resolve crimes has produced an incentive to work old, unprocessed, or cold cases. Cases that were not processed for DNA because the technology was not available at the time, or the available technology was not sensitive enough, or a suspect sample was not available for comparison, can now be worked in an attempt to identify a suspect using the CODIS database.

2.8.6 Mitochondrial DNA (mtDNA) Sequencing

What many people do not realize is that there is more than one type of DNA in a cell. All of the discussion to this point in this chapter has been in reference to "nuclear DNA," which is specific to an individual (refer to Sect. 2.8). The second and less commonly discussed type of DNA in a cell is mitochondrial DNA (mtDNA). Mitochondria are very small organelles found outside the cell nucleus within a cell's cytoplasm. Each mitochondrion has its own DNA. MtDNA is only inherited maternally; therefore, mtDNA is not unique to any one person. Each individual will share the same mtDNA sequence with their mother, siblings, and other maternal relatives. Because of the shared mtDNA profile between maternal family members, mtDNA is not as discriminating as nuclear DNA analysis. However, mtDNA has several properties that make it useful in forensic science.

MtDNA is circular in shape in contrast to nuclear DNA, which has a long, linear configuration that is packaged into chromosomes. MtDNA's circular shape enables it to be more stable over time because it is less susceptible to degradation. There are also many more copies of mtDNA per cell than nuclear DNA, making mtDNA testing much more sensitive than nuclear DNA testing. This stability and additional sensitivity allows mtDNA to be utilized in cases involving skeletonized remains or old biological samples that are not able to yield a nuclear DNA profile. MtDNA is also useful in cases of mass disaster, where remains may be subjected to harsh conditions such as salt water, charring, or other elemental conditions that degrade DNA. As a consequence of the maternal inheritance of mtDNA, mtDNA analysis also allows for the comparison of remains to more distantly related individuals than nuclear comparisons allow. This aspect is helpful in cases where no immediate family members are available to supply a reference sample.

One of the most famous remains identification cases in which mtDNA sequencing was utilized involved the identification of the Romanov family [11]. STR analysis established that the remains from a mass grave in Ekaterinburg, Russia were of a family unit (both parents and three daughters) and four unrelated individuals. Because the Romanov family disappeared in 1918, no immediate living relatives were available to confirm the identity of the remains by STR testing. Instead, Tsarina Alexandra was identified through a mtDNA sequencing comparison between her remains and that of Prince Philip, Duke of Edinburg, a maternal grandnephew. Tsar Nicolas II was identified using an mtDNA comparison with two separate individuals: his sister's great granddaughter and his maternal grandmother's great-great grandson.

In addition to remains identification cases, mtDNA analysis is routinely used to compare DNA derived from single hairs with known reference samples. Hairs with intact roots can yield enough nuclear DNA for STR analysis, but hairs without available roots will typically be unable to produce any analyzable nuclear DNA. Even very small cut hairs are capable of generating an mtDNA profile for comparison. Because mtDNA analysis is time consuming and not as statistically discriminating as nuclear analyses, mtDNA analysis is usually only performed on hair or other evidence when there is no other physical evidence available in an investigation.

Unlike STR analysis, which looks at repetitive segments of DNA, mtDNA analysis actually compares the DNA sequence between individuals. DNA sequencing breaks down the DNA fragment by order into its respective bases (A, C, T, or G). To facilitate interpretation, the sequence is then compared with a reference sequence and any difference from the reference sequence is noted. This annotation becomes a mtDNA profile or haplotype. MtDNA haplotypes can be compared between evidence and reference samples and conclusions can be drawn as to whether a certain individual may have contributed to the mtDNA on an item. If the profiles are consistent between a reference sample and an evidentiary sample, statistics can be generated to indicate how many times that mtDNA haplotype has been observed in a given population.

More recently, a method using sequence specific oligonucleotide (SSO) probes, similar to DQ and Polymarker for nuclear DNA (Sect. 2.8.4), has been developed in attempt to circumvent the need for actual sequence determination, thereby decreasing the time necessary for mtDNA analysis [12]. These probes have been used in some instances, but may require sequencing for confirmation [13]. The SSO probe approach to mtDNA analysis may be helpful to laboratories who would like to begin mtDNA analysis but do not want to have to purchase costly equipment. One drawback is that SSO probes do not provide as much genetic information as actual sequencing of the mtDNA molecule.

Like STR analysis, reagent blanks and amplification positive and negative controls must be processed through sequencing to determine if there is any underlying DNA present in any of the chemicals used during analysis. Because mtDNA amplification is so sensitive, evidentiary samples are usually processed individually, each with their own reagent blank to closely monitor for contamination. Due to the necessity of processing evidentiary items singly and because of the time involved in the sequencing analysis, mtDNA casework takes many times longer to complete than STR casework. Generally, laboratories that perform mtDNA sequencing can only process one or two mtDNA cases per analyst per month [14].

MtDNA analysis for criminal cases can only be performed when a reference sample is available for comparison. Unlike nuclear DNA analysis, a database does not exist for the comparison of unknown mtDNA profiles from criminal cases. MtDNA profiles are not unique to individuals, so any database match would not necessarily aid an investigation. On the other hand, a mtDNA database does exist for searching profiles obtained from unidentified remains against relatives of missing persons. Databases similar to a missing person database are also useful in mass disaster identifications and identifying remains from mass graves, human right violations, or war.

2.8.7 Y-Chromosome STR Analysis

Because many sexual assault cases involve the DNA typing of a semen donor and most case samples are a mixture of complainant and semen donor sources, a technology focusing on the Y-chromosome, which is only present in males, has been developed. Y-STRs are useful in forensic testing because they are specific to the Y chromosome, and therefore to male DNA. Y-STR analysis is able to simplify interpretation in cases where there is a mixture of male and female DNA by focusing on the male portion of DNA only. Y-STR is also applicable to cases where there is a mixture of more than two people. In complex mixtures such as these, Y-STR analysis can provide information on how many male donors have contributed to a sample. Y-STR is also instructive in cases where semen is present on a sample but no sperm type is detected because the ratio of complainant to sperm DNA is too large. In cases where the complainant is female, the complainants contribution to the DNA in a sample is ignored and a Y-STR profile can be identified for the semen donor. Using Y-STR analysis on a sample may also preclude the need for performing a differential extraction in cases of male–female sexual assaults because separation of male and female DNA becomes unnecessary.

While Y-STR is practical for many sexual assault cases, it is not without limitations. Similar to mtDNA, the Y-chromosome is inherited uniparentally, meaning it is passed from father to son. Therefore, male relatives will have the same Y profile as other male members of their family. For this reason, Y-STR testing is not as statistically discriminating as nuclear DNA. Consequently, Y-STR analysis is usually employed as an extension of nuclear DNA testing to provide additional information and will not replace traditional nuclear DNA testing. Like mtDNA testing, there is not a searchable database for comparing unknown Y-STR profiles from crime scenes to known individuals. For Y-STR casework to be useful, a reference sample must be available for comparison.

Y-STR analysis is essentially the same as STR analysis. The only real difference is that the primers for Y-STR analysis are specific to male, human DNA instead of only being human specific. Male-specific quantification kits have been developed to determine the amount of male DNA in a sample prior to amplification. Testing with these kits can be performed either separately or in conjunction with autosomal DNA quantification (see Sect. 2.8.3).

2.8.8 Single-Nucleotide Polymorphism (SNP) Analysis

Single-nucleotide polymorphisms (SNPs) are scattered throughout the genome. A SNP is one base pair of DNA that is variable between people. SNP technology for forensic science applications is currently under development for nuclear DNA, mtDNA, and Y-chromosome testing. It has already been used to help identify victims of the World Trade Center collapse in New York.

Research into SNP technology is aimed at the identification of meaningful markers and grouping as many probes as possible for these informative sites onto a microchip or similar technology so that many sites can be screened at once with very low quantities of DNA. This new technology should be better able to produce a profile from degraded DNA because the probes utilized are very short sequences. Each SNP site on its own is less informative than a single STR locus, so more SNPs will have to be processed to achieve the level of discrimination of current STR analysis. However, using microchip technology, hundreds or more SNPs can be analyzed at the same time, offering a much higher level of discrimination than current STR analysis. The more SNP sites assayed, the more discriminating the testing ability to be able to individualize evidentiary stains.

2.8.9 Mini-STR

Mini-STRs are a recent addition to the repertoire of DNA tests that a forensic scientist can use. Mini-STRs test some of the same DNA locations that are analyzed in the traditional STR method described in Sect. 2.8.5, but the size of the amplified DNA segment is shorter in the mini-STR method [15]. Another difference between traditional and mini-STRs is that mini-STRs were developed to be more sensitive than the traditional method. Mini-STRs use more PCR cycles in order to amplify more DNA for analysis. These extra cycles make the mini-STR test more sensitive. Because the amplified DNA fragments are also shorter, it is possible to detect DNA from degraded samples. Currently, mini-STRs are not a replacement to traditional STR testing because they do not allow all of the standard STR loci to be tested and are therefore available as a supplemental testing method only.

2.8.10 Low Copy Number (LCN) DNA Testing

In general, low copy number DNA testing refers to the testing of samples containing less than 100pg of DNA. Laboratories may employ several different techniques to enhance the DNA signal to a detectable level for samples in this range. One method is to use additional PCR cycles over the standard cycle number to boost the amount of detectable DNA [16]. Some laboratories may also use mini-STRs to analyze samples containing such small amounts of DNA (refer to Sect. 2.8.9). Another technique is to use a post-PCR purification procedure to boost DNA signal during capillary electrophoresis [17].

The additional sensitivity that LCN testing offers is not without its drawbacks. LCN samples have such a low abundance of DNA that the profiles from these samples can be difficult to reproduce because of sampling effects. Furthermore, as the sensitivity of the testing increases, so do the chances of detecting low-level

contamination that may be present below the detection limit of standard DNA testing procedures. To combat these issues, some laboratories test replicate samples and only analyze DNA alleles that are observed in the majority of replicates tested (Fig. 2.4).

2.9 Combined DNA Index System (CODIS) Database

The Combined DNA Index System, or CODIS, is a database of DNA profiles maintained at the local, state, and national level. Its purpose is to help aid criminal investigations by linking perpetrators to biological evidence. In order for a laboratory to participate in the CODIS system within the United States, the laboratory must follow the Quality Assurance Standards for Forensic DNA Testing Laboratories [18,19] or the Quality Assurance Standards for Convicted Offender DNA Databasing Laboratories. Locally, laboratories participating in CODIS may enter DNA profiles obtained from forensic evidence. These profiles are then uploaded to a designated state laboratory and searched against forensic DNA profiles from other cases within the state and also against the DNA profiles of convicted offenders from that state. In this way, the investigation of crimes for which there is no known

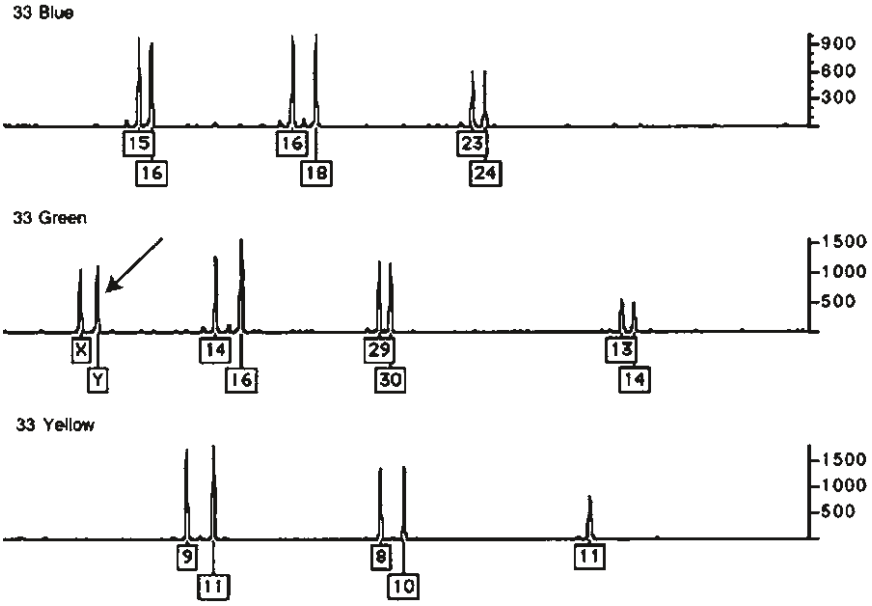

Fig. 2.4 The DNA profile of a male individual. The presence of an "X" allele and a "Y" allele at the amelogenin locus (*arrow*) indicates that this profile is from a male. Each locus has no more than two alleles, each with similar height, indicating that the source of this profile is from a single individual. This individual contributed to the mixture profile from Fig. 2.3

suspect may be aided by linking the biological evidence to either another case perpetrated by the same individual or to an individual who has been previously convicted of a felony. Each state participating in CODIS can upload their forensic unknown and convicted offender profiles to the national CODIS database, administered by the Federal Bureau of Investigation (FBI). Searches at the national level can link cases and offenders from across the country. In 2008, the national database contained more than six million convicted offender profiles and more than 200,000 evidence profiles from all fifty states.

Internationally, there are approximately thirty countries outside the United States that have their own CODIS databases, including countries in Europe, Asia, and North and South America. Because many countries use some of the same loci for DNA analysis, it is possible for profiles to be sent to these countries to be searched against their CODIS databases if warranted by the investigation.

2.10 DNA in Criminal Proceedings

Typically, DNA evidence does not stand alone in a criminal investigation. DNA evidence must be used in conjunction with the other case evidence to provide a whole scenario to allow jurors to make the best decision on the alleged course of events. The most important thing to remember when dealing with DNA during criminal proceedings is that the presence of an individual's DNA on an item does not prove their guilt; conversely, a lack of DNA does not necessarily prove their innocence. DNA evidence, in and of itself, is only as probative as the piece of evidence on which the DNA is found. DNA from semen in a sexual assault case that is consistent with the defendant's DNA would only have evidentiary value if the defendant denies knowing or having sexual contact with the victim. This same DNA would not be probative if both parties admit that a sexual encounter occurred but the question is one of consent. If the DNA profile of a semen sample in a case of sexual assault does not match the defendant, it could either mean that he was not the perpetrator, or that he did not ejaculate, and the semen may belong to a sexual partner of the victim. Likewise, if semen is not present on samples from a sexual assault case, it does not necessarily mean that a sexual assault did not occur.

2.11 Sample Processing

Forensic biology laboratories use different strategies to get as many cases processed each year as possible. This is important because governmental crime laboratories have backlogs sometimes reaching thousands of cases awaiting DNA analysis. Each lab must consider available personnel and laboratory equipment and determine how to allocate resources effectively. Federal grant funding has also been available to help laboratories equip, staff, train, or outsource DNA casework in attempts to reduce the number of cases waiting for DNA testing.

2.11.1 Case Batching

Batching, or processing more than one case at a time for DNA analysis, is one of the ways that laboratories increase their sample throughput. Traditionally, DNA laboratories have practiced case ownership where one analyst works one or multiple cases at a time from start to finish. Private DNA laboratories and some of the larger governmental labs process cases in batches using an assembly line approach. In this way, multiple people participate in sample processing in each case and a larger number of samples can be processed simultaneously. Other methods utilized by laboratories to increase case throughput include limiting the number of samples that are tested per case in order to be able to perform DNA testing on as many cases as possible and restricting the types of cases that the laboratory will accept for processing to personal crimes (homicide, sexual assault, assault) instead of property crimes (burglary and theft).

2.11.2 Laboratory Automation

Laboratory automation means using robotic systems to process case samples. The 1, 4, 16, and 96 capillary genetic analyzers used for fluorescent detection that DNA labs have been using for the past decade was the first step to be automated in the DNA process. These instruments replaced the need for laboratory personnel to pour and load polyacrylamide gels. This invention saved the analysts time, improved sample quality, and was also a safety improvement.

More recently, forensic biology laboratories are beginning to automate all aspects of DNA processing. There are a variety of robotic systems that can be automated for DNA extraction, quantification, and amplification. There are even automated systems for data analysis, but these are only beginning to be used for reference samples in databasing laboratories. Automation frees personnel to focus on laboratory processes that cannot be automated, such as serology screening, profile interpretation, and expert testimony. Automation can also be a quality improvement measure because samples are processed by machine and therefore theoretically free of human error.

2.11.3 Outsourcing

The National Institute of Justice has provided millions of dollars to laboratories for capacity enhancement and backlog reduction. This grant funding has allowed laboratories to increase the number of cases that they can process by buying new equipment and improving laboratory technology. Grant funding has also allowed laboratories to send unworked cases to private laboratories for analysis. This has been an effective means of reducing the number of backlogged cases awaiting DNA analysis.

2.12 Quality Assurance

Forensic testing must be reliable. To achieve this end, forensic laboratories are required to have comprehensive quality assurance and quality control programs. For forensic biology laboratories that participate in CODIS, the minimum required standards were originally developed by the DNA Advisory Board and issued by the FBI Director: the Quality Assurance Standards for Forensic DNA Testing Laboratories (July 1998) and/or the Quality Assurance Standards for Convicted Offender DNA Databasing Laboratories (April 1999). These standards have been revised and were reissued in 2008 as the Quality Assurance Standards for Forensic DNA Testing Laboratories and the Quality Assurance Standards for DNA Databasing Laboratories. The newer versions of the standards will take effect on July 1, 2009. These standards contain requirements pertaining to quality assurance, organization and management, personnel, facilities, evidence control, validation, analytical procedures, equipment calibration and maintenance, reports, review, proficiency testing, corrective action, audits, safety, and subcontracting. Laboratories that participate in CODIS, which includes nearly all public forensic laboratories in the nation, must be audited against these standards every year.

2.13 Laboratory Accreditation

There are two accrediting bodies for forensic crime laboratories that operate in the United States: Forensic Quality Services (FQS) and the American Society of Crime Laboratory Directors Laboratory Accreditation Board (ASCLD/LAB). Both agencies offer accreditation under International Organization of Standardization (ISO) and use the Quality Assurance Standards during their inspection. As of November 2008, 350 crime laboratories were accredited by ASCLD/LAB, including 179 state laboratories, 114 local agency laboratories, 22 federal laboratories, 11 international (non-US) laboratories, and 24 private laboratories. Of these, only 71 crime labs are accredited under ISO (http://www.ascld-lab.org/legacy/aslablegacylaboratories.html). An additional 53 crime laboratories are accredited under ISO through FQS (http://www.forquality.org/fqs_I_Labs.htm). As of this writing, only four states - New York, Texas, Oklahoma and Missouri - require their crime labs to be accredited; however, federal rules require that CODIS-participating laboratories must be accredited.

2.14 Educational Requirements for Forensic Biology Personnel

To work at an accredited crime laboratory, or one that participates in CODIS, a minimum of a Bachelor's degree is required. For personnel who interpret DNA profiles, their degree must be in the field of Biology, Chemistry, Forensic Science,

or a related area. These individuals must also have coursework covering Genetics, Biochemistry, and Molecular Biology and have at least some training in Statistics or Population Genetics. Individuals serving as DNA Technical Leaders must have a minimum of a Master's degree or possess a degree requirement waiver from the American Society of Crime Laboratory Directors Laboratory Accreditation Board (ASCLD/LAB).

2.15 Proficiency Testing

Part of the quality assurance program requires analysts performing casework to undergo proficiency testing. For DNA analysts, two external proficiency tests are required each year the analyst is performing casework. An external proficiency test is one that is administered by a separate agency. The analysts that are taking the test may know that they are being tested, but no one at that agency will know what the corresponding results of the test should be until the results are all turned in and graded and the test results released. Proficiency testing is a quality assurance measure used to monitor performance and identify areas in which improvement may be needed.

2.16 Certification

Certification is a voluntary process of peer review by which a practitioner is recognized for attaining the professional qualifications necessary to practice in one or more disciplines of criminalistics (http://www.criminalistics.com/cert_ovw.cf). Currently, certification is not required for forensic biologists. The only certifying agency for forensic biology is the American Board of Criminalistics. They offer certification as a comprehensive criminalist (general certification in forensic science) or in molecular biology, which is the specialty area for forensic biologists. It is estimated that in 2008, only 10% of forensic biologists were certified by the American Board of Criminalistics.

2.17 Case Studies

2.17.1 Case Study: Probable Saliva for CODIS

In June of 2002, a woman's car was reported stolen. The car was later recovered and a white styrofoam cup, a straw, and white plastic spoon were collected from the interior of the vehicle and submitted to the laboratory for analysis. Serology testing was not performed on these items to save as much sample as possible for DNA

testing. Instead, swabbings were collected from areas that were suspected to contain saliva, the lip of the cup, the entire straw, and the spoon, and all were extracted and processed for DNA.

A DNA profile was obtained from the white cup that was consistent with a single male individual (Table 2.1). A DNA profile was also obtained from the straw consisting of a mixture of DNA from more than one person; the major portion of the DNA was different from the male type from the white cup (Table 2.1). A DNA profile was not obtained from the white plastic spoon. Because no suspects had been developed for this case, the profiles from the white cup and straw were both submitted to the CODIS database.

2.17.2 Case Study: Aggravated Sexual Assault

Also in June of 2002, a woman was abducted and sexually assaulted by two men. A sexual assault kit was collected at a local hospital and submitted to the laboratory for analysis. Serology testing was performed on the items from the kit and seminal fluid (AP-positive reaction) was detected on the vaginal and anal swabs. Spermatozoa were visualized on the vaginal and anal smears (microscope slides). These items were saved for DNA analysis.

A differential DNA extraction was performed on the vaginal and anal swabs and the profiles that were obtained were compared with the profiles obtained from the complainant and two suspects (Table 2.2). The sperm fraction of the vaginal swabs was consistent with one of the two suspects identified in the case (suspect 2). The sperm fraction of the anal swabs was consistent with a mixture of DNA from more than one individual; both the complainant and the same suspect (suspect 2) were included as possible contributors to the mixture.

Because of the DNA evidence, other evidence from the case, and extenuating circumstances, both suspects pled to a considerable jail sentence. The profile from the sperm fraction of the vaginal swabs was entered into the CODIS database, as was the profile from the other suspect (suspect 1). These profiles later produced a high stringency match at the local level with the profile from the straw (to the sperm fraction of the vaginal swabs) and the styrofoam cup (to suspect 1) from the case above (Sect. 2.17.1). Since both suspects were already serving an extended sentence, the investigation into the stolen car case was closed.

Recommended Readings

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http://ystr.charite.de/
http://www.mitomap.org/
http://usystrdatabase.org/
http://www.criminalistics.com/

2.18 Glossary

Acid phosphatase	An enzyme present in high concentrations in seminal fluid.
AP	Acid phosphatase.
Allele	Alternate forms of DNA that occur at any one locus.
Amylase	An enzyme highly concentrated in saliva.
CODIS	Combined DNA Index System.
CODIS database	A repository of DNA profiles from forensic evidence and convicted offenders.
Conceptus	Child or offspring; in criminal paternity testing, may be tissue from an aborted fetus.
Confirmatory testing	In serology analysis, testing that confirms the presence of a body fluid on an item.
Contamination	The presence of foreign DNA in a sample.
Criminal paternity testing	A comparison of the DNA profiles of a conceptus, an alleged father, and a mother/complainant (if available) to establish or disprove parentage.
Cytoplasm	The portion of a cell outside the nucleus.

Differential extraction	A DNA extraction that attempts to separate spermatozoa DNA from all other DNA in a sample.
DNA	Deoxyribonucleic acid.
DNA profile	A listing of all observed alleles at each locus.
Electrophoresis	A method to separate proteins or DNA, usually by size, using an electrical current.
Epithelial cells	Cells lining the skin surface and body orifices.
False positive	In serology analysis, a substance other than the specific body fluid in question that may produce a positive reaction during presumptive testing.
Heterozygous	Having two alleles at one locus.
Homozygous	Having a single allele at one locus.
Inhibitors	Chemicals or other compounds in a sample that interfere with DNA analysis.
Loci	Plural of "locus."
Locus	A location on the DNA strand.
Low copy number (LCN) DNA	Samples containing less than 100pg of DNA.
Lyse	In DNA extraction, to break open cells in order to release their components.
mtDNA	mitochondrial DNA.
Mitochondrial DNA	DNA that is contained within mitochondria, found outside a cell's nucleus, in a cell's cytoplasm.
Mini-STR	STR loci where the primers have been redesigned closer to the loci to produce smaller sizes of amplified DNA fragments.
Mixture	In DNA analysis, the presence of more than one individual's DNA on a sample.
Negative control	In DNA analysis, PCR (amplification) reagents without the addition of sample DNA to monitor for contamination of the amplification reagents.
Nuclear DNA	DNA that is found inside a cell's nucleus; unique to an individual.
Nucleus	A portion of a cell that contains (nuclear) DNA.
p30	Also known as PSA (prostate-specific antigen), a protein found in seminal fluid.
Paternity testing	Comparing DNA profiles from a child/offspring and an alleged father to establish or disprove paternity.
PH	Phenolphthalein.
Phenolphthalein (PH)	A chemical used for the presumptive testing of blood.
Presumptive testing	In serology analysis, testing that indicates that a body fluid might be present on an item.
Probative	Referring to items that have evidentiary value, or that are substantiating, especially when presented at court.

PCR	Polymerase chain reaction.
Polymorphic regions	Sections of the DNA strand that are highly variable between individuals.
Positive control	In DNA analysis, a sample for which a DNA profile is established.
Primers	Short segments of DNA that are used to target portions of the DNA strand for amplification by PCR.
Reagent blank	All of the reagents in the extraction process without any sample added; used to detct contamination of the extraction reagents.
Reagents	Chemicals used in laboratory processes.
Remains identification or body identification	Comparing DNA profiles from a body or set of remains to a family member to determine whether the two are related.
RFLP	Restriction fragment length polymorphism.
Semen	A body fluid containing seminal fluid and spermatozoa produced by male individuals for fertilization.
Seminal fluid	A protein-rich body fluid originating primarily from the prostate and seminal vesicles.
Sequencing	A process that breaks down the DNA strand by order into its respective bases (A, C, T, or G).
SNP	Single-nucleotide polymorphism.
Spermatozoa	Male sex cells produced in the testis, also known as sperm.
STR	Short tandem repeats.
Tetramethylbenzidine (TMB)	A chemical used for the presumptive testing of blood.
TMB	Tetramethylbenzidine.
UV	Ultraviolet.
VNTR	Variable number of tandem repeats.
Y-STR	Short tandem repeats on the Y chromosome.

2.19 Questions

1. In the forensic laboratory, what is “serology analysis”?
2. Why is the planning of analysis the biggest challenge to the forensic DNA analyst?
3. What are the advantages of an electronic LIMS system over a paper system?
4. What is the CODIS database?
5. Define the terms “presumptive test” and “confirmatory test.”
6. What is the function of DNA extraction?
7. Why is differential extraction important?

8. What are the benefits of STR analysis over RFLP analysis?
9. In what ways is mitochondrial DNA analysis different than nuclear DNA analysis?
10. What types of sample processing steps can laboratories use to increase productivity in forensic DNA testing?

2.20 About the Authors

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Chapter 3
Forensic Chemistry/Controlled Substances

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Contents

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3.1 Introduction

Forensic chemistry is a broad term that, if taken literally, would encompass most of the functions within a crime laboratory. Techniques used here are also used by many other analytical sections. However, in modern terms, forensic chemistry generally refers to controlled substance or drug analysis.

Traditionally, an examiner enters a crime laboratory career through the forensic chemistry door. Working in this section provides the opportunity for the new examiner to develop the tools required to move on to more complex and subjective examinations. He learns the fundamentals of evidence handling, note taking, and report writing taught and mastered through processing the large volume of cases that pass through this section. The opportunity to learn and hone testimony skills is also available for similar reasons.

The generic educational requirements for an examiner/forensic chemist are the same in most U.S. forensic laboratories. A degree in a hard science with a minimum number of hours of chemistry is generally accepted as the baseline educational standard. This standard is reflected in the recommendations of the Scientific Working Group for the Analysis of Seized Drugs (SWGDRUG). This basic education serves as the necessary foundation for the balance of the examiner's career. To paraphrase a former colleague, "We can teach you forensic applications. We don't have time to teach you chemistry."

Developing a specific thought process is also taught during an examiner's early years in the forensic chemistry section. Deductive reasoning skills are cultivated. The examiner is taught how to utilize their education and training to identify and defend the identification of controlled substances in an exhibit using the information from a series of nonspecific tests. The examiner then supports their findings with a specific test, confirming the presence of the controlled substance.

The analysis of controlled substance exhibits is a straightforward process. The examiner uses a series of nonspecific tests and deductive reasoning to form an opinion concerning the contents of the exhibit under examination. The opinion is supported using modern instrumentation, which provides documentable confirmation. The thought process learned and developed performing these black and white examinations will be invaluable experience to the examiner as the examiner moves onto types of examinations whose results are at best seen as shades of grey.

3.2 Examination Process

The controlled substances section receives a variety of evidence types ranging from botanicals to pharmaceuticals. They can be in any physical state (i.e., solid, liquid, or gas). Controlled substance examinations can be simply divided into two basic forms: biological and chemical. Botanical examinations identify physical characteristics of plants that are considered controlled substances. Chemical examinations use wet chemical or instrumental examination techniques to identify specific substances that are controlled by statute.

3.2.1 Scope of Analysis

Local laws and criminal procedures will be the driving force behind the scope of the analytical process. The laboratory's mission within its agency will also weigh heavily into the depth of analysis each exhibit will receive. For example, the amount of analytical effort involved in the identification of a controlled substance for criminal prosecution purposes is significantly less than that required for intelligence gathering and investigative purposes. The only information required in a criminal prosecution is the identity and amount of controlled substance contained in an exhibit. Laboratories responsible for intelligence gathering will also identify the types and quantity of the exhibit's diluents and adulterants.

The level of analytical detail required not only affects the time involved but the type of instrumentation required. Most forensic chemistry sections can provide a complete range of analytical service wet chemical techniques, basic mass spectroscopy (MS), or infrared (IR) spectroscopy. As the level of information detail increases, so does the type and sensitivity of the instrumentation required. For example, the equipment and procedures required to confirm the presence of heroin in a street sample is far less sophisticated than the one needed to identify the region of the world in which the opium used to produce the heroin was grown.

The final issue that determines the depth of analysis is laboratory policy. The laboratory's policy is generally developed through collaboration between the laboratory's management and a peer group consisting of the examiners who perform the examinations on a daily basis. This represents a balance between the need to produce timely results that meet the applicable legal criteria while at the same time not compromising the scientific integrity of the examination.

An example of this collaboration is the need for quantitative analysis. Unless mandated by statute, the amount of a controlled substance in an exhibit is not an element of the crime. However, this information may have investigative significance and can also be used as part of an internal quality control (QC) procedure. It may not be realistic to quantitate every exhibit submitted for analysis. Therefore, laboratory and investigators work together to establish a quantitation policy that satisfies the needs of both parties.

3.2.2 Planning

The examination planning process begins before the examiner ever encounters the evidence. It begins as the examiner reviews the "request for analysis" form. Every laboratory has its own version of this document. However, they all contain a section listing who requested the analysis, the type of examination, a description of the exhibits submitted for analysis, and chain of custody sections.

During the initial review, the examiner compares the type of evidence that has been submitted to the information the submitter wants from the examination. The examiner evaluates whether the available technology will provide the information the submitter desires. The examiner compares the submitter's request to the applicable statutes and laboratory policy. The examiner evaluates other examination requests for the same exhibits to ensure that the analysis will not affect the results of the other examinations.

Local laws and criminal procedure codes influence the examiner's analysis. For example, criminal procedures in the United States provide examiners more latitude in planning their examination than laboratories in former Soviet Republics. The request for analysis document in the former Soviet Republics is actually a request from the Court to perform a specific examination that will answer a specific question. In the United States, the examination of physical evidence is a fact-finding exercise used to identify the contents of the exhibit. Once the presence or absence of a controlled substance is determined, the appropriate criminal charge can be applied or dismissed.

The ability of the examiner to perform the tests they think appropriate may be both a blessing and a curse. On the positive side, it provides the examiner the ability to identify and report the presence of any controlled substances detected during the examination. On the other hand, the examiner may have to justify why the examinations that were performed were outside the scope of those requests listed on the submission form.

As the examiner reviews the analysis request, a list of questions that must be answered is subliminally formulated. The examiner evaluates what information the investigator desires and what information is required by statute. The questions that need to be addressed in controlled substance examinations are the same in most cases. The basic issues that must be addressed are:

"How much does the exhibit weigh?"
"What controlled substance does the exhibit contain?"
"What is the statutory classification of the controlled substance?"
Auxiliary questions that may need to also be asked and answered are:
"What percentage of the exhibit contained a controlled substance?"
"What adulterants and diluents were identified?"

Below are two examples of an examiner working outside the parameters listed on the request form:

A sample from a clandestine lab was submitted with a request to examine for the presence of methamphetamine. The analysis did not detect methamphetamine.

However, the sample did contain a controlled hallucinogen, diethyltryptamine. As a result of the examination, the charges against the suspect were amended to reflect the controlled substance that was present.

A narcotics officer requested a qualitative and quantitative examination of an exhibit suspected to contain cocaine. When the examiner was asked why the quantitative portion of the exam was not performed, the examiner replied that neither the statute nor laboratory policy required quantitative examination.

In the first case, the examiner went beyond the scope of the request. The standard analytical scheme screened for all controlled substances. If one was detected, the examiner confirmed its presence. This method allowed the charges to be modified to include the identity of the controlled substance that was detected.

The second examiner's refusal to quantitate the exhibit did not affect the legal proceedings. The governing statutes and sentencing structure did not contain language that required quantitation. Additionally, laboratory policy did not require quantitation as part of the analytical scheme due to the lack of legal foundation.

The legal system in the United States is adversarial. The examiner must be able to articulate, to the prosecutions and the defense's satisfaction, the rationale behind each step of the examination process. The examiner must keep this in mind as the analytical road map is drawn up. The examiner must ask, "Can I explain how and why I performed this examination on this exhibit?" for every step of the process.

Once the examiner receives the exhibit, the same decision-making process is gone through for each item. Like a computer, the examiner routinely goes through a series of yes/no or if/then questions during the examination. This analytical approach should be the same with each piece of evidence to avoid a perception of bias on the part of the examiner. If accused of preconception, the examiner can successfully defend their process by responding that the same analytical scheme was always used and that the test results themselves dictated the direction of the analysis.

3.2.3 Documentation

Documentation is the life blood of the legal system. It has been said that if it is not written down it does not exist. Therefore, it is essential that each step of the examination process be documented.

This adage has become more important since the O.J. Simpson defense team implemented the "Call you a liar" defense. Investigators and forensic personnel were required to prove tests were performed and the results presented in court represented the results observed in the laboratory or at the crime scene. This defense strategy forces the forensic examiner out of the shadows of the "Trust me: I am from the government and here to help" mentality to an objective seeker of scientific truth.

Documentation provides a mechanism for peer review that is the mark of good science and a cornerstone of a quality assurance (QA) program. An examiner's notes and analytical data must justify the conclusion articulated in the final report. More importantly, a reviewer in the same area of expertise should agree with the

report's conclusion after reviewing the original examiner's notes and analytical data. The reviewer may have a different opinion. However, the reviewer agrees that the examiner's data supports the examiner's conclusion.

Documentation of physical evidence has three critical components. Each component has its own documentation requirements. Every laboratory and laboratory section may have its own format in addressing these documentation requirements. However, each component must still be addressed. These common components are chain of custody, working notes, and final report.

3.2.4 Chain of Custody

The chain of custody is a document that establishes the integrity of a sample by tracking its handling and storage from its point of collection to its final disposition. Simply put, the chain of custody is a document (or series of documents) that tracks the location of an exhibit from crime scene to courtroom and beyond.

The forensic chemistry section's chain of custody issues are simple for the most part. The examiner documents when and from whom the exhibit(s) was initially received and when and to whom the exhibits were returned after the examination was completed. It is generally accepted that the exhibit is in the examiner's sole care and custody during this time frame. The documentation is usually accomplished through the use of an official form and supplemented by notations in the examiner's working notes.

What happens to the exhibit once it is received by the examiner is rarely addressed, but equally requires documentation. The date and time an examination occurred have become issues. The identity of the person who actually performed one or more of the tests is another issue that must be documented as well as the time and date the exhibit or test sample was transferred to a different examiner for specific testing.

Intra-laboratory transfers of exhibits or samples from an exhibit should be treated the same as inter-laboratory transfers. The examiner transfers control of the exhibit or sample to another individual for a specific examination. The time of the transfer and the identity of the second examiner are just as relevant in a legal proceeding as the transfer into and out of the laboratory. Therefore, they should be documented in a similar manner.

The early use of mass spectrometry is an example of when this transfer should be documented. The mass spectrometer was an expensive, highly specialized piece of instrumentation when it was first introduced into the forensic laboratory. The primary examiner had to rely on the mass spectroscopist to perform examinations specific to the mass spectrometer. Often the primary examiner had no direct knowledge of how the sample was handled once it was transferred to the mass spectroscopist. Even though the primary examiner interpreted the resulting data and possessed theoretical knowledge of the instrument's operation and the sample preparation techniques used, the primary examiner could not provide direct knowledge that every procedure was followed. This is a chain of custody issue that demands documentation.

3.2.5 Working Notes

The examiner's working notes are the second component of the documentation process. They consist of a compilation of handwritten notes, worksheets, and instrumental data with three functions. First, they document the examination actually occurred. Second, they serve as a foundation for the examiner's opinion that can be subjected to peer review. Third, they are used to refresh the examiner's memory during the report-writing phase or before and during trial testimony.

Handwritten notes have two formats. Notes can be simply a series of notations on a blank sheet of paper. Preprinted worksheets can alternatively be used to streamline the documentation of the repetitive testing procedures used in drug analysis. No matter which form notes take, each page should contain the examiner's initials, date the examination occurred, case number, exhibit number, page number, and total number of pages (including pages of instrumental data).

Legibility is a key component of handwritten notes. Notes are not only used to refresh the examiner's memory, but are also a part of the peer review process. If the examiner uses shorthand, it must be decipherable if the peer review process is to be effective. If the shorthand is confusing, then its meaning may be misinterpreted, leading to ambiguity rather than clarity.

3.2.6 Final Report

The official report is the final component of the documentation procedure. This report summarizes the examination of the evidence into a single concise document. All of the information in the case notes, analytical data, and the examiner's professional opinions should be reflected in this report. The final report should provide the reader a road map of the trip the exhibit took through the forensic examination process. Ideally, this report should be able to stand on its own and not require courtroom explanations from the examiner.

Every laboratory has its own examination report format. Most of these formats are based on the criteria set forth by the American Society of Testing Materials (ASTM), the American Society of Crime Laboratory Directors/Laboratory Accreditation Board (ASCLD/LAB), or one of the various scientific working groups (SWGs). Although visual layout may vary, every report should include:

Examining laboratory identity
Case file number
Name of the individual requesting the examination(s)
Examiner's name
A list and description of the exhibit(s) submitted for examination
Description of the examination(s) performed
Results of the examination
Chain of custody information

ARIZONA DEPARTMENT OF PUBLIC SAFETY
SCIENTIFIC EXAMINATION REPORT

AGENCY Phoenix Fire Department DR NO 97-48812

FILE NO. 97125119 PAGE 1 of 4

OFFICER Wilson; F1810

DATE 10/22/97

SUSPECT

ITEM #1

SEALS Tape Seal CONTAINER 1 gal Paint Can

CONTENTS Burned Wood + Carpet

ODOR —

SAMPLE PREP SOLVENT DILUTION
PASSIVE ABSORPTION (E 1412)
SOLVENT WASH (E 1386)

SOLVENT CARBON DISULFIDE PENTANE

GAS CHROMATOGRAPHY (E 1387)
75% Weathered Gas

MASS SPECTROMETRY (E 1618)
— N/A —

CONCLUSION Contained Gas Residue

CUSTODY OF EVIDENCE

RECEIVED SJD - 10/22/97 1335

DISPOSITION SJD 10/25/97 1145

EXAMINER

Donnell R. Christian, #3239
Central Regional Crime Lab
223-2394

Accredited by the ASCLD Laboratory Accreditation Board

Fig. 3.1 Example of a scientist's working notes

As previously stated, there should be sufficient information in the final report to make the testimony of the examiner unnecessary. Simple one- and two-word answers in the administrative sections are usually adequate. The examination descriptions and results sections do, however, require more detail. Some formats have already separated these sections. Other formats include a description of the

testing process in the results narrative. In either case, the report's reader should be able to discern what controlled substance was identified and what the testing process was that was used to make that determination.

Below are two examples of styles of reporting examination results.

Example 1

Items	White powder Plant material
Exam	Drugs
Results	Contained cocaine, a narcotic drug. Substance weight 1.32 g. A usable quantity Contained marijuana. Substance weight 6.29 g. A usable quantity

Example 2

Items	Item 1 contained a paper packet containing a white powder Item 2 contained a plastic bag containing green leafy plant material
Results	The examination of Item 1 using wet chemical tests, microcrystal tests, gas chromatography (GC), and IR spectroscopy concludes that Item 1 contained a usable quantity of cocaine. The total substance weighing was 1.32 g, which is considered a usable quantity. Cocaine is defined as a narcotic drug under ARS 13–3401.20 The examination of Item 2 using microscopic and wet chemical techniques concludes that Item 2 contained marijuana. The total substance weighing was 6.29 g, which is considered a usable quantity. Marijuana is defined as a narcotic drug under ARS 13–3401.20

Example 1 provides the basic information in a no-nonsense format. The reader can quickly identify what each exhibit contained, the quantity of the substance, its classification under the governing statutes, and a case law-required opinion concerning the amount of substance seized. However, information concerning how the examiner reached his conclusions is not presented. This omission may lead to an unnecessary and time-consuming court appearance.

Example 2, by contrast, includes information concerning how the examiner reached his conclusions. The key pieces of information, i.e., the identity, weight, and classification of the controlled substance, do not jump out at the reader as in Example 1. However, the information concerning the basis for the examiner's conclusions is included. This addition may lead to more stipulations by the opposing attorney, thus reducing the number of court appearances required by the examiner.

Figure 3.2 presents a compromise in report writing style. It provides an individual section in which the examiner can provide the details required to satisfy the ASTM formatting suggestions as well as place this information in a concise, easy-to-read format.

PBSI
PROFESSIONAL BUSINESS SOLUTIONS, INC.
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Scientific Examination Report

Agency Name	Maricopa County Sheriff's office	Case # 09-01-021
Agency #:	09-24567	
Officer	Eccles #2543	
Date:	27 January 2009	

Exhibits

Exhibit 1 contained a paper packet containing a white powder.

Exhibit 2 contained a plastic bag containing green leafy plant material.

Examinations

The examination of Exhibit 1 used a combination of wet chemical tests, microcrystal tests, gas chromatography and infrared spectroscopy.

The examination of Exhibit 2 used a combination of microscopic examination and wet chemical techniques.

Results

Exhibit 1 contained cocaine, a narcotic drug as defined in under ARS 13-3401.20. The total substance weighing was 1.32grams, which is considered a usable quantity.

Exhibit 2 contained marijuana, a narcotic drug as defined under ARS 13-3401.20. The total substance weighing was 6.29 grams, which is considered a usable quantity.

Chain of Custody

Received: John Smith, 24 January 2009 **Examiner** Donnell Christian

Disposition: Mary Jones, 26 January 2009

1001 Boardwalk Springs Place, Suite 111
O'Fallon MO 63368-4777
866-965-9222
WWW.EPBSI.COM

Fig. 3.2 Scientific examination report example

3.3 Analysis

In October 2000, the SWGDRUG met in Vienna, Austria to finalize its recommendations concerning the examination and identification of controlled substances. Some of these contained recommendations for the minimum examination requirements for the identification of controlled substances. Although these recommendations do not hold any statutory authority, they do represent the accepted analytical standards established by a consensus of the scientific community engaged in the analysis of drugs of abuse.

The identification of controlled substances is divided into botanical and chemical examinations. Botanical examinations identify physical characteristics specific to plants that are considered controlled substances.

Chemical examinations use wet chemical or instrumental techniques to identify specific substances that are controlled by statute. The analytical testing sequence is represented by a simple flow chart. For each examination, a series of tests is administered to the sample. Each test is more specific than the last. At the end of the sequence, the examiner is able to determine if there is a controlled substance in the sample and to identify it.

3.3.1 Botanical Examinations

Botanical examinations are the most common analyses performed in the controlled substance section. It is not unusual for marijuana examinations to exceed 50% of the controlled substance's caseload. Programs utilized by some agencies allowing trained law enforcement personnel to provide preliminary cannabis identifications have dramatically reduced the number of laboratory examinations.

The forensic chemist walks a tightrope when performing botanical examinations. The examiner is identifying plants and plant material, not the specific psychoactive ingredient. Generally, the examiner is a chemist by education and training, not a biologist or a botanist. Although the examiner has been trained in the identification of specific types of plants or plant parts and can identify whether plant material is or is not marijuana, peyote, or opium, beyond that, the examiner should not render an opinion as to the identity of the substance.

Plants that require botanical examinations by the forensic chemistry section include marijuana, peyote, mushrooms, and opium. Marijuana is by far the most common botanical examination. The examination of mushrooms, peyote, and opium poppies samples is rare in the United States. However, the examiner must know the physical characteristics of these plants in order to be able to recognize them when they are presented in case samples (Fig. 3.3).

The examination techniques that are used for botanical examinations are subjective and cannot be easily documented in a manner that can be objectively reviewed. The peer reviewer only has the comments in the working notes to evaluate, unless some form of photography is used to document the visual and wet chemical examinations.

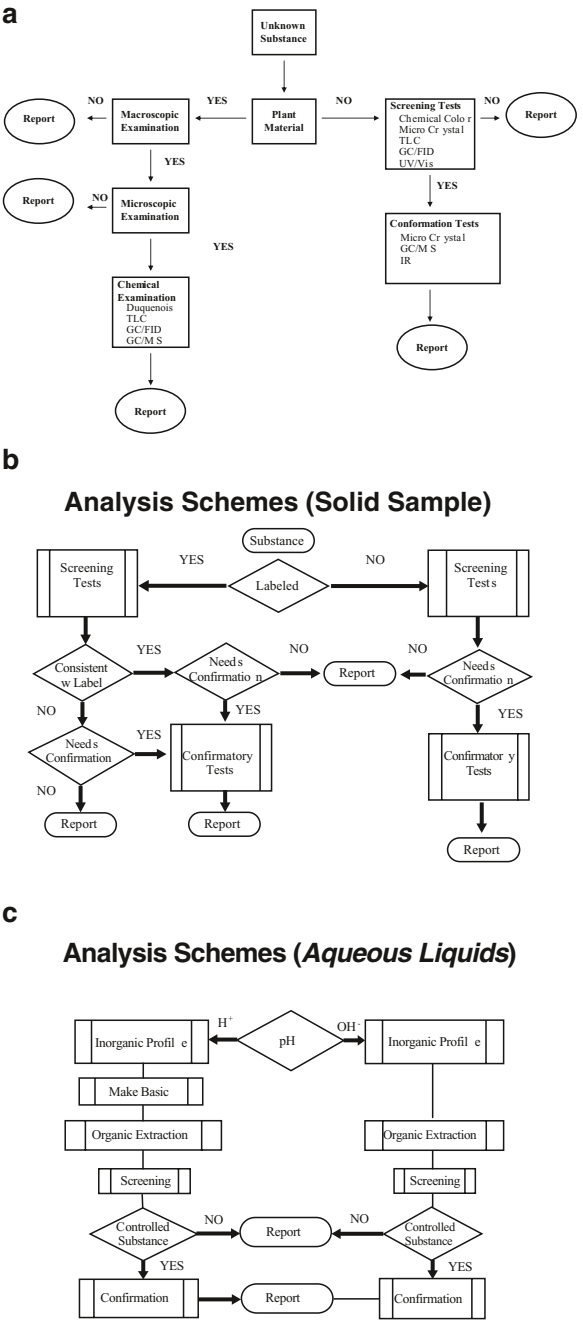

Fig. 3.3 (**a**) Plant material exam flowchart. (**b**) Solid sample exam flowchart. (**c**) Aqueous sample exam flowchart

Therefore, the examiner's working notes should contain as much detail as possible when describing the visual examination.

There are documentable instrumental techniques that can be employed to identify specific chemical components within the botanical sample. However, the presence or absence of the component in question may or may not be an element of the identification criteria. Below are four legal definitions of plants that are considered controlled substances that demonstrate the variation of need to identify specific chemical compounds.

The term "marijuana" means all parts of the plant *Cannabis sativa L.*, whether growing or not; the seeds thereof; the resin extracted from any part of such plant; and every compound, manufacture, salt, derivative, mixture, or preparation of such plant, its seeds, or resin. Such a term does not include the mature stalks of such plant, fiber produced from such stalks, oil or cake made from the seeds of such plant, any other compound, manufacture, salt, derivative, mixture, or preparation of such mature stalks (except the resin extracted therefrom), fiber, oil, or cake, or the sterilized seed of such plant that is incapable of germination.[1]

"Marijuana" means all parts of any plant of the genus cannabis, from which the resin has not been extracted, whether growing or not, and the seeds of such plant. Marijuana does not include the mature stalks of such plant or the sterilized seed of such plant that is incapable of germination.[2]

"Coca leaves," means cocaine, except coca leaves and extracts of coca leaves from which cocaine, ecgonine, and derivatives of ecgonine or their salts have been removed.[3]

"Coca leaves" means cocaine, its optical isomers and any compound, manufacture, salt, derivative, mixture or preparation of coca leaves, except derivatives of coca leaves that do not contain cocaine, ecgonine, or substances from which cocaine or ecgonine may be synthesized or made.[4]

The above legal definitions establish the baseline from which the analytical process is derived. In one instance in which identifying the presence of the psychoactive component of the plant is not a requisite element of the definition. However, some laboratories do require the chemical identification of the psychoactive component to enhance the level of the examination's specificity. The other examples are instances in which the presence or absence of specific psychoactive component(s) determine the botanical's legal status.

Botanical examinations are the only area of controlled substance examination in which DNA analysis has a potential application. However, no genetic markers are forensically accepted for use in identifying specific types of plants. Time and financial constraints also discourage the use of DNA for plant identification.

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[1] Title 21 of the United States Code (21 USC) chapter 13, Subchapter I, Part A, Section 802.16.

[2] Arizona Revised Statutes, Title 13, chapter 34, 13–3401.19.

[3] Title 21 of the United States Code (21 USC) chapter 13, Subchapter I, Part A, Section 802.17c.

[4] Arizona Revised Statutes, Title 13, chapter 34, 13–3401.5.

3.3.1.1 Marijuana

Marijuana is the common name for the plant *Cannabis sativa L.* Numerous treatises concern themselves with the number of species of cannabis, but it is generally accepted that there is only one species. The different varieties of marijuana, indica, rhutamalus, etc., are simply variations of the sativa species. To avoid this ongoing debate, some jurisdictions have opted to control all varieties of marijuana by defining the genus cannabis as the controlled substance.

The identification of marijuana is a two-step process. The first step establishes the plant or plant material as marijuana through its physical characteristics. The second step is to establish the presence of the plant resin that contains the psychoactive components.

The identification process begins with a macroscopic examination of the plant material to establish if the plant material has the class characteristics of marijuana. The marijuana plant structure has palmate leaf configuration and pinnate leaf structure with serrated edges. The plant stems have a fluted structure. These class characteristics may not be readily observed in samples of crushed plant material that has been submitted for analysis. However, with experience, the trained eye can recognize plant material with the macroscopic consistency of marijuana (Fig. 3.4).

A microscopic examination is used to identify the individual characteristics that are unique to marijuana (Fig. 3.5).

This examination includes the identification of cystolithic (bear claw shaped) hairs on the top surface of the leaf and finer clothing or guard hairs on the underside of the leaf. The bud material of the plant may have the presence of a red "thread" entwined in it.

The identification of cannabis resin, which contains the psychoactive components, is the second phase of marijuana examination. The Duquenois–Levine test is the chemical color test used to confirm the presence of compounds called cannabinoids. Delta 9 tetrahydrocannabinol (THC) is the primary psychoactive compound in this class. The exact mechanism of the reaction of this chemical color test has not been established. However, it has been accepted as specific for the identification of marijuana resin.

Additional chemical tests for marijuana resin include chromatographic examination to establish the presence of specific cannabinoids. Thin-layer chromatography (TLC) has been the traditional method of choice. It separates the cannabinoids in the resin and provides a chemical color test to identify their location on the thin-layer plate. The questioned sample's pattern of colored spots is compared with a known sample of cannabis resin that is examined at the same time. It is considered a match if the patterns of the known and the questioned samples have the same sequence of colored spots.

The use of GC to identify cannabis resin has increased in popularity. GC provides the examiner a documentable method of establishing the presence of various cannabinoids. It also provides a means of establishing the relative amount of each compound in the sample by comparing the size of each peak in the chromatogram. It is considered a match if the retention time (Rt) of a predetermined number of cannabinoids appear in the chromatogram. The relative size of the peaks is not an issue in the identification process.

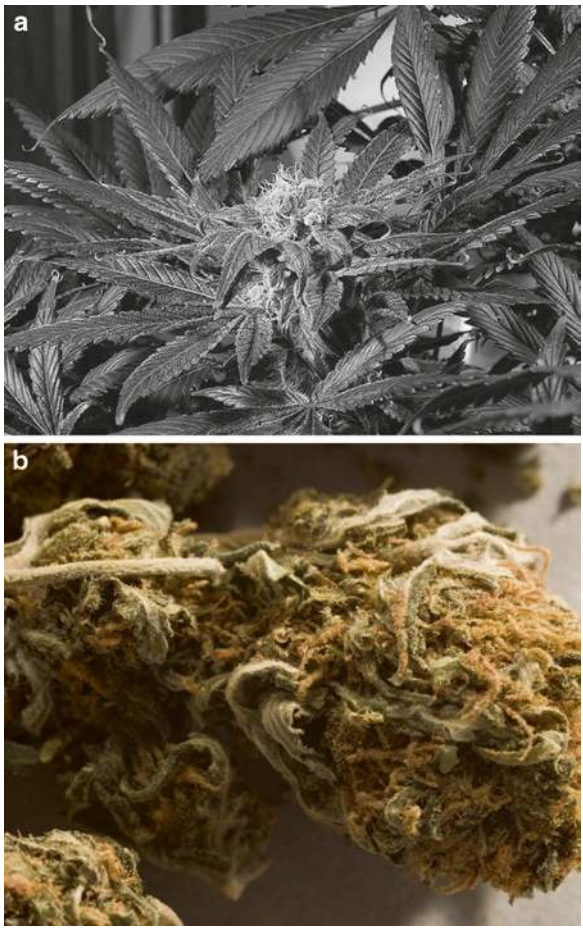


Fig. 3.4 (**a**) Marijuana leaves. (**b**) Marijuana bud

Fig. 3.5 Microscopic marijuana leaves

Mass spectroscopy can be used to positively identify individual components of the cannabis resin, specifically THC. One school of thought considers this testing excessive because the law governing the possession of marijuana states the plant material only needs to contain the cannabis resin, not any specific component. Since the Duquenois–Levine test is considered specific for cannabis resin, the mass spectrum of any or all of the cannabinoids is unnecessary. Another school of thought considers the MS examination necessary to positively establish the presence of one or more of the cannabinoids, specifically the psychoactive ingredient THC.

3.3.1.2 Hashish

Contrary to common belief, hashish is not a potent form of marijuana. Hashish is the resin from marijuana that has been isolated from the plant material. It can be found as oil or in cake form. The oil is added to other substances and smoked. The cake can be smoked separately or added to other materials and smoked.

The analysis of hashish depends upon the statute regulating its possession. The federal law does not distinguish between marijuana and hashish. Some state and local jurisdictions define hashish separately. If the hashish statutes mirror marijuana's, a Duquenois–Levine test may be all that is required to establish the presence of cannabis resin. If the statute identifies specific compounds that must be present (e.g., THC), a confirmatory test such as mass spectroscopy should be performed. Internal laboratory protocols also assist the examiner in establishing the requisite analytical scheme.

3.3.1.3 Peyote

Peyote is the common name for the small Mexican cactus *Lophophora williamsii*. The indigenous people of Mexico and the southwestern United States have used it in religious ceremonies for centuries. *Lophophora diffusa* is a rare species of peyote that is occasionally encountered. Each variety contains mescaline (3,4,5 trimethoxyphenethylamine), which produces hallucinogenic effects.

The identification of peyote begins with a macroscopic examination of the plant material. The peyote "button" is approximately 1 in. in diameter. It can be divided into five to ten orange-like segments or has a soccer ball-like appearance. Each segment contains a small white tuft of material similar to a cotton ball. Peyote does not have specific microscopic characteristics that can be used for identification purposes. The presence of the cotton-like tuft is generally used as a predecessor to the chemical examination steps (Fig. 3.6).

A chromatographic examination is used to confirm the identity of peyote. The examiner uses this examination to identify a pattern of alkaloids characteristic of peyote in a manner similar to the comparison of marijuana resin to known cannabis resin. The chromatographic pattern can also be used to identify the specific peyote species. TLC and gas chromatography techniques work equally well.

Fig. 3.6 Peyote cactus

The identification of mescaline is not an essential element of the peyote identification process. However, it should be in the chromatographic pattern that is used to identify peyote. A confirmatory test for mescaline is not required since the examiner is identifying the plant, not the psychoactive components.

3.3.1.4 Mushrooms

The analytical approach to mushrooms is different from the approach to marijuana and peyote, since the possession of mushrooms is not illegal per se. The components within the mushrooms (i.e., psilocin and psilocybin) are the items that are controlled. Therefore, the addition of a step to confirm the presence of psilocin or psilocybin is required.

The physical identification of mushrooms that potentially contain psilocin or psilocybin is the initial step in the identification process. Over a dozen species of mushrooms contain these compounds. Figure 3.7 is a photograph of a variety of commonly encountered psilocybe mushrooms. The stems of the species most commonly encountered are off-white in color with a blue-gray staining throughout. The color of the mushroom caps ranges from off-white to light brown or tan.

The next step in the screening process is testing for the presence of psilocin and psilocybin. These tests include chemical color tests, TLC, and examination of extracts using ultraviolet light (UV). Two chemical color tests are useful in the screening process. Color test reagents, such as Van Urk's, that contain para-dimethylaminobenzaldehyde (pDMBA) turn purple in the presence of psilocin and psilocybin. An aqueous solution of fast blue B turns red when exposed to mushrooms containing psilocin and psilocybin. This solution turns blue with the addition of concentrated hydrochloric acid (HCl). For UV and TLC analysis,

Fig. 3.7 Mushrooms

methanol can be used to extract psilocin and psilocybin from mushrooms. Psilocin and psilocybin absorb UV light, producing a characteristic UV spectrum. They can be separated chromatographically using TLC. Visualization can be achieved using UV light or by spraying the TLC plate with Van Urk's reagent. Psilocin and psilocybin spots on the thin-layer plate glow when exposed to UV light and turn violet when over sprayed with Van Urk's reagent.

The preliminary identification of psilocin and psilocybin is critical in determining the confirmatory test and the sample preparation technique that will be used. Psilocybin is a fragile molecule. Certain sample preparation techniques convert the psilocybin into psilocin. If the preliminary identification is not done prior to the confirmatory test, the examiner cannot definitively say that the psilocin identified in the confirmatory test was originally in the sample or was a result of the conversion of psilocybin during the extraction. Therefore, the determination of the presence of the compounds prior to the confirmatory test is necessary to evaluate the results properly.

Wet chemical extraction techniques must be used for infrared spectroscopy confirmation of psilocin. Two facts should be considered when using this technique. First, wet chemical extractions cannot separate psilocin from psilocybin. Second, psilocybin may be converted into psilocin during the extraction process. Therefore, if the examiner has not predetermined the presence of psilocin in the sample, it may be erroneously identified.

Gas chromatography–mass spectroscopy (GC/MS) can be used to identify both psilocin and psilocybin. As in IR analysis, the determination of whether psilocin or

psilocybin is present prior to analysis is an issue. Direct injection of an extract containing both psilocin and psilocybin into a gas chromatograph results in the detection of only psilocin. The psilocybin does not chromatograph well and can decompose into psilocin. This raises the question of whether the psilocin was there prior to the injection. Chemical reagents can be added to extracts containing psilocybin. These reagents react with the psilocybin to create a stable molecule that can be analyzed using GC/MS. The resulting molecule will produce a mass spectrum that is considered specific to psilocybin.

3.3.1.5 Documentation

In general, no supporting documentation is generated during the identification of marijuana or peyote, other than the examiner's case notes. The case notes do not independently demonstrate that the examination occurred. Even so, they should describe the visual observations the examiner used in making the conclusions. Drawings of the observed characteristic structures can be made to support such conclusions. Descriptions of the color changes during the Duquenois–Levine test are equally important. A positive identification is dependent upon positive results in both steps of the test.

The use of TLC is not a documentable analytical technique. Unless photographs are taken of the thin-layer plate after it is developed, there is no way of verifying that the examination took place. A sketch of the developed thin-layer plate aids in documenting the test results. However, sketches do not allow for an independent interpretation of the plate by a case reviewer or independent examiner. On the other hand, GC is a documentable technique. To document that the examination occurred, the examiner should mark all paperwork related to GC analysis with the information outlined in the instrumental analysis portion of the chemical analysis section.

The documentation requirements for mushroom examinations are different from those for marijuana and peyote because of the need to identify the specific substance that is the subject of the control. Screening tests should be documented in the examiner's case notes in the same manner as marijuana and peyote are documented. However, because the examiner is identifying a specific controlled substance, they should use a documentable confirmatory test whose data is included in the case notes. This documentation should include the information outlined in the instrumental examination section of this chapter. This information allows for an independent interpretation of the test by a case reviewer or an independent examiner.

3.3.2 Chemical Examinations

The balance of the samples encountered by the controlled substances section requires the identification of specific compounds within a mixture. Composition of

the samples may vary, but the identifying procedure remains the same. Each sample requires a screening step, an extraction or sample preparation step, and a confirmatory step to be performed (Fig. 3.3).

The SWGDRUG recommendations divide chemical tests into three categories based upon specificity and documentability. Category A tests are specific and documentable. Category B examinations are documentable and characteristic in nature. Finally, Category C tests are characteristic examinations with less specificity, which may or may not be documentable. Ideally, one or more Category B and C tests are used to screen for the presence of a controlled substance within a sample. Category A tests are used to positively identify the controlled substance present.

Chemical examinations can be simply subdivided into wet chemical and instrumental procedures. Wet chemical procedures are used as a screening method or for sample preparation. Instrumental procedures are used for screening or as a confirmation tool.

Wet chemical procedures are used during the initial stages of the identification process. They consist of chemical color tests, microcrystalline tests, TLC, and liquid extraction techniques. These nonspecific tests provide a method to quickly determine whether a controlled substance may be present within a sample. Some procedures can be used to isolate controlled substances for confirmatory testing using instrumental techniques. A series of these tests can be used to deductively identify a controlled substance.

Instrumental examinations are documentable testing methods. This point is a key element of the confirmation and peer review process. It is not enough for the examiner to be able to claim the compound has the same chemical fingerprint as a controlled substance. In a criminal proceeding, the examiner has to be able to prove it beyond a reasonable doubt, which includes subjecting the examination to peer review. Instrumental examinations provide the vehicle for this review.

3.3.2.1 Wet Chemical Procedures

Wet chemical procedures are used in the initial stages of the controlled substance identification process. These nonspecific tests provide a method to indicate quickly whether a controlled substance is or is not present within a sample. These procedures can be used to isolate controlled substances for confirmatory testing using instrumental techniques. Wet chemical procedures consist of chemical color tests, microcrystalline tests, TLC, and liquid extraction techniques. A series of these tests can be used to identify a controlled substance deductively.

3.3.2.2 Chemical Color Tests

Chemical color tests are chemical reactions that provide information regarding the structure of the substance being tested. Certain compounds or classes of compounds produce distinct colors when brought into contact with various chemical

reagents. These simple reactions can indicate the presence of a generic molecular structure.

Chemical color tests are generally conducted by transferring a small amount of the substance being tested to the well of a spot plate or into a test tube. The test reagent is added to the substance. Some tests may be conducted in a sequential fashion utilizing multiple reagents. The results of each step in the sequence are observed and noted. Positive and negative controls should be run on a regular basis to ensure the reliability of the testing reagents.

A certain amount of subjectivity is involved when a color is reported. It is not uncommon for two people to describe the same color differently. Colors can also be influenced by the concentration of the sample, the presence of diluents and adulterants, and the age of the reagent. The length of time the reaction is observed may also influence the color reported. Color transitions and instabilities are not unusual. Allowances should be made for these differences.

3.3.2.3 Microcrystal Tests

Microcrystal tests are used as a screening tool to confirm a diagnosis made with other testing methods. They are fast and simple to administer, and can be highly specific (although whether they are specific enough to be used as a confirmatory test has been debated).

In microcrystal tests, the test sample is dissolved in a solution. A test reagent either is added to the solution or is already present in the solution in which the sample is dissolved. A reaction between the compound of interest and the test reagent forms a solid compound that is not soluble in the test drop. The solid forms uniquely shaped crystals that can be observed with a microscope (Fig. 3.8).

Microcrystal identification relies upon the comparison of the crystals formed by the unknown with those formed by a reference standard using the same reagent. Difficulties obtaining an exact match between the crystals of the unknown and those of the reference sample may arise. Impurities in the unknown may lead to the formation of deformed, irregular, or unusual crystals. This can be overcome by utilizing a cleanup procedure such as TLC, extractions, or particle picking prior to microcrystal analysis.

Other differences in crystal appearance can arise from the concentration of the solution. The crystals in highly concentrated test drops develop rapidly, resulting in a distortion of the classic crystal shapes. Concentrated test drops should be diluted to a concentration that produces classic crystal forms that are conducive to comparison and identification. Reagent age can also affect crystal development. Unknown and reference samples should be run using the same reagents, under the same conditions, and at approximately the same concentration. Polymorphism is occasionally a source of trouble. Sample concentration and reagent age can lead to the creation of different microcrystalline forms. This reemphasizes the comparative nature of microcrystal identification. The comparison should be done using the same sample concentration with the same crystal reagent.

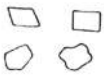
Crystal	Shape	Description
Blade		Broad needle
Bunch / Bundle		Cluster with the majority of the crystals lying in one direction
Burr / Hedgehog		Rosette, which is so dense that only the tops of the needles show
Cluster		Loose complex of crystals
Cross		Single cruciform crystal
Dendrites		Multibrachiate branching crystals
Grains		Small lenticular crystals
Needles		Long thin crystals with pointed ends
Plates		Crystals with the length and width that are of the same magnitude
Prisms		Thick tablet
Rod		Long thin crystals with square cut ends
Rosette		Collection of crystals radiating from a single point
Sheaf		Double tuff
Splinters		Small irregular rods and needles
Star		Rosette with 4 or 6 components
Tablet		Plates with appreciable thickness
Tuff / Fan		Sector of a rosette

Fig. 3.8 Crystal descriptions

Microcrystal tests can also be used to determine the optical isomer of a compound. Single isomer compounds (*d* or *l*) produce a different crystal form than a racemic mixture (*d* and *l*) of the same compound. Single isomer crystals will form if a substance with the same isomer is added to the test solution prior the test reagent. Racemic crystals will form if the opposite isomer configuration is added to the test solution prior to analysis.

The microscopic crystalline structures of a compound can be used to tentatively identify components within a mixture. The examiner can obtain a profile of the various components within the mixture by placing a sample into a liquid test drop in which most, if not all, of the components are insoluble (mineral oil works well for this type of analysis). The component's physical and optical characteristics are then observed using a polarized microscope.

3.3.2.4 Thin-Layer Chromatography (TLC)

TLC is the third wet chemical test used to screen for the presence of controlled substances. It is a separation technique that utilizes molecular mobility and solvent compatibility to separate and distinguish compounds within a mixture. Compounds are separated by their size, shape, and reactivity with the solvent, like rocks flowing down a river. Small compact molecules travel across the TLC plate at a different rate from that of large rambling molecules.

The typical TLC procedure places a sample of the unknown toward the bottom of a glass plate containing a thin layer of silica gel. A sample of a reference compound is placed the same distance from the bottom of the plate. The TLC plate is placed into a tank containing a solvent (or mixture of solvents). As the solvent moves up the TLC plate, the various components within the sample are separated.

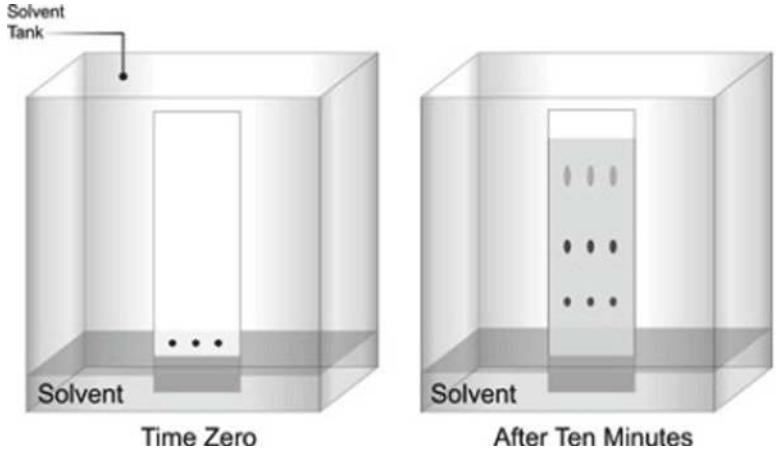


Fig. 3.9 Thin-layer chromatography (TLC)

When the solvent migration is stopped, the TLC plate is removed from the tank and the solvent is allowed to evaporate. The compound movement is then visualized through observation under UV light or through development with a chemical color reagent designed to react with various compounds.

The Rf value is used to establish the identity of the spots on the TLC plate. The Rf value is the ratio of the distance the solvent travels to the distance the compound travels (see Fig. 3.9). The distance the sample travels is measured from the center of the original sample spot to the middle of the densest portion of the spot after the solvent has traveled across the thin layer plate. The distance the solvent travels is measured from the same origin to the leading edge of the solvent front when the thin layer plate is removed from the developing tank.

Many compounds can have the same Rf value with a given solvent system. Multiple solvent systems are necessary when utilizing TLC for identification purposes. Each solvent system should have differing chemical properties to be able to separate compounds with similar Rf values. The solvent choice for the mobile phase will vary depending upon the compound of interest. If the target compound or group of compounds is known, reference material can be used to select a solvent system that works for that compound.

The use of Rf values for a known solvent system provides only a general insight into the identity of the unknown spot. Rf values should not be relied upon for confirmation of unknowns. A known reference sample, run on the same TLC plate, should be used for comparison.

Many factors can affect Rf values. The adsorbent uniformity on the thin layer plate, sample concentration (spotting is too weak or strong), room temperature during the mobile phase, and development distance of the solvent during the mobile phase can all affect the results. Care should be taken to eliminate variances in the method caused by any of these factors. Placing a reference sample containing the suspected compound on the TLC plate with the questioned sample reduces the variables involved in TLC comparisons.

3.3.3 Extractions

Extractions are used to separate the compound of interest from the rest of the sample. The type of extraction used depends upon the compound of interest and the matrix in which the compound is located. In some cases, multiple extraction techniques are necessary to separate the substance of interest from the remainder of the sample. In other instances, instrumental analysis is the only way to separate compounds with similar chemical properties for confirmation.

Extractions are not screening tests per se. However, the fact that the compound is isolated as a result of the extraction indicates that the compound has certain chemical characteristics. These are class characteristics that can be used to support the confirmatory test deductively.

The screening techniques used should be designed to identify as many of the components of the sample matrix as possible. This allows the examiner to select the extraction technique that efficiently and effectively isolates the component of interest from the rest of the compounds. Missing or failing to identify the components within a sample mixture may lead to the selection of an inappropriate extraction technique, which, in turn, may affect the results of the confirmatory test.

The basic types of extractions include physical extractions, dry washing, dry extractions, and liquid/liquid extractions.

3.3.3.1 Physical Extraction

Physical extractions are the simplest. They involve physically removing the particles of interest from the balance of the sample for later analysis. Physical extraction is appropriate when the examiner observes particles of different size, shades, and consistency within the sample. The particles are separated from the bulk sample by the use of stereomicroscopes, tweezers, sieves, or other devices designed to physically isolate particles of different sizes.

3.3.3.2 Dry Wash and Dry Extraction

Dry washes and dry extractions are different versions of the same process. The only difference is the substance that is removed from the sample matrix. A dry wash uses a solvent to dissolve and remove adulterants and diluents from the sample matrix, leaving the compound of interest. A dry extraction uses a solvent to dissolve and remove the compound of interest from the sample matrix.

3.3.3.3 Liquid/Liquid Extractions

The ability of a substance to dissolve in a liquid can change with the liquid environment. Liquid extractions utilize these solubility characteristics to separate a substance from a mixture.

During a liquid/liquid extraction, the sample is initially dissolved into a water solution in which the compound of interest is soluble. This liquid is washed with an organic liquid in which the compound of interest is not soluble, but the diluents and adulterants are. Once the organic liquid is separated, the pH of the water is changed to make the compound of interest insoluble in the water solution. An organic liquid is used to separate the purified substance from the water. Care must be taken when selecting the acidic environment and the organic solvent used in liquid/liquid extractions. Some drugs are subject to ion pairing. This means that hydrochloride salt of the drug is soluble in chlorinated solvents (e.g., chloroform) and will choose the chlorinated solvent over an acidic environment with a high chloride concentration (e.g., HCl).

Ion pairing can be used to the examiner's advantage when multiple basic drugs within a matrix need to be isolated. If one of those drugs is subject to ion pairing, it can be isolated from the other drugs that under normal circumstances could not be separated.

In some instances, the compound of interest cannot be isolated because the sample matrix contains multiple drugs of the same salt type. In these instances a combination of techniques may be necessary to isolate the component of interest. An example of a combination extraction is a TLC separation of the final extract of a liquid/liquid extraction. The silica gel around the spot corresponding to the compound of interest is physically removed from the TLC plate. A dry extraction or another liquid/liquid extraction is performed to isolate the substance from the silica gel.

3.3.4 Documentation

Chemical color tests are a nondocumentable technique. There is no independent record of the performance of the test. The test documentation solely rests on the examiners handwritten notes, so the examiner should describe as completely as possible the colors or transitions of colors that were observed during the course of the test. A plus (+) or minus (−) notation next to a test name does not provide a peer reviewer insight into what the examiner saw during the performance of the test.

Photographing a chemical color test may or may not be a solution to the documentation issue. Photography does demonstrate the color that was observed during the examination. However, it preserves only a portion of the test. Many chemical color tests have a transition of colors from the beginning of the test to the end, so photographs do not adequately reflect the examiner's observations.

As with color tests, no supporting documentation is generally generated with microcrystal examinations. The examiner's description of his or her observations should be as complete and accurate as possible. When definite crystals are formed, their form and habit should be noted (described, sketched, or photographed). Figure 3.8 is a list of descriptive terms that can be used to describe the observed crystals.

Lack of supporting documentation may be less significant if microcrystal tests are used as a screening tool. However, if they are to be used as a tool to specifically identify a compound or isomer, steps should be taken to provide reliable documentation concerning the examiner's observations. Photomicrographs should be taken of the microcrystals that were used to make the identification. The photomicrographs should be included in the examiner's notes for peer review when necessary.

As with color and microcrystal examinations, no supporting documentation is usually generated with the use of TLC. Accurate notes regarding the type of solvent system used should be included in case notes, along with the Rf calculations for the spots used for compound identification. Any deviations from the referenced method

or unusual occurrences noted should also be documented. The examiner should thoroughly describe the observations used to make his or her conclusions, including the colors and patterns observed on the TLC plates as well as any observations made under UV light.

Photography of TLC plates is an option. Photographs can document the examiner's observations of the color and position of the sample spots. If the photograph is scaled properly, a peer reviewer or independent examiner can calculate Rf values.

The extraction phase of the analysis is not used for preliminary or confirmatory identification purposes. However, it is a means to those ends and it should be documented. Peer reviewers should be able to evaluate the extraction technique used to prepare the sample for any subsequent testing.

3.4 Instrumental Examinations

Instrumental examinations are documentable testing methods. This point is key to the confirmation process. It is not enough for the examiner to be able to say the compound had the same chemical fingerprint as a controlled substance. The examiner has to be able to prove it beyond a reasonable doubt. That includes subjecting the test to peer review. Instrumental examinations provide the vehicle for this review.

Four basic instruments are routinely utilized in the controlled substances section. This section describes how each of the instruments can be used to identify controlled substances and drugs of abuse. The UV spectrophotometer and the gas chromatograph are used as screening and quantitative tools. The infrared spectrometer and the mass spectrometer are instruments used to confirm the identity unknowns.

Other instrumental examination techniques are available to the examiner. However, these techniques are not generally utilized by the majority of forensic laboratories conducting controlled substance examination and will not be discussed in detail in this text. These additional examination techniques include: Fluorescence Spectroscopy, Immunoassay, Melting Point, Capillary Electrophoresis (CE), Liquid Chromatography (LC), Nuclear Magnetic Resonance Spectroscopy (NMR), and Raman Spectroscopy.

3.4.1 Nonspecific Examinations

3.4.1.1 Ultraviolet Spectroscopy

Ultraviolet spectroscopy is an instrumental technique that provides compound classification. It is a screening tool, not a confirmatory test. Although some compounds exhibit unique UV spectra, the spectra are considered class characteristics

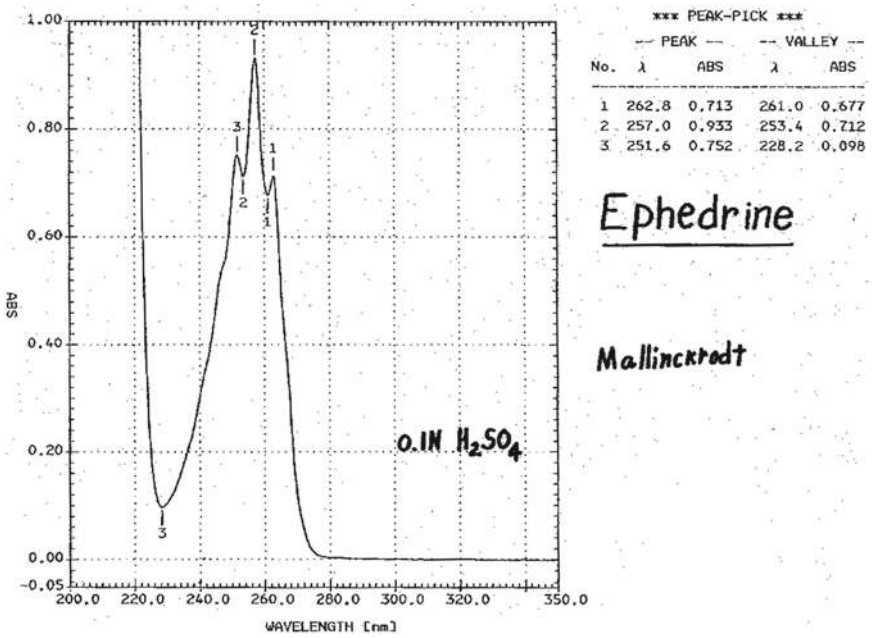


Fig. 3.10 Ephedrine UV spectrum

and do not contain sufficient detail (individual characteristics) to be considered a compound's chemical fingerprint. The two general uses for UV spectroscopy in the controlled substances unit are general screening and quantitation. The shape of the spectrum provides insight into the identity of the compound. The amount of UV light absorbed can correlate to the amount of substance in the sample.

As a screening tool, UV spectroscopy can identify a class or group of compounds in a sample. Many drug groups produce characteristic UV spectra. Figure 3.10 is an example of the UV spectra of a phenethylamine class of drugs. This class includes amphetamine, methamphetamine, ephedrine, pseudoephedrine, and phenylpropanolamine. Amphetamine and methamphetamine are considered controlled substances, and ephedrine and phenylpropanolamine are not. Nevertheless, the five different compounds exhibit similar UV spectra.

Ultraviolet spectroscopy is a useful tool for single component analysis of samples with a known or suspected composition, such as pharmaceuticals. The UV spectrum can confirm or refute the composition of the preparation under examination. However, if compound identification is required, it should be done using a specific test such as infrared or mass spectroscopy.

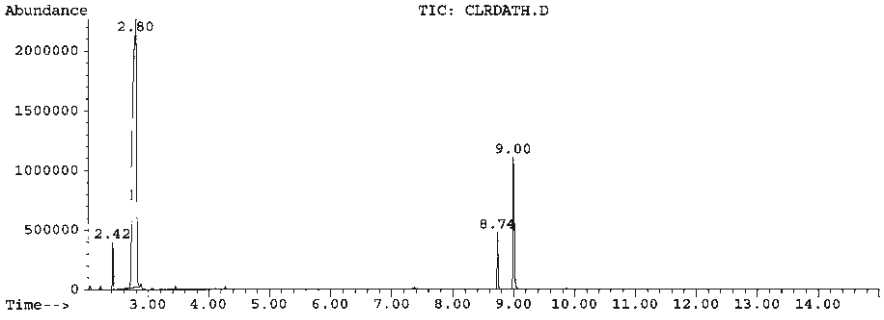
Mixtures of compounds capable of absorbing UV energy can present an analytical problem. Compounds have differing capacities to absorb UV light. If a noncontrolled substance that is a strong UV absorber is mixed in with a controlled substance that is a weak UV absorber, the resulting UV spectrum may not reflect the presence of the controlled substance.

Quantitation is another venue in which UV spectroscopy is useful. To be effective the sample should contain a single UV-absorbing component. If the sample contains multiple UV absorbers, the component of interest should have distinct resolvable absorption bands. The quantitation procedures can be as simple as comparing the concentration of the suspected tampered sample with that of a known unaltered sample. The UV absorbances should be the same if the concentrations and compositions are identical. A detailed analysis can determine the concentration of the substance in question. The absorbance value of the test sample is compared with the absorbances of a series of known solutions. The concentration of the test sample can be taken from the graph of concentration vs. absorbance values of the reference samples.

3.4.1.2 Gas Chromatography

Gas chromatography is a documentable chromatography form that can be used in lieu of TLC. The gas chromatograph separates compounds by their size, shape, and reactivity with the chemical coating of the GC column. It is not a specific confirmatory test for controlled substances. However, dual column techniques and the evaluation of alkaloid peak patterns can be used for identification purposes.

Chromatograms from GCs (Fig. 3.11) are used to identify unknowns on the basis of the retention time (Rt) or relative retention time (RRt) of a peak under certain operating conditions. The Rt is the time it takes a compound to travel from the injection port of the GC to the detector. The RRt is the ratio of the retention time of the substance to the retention time of an internal standard that is placed into the sample. The RRt is considered a more reliable value. The internal standard provides a reference point to calculate RRt values. It also can be used to demonstrate the precision and accuracy of the instrument. The internal standard eluting at the proper time indicates



TIC: CLRDATH.D
sample 8 for the clan lab analysis workshop

Peak#	Ret Time	Type	Width	Area	Start Time	End Time
1	2.419	BV	0.032	4612816	2.383	2.461
2	2.802	PV	0.060	101598026	2.461	2.862
3	8.737	BV	0.023	6325894	8.694	8.850
4	9.003	PV	0.026	17448828	8.850	9.115

Fig. 3.11 GC chromatogram

that the gas flow and oven conditions are operating properly. The size of the peak of a known concentration of internal standard indicates proper operation of the detector.

Analysis by GC alone is not generally considered confirmation of a controlled substance. More than one compound could possibly have a given Rt or RRt. With conventional detectors (i.e., flame ionization, electron capture, nitrogen/phosphorus, etc.), the examiner cannot definitively tell what compound elutes at a given Rt or RRt. Dual-column GC has been used as a confirmatory test. A single sample is injected into a GC that divides the sample into two chromatographic columns. Each column contains a different liquid phase (the interior coating that causes compound separation). A compound is considered identified if the compound has the proper Rt or RRt on both columns.

Commonly, GCs are used as the separation tool for the confirmatory tests of mass spectroscopy and infrared spectroscopy. The GC separates the compounds, and the MS or the IR provides information concerning the chemical properties of each of the compounds as it elutes from the chromatographic column.

Quantitation is another use for GC. This can be accomplished through a serial dilution method similar to that used in UV analysis, or with a relative response technique. As a quantitation tool, GC has an advantage over UV. The effects of multiple components within the sample are reduced or eliminated because GC separates the components of the sample during the analysis.

3.4.1.3 Liquid Chromatography

Liquid chromatography (LC) utilizes the same generic principles as gas chromatography to separate components of a mixture. It is considered a softer or gentler chromatographic technique because it uses the chemical properties of the liquid or liquid mixture used as a carrier to perform the function of changes in temperature on the GC column. This is the preferred technique for compounds that are unstable or thermally reactive.

The availability of detectors that can be used with broad range or specific applications has limited the use of LC in the forensic laboratory. However, recent advances in LC detector technology have slowly expanded the number of detectors available for use with liquid chromatography. Specifically, mass spectroscopy applications have been incorporated into use with liquid chromatography.

3.4.2 Specific Examinations

3.4.2.1 Mass Spectroscopy

Mass spectroscopy uses the pattern of molecular pieces (ions) that is produced when a molecule is exposed to a beam of electrons. This characteristic pattern is called the mass spectrum. It is considered one of a compound's chemical fingerprints. Figure 3.12 is an example of the mass spectrum of heroin.

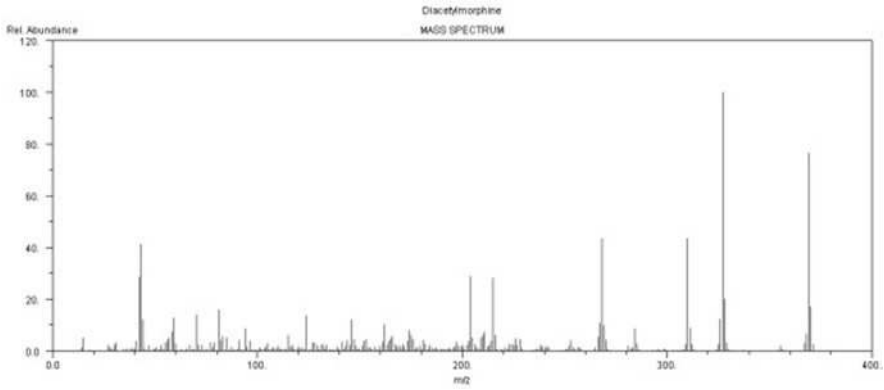


Fig. 3.12 MS chromatogram of NIST heroin standard

Mass spectroscopy cannot differentiate between certain types of isomers. Stereoisomers (molecules that are mirror images of each other) have identical mass spectra. The chromatographic retention times of these compounds are also the same. Ephedrine and pseudoephedrine are examples of stereoisomers that cannot be differentiated by mass spectroscopy. Geometric or positional isomers also produce similar, if not the same, mass spectra. Many times, they can be differentiated by the chromatographic retention time of the compound. Other times, one or two clusters of ions have ion ratios that are specific to a particular isomer. Methamphetamine and phentermine are two geometric isomers that can be differentiated through the use of mass spectroscopy.

The mass spectrometer cannot distinguish between the salt and free base form of a drug. The salt portion of the compound is below the detection range of the MS, and the detector sees only the free base portion of the compound.

A number of mass spectra libraries are available to assist in the identification of unknowns. However, final confirmation is accomplished only by comparing the mass spectra of the unknown to the mass spectra of a known reference standard. The reference spectra should be obtained on the same instrument, under the same operating conditions.

The operating conditions of mass spectrometers vary slightly among instruments. This variation can cause shifts in ion ratios in various parts of the mass spectrum. Confirmation of a compound's identity must be done by comparing the spectrum of the unknown to the spectrum of a known reference sample that was analyzed on the same instrument under the same operating conditions.

Large concentration differences commonly lead to differences in ion ratios in the mass spectrum.

These differences may be evident across the chromatographic peak. The spectrum at the apex may be different from the spectrum on the leading or tailing ends of the peak. Diluting the concentration of the sample can remove these differences, resulting in the same spectra produced across the chromatographic peak.

3.4.2.2 Infrared Spectroscopy

Infrared spectroscopy has been the traditional method of confirming the identity of a controlled substance. Traditionally the sample was subjected to a series of screening tests to establish the compound's suspected identity. The identity of any adulterants and diluents were determined. The controlled substance was then extracted and purified. Finally, an IR spectrum was obtained. Modern technology has introduced instrumentation that can obtain an IR spectrum from a single particle or from a peak in a GC, eliminating the need for complicated procedures.

IR spectroscopy uses a compound's ability to absorb IR light as a means of identification. Organic compounds absorb different portions of the IR spectrum. The pattern that results from charting the absorbance and transmittance of IR light that is passed through (or reflected from) a sample is considered a chemical fingerprint.

Isomer determination is a benefit of using IR spectroscopy as a confirmation tool. Compounds with isomers that are indistinguishable by MS may be differentiated though the use of IR spectroscopy as is demonstrated with the comparison of the IR spectra of ephedrine and pseudoephedrine. The salt form of a compound also affects its IR spectra. Each salt type (hydrochloride, sulfate, etc.) contributes to the spectra differently. These differences provides the examiner with a tool to identify and document the salt form of a compound is a comparison of free base cocaine (crack) and cocaine hydrochloride (Figs. 3.13 and 3.14).

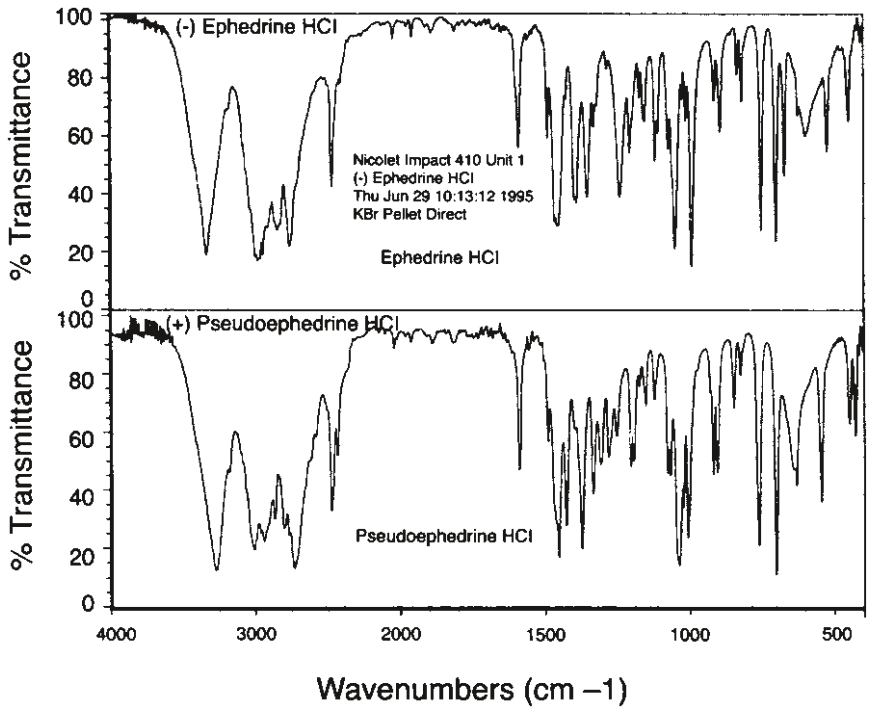


Fig. 3.13 Ephedrine FTIR comparison

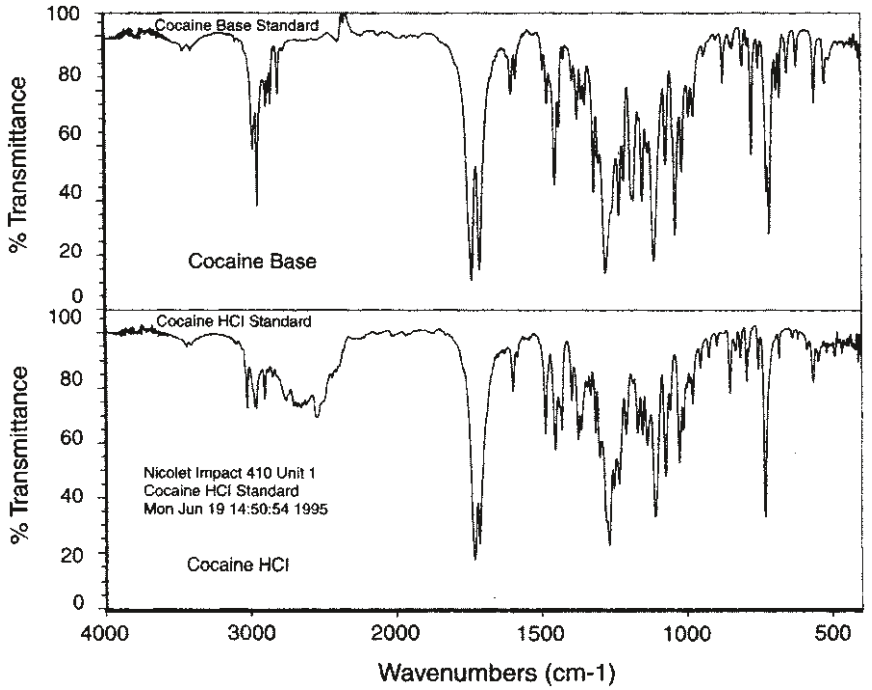


Fig. 3.14 Cocaine FTIR comparison

Advances in technology have reduced the time required for sample preparation and analysis. Extractions can be done using a GC. The Fourier transform infrared (FT-IR) spectrophotometer can obtain an IR spectrum of individual peak traveling through the chromatographic column. Micro FT-IRs can isolate and obtain IR spectra of individual particles within a mixture.

Infrared spectroscopy analyzes the vibrations of different parts of a molecule when it is exposed to IR light. Changing the sample method may affect the way different parts of the molecule can vibrate, which will cause shifts in the peak intensities in the resulting IR spectra. The way the compound crystallizes (or does not crystallize) within the sample matrix that is presented to the instrument will affect the resulting IR spectrum. Transmittance spectra differ from reflectance spectra. The IR spectrum of a vapor phase sample is different from that of a liquid sample, which is different from a sample pressed into a Ker pellet or recrystallized on a salt plate.

Polymorphism can affect a compound's IR spectrum. A single compound may have more than one crystalline form, along with an amorphous form. The way a compound crystallizes affects the vibration within the molecule, which in turn affects the resulting IR spectrum. These variations can occur in the same sampling technique and will have a slightly different IR spectrum.

Because of the variation of IR spectra among sampling techniques, a library of known spectra from traceable sources should be maintained for compound

confirmation purposes. The various IR spectra libraries that are available should be used as a screening tool, not as a reference for confirmation. As with MS, final confirmation is accomplished only by comparing the IR spectra of the unknown with the IR spectrum of a known reference standard. The spectra should be produced on the same instrument, under the same conditions.

3.4.3 Documentation

Instrumental techniques are documentable because they generate analytical data in a form that demonstrates the analysis was performed. The data itself is objective and can be subjected to peer review as part of a quality assurance program or independent evaluation at a later date. The interpretation of the data is less subjective than in other areas of the forensic laboratory, although it is still subject to interpretation.

For peer review purposes, case notes or instrument printouts should include the operating conditions of the instrument during the analysis. This allows the reviewer to evaluate whether instrumental results are consistent with the analytical conditions. If necessary, an independent examiner should be able to achieve the same results under the same test conditions. All data should contain, at a minimum, the examiner's initials, case number, solvent information, and date of the analysis. The examiner should have the instrument print this information on the spectra at the time of analysis if the instrument has the capacity to do so. For GC analysis, the calculated RRt value should be on the chromatogram or on the printout of the peak retention times. The divisions of the mass value axis on MS data should be such that the examiner can easily determine the mass value of each of the ions of the spectra. The wave number of the significant peaks of an IR spectrum should be labeled or should be easily determinable by a peer reviewer. The examiner should have the instrument print this information at the time of analysis if the instrument has the capacity to do so.

3.4.4 Data Interpretation

Over time, a forensic chemist develops an intuition that can identify the controlled substance in an exhibit by simply observing the consistency of the powder, the texture of the plant material, or the odor of the liquid. Observations and intuition are not documentable objective tests that can be subject to peer review. Documentable data that can be interpreted and reviewed is required to support the examiner's sixth sense.

The analysis of controlled substances can be considered a black and white type of examination. The exhibit under examination either contains a controlled substance, or it does not. The comparison of the chemical "fingerprint" of the unknown to the fingerprint of a known reference standard is more complicated

laying one on top of another. Spectra can and do vary for a number of reasons. The lack of superimposability of two spectra does not preclude identification.

The term chemical fingerprint can be misleading. It implies a given chemical will produce one unique spectrum using a given technique without regard to sampling technique or the instrumental conditions at the time of analysis. Conceptually, the term is correct in that a given chemical will produce a unique spectrum using a given technique. However, the resulting spectrum can have slight variations as a result of the sampling technique used to prepare the sample for examination and the operating conditions of the instrument at the time of analysis.

Library spectra should never be used for conclusive identification purposes because of spectral variations. Library spectra present a wonderful tool for preliminary identification purposes. Conclusive identifications should only be made after the comparison of spectrum of the unknown to one of a traceable primary reference produced on the same instrument. A new reference spectrum must be produced each time a suspected controlled substance produces an unfamiliar spectral variation. This demonstrates the reproducibility of the substance's spectrum on the instrument being used.

3.5 SWGDRUG

3.5.1 Examination Categories

As previously stated, SWGDRUG has established three categories of analytical techniques that can be used for the identification of controlled substances. The groupings are based upon the technique's discriminating power. Below are listed the categories and associated analytical techniques:

	Category C nonspecific techniques
Chemical color tests	A non-documentable technique that uses the colors produced by chemical reactions to provide information regarding the structure of the substance being tested
Fluorescence spectroscopy	A documentable analytical technique that uses the release characteristic wavelengths of radiation following the absorption of electromagnetic radiation (fluorescence) to establish a compound's potential identity
Immunoassay	A documentable laboratory technique that uses the binding between an antigen and its homologous antibody to identify and quantify the specific antigen or antibody in a sample
Melting point	The temperature at which a solid becomes a liquid at standard atmospheric pressure. The documentability of this technique depends upon the instrument used
Ultraviolet (UV) spectroscopy	A documentable technique that uses of the absorption of ultraviolet radiation to classify a substance
	Category B moderately specific techniques

(Continued)

(Continued)

Capillary electrophoresis (CE)	A documentable separation technique using the differential movement or migration of ions by attraction or repulsion in an electric field through buffer-filled narrow-bore capillary columns as an identification tool
Gas chromatography (GC)	A documentable separation technique that uses gas flowing through a coated tube to separate compounds by their size, weight, and chemical reactivity with the column coating
Liquid chromatography (LC)	A documentable separation technique that uses liquid flowing through a coated tube to separate compounds by their size, weight, and chemical reactivity with the column coating
Microcrystalline tests	A technique that uses the microscopic crystals produced by chemical reactions to provide information regarding the identity of the substance being tested. A series of positive microcrystalline tests can be considered to be a conclusive test. This technique can be considered documentable if photomicrographs of the crystals used for identification are taken at the time of the examination
Pharmaceutical identifiers	Comparing the physical characteristics of a commercially produced pharmaceutical product to known reference material to tentatively establish the composition of the preparation
Thin-layer chromatography (TLC)	A traditionally non-documentable technique that uses solvent(s) traveling through a porous medium to separate compounds by their chemical reactivity. This technique can be documented through photographing or photocopying the developed thin-layer plate
	Category A specific examinations
Infrared spectroscopy (IR)	A specific documentable technique that uses the absorption of infrared radiation to produce a chemical fingerprint of a substance. This technique can be used in conjunction with gas chromatography
Mass spectroscopy (MS)	A specific documentable technique that uses molecular fragment (ion) patterns to produce a chemical fingerprint of a substance. This technique can be used in conjunction with gas and liquid chromatography.
Nuclear magnetic resonance spectroscopy (NMR)	A specific documentable technique that monitors the splitting of nuclear energy levels within a molecule when it is exposed to oscillating magnetic fields
Raman spectroscopy	A specific documentable technique that uses the inelastic scattering of light by matter to produce a chemical fingerprint of a substance

3.5.2 Recommendations

The SWGDRUG guidelines provide recommendations for the types and minimum number of tests required to identify seized drugs. A validated Category A technique, with documentable data, supported by one Category A, B or C technique is the suggested minimum examination criteria. A combination of three different

Category B and C techniques can be used if a Category A technique is unavailable. The Category B techniques must produce reviewable data.

3.6 ASTM Standards

The E-30 Committee of the ASTM has reviewed recommendations of the SWGDRUG analytical protocols and has initiated the process of adopting them as ASTM standards. If the SWGDRUG protocols are adopted as a "guide," they will serve as a best practices reference that does not recommend a specific course of action. If adopted as a "practice" or a "test method," the described analytical protocols would affect how a forensic laboratory examines controlled substance exhibits.

ASTM standards are considered the analytical benchmark. Standard practices are a definitive set of instructions for performing specific operations that does not produce a test result. A standard "test method" is a definitive procedure that produces a result. These standards should be considered when developing a laboratory's analytical protocols. If they are not used as the foundation of the examination procedure, the analytical results may not be readily accepted in court.

3.6.1 Controlled Substance Specific Standards

The standard practices developed by the ASTM E-30 committee concerning the analysis of controlled substances are:

E2326: Standard Practice for Education and Training of Seized-Drug Analysts
E2327: Standard Practice for Quality Assurance of Laboratories Performing Seized-Drug Analysis
E2328: Terminology Relating to Forensic Seized Drug Analysis Combined into General Forensic Science Terminology, E 1732.
E2329: Standard Practice for Identification of Seized Drugs
E2548: Standard Guide for Sampling Seized Drugs for Qualitative and Quantitative Analysis

3.6.2 Generic Analytical Standards

ASTM standards reach beyond the specific application used for an examination. Some of the standards address the use, care, and maintenance for the instrumentation used to perform the examination. Others address functions within the forensic laboratory. Each should be addressed when developing an examination protocol, quality assurance program, or laboratory standard operating procedures. Some of the auxiliary standards that directly affect the examination of controlled substances include, but are not limited to:

3.6.3 Chromatography Analysis Standards

E260: Practice for Packed Column Gas Chromatography
E355: Practice for Gas Chromatography Terms and Relationships
E516: Practice for Testing Thermal Conductivity Detectors Used in Gas Chromatography
E594: Practice for Testing Flame Ionization Detectors Used in Gas Chromatography
E697: Practice for Use of Electron Capture Detectors in Gas Chromatography
E1140: Practice for Testing Nitrogen/Phosphorus Thermionic Ionization Detectors for Use in Gas Chromatography
E1510: Practice for Installing Fused Silica Open Tubular Capillary Columns in Gas Chromatographs
E1642: Practice for General Techniques of Gas Chromatography Infrared (GC/IR) Analysis
D3016: Practice for Use of Liquid Exclusion Chromatography Terms and Relationships
E1151: Practice for Ion Chromatography Terms and Relationships

3.6.4 Infrared Spectroscopy Analysis Standards

E131: Terminology Relating to Molecular Spectroscopy
E168: Practices for General Techniques of Infrared Quantitative Analysis
E334: Practice for General Techniques of Infrared Microanalysis
E573: Practices for Internal Reflection Spectroscopy
E932: Practice for Describing and Measuring Performance of Dispersive Infrared Spectrophotometers
E1252: Practice for General Techniques for Obtaining Infrared Spectra for Qualitative Analysis
E1866: Guide for Establishing Spectrophotometer Performance Tests
E1944: Practice for Describing and Measuring Performance of Fourier Transform Near-Infrared (FT-NIR) Spectrometers: Level Zero and Level One Tests
E1421: Practice for Describing and Measuring Performance of Fourier Transform Infrared (FT-IR) Spectrometers: Level Zero and Level One Tests
E1642: Practice for General Techniques of Gas Chromatography Infrared (GC/IR) Analysis

3.6.5 Mass Spectrometry Analysis Standard

E1504: Standard Practice for Reporting Mass Spectral Data in Secondary Ion Mass Spectrometry (SIMS)

3.7 Quality Assurance (QA)/Quality Control (QC)

There was a time that the phrase "Trust me; I'm from the government and here to help" had a positive connotation. The forensic laboratory used to be considered a source of unquestionable truth. Unfortunately, that trust has been compromised through sloppy laboratory practices, unscrupulous examiners, and mismanagement. Additionally, the United States' adversarial legal system has placed additional scrutiny upon the analytical results generated by the forensic laboratory. As a result, forensic laboratories have adopted systematic checks and balances that had been common practice in clinical and industrial laboratories.

A documented quality assurance (QA) and quality control (QC) program is just as important as documenting the results of individual examinations. The examination results may not be accepted by the court if the reliability of the instruments, protocols, and chemicals used to perform the examinations cannot be established. Individual quality control programs demonstrate the reliability of the examination process. It is the combination of both that displays the reliability of the whole process (quality assurance).

Quality assurance is a documented system of protocols used to assure the accuracy and reliability of analytical results; and, as such, it consists of a variety of components. Proficiency testing and employee qualifications and training standards are directed at the forensic chemists performing the examinations. Documented evidence collection and handling procedures as well as documented, standardized, and validated analytical protocols are used to ensure the analytical methods used to meet an accepted scientific standard. Instrument maintenance logs, reagent preparation records, and the use of traceable chemicals used in preparation (to testing reagents) document the reliability of the chemicals and equipment used in the examination process. The use of traceable reference material ensures the material being used to generate the data being used for identification purposes is from a known source.

A quality assurance program produces intangible affects that may be difficult to assess. Service is improved through streamlining operation. The numbers of challenges to the analytical results are reduced because of the documented reliability of the equipment, chemical, and protocols used. The need for reanalysis is reduced, saving the laboratory time and money. The laboratory's image and credibility is improved, which leads to fewer court appearances from testimony stipulation. Each of these effects enhances those of the others. Quality work leads to credibility, which enhances staff morale and ultimately produces a more productive work environment.

3.8 Clandestine Labs

Clandestine drug labs are illicit locations that manufacture controlled substances. The types and numbers of labs seized reflect national and regional trends concerning the types and amounts of illicit substances that are being manufactured,

trafficked, and abused. Clan labs, as they are called by law enforcement officers, have been found in remote locations, in urban and suburban neighborhoods, hotels and motels, and industrial complexes, as well as academic and industrial laboratories. Each location produces toxic and explosive fumes that can pose a significant threat to the health and safety of local residents as well as respondents, such as police, fire, and hazardous materials (HAZMAT) officers.

The sophistication of clandestine labs varies widely. The production of substances such as methamphetamine, phencyclidine (PCP), methylenedioxy methamphetamine (MDMA/Ecstasy) and methcathinone requires little sophisticated equipment or knowledge of chemistry. The synthesis of drugs such as fentanyl and LSD requires much higher levels of expertise and equipment.

The investigation of clandestine labs is one of the most challenging efforts of law enforcement. No other law enforcement activity relies on forensic science as heavily. The controlled substances section's involvement commences with the drafting of the affidavit used to obtain the search warrant. Their expertise is needed to process the crime scene. They analyze the evidence in laboratory. Finally, they render opinions in a written report or in courtroom testimony. Occasionally, they are called upon to testify on auxiliary issues concerning the clandestine lab investigation that occur after the case has been adjudicated.

The controlled substance section addresses the what, where, why, and how questions of investigation. What controlled substance were the operators making? What are the chemicals and equipment that were purchased by the operators used for? Where were the operators manufacturing the controlled substances? Why did the operators use a certain chemical or type of equipment? How did the operator manufacture a controlled substance using chemicals and equipment commonly found in kitchens or bathrooms? Investigators must use other investigative techniques to fill in the "who" and "when" questions.

3.8.1 Crime Scene Support

The amount and type of crime scene support provided to clandestine labs seizures varies from forensic laboratory to forensic laboratory. Some laboratories provide a full range of support, with a group of chemists dedicated to providing crime scene and analytical support for clandestine lab investigations. Other laboratories provide support by sending to crime scenes chemists who may or may not have specialized training in clandestine labs.

The on-scene chemist provides a variety of technical support. The on-scene chemist identifies the chemicals and equipment that can potentially be used in the manufacturing of illicit drugs; assists in the sampling process; and can also provide preliminary opinions as to the proposed final product and the manufacturing method used by the operation. The scene report is used by the laboratory examiner as a guide to assist in devising the analytical scheme used to identify the controlled substance being manufactured as well as in establishing the manufacturing method used.

3.8.2 Laboratory Analysis

The laboratory analysis of samples taken from the scene of a clandestine lab is the link between the investigation and the opinions. It provides the scientific foundation that corroborates the investigator's theories and is used to support the opinions rendered in reports, legal depositions, and court testimony. Without complete and thorough laboratory analysis, the case may remain unresolved.

The analysis of exhibits from clandestine labs involves the use of a variety of scientific techniques. Some examinations use techniques outside of those normally associated with drug identification. These techniques range from simple chemical color tests to the use of X-ray and infrared energy to elicit the compound's chemical fingerprint. The type of test used depends upon the information desired from the sample and the burden of proof required to establish its identity.

The laboratory analysis of clandestine lab exhibits is more involved than the simple identification of a controlled substance. The identification of the components of the sample matrix may be just as important. A complete analysis is essential to establish the manufacturing method. Yet, in some instances, it may not be absolutely necessary.

Ramifications outside the laboratory should be considered when the examiner maps out his analysis. The lack of a complete analysis may affect aspects of the investigation or prosecution of which the examiner is not aware. If the examiner is asked to render opinions concerning the manufacturing operation, he must have documentation to support his opinion. A complete laboratory analysis is one source of the information he needs to support his opinions.

It is not sufficient to say that the clandestine lab operator was using a particular method simply because some or all of the ingredients were found at the site. The presence or absence of a particular precursor or reagent chemical cannot be established beyond a reasonable doubt without laboratory examination. The relabeling of ingredients by the lab operator or lack of labels on the containers at the scene often makes the actual identity of the chemicals at the location questionable.

Below is an excerpt of an analytical chemist's testimony[5]. The defense contended that the lack of the presence of hydriodic acid precluded the operator from manufacturing the controlled substance that the state contended. The cross examination of the analytical chemist charged with analysis of the evidence proceeded as follows:

This whole exchange could have been avoided if the items at the scene were sampled properly. This would have provided the analytical chemist the opportunity to identify the contents of each container.

The same holds true with reaction mixtures. The chemist should identify the ingredients within the reaction mixture. The fact that a chemical or chemical container was located at the scene does not establish its presence in a reaction mixture. It only provides the chemist information he can utilize in developing his analytical scheme.

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[5] Donnell R Christian, *Forensic Investigation of Clandestine Laboratories*, pg. 204, CRC Press 2004.

Defense attorney	You stated exhibit 12 contained HCl?
Chemist	Yes sir
Defense attorney	So there was no hydriodic acid found at the scene?
Chemist	No sir, I cannot say that
Defense attorney	But your report states that you found HCl, not HI. How can you say that there was hydriodic acid present?
Chemist	The items in exhibit 24 and exhibit 31 were not sampled. The packaging and the color of the liquid are consistent with hydriodic acid
Defense attorney	But your report states that HCl was the only acid identified
Chemist	That is correct. However, the items in exhibit 24 and 31 were not sampled so I could not analyze the contents. Without laboratory analysis I cannot comment on the contents
Defense attorney	So you are saying you did not find any hydriodic acid?
Chemist	What I am saying is that I cannot say that there was no hydriodic acid at the scene. The packaging and color of the liquid of items 24 and 31 is consistent with commercially packaged hydriodic acid

3.8.3 The Chemist

The chemist performing the laboratory examinations should specialize in clandestine lab analysis. In bookkeeping, all CPAs are accountants but not all accountants are CPAs. The same is true with forensic chemists. All clandestine lab chemists are forensic chemists, but not all forensic chemists are clandestine lab chemists. The clandestine lab chemist has additional training in clandestine manufacturing techniques as well as in inorganic analysis. This allows the clandestine lab chemist to expand their analytical scheme to identify all of the chemicals used in the manufacturing process. The analytical scheme is geared to identifying the manufacturing process, not just the controlled substance involved.

The clandestine lab chemist's role in a clandestine lab investigation requires a different thought process when approaching his analysis. The examination reaches beyond the basic identification of a controlled substance in an exhibit. The clandestine lab chemist approaches each sample with the thought of having to explain to a jury what components are in the sample and how the components fit into the manufacturing process. From an investigative standpoint, the analytical approach is geared toward profiling the sample to provide the investigators information concerning the sample's composition so that the investigators know what components to look for.

3.8.4 Expert Opinions

A clandestine lab is a Pandora's Box of illegal activities. Controlled substances are produced using household chemicals mixed in ordinary utensils in what some have called a "kitchen of death." What appears at first glance to be simply atrocious housekeeping or even just a hobby gone awry may actually be the final step in the

production of many of the drugs sold on the street or the explosives used in various forms of domestic terrorism.

The clandestine lab chemist provides the expert opinions that draw calm from the chaos. The clandestine lab chemist couples clandestine lab training and experience with deductive reasoning ability and laboratory examination results to develop a plausible scenario concerning the clandestine manufacturing operation in question. The clandestine lab chemist combines the black and white answers of the laboratory analysis with the crime scene information to provide answers to the investigation's and prosecution's "who, what, when, where, why, and how" questions.

Many types of opinions can only be generated from the laboratory analysis of evidentiary samples. Some opinions are a result of generalities that do not require the support of analytical data. For example, just because a red powder is found at the scene of a suspected ephedrine reduction lab does not make the powder the critical red phosphorus. It is absolutely essential for an analytical chemist who is going to render an opinion concerning a clandestine lab to have the analytical data ready to support that opinion.

As with laboratory analysis, opinions concerning clandestine lab operations should be able to withstand peer review. A component chemist or other forensic expert should be able to review the facts of the case or the laboratory data and draw the same conclusion the original expert did. Alternative opinions can and do exist, as is evidenced by prosecution and defense differences. However, the information must support the opinion or the opinion is worthless.

3.9 Summary

The forensic chemistry section of a traditional crime laboratory generally refers to the drug analysis or controlled substance identification section. Many forensic examiners begin their career in this section. Here they learn the tools of their trade by performing a wide variety of examinations using a plethora of analytical methods. They learn and develop the deductive reasoning skills to move from straightforward identification of controlled substances, to examinations that require professional opinions, to questions that just do not have black and white answers. The skills and knowledge the examiners cultivate here will serve them well if they transfer to other sections of the forensic laboratory.

3.10 Glossary of Terms

This glossary of terms was developed and adopted by the SWGDRUG Core Committee from a variety of sources. Some definitions are found in *The United Nations Glossary of Terms for Quality Assurance and Good Laboratory Practices*. Some were formulated and decided upon by reviewing the three SWGDRUG

recommendations and selecting terms or phrases that may impact an interpretation, but were not published elsewhere.

Accreditation	Procedure by which an accreditation body formally recognizes that a laboratory is competent to carry out specific tasks.
Accreditation Body	Independent organization that has the authority to grant accreditation.
Accuracy	The ability of a measurement to match the actual value of the quantity being measured. Correctness
Adulterant	A substance used to increase the mass of a controlled substance. These substances produce a physiological effect on the body and are used to give the illusion that there is more controlled substance present than actually is present.
Alkaloid	A class of substances occurring readily formed in the tissues of plants and the bodies of animals. e.g., morphine and codeine are alkaloids of opium.
Analysis	Technical operation to determine one or more characteristics of, or to evaluate the performance of, a given product, material, equipment, physical phenomenon, process, or service according to a specified procedure.
Analyst	A designated person who: Examines and analyses seized drugs or related materials, or directs such examinations to be done. Independently has access to "open" (unsealed) evidence in order to remove samples from the evidence for examination. As a consequence of such examinations, signs reports for court or other purposes.
Aqueous	Made from, or by means of, water.
Audit	A review conducted to compare the various aspects of the laboratory's performance with a standard for that performance.
Blank	Specimen or sample not containing the analyte.
Calibration	Set of operations that establishes, under specified conditions, the relationship between values indicated by a measuring instrument or measuring system, or values represented by a material measure, and the corresponding known values of a measured certified reference material.
Certified reference material (CRM)	A reference material, one or more of whose property values have been certified by a technical procedure, accompanied by or traceable to a certificate or other documentation that has been issued by a certifying body.

Certifying body	Independent organization that has the competence to grant certification.
Chain of custody	Procedures and documents that account for the integrity of a sample by tracking its handling and storage from its point of collection to its final disposition.
Class Characteristic	A feature of an item that is unique to a group of items.
Control Sample	A standard of comparison for verifying or checking the finding of an experiment.
Controlled substance	Any substance, commonly drugs, whose possession or use is regulated.
Controls	Samples used to determine the validity of the calibration, that is, the linearity and stability of a quantitative test or determination over time. Controls are either prepared from the reference material (separately from the calibrators, that is, weighed or measured separately), purchased, or obtained from a pool of previously analyzed samples. Where possible, controls should be matrix-matched to samples and calibrators.
Deductive reasoning	Using nonspecific details to infer a specific fact.
Depressant	A drug that reduces excitability and calms a person.
Deficiency of analysis	Any erroneous analytical result or interpretation, or any unapproved deviation from an established policy or procedure in an analysis.
Diluent	An inert substance used to increase the mass of the controlled substance. These substances have no physiological effect on the body and are used to give the illusion that there is more controlled substance present than actually is present.
Drug	A substance other than food intended to affect the structure or function of the body.
False positive	Test result that states that a drug is present when, in fact, such a drug is not present in an amount less than a threshold or designated cut-off concentration.
Gas chromatography (GC)	The use of gas flowing through a coated tube to separate compounds by their size, weight, and chemical reactivity with the column coating.
Gravimetric quantitation	Using the ratio of pre- and post-extraction weights to determine concentration.
Hallucinogen	A psychoactive drug that induces hallucinations or alters sensory experiences.
Health & safety manager	A designated person who is responsible for maintaining the laboratory health and safety program

	(including an annual review of the program) and who monitors compliance with the program.
Independent test result	Result obtained in a manner not influenced by any previous results on the same or similar material.
Individual characteristic	A feature that is unique to a specific item.
Inductive reasoning	Using specific facts to infer a general conclusion.
Infrared (IR) spectroscopy	The use of the absorption of IR radiation to produce a chemical fingerprint of a substance.
Laboratory	Facilities where analyses are performed by qualified personnel using adequate equipment.
Limit of detection	Smallest measured content from which it is possible to deduce the presence of the analyte with reasonable statistical certainty.
Macroscopic examination	Visual examination, generally performed with the unaided eye, used to identify class characteristics.
Method	Detailed, defined procedure for performing an analysis.
Microscopic examination	Visual examination, performed utilizing some type of magnification, used to identify individual characteristics.
Mass spectroscopy (MS)	The use of molecular fragment (ion) patterns to produce a chemical fingerprint of a substance.
Narcotic	An addictive substance that reduces pain, alters mood and behavior, and usually induces sleep or stupor.
Organic	The class of chemical compounds having a carbon basis; "hydrocarbons are organic compounds"
Polymorphism	Crystallization of a compound in at least two distinct forms.
Precision	The ability to achieve the same result. Reproducibility.
Procedure	Specified, documented way to perform an activity.
Proficiency testing	Ongoing process in which a series of proficiency samples, the characteristics of which are not known to the participants, are sent to laboratories on a regular basis. Each laboratory is tested for its accuracy in identifying the presence (or concentration) of the drug using its usual procedures.
Qualitative analysis	Analytical technique used to determine the composition of a substance or mixture.
Quality assurance (QA)	System of activities whose purpose is to provide, to the producer or user of a product or a service, the assurance that it meets defined standards of quality with a stated level of confidence.

QA manager	A designated person who is responsible for maintaining the quality management system and who monitors compliance with the program.
Quality management	That aspect of the overall management function that determines and implements the quality policy.
Quality manual	Document stating the general quality policies, procedures, and practices of an organization.
Quantitative analysis	Analytical technique used to determine the concentration of one or more of the components of a mixture.
Racemic mixture	A combination of the different types of stereoisomers of the same compound.
Reference material	Material or substance, one or more properties of which are sufficiently well established to be used for calibrating an apparatus, assessing a measurement method, or assigning values to materials.
Retention time (Rt)	The time require for a substance to travel from the injection port to the detector.
Relative Rt	The ratio of the Rt of the substance of interest divided by the Rt of an internal standard run on the same instrument at the same time.
Report	Document containing a formal statement of results of tests carried out by a laboratory.
Representative sample	Statistically, a sample that is similar to the population from which it was drawn. When a sample is representative, it can be used to make inferences about the population. The most effective way to get a representative sample is to use random methods to draw it. Analytically, it is a sample that is a portion of the original material selected in such a way that is possible to relate the analytical results obtained from it to the properties of the original material.
Reproducibility	Closeness of agreement between the results of successive measurements of the same analyte in identical material made by the same method under different conditions, e.g., different operators and different laboratories and considerably separated in time.
Sample	A portion of the whole material to be tested. Statistically, it is a set of data obtained from a population.
Sampling	Analytically, the whole set of operations needed to obtain a sample, including planning, collecting, recording, labeling, sealing, shipping, etc. Statistically,

	it is the process of determining properties of the whole population by collecting and analyzing data from a representative segment of it.
Selectivity	Extent to which a method can determine particular analyte(s) in a mixture without interference from the other components in the mixture. A method that is perfectly selective for an analyte or group of analytes is said to be specific.
Standard operating procedures (SOPs)	A written document that details the method of an operation, analysis, or action whose techniques and procedures are thoroughly prescribed and that is accepted as the method for performing certain routine or repetitive tasks.
Stereoisomers	Compounds with identical structural formulas whose differences are in the way the molecule is arranged in space.
Stimulant	A drug that produces a temporary increase of the functional activity or efficiency of an organism or any of its parts.
Structural isomers	Compounds that contain the same number and type of atoms but differ in the order in which the atoms are arranged. The types of structural isomers include chain, positional, and functional group.
Supervisory chemist	A designated person who has the overall responsibility and authority for the technical operations of the drug analysis section.
Technical/assistant analyst	A person who analyses evidence, but does not issue reports for court purposes.
Technical support personnel	A person who performs basic laboratory duties, but does not analyze evidence.
Thin-layer chromatography	The use of a solvent(s) traveling through a porous medium to separate compounds by their chemical reactivity with the solvent(s).
Traceable	Ability to trace the history, application, or location of an entity by means of recorded identification. See also Chain of custody.
Traceability	The property of a result of a measurement whereby it can be related to appropriate standards, generally international or national standards, through an unbroken chain of comparisons.
Ultraviolet (UV) spectroscopy	The use of the absorption of UV radiation to classify a substance.
Validation	Confirmation by examination and provision of objective evidence that the particular requirements for a specific intended use are fulfilled.

Verification	Confirmation by examination and provision of objective evidence that specified requirements have been fulfilled (that the method works in your laboratory as well as where the method was validated.)

3.11 Questions

1. List two plants that are considered controlled substances that require a botanical examination as part of the identification process.
   Marijuana (*Cannabis sativa L.)* and peyote (*Lophorphora williamsii*)
2. When is it necessary to confirm the identity of the controlled substance in plant material? Give an example.
   The identity of a controlled substance in plant material needs to be confirmed when the plant material is not subject to control but a specific component within the plant is. Mushrooms are not illegal to possess per se. However, the psilocin and/or psilocybin contained in some species of mushrooms are.
3. List four wet chemical techniques that can be used in the analysis of controlled substances.
   Chemical color test, Microcrystal tests, Thin-layer chromatography (TLC), Chemical extractions.
4. List two wet chemical techniques that can be used as both screening tools and sample preparation techniques.
   TLC and wet chemical extractions
5. List two disadvantages to wet chemical techniques.
   Lack of specificity and lack of supporting documentation to support that the test was administered.
6. List two specific and two nonspecific instrumental techniques.
   (a) Nonspecific: UV spectroscopy and GC.
   (b) Specific: IR spectroscopy and MS.
7. What information should accompany instrumental data?
   Case and item numbers, examiner's name or initials, date, and instrumental operating parameters.
8. When is a library search considered a confirmation and why?
   Never. Each instrument will produce slight variations in the spectra that are produced. All conformations must be done by comparing the spectra of the unknown to the spectra of a known reference sample produced on the same instrument under the same operating parameters.
9. Which instrumental technique's spectra are most subject to variations due to sample preparation techniques. Why?

IR spectroscopy. The sample preparation technique affects the sample matrix, which will affect the molecular vibrations that result in the IR spectrum of the compound.

10. List three quantitation techniques in order from most specific to least specific.
    GC, gravimetric analysis, microscopic examination, UV spectroscopy

11. What are the minimum qualifications for a clandestine lab chemist?

    (a) A baccalaureate degree in chemistry.
    (b) Training in the analysis of controlled substances.
    (c) Specialized training in the clandestine manufacture of controlled substances.
    (d) All the above.

12. What is the forensic chemist's objective during the analysis of evidence seized in a clandestine lab investigation?

    (a) Identify only the controlled substance
    (b) Identify every chemical in the sample matrix
    (c) Establish the manufacturing route
    (d) None of the above

13. When does the controlled substance section's participation in a clandestine lab investigation begin?

    (a) The drafting of the search warrant affidavit
    (b) The search of the crime scene
    (c) The laboratory analysis of the physical evidence
    (d) Court testimony concerning the clandestine lab seized

14. The guidelines of which professional group should be considered when developing examination techniques used to examine controlled substances?

    (a) Working Group for the Analysis of Seized Drugs (SWGDRUG)
    (b) American Society of Testing Materials (ASTM)
    (c) American Society of Crime Laboratory Directors (ASCLD)
    (d) a and b
    (e) None of the Above

15. The guidelines of which professional group hold the weight of law concerning the examination techniques used to examine controlled substances?

    (a) Scientific Working Group for the Analysis of Seized Drugs (SWGDRUG)
    (b) American Society of Testing Materials (ASTM)
    (c) American Society of Crime Laboratory Directors (ASCLD)
    (d) All the above
    (e) None of the above

3.12 About the Author

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Chapter 4
Crime Reconstruction and Evidence Dynamics

W. Jerry Chisum, BS

Contents

4.1 Introduction

Have you ever wondered how the great fictional detectives of literature, such as Hercules Poierot, Sherlock Holmes, and Mrs. Marple were able to "solve" crimes, yet it takes so long for the police to do the same? The authors of these fictional novels have a license to write and shape things as they want, while the police must

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work under specific rules. The authors can create "clues" that are used by the sharp minds of their detectives to eliminate the innocent, identify the guilty, and to reconstruct what happened. The authors have studied human behavior and the environments in which they live so they are able to point out those things that are out of the ordinary. They use the logical extension of the clues that they have created to develop the story. Law enforcement must find and recognize the clues associated with the physical evidence. Other law enforcement personnel have studied the behavior of criminals and the environment in which they work. They use the same logical extension of the clues to develop a theory (or a story) about the crime. This is crime reconstruction. Crime reconstruction tells us what happened and what could not have happened.

Not all law enforcement personnel can perform crime reconstruction. That person must be someone who is a keen observer, understands science, recognizes evidence, and can apply critical thinking[1] and logic. The criminalist, forensic scientist, or scientific investigator uses "clues," critical thinking, and logic in the process of crime reconstruction. Crime reconstruction can be defined as the logical analysis of the physical evidence and other facts into the formulation of a theory regarding the actions that took place in the commission of a crime.

Henry Lee points out that it is not just the physical evidence that is incorporated into forming a theory. "Reconstruction not only involves the scientific scene analysis, interpretation of scene pattern evidence and laboratory examination of physical evidence, but also involves systematic study of related information and the logical formulation of a theory [1]."[2]

Dealing with human action and trying to determine details of what happened at a particular time in the past is not an easy process. This may not be a full picture; we can sequence events, but we cannot tell what happened in between those events. As John Thornton[3] stated, "Recognize that the physical evidence may not tell the whole story of what happened, but only isolated bits of the whole story. The entire landscape provided by the physical evidence may in fact be akin to looking at a tapestry from the back side [2]." The person who approaches the crime scene, either in fact or through documentation, must be able to understand that the entire story may not be revealed.

Reconstructionists must have an understanding of how things work. They must be able to use both inductive and deductive logic in their analysis of the crime. Inductive logic is used to formulate a theory. If the theory is true, then deductions

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[1] Critical thinking is a purposeful, reflective, and goal-directed activity that aims to make judgments based on evidence rather than conjecture. It is based on the principles of science and the scientific method. Critical thinking is a reasoned, interactive process that requires the development of strategies that maximize human potential. (Old Dominion University, School of Nursing faculty minutes, 1997).

[2] Dr. Henry Lee was the Director of the Connecticut State Police Crime Laboratory, Commissioner of the State Police, and Professor of Criminalistics at the University of New Haven. He is now the director of the Lee Institute for Criminalistics.

[3] Dr. Thornton retired as Professor of Criminalistics at the University of California, Berkeley.

can be made regarding what happened. However, one must be careful in making deductions, because the theory must be true. The testing of the theory is done by the "scientific method." Usually, more than one theory is postulated, and then the scientific method is applied to eliminate the impossible.

4.2 The Scientific Method

Crime reconstruction is observing the results of an act or action then postulating the cause of those results. In the scientific world this is not unusual. Phenomena are observed. The scientist postulates or forms a hypothesis about what caused the phenomena; then designs experiments to test the hypothesis. If the experiments fail, a new hypothesis is formed and more testing is done until the experiments work. Then the hypothesis is supported by data. Of course, this hypothesis is only as valid as the experiments. One more experiment along a different approach might prove this to be a wrong hypothesis.

This same approach is used in crime reconstruction. A theory is formed about the crime then that theory or hypothesis is tested against the physical evidence found at the scene or developed through laboratory analyses. If an item of physical evidence is contrary to the theory, then that theory must be abandoned and a new theory formulated. Again, we must realize that the hypothesis may not be valid, but it needs to be presented so that it may be tested.

In our normal lives, an effect is frequently observed and we conclude or surmise what happened. For example, a broken vase is on the floor and there are cat footprints in the dust on the table near where the vase was sitting. The obvious conclusion is that the cat pushed the vase off the table. This is putting the clues together to explain an event. If, however, the dog's teeth marks are in the table cloth on which the vase was sitting, a different conclusion would be reached and the cat exonerated.

The following is an example of an observation and the application of scientific methodology. We see a ball of clay sitting on the floor and we observe that the clay is flat on one side. We hypothesize that the clay ball was dropped onto the floor because there is nothing above the ball from which it could have fallen. Therefore, our hypothesis appears to be true.

We can now also determine more about the incident. We can measure the flattened area and weigh the clay. Then we make balls of the same weight out of the same type of clay. We drop them from various heights and compare the size of the flattened areas until we find one that matches. We then theorize about how far the clay fell. That is a simple experiment to determine a cause from the effect.

To complicate the experiments, we see a second ball of clay sitting near the wall. We see a "greasy" spot[4] on the wall above the ball of clay and the ball has two flattened sides. We form the hypothesis that one was side was flattened by throwing

[4]Hypothesis: the greasy spot was caused by the clay. The reader is encouraged to design an experiment that would test this hypothesis.

the ball against the wall. The other side was flattened by falling to the floor. We can tell which was first by application of logic. If the ball is on the floor then it must have fallen there after it hit the wall. We note which flattened area is touching the floor, then we can compare our previously collected measurements with our measurements to the height of the greasy spot. We have sequenced the events. Now we measure the flattened area that was not on the floor. This flattened area may have been changed or altered when the ball fell to the floor. Therefore, our measurement may be of an area of flattening *plus an area that should have existed.*

We project (throw) clay against the wall until we produce a flattened side of the same size as the second measured area. By measuring the velocity at which each ball struck the wall we can now say how fast the original ball was traveling when it hit the wall. We must consider any other factors that might affect the results. For example, if the temperature was considerably different between the time of the events and the experiments, then the conclusions we reached are not valid because the physical properties of the clay are changed by temperature.

These experiments sound simple; however, as illustrated, many factors must be considered in even these simple experiments. The reconstructionist must be able to design and conduct the same types of experiments with blood drops, bullets, and other types of physical evidence. In the above experiment, data was available after the first set of experiments that could be used to determine the cause in subsequent events without having to redo the experiments. "Crime reconstruction requires a broad base of knowledge regarding forensic science and an ability to determine the cause from the effect [3]."

In the scientific method, we cannot establish absolutes. The alternative solutions we start with are eliminated to the most logical solution. The alternatives involving aliens, ghosts, and other outlandish creatures or events are not even considered. The alternatives can be considered falsehoods. Falsification is the central concept behind the scientific method [4]. Consequently, when developing a reconstructive analysis, the reconstructionist develops an hypothesis that he or she will attempt to disprove. If the hypothesis is falsified, the reconstructionist can opine that this hypothesis (or theory of the crime) is not conceivable or compatible with the evidence submitted and analyzed. The scientific method appears very similar to the writings of Sir Arthur Conan Doyle[5] when he stated, "Eliminate the impossible; whatever is left, however improbable, is the truth."

4.3 Types of Evidence Analyzed

In the past few years, there has been a great emphasis on the training of law enforcement personnel in the ability to recognize and interpret bloodstain evidence. At this time, bloodstains are probably the most common of the types of evidence

[5]The quote from A.C. Doyle in The Sign of Four reads, "Eliminate the impossible, then whatever is left, however improbable, is the truth."

examined for a reconstruction. However, the entire crime scene must be examined and all the evidence taken into account. Errors in reconstruction occur when only one evidence type is examined. A "holistic" approach must be followed, accounting for all the evidence in the case. Nothing can be ignored or "sorted out" as is done in some departments for efficiency and expediency.

Everything is evidence of something; the hard part is deciding whether or not that evidence is part of the crime. Some things are predictable, like the flattening of the clay in the above examples, while other things are unpredictable, such as damage done by insects or animals. Evidence can be transitory, disappearing within a short time, such as the odor of cologne in a room, ice cubes in a glass, or footprints in sand on a windy day, or destroyed or altered by improper procedures in the investigation.[6]

4.3.1 Blood

Blood drops (and raindrops) are almost perfect spheres. We observe a teardrop shape in the pattern they leave when they strike a surface at an angle. The tail is pointing in the direction it is going![7] The reconstruction expert must conduct experiments to determine the striking angle that causes the particular shape of the drop. This is just one of several experiments they must perform; they must have a good understanding of how various bloodstain patterns are produced and the role of bloodstains in crimes.

4.3.2 Firearms

The same is true with firearms evidence. The reconstructionist must conduct or witness experiments that show how various evidence is produced. This includes, but is not limited to:

1. Distance determinations from powder or lead residues at various angles and with different types of cartridges (calibers and manufacturer).
2. Deflections of bullet paths caused by penetrating or perforating various materials.
3. Shape and size of the holes made in various materials.
4. Ricochet marks on various surfaces.
5. Damage to the bullet from ricocheting.
6. Path change by ricocheting, including left vs. right twist.

The list could go on for a number of pages; reconstructionists should consult the literature for experiments performed by others for ideas to approach special problems.

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[6]The changes that occur to the evidence after the crime are called "Evidence Dynamics."

[7]This phenomenon can be seen by observing the stains left by vehicles dripping oil or paint while traveling. The tail of the oil or paint points in the direction of traffic.

4.3.3 Trace Evidence

The role of trace evidence in reconstruction is often overlooked. Hairs and fibers can show that a particular person was present. Trace evidence can show contact between the victim and suspect or the suspect and the environment of the crime, including the path taken and some of the actions. These clues need to be incorporated into the reconstructive analysis. The problem with this type of evidence is that it requires crime laboratory analysis before it becomes useful. Therefore, it is available for court purposes but the information is usually not available for the investigative phase.

4.3.4 Position of Evidence

The position of an item may be extremely important in determining its role in a crime. This is information that can not be determined by looking at the object in the lab. This information must be documented and processed at the scene. Without information regarding the location of the item, the item may be of no value for reconstructive purposes. This is true not only for crime reconstruction, but for the reconstruction of human behavior by the archeologist as well.

> "The patterning of human behavior is key to the concept that the study of the spatial arrangement of artifacts can be used to infer the behavior from which they result. Because of this, the spatial context of artifacts, including their relationship with the natural environment, is more important than the artifact itself. Removing an artifact from its context destroys much of its potential to help reconstruct human behavior [5]."

The "tag and bag" approach to the crime scene will destroy the potential that the crime reconstructionist uses to reconstruct recent human behavior. According to Ogle "It is important to remember that crime scene reconstruction begins with a systematic, meticulous, and competent endeavor by the crime scene processing team [6]." The reconstructionist must rely upon documentation of the scene to establish these relationships. For example, the location of a gun may yield information regarding whether a death is a suicide, homicide, or an accident. Firing the weapon and comparing the test bullets with the fatal bullet can only show that the gun in question was the one responsible, not the cause of death.

4.4 What Can Be Determined

The position and/or actions of the people involved in the incident can also be established through the physical evidence they left behind or altered. The functional condition of an item yields information. A bullet through a clock may stop its functioning at a specific time, establishing when the shooting occurred.[8]

[8]The Far Side cartoon by Gary Larson showing several bullet holes in the clocks at a clock shop while the detective states he wishes there was some way to establish the time of death is brought to mind.

4.4.1 Case One

An elderly man called to say his wife had committed suicide with a shotgun. She was lying in front of the TV with a coat hanger bent to push the trigger. However, the shotgun was fully loaded. He always reloaded after shooting and it didn't occur to him that the gun's functionality would be checked.

These relationships that are important items of evidence cannot be packaged and brought to the laboratory for examination. You can swab and collect the blood from the kitchen counter, but the importance of its location is in the relationship of the bloodstain to the knife drawer. The footprint impression in the carpet or the location of blood streaks on the wall have reconstructive information regarding location and activity but cannot be packaged. This information must be carefully documented and recorded in sketches and photographs, and the items must be accurately measured so their positions can be reflected in the sketches.

The evidence clues can tell us information about the sequence of events and establish direction. The blood drops on the sidewalk show the direction the victim was going. Of course, if the body is at the scene, it is not difficult to tell the direction of the blood trail. The sequence of events is simple logic: he was stabbed, walked a distance, then fell to this location. This is a simple example of establishing sequence and directions; most crime scenes will have some evidence that will give information regarding the sequence of events, but it may not always be this simple.

The position of a shooter can be established by tracing back the bullet paths and/or by the location of the cartridge casings.

4.4.2 Case Two

The driver of a car was shot by his jealous girlfriend. She said she accidentally fired the gun approximately 3 feet from the car. The gun she used was a .25 automatic. The ejection of the cartridge casing from this gun is to the right rear. The cartridge casing was found in the passenger's seat. It can be concluded that she reached inside the vehicle through the passenger window to fire the weapon. Her position was established through the analysis of the physical evidence, i.e., the location of the casing and the trajectory of the bullet.

Reconstruction evidence can also be things that are not at the scene but are inferred or derived conclusions. This inferred evidence is frequently used to establish the apparent motive. The empty wallet lying beside the body, the jewelry removed from the open drawer, or the photo missing from a frame, are motive evidence. Their absence is the clue; we infer that they existed. Shadow patterns are another example of inferred evidence. The lack of a portion of the blood spray behind the victim of a shotgun blast shows that something was removed after the shot. The shape of this void may also yield information. We also expect a blood spray to be present on the item if it is located.

4.5 Tying It All Together

Simply utilizing the scientific method to establish certain activities or facts from the clues is not reconstruction. Logic and critical thinking must be applied to the separate events or facts that have been determined. At this point, the alternatives must be considered. The theories of the detectives, the attorneys, the witnesses, the suspect, and, if living, the victim, must be tested against the established events or facts.

The reconstructionist must take facts from different areas to determine if there is a connection. One fact will affect the way in which another could have happened. Critical thinking is applied to these facts. However, one must be cautious in this approach to reconstruction. It is easy to go too far and say things that can not be supported. This may be acceptable in the investigative phase, but not for court, where each and every point must be explained and supported by the evidence. The following shows how extensive the reconstruction can be.

On Christmas night, two women were found shot in a bloody scene in a suburban neighborhood. The scene had several types of physical evidence including shoeprints, blood, and clothing. The suspect's overcoat had a bloodstain pattern and a bullet hole with powder residue surrounding only one half of the hole. He also had makeup under this hole, on his forearm, and near the bloodstain. The autopsies showed both victims had been shot, one of them three times, and the other once.

Based upon examination of the evidence, it was determined that one of the women had taken a bath, and was getting dressed when the suspect entered the bedroom and hit her with a baseball bat. She was temporarily incapacitated, but due to a ¾" skull thickness, she was not killed. The suspect then grabbed the other woman, held her in a headlock, and put the gun to her temple, catching a fold of his coat when he shot her. He let her fall to the floor and caught the first woman approaching the door. He shot her in the neck; as she fell, he shot her in the cheek and in the eye.

He then removed his coat and proceeded to arrange the bodies into a "crucifixion" pose. The arms outstretched and the feet crossed. He then went to the bathroom, relieved himself and washed. He put on his coat and left the house. He disposed of the weapon before his mother told him to go to the police because he had blood on his coat.

The case did not go to trial; the defendant pled guilty.

4.6 Why Reconstruct A Crime?

Robert Ogle wrote, "Crime scene reconstruction is one of the major purposes for the collection of physical evidence [7]." One may ask: why is this so important?

Crimes are reconstructed for several reasons, depending upon the phase of the case. The investigation, the trial preparation, the defense preparation, and the trial itself all can benefit from reconstruction. Knowing what happened makes the task of dispensing justice easier.

4.6.1 Was There A Crime?

Reconstruction can help to determine if there was a crime or what crime has been committed. For example, the edge of a piece of glass will indicate the direction of the force applied to it to break it. This can be used to determine if a person broke the window from outside as in a burglary or from the inside for insurance fraud or just for attention. The finding of bear hair on a cloth found on an elderly woman's porch showed it came from inside the house where there was a bearskin. It was not a "death threat" or an "alien invasion" as she suspected.

4.6.2 Crime Elements

Once a crime is established, then crime reconstruction is used to aid in determining the what, who, when, how, and why of the crime. The reconstructionist becomes part of a team of persons involved in the investigation. The information developed in reconstruction is used by:

- Investigators in locating the suspect.
- Investigators conducting interviews to test the veracity of the statements.
- Criminal profilers in establishing a "profile" of the perpetrator.
- District Attorneys or defense attorneys to determine how to prepare and argue their cases in court.
- The Court in determining sentences.

The following case illustrates how the use of reconstruction would have saved the city and county from prosecuting the wrong person. The case seems trivial except that Betty was in jail for 8 months awaiting trial before the evidence was examined for reconstruction purposes.

4.6.2.1 Case One

Sue and Betty were competing for the same man's attention. Sue had been living with him, but now he had moved in with Betty. Sue claimed she was walking home from work when Betty and three other women came upon her in their car. She was thrown to the sidewalk on her back, then flipped over and held by three of the women while Betty cut her shirt and back. She said she could feel the blood running down her back so she struggled until she could finally get up and get away.

At the urging of a friend, Sue called the police to report how she was assaulted. It was 1½ h before an officer arrived at her home. He said she had about 20 cuts on her back, which were still "dripping blood." Betty was charged with assault.

The photos show very superficial cuts, more like scratches that could be self inflicted. The shirt was cut only part way up the back, with jagged cuts at the top where the shirt was bunched up. Examination of the shirt revealed no blood on the inside back.

This case shows how physical evidence is used to determine the veracity or a statement. This is one of the more common uses of reconstruction. The stories told by the victim (if living), the suspect, and the witnesses should all be tested because in some cases there are fabricated stories that sound good but are false. The statement was made, in this case, by the alleged victim. The story does not agree with the physical evidence. The "victim" should be charged with filing a false report.

This case involves what is called a "staged crime scene." A staged crime scene is one in which the evidence is altered or created to shift the direction of the investigation [8]. When physical evidence is changed or created to direct the investigation toward a specific individual, as in this case, this type of staged crime scene is called a "frame." Usually the evidence in a staged scene is altered to cover up the crime. The removal of a body from the house, dumping it in a remote area, and cleaning the house are the most common cover ups. This is almost always the act of someone living with the decedent.

If there is an idea how the crime was committed, then the evidence can be easier to locate and identify. The reconstructionist at the crime scene will see relationships that can quickly lead to other evidence. For example, multiple blows to the head of a body indicate there should be blood cast off the weapon. If there is no cast-off blood nearby, then the beating did not occur at this location. A blood trail should lead to the original scene. Lacking a trail and lacking cast-off blood stains, one would have to consider a "staged" crime scene or the premise that this is a beating is incorrect. A wrong hypothesis at the crime scene can send the investigation and conclusions completely off track.

4.6.2.2 Case Two

A man had reportedly committed suicide by pouring gasoline on himself inside a house and igniting it. The reconstructionist was not at the crime scene but was presented with the facts later. The man had run from the hallway, where the gasoline can was located, into a bedroom, onto the bed, then jumped through a window before being overcome by the flames. In looking at the sketch of the house (floor plan), the reconstructionist asked where the heater was located. It was a floor heater located where the fire started. This was no suicide, it was an accident. When the fumes from the gasoline reached the pilot light on the gas heater they caused the gasoline can to explode and saturated the would be arsonist with gasoline.

As in this case, the use of physical evidence for a reconstruction may determine if the death is accidental, suicide, homicide, or natural. The determination of a natural death is left to the pathologist and the toxicologist.

4.6.2.3 Case Three

In the following case, the bloodstain patterns, the direction of the shot, and the way clothing was arranged were the clues that yielded information to prove a homicide.

A second grader came home from school to find the doors locked. Because her mother was 9 months and a day pregnant, the second grader was sure that her mother went to the hospital. She went into the garage to get the house key and saw a shape that looked like a person. She ran two blocks to her grandparents and told them that her mother had gone to the hospital and someone was in the garage. Because they were supposed to take their daughter to the hospital, the grandparents were very concerned. The grandfather went to the garage and found his daughter in a lawn chair with her head split down the middle and a shotgun at her feet. He called the police.

Examination of the crime scene led the reconstructionist to the conclusion that this was a staged crime scene. The following clues were the basis for this conclusion:

- The bloodstains on the arms and hands were not consistent with the blood that would result from a shotgun blast to the head.
- The shot was directed parallel to the floor as evidenced by the blood spatter on the wall behind her.
- Her belt was above her breasts.

These clues show that the victim was beaten elsewhere, placed in the chair, and then shot with the shotgun. Later a search warrant was obtained allowing entry to the house. Inside the house were cast-off blood stains and spatter patterns on the walls and ceilings of the dining room and kitchen. There were two heavily bloodstained cast iron skillets with the bottoms broken out. A similarly bloodstained cast iron sauce pan with a broken handle and a second sauce pan were also spattered with blood.

The husband had a perfect alibi: he was seen at work an hour before his daughter left for school and was not missing at any time during the day. Investigation led to an old Army buddy of the husband who had been staying at the home for a couple of weeks. He had been paid $10,000 worth of cocaine by the husband to kill the wife. The suspect stated, “She didn’t want to die.” Her husband and his buddy were convicted of two counts of murder for hire. The actual killer was sentenced to two life sentences; the husband to two death penalties.

This was another staged crime scene. If the “plan” had succeed and she had been knocked unconscious with the first blow and no blood shed in the house or on her clothing, would the responding officer have been able to recognize the clues that showed this was a homicide? Probably not. This would have been a “perfect crime.” Fortunately, if anything can be fortunate in a homicide, the victim didn’t respond as planned.

4.7 Reconstruction in Behavioral Analysis

Criminal Profiling or analysis of the behavior of the criminal at the scene is a relatively new approach in criminal investigations. Crime reconstruction is an important component of these profiles. The Academy of Behavioral Profiling

has stated that a reconstruction must be made before a behavior analysis is rendered [9].

Craig Cooley wrote an on-line article titled *Crime Scene Reconstruction: The Foundation of Behavioral Evidence Analysis*. He states in the introduction that: "The chief goal of this report is to argue that the foundation of any competent criminal profile is that of a complete crime scene reconstruction, brought about by the physical evidence documented and collected at the crime scene(s) [10]." In other words the profile is based on the evidence and what it can tell the reconstructionist about the actions at the crime scene. Cooley goes on to compare the processes of reconstruction and profiling. "Crime scene reconstruction like behavioral evidence analysis is both a science and an art. The process is founded on the scientific method, while the practice and degree of success is dependent upon the skill and experience of the reconstructionist, the important aspect being that its foundation is that of the scientific method. With reconstruction and behavioral evidence analysis both relying upon the scientific method the end result of one's analysis will be shielded from attacks on its reliability and validity [11]." Both processes use the scientific method; however, one process is dependant upon the other. If the reconstruction is flawed, it follows that the profile will also be flawed.

4.8 Ethics

Reconstruction experts must be aware that the analysis rendered is, in many cases, going to be the deciding factor in how justice is dispensed. They cannot afford to allow speculation into their findings. They must pursue as much information as they can about a case. A reconstruction can not be made without all the evidence.

It is also necessary to know the limitations of one's abilities. A disagreement between experts can usually be traced to one of them lacking knowledge about a type of evidence and the cause and effect in its production. For example, arterial spurting is a known phenomenon, but when the torso is upright or has clothing on, this is not a factor due to the chest cavity filling or the clothing absorbing the energy of the blood stream. Arterial spurting comes from arm or neck wounds but seldom from torso stabbings.

The understanding of critical thinking and logic is absolutely necessary for the reconstructionist. Even with a clear understanding of these processes, not knowing how to interpret a piece of evidence will result in a faulty analysis because a wrong premise is the starting point in the process. It is also important to remember the difference in inductive and deductive logic that starting with a faulty premise will lead to wrong conclusions. As John Thornton states, "Induction is a type of inference that proceeds from a set of specific observations to a generalization, called a premise. This premise is a working assumption, but it many not always be valid. A deduction, on the other hand, proceeds from a generalization to a specific case,

and that is usually what happens in forensic practice. Providing that the premise is valid, the deduction will be valid. But knowing whether the premise is valid is the name of the game here; it is not difficult to be fooled into thinking that one's premises are valid when they are not."

> "Forensic scientists have, for the most part, treated induction and deduction rather casually. They have failed to recognize that induction, not deduction, is the counterpart of hypothesis testing and theory revision…..too often a hypothesis is declared as a deductive conclusion, when in fact it is a statement awaiting verification through testing [12]."

The reconstruction can also be faulty because evidence was not available for analysis. This can be because law enforcement did not think it would be of value and therefore did not submit it for laboratory analysis. Occasionally, the evidence is set aside by the prosecutor or investigator because the analysis might be counterproductive to their theory of the case. This is a question of ethics and is something over which the reconstructionist may not have control nor be aware. The reconstructionist should ask for all the photos, diagrams, evidence logs, and reports. That will ensure that all the evidence is available to help interpret the evidence.

The next paragraph shows how bias comes into laboratory examinations. When the detective, District Attorney, or defense attorney make the decision regarding what evidence will be examined, there is a built in bias. The reconstructionist cannot proceed without having judged all of the evidence or must issue a statement that the reconstruction is limited because it is based upon the material submitted and could be changed if additional evidence is submitted.

In a recent court case, the criminalist testified that the laboratory only does what the police ask them to do regarding the evidence. They do not look at the whole case to try to determine the interpretation of the evidence unless an outside expert is looking into the case.

One of the most difficult things the criminalist has to do is recognize the different forms of bias and strive to eliminate it from the conclusions that are reached.

4.9 Evidence Dynamics

Evidence Dynamics refers to the integrity of the physical evidence [13]. Physical evidence is seldom pristine at the scene of a crime. It may have been altered, destroyed, moved, contaminated, created or changed. Some of these changes are natural, such as decomposition or thermal adjustment. Changes may be caused by weather, by animals or insects, or by humans.

Humans change the evidence for various reasons. Some are accidental: someone in the field accidentally stepping on evidence; handling a piece of evidence before it was examined for prints, DNA, or trace evidence, or before its location has been documented. Sometimes these changes are purposeful. Collecting the evidence changes the evidence; packaging is done to protect the evidence, but sometimes causes change itself. However, most of these are predictable changes. The unpredictable changes are not so easy to identify.

The reconstructionist is using evidence that was generated by an incident to determine the event. The interpretation of the cause from the results can be faulty if the evidence dynamics are not known or understood. Not identifying and accounting for these changes may cause the wrong interpretation. It is better to offer no opinion than to offer one based on evidence that has been changed prior to documentation.

4.9.1 Case

In a recent case where the question was suicide or murder, evidence had been moved, created, changed, and destroyed prior to any documentation. The husband claimed he and his wife were drinking in the living room. She had gone to the bedroom. He heard a loud noise, then it sounded like she fell. He ran to the room; she was on the floor on top of a .22-caliber semi-automatic rifle. She was breathing but unresponsive. He called 911 and said he was afraid she might come to and shoot again, so he moved the rifle onto the bed. The operator told him not to touch the gun but it was too late.

The first officer arrived in a few minutes. He had a problem entering the bedroom as the woman's feet were against the door. The husband had moved her to "make her more comfortable." The deputy saw the rifle on the bed and moved it to the floor away from the husband.

A second deputy came to the scene. He saw the loaded rifle on the floor and proceeded to remove the magazine and cartridge and place them carefully on the bed next to the scabbard for the rifle. He said he got blood on his hands from the rifle.

The second deputy said there was no blood in the hall approaching the bedroom.

There was blood in the bathroom sink; the husband says he did not wash his hands. There were spatters and cast off blood in the hall. There were a couple of 1-in.-diameter spots and a streak of blood on the bed. The husband had various bloodstains on his clothing.

The prosecution expert stated this was "definitely a murder" due to all of the blood evidence. He found several blow-back drops, i.e., drops approximately 1-mm in diameter in the barrel of the weapon. Based on that finding, he stated that the muzzle was within 3 in. of the entry wound. Actually, there was a muzzle imprint on her forehead, which indicates tight contact with the muzzle.

The expert found a few very small drops on the husband's clothing and a couple on the rifle, which he also called blowback. With a .22, there is essentially no blow-back with tight contact except into the barrel. The expert was only looking at the blood stain patterns not at all of the evidence. "High impact" drops are caused by breathing with blood in the nose and/or mouth. They are also consistent with CPR efforts. The source of these tiny drops could have been caused by the actions of the husband after he found his wife.

The blood on the bed is probably from the rifle when it was placed there by the husband as there is no trail showing that a bleeding object was moved.

That the rifle was moved twice by law enforcement shows a lack of understanding of evidence.[9]

The bloodstains in the hallway were not present when the second deputy came into the area. He stated they were caused when they moved the body.

In the case described above we have several instances of evidence dynamics. The husband altered and created evidence, which was interpreted by an "expert" resulting in a murder charge. The deputies also altered, created, and destroyed evidence that contributed to the prosecution expert's opinion. It was only by presenting the alternative sources of the evidence and pointing out the evidence dynamics that the husband was exonerated by a jury.

At every scene it must be realized that evidence has the potential to have been moved, removed, destroyed, altered, or created before the crime scene investigator or reconstructionist arrive. The failure to realize that fact can result in a faulty reconstruction and a miscarriage of justice.

4.10 Conclusion

For reconstruction purposes, the value of physical evidence and documentation of the crime scene by competent personnel can not be overemphasized. The reconstruction analyst relies on correct complete information to render a reconstruction of the events of a crime. Not all cases can or need to be reconstructed, and the evidence in some of the cases does not need to be collected. In others, competent personnel are not available to respond to the crime scene; therefore a reconstruction is not possible. "The value of physical evidence varies from type to type and case to case. In some investigations, its potential may never be fully appreciated. In some jurisdictions it is a matter of the availability of trained personnel who can respond to crime scenes and collect the appropriate evidence [14]."

The workload in crime laboratories has become so great that many of them no longer respond to crime scenes. They do not develop the expertise necessary for crime reconstruction. The forensic scientists never understand the uses of the physical evidence in reconstructing the crime. A valuable tool for Justice is being lost.

4.11 Questions

1. What are the steps involved in the Scientific Method?
   (a) Observation
   (b) Postulation (hypothesis)

[9]It has always puzzled me why law enforcement officers are so concerned with a loaded gun at the scene that they destroy evidence (position, mechanical function, fingerprints, etc.) by unloading the weapon when they each have at least one loaded gun on their person.

(c) Testing (experiments)
(d) Support or refute hypothesis
(e) Reiteration

2. Give an example of three of the following types of evidence:

(a) Transitory (anything that disappears within a short time)
(b) Predictable (changes due to weather, time, decomposition, etc.)
(c) Unpredictable (changes due to interference with the scene by animals, insects, captains)
(d) Directional (something that indicates the direction – bullets, footprints, etc.)
(e) Location (a gun next to the shooter, the location of the evidence that gives information)
(f) Temporal (a stopped clock, a phone call, etc.)
(g) Functional (how a gun works, any mechanical or electronic device)
(h) Missing (outline of a gun in blood, jewelry, wallet, etc.)

3. Define: staged crime scene

(a) A staged crime scene is one in which the evidence is altered or created to shift the direction of the investigation.

4. Crime Reconstruction is important in which parts of a criminal investigation?

(a) Corpus delecti: proof that a crime was committed.
(b) Investigation
    (i) What – weapon used, what evidence should be obtained
    (ii) Who – investigative leads, behavioral profiling
    (iii) When – what was the time of the incident, how long did it take
    (iv) How did the crime occur
    (v) Sometimes Why – motive, i.e., missing wallet may indicate robbery
(c) Prosecution: helps the DA formulate the theory of the crime
(d) Defense: can help prevent wrongful prosecutions by eliminating theories.

5. What is the difference between inductive and deductive logic?

(a) An induction is an inference that proceeds from a set of observations to a theory.
(b) A deduction proceeds from a generalization to a specific case.

6. When should a reconstructionist refuse to reconstruct a crime?

(a) When not all of the evidence is made available
(b) When there is insufficient or inadequate crime scene documentation.

7. What does Evidence Dynamics mean?

(a) Evidence Dynamics refers to the integrity of the evidence. At every scene, evidence may have been moved, removed, destroyed, altered, or created.

8. How does crime scene documentation affect crime reconstruction?
   (a) The crime scene evidence must be accurately documented at the scene by sketch, measurement, photography, and notes for a reconstruction to be attempted. A mislocated item may lead to a wrong interpretation.
9. What is a source of bias that must be overcome in the crime laboratory?
   (a) The submitter of the evidence may relate a theory that may cause bias. Work to eliminate that theory if possible.
10. What are the tools of the reconstructionist?
   (a) Clues
   (b) Critical thinking
   (c) Logic

4.12 About the Author

Jerry Chisum started his career as a student assistant for Professor Paul L. Kirk at U.C. Berkeley. After graduation he was employed by the San Bernardino Sheriff's Crime Laboratory as an associate criminalist for 4 years, and then took a position with Kern County Sheriff's Office to set up and direct their laboratory. Mr. Chisum left to work for the State of California as a criminalist, supervisor, and manager with a short hiatus with SRI as a research scientist and NASA Technology Transfer agent. However, his love was the laboratory, and he went back to the state laboratory to set up a training program offering courses that had never been offered in the field. He was transferred to set up and direct the Modesto laboratory. Mr. Chisum was there for 15 years, during which time, he became President of the California Association of Criminalists (CAC) twice and President of the American Society of Crime Laboratory Directors (ASCLD). He transferred back to Sacramento as a member of the California Criminalistics Institute, where he was Crime Scene Investigation and Reconstruction Program Manager. While there, he was elected President of CAC for an unprecedented third term. He was also employed part time by California State University, Sacramento, to teach courses in Criminal Investigation, Criminal Identification, and Introduction to Criminalistics he resigned from the university due to health considerations.

On their vacations, Jerry and partner Joe Rynearson taught law enforcement officers an intensive course on crime scene investigation and reconstruction for 25 years. He has also lectured at UC Berkeley, at Bond University in Australia, Taiwan National Police, and has taught in Tanzania. Since his retirement from CA DOJ in 1998, he has been in private practice as a consultant and writing. He has chapters in several books and has written/co-edited Crime Reconstruction, a text.

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Chapter 5
Explosives and Arson

James B. Crippin, BS

Contents

Explosives and arson cases, as they relate to forensic science, are can be very hard to separate. It is a rare occasion when a fire does not occur after an explosion. That is why they have been placed together for this chapter.

In the past, there has been little education regarding forensic science let alone in the fields of arson/explosion investigation and or analysis. Only in recent years has forensic science benefitted from what is commonly referred to as the "Hollywood" effect. This occurs when movies and TV glamorize something and make it very appealing to the general public. Many recent movies and the television series "CSI" have done so in the case of forensic science. However, because arson and explosion investigations and analysis are so specialized, the Hollywood effect has done us no favors in this regard.

Both arson and explosive case/evidence can be very tedious and time consuming to analyze. Because of the materials involved, if the materials are not handled in a

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safe manner, they can also be very dangerous to the analyst's health. Laboratory analysis, as anyone in forensic science knows, is tied directly to how well the crime scene is processed and evidence correctly identified and collected. If the evidence is not located and collected properly, it will be of little, if any, use when it gets to the lab, let alone when it is used in court.

This chapter is organized in two parts: Investigations and Laboratory Analysis.

5.1 Investigations

Not much has changed with bombing and fire investigations in the last few years. Very few if any investigations occur as they do on TV. There is no script; it is more like a puzzle with many of the pieces missing. Many agencies still send their laboratory personnel to the actual scenes to help in the identification and collection of evidence. Not all personnel are interested in doing this, but some are. The reasons are many.

5.1.1 Hazards

For the most part, a bombing or fire scene is one of the most dangerous places a person can be. Generally the area can be very hazardous to the responders' health for any number of reasons. The main reason is the fact that once a bomb has gone off or a fire has occurred, the scene is generally no longer structurally sound (Figs. 5.1 and 5.2).

These are just a few of the hazards. On top of these, add in that the bad guys may be actively trying to kill the responders who show up. On January 16, 1997, officers responding to the scene of a bombing incident, where one person was killed and another seriously injured, were targeted by the bomber. Street officers, EMS personnel, and investigators of all types quickly arrived on scene. They were all in extreme danger just by doing their jobs. The bomber left what is called a secondary device behind timed to go off approximately one hour after the first device (Fig. 5.3).

Although the device detonated, no officers were seriously injured simply because a late arriving officer had parked his car directly in front of the device. Less than a month later the same situation occurred again. This time however, the responding officers modified their procedures and searched the response area prior to beginning the evidence processing. Because of this alteration of their response, the device was discovered and disarmed before it could detonate. Walking into an area that has a device intentionally left behind, designed to kill the responding officers, can be a sobering experience. While street officers may realize these dangers, most crime scene response personnel are unfamiliar with them. I personally have been on a response where I was later informed by the suspects that they had me and several other responders in the cross-hairs of a sniper rifle. The only reason they did not shoot was because they did not want to give away their position. There is story after story that parallel this instance from other responders.

Fig. 5.1 Buildings can and do explode

Fig. 5.2 Cars are reduced to jagged pieces of metal

5.1.2 Crime Scene Personnel

Crime scene personnel are chosen and trained for their ability in evidence recognition and collection. They have to be cognizant of and know how to deal with all types of evidence. Both bombings and arson scenes can be quite a mess. Both will have evidence present, because they deal specifically with accelerants and explosives, in two

Fig. 5.3 Components of an incendiary device

primary physical forms: residues or intact material. Most people are under the false impression that when an explosion occurs, all of the components of the explosive device as well as the explosive itself are consumed or destroyed. The same impression is thought of fires. Everyone, including many investigators themselves, think that ignitable liquids and other accelerants are consumed by a fire. Nothing is further from the truth. Both residues and unconsumed (intact) materials can be located at the scene and in debris recovered from the scene if the investigator knows what to collect. In addition to the residues and unconsumed explosive, there may also be intentional materials left behind. Over recent years, there have been various methods used to help in tracking explosives that could be used by the investigator in bombings.

5.1.3 Taggants

5.1.3.1 Micro

One method that was tried and still being considered is micro-taggants. Micro-taggants are small, virtually indestructible layer chips that are mixed with explosives to be left behind after an explosion. This method has proven unwieldy because these taggants, although magnetic and UV reactive, are almost impossible to recover in a timely manner (Fig. 5.4).

5.1.3.2 Chemical

Another method that is currently being used is chemical taggants. Instead of actual physical inert materials, specific chemicals are mixed with the explosives as

Fig. 5.4 Micro-taggant

markers. After an explosion, these chemical markers can be recovered, showing what explosive had been used. This method is being used to tag several different forms of organic high explosives here in the United States. It is a much better methodology and is finding wide acceptance in both the manufacturing industry as well as forensic science.

5.1.4 Contamination

This brings us to an extremely important point: anyone working at a bombing or arson crime scene must be constantly aware of contamination. The techniques and equipment that are currently available to personnel who analyze evidence from bombings and arsons is much, much more sensitive that in the past. This means that what could not have been detected in the past now can be very easily. This leads to the question if something is found in trace amounts: "Is this evidence or is it just contamination from another scene?" Boots, clothing, tools, and even vehicles can contaminate a scene. Agencies have to be aware of contamination problems and have procedures in place to combat them. Most agencies have thought this through and already have procedures in place to minimize these concerns.

5.1.5 What Happened?

In addition to collecting the evidence at bombing and arson scenes, crime scene investigators are tasked with determining what actually has happened at the scene. These investigators want to be able to determine what was the size of the bomb, where was it placed, how was it initiated, of what was it composed, what type of flammable liquid was used, and how was it ignited? All of these questions run through your mind when you arrive on scene (Fig. 5.5).

Fig. 5.5 Starting to process the scene for evidence

5.1.6 Evidence Collection

Once the evidence has been identified, it must be properly collected. The evidence must be placed into secure containers for transportation to the lab for analysis. These containers may be plastic bags, metal cans, or glass jars. The container type is somewhat dependent upon what type of evidence is going to be placed into it. Organic materials are unsuitable to be placed into certain types of plastic bags because they tend to pass through the plastic barrier and evaporate. However, there are specific types of plastic bags made to contain organic materials (Figs. 5.6 and 5.7).

Evidence from bombing scenes is collected into the same types of containers. By using the proper containers to collect and transport the evidence, any contamination or loss of the evidence can be avoided. It may be months before the analyst has time to examine the evidence. If the evidence is packaged improperly, materials could be lost or could even be contaminated sitting in the evidence locker. Without good evidence, the best forensic lab in the world cannot produce valid, acceptable results.

5.2 Laboratory Analysis

Once the lab does get the evidence, various types of analyses can be performed based upon agency protocols. Most agencies provide limited if any explosive evidence analysis. Agencies, if they have a full service lab, will do fire debris analysis.

Fig. 5.6 In most situations, arson evidence is generally placed into specific types of bags

Fig. 5.7 Metal cans are used to collect arson samples

This is because there has been more fire debris training offered in the US during the last ten years than there has been explosive analysis training. The National Center for Forensic Science (NCFS) has been providing this fire debris training. They are the home of the Technical Working Group for Fire & Explosions (TWGFEX). This group is made up of forensic personnel, both government and private, from agencies across the company as well as several foreign countries, who are specialists in various areas of fire debris/explosive investigations or analysis.

5.2.1 Explosive Analysis

As with any type of evidence, first thing that is done is a visual examination of the debris for possible fragments of the device or any unconsumed explosive materials. Every small bit and piece could be important. All must be separated and, if possible, identified. Timing mechanism, firing circuit, device casing, what else? By looking at the bits and pieces, their size, and what type of damage is present, an experienced forensic examiner can start to deduce many things about the device. For instance, what type/class of explosive was probably used, and whether or not the device functioned properly (Fig. 5.8).

Additionally, there may be unconsumed explosives present imbedded in the pieces along with residues coating them. TWGFEX has developed suggested guidelines for the analysis of both intact explosives and residues. Each is comprised of a table that shows the analysis in four categories:

- Those that provide significant structural and/or elemental information
- Those that provide limited structural or elemental information
- Those that provide a high degree of selectivity
- Those that are useful but do not fall in either of the other categories

Table 5.1 is applicable to both intact explosives and explosive residues.

The table is used in the following manner: A technique identified with a numeral 1 is sufficient for identification, a technique identified with a numeral 2 requires one more supporting technique for identification, a technique identified with a numeral 3 requires two more supporting techniques for identification, and a technique identified with a numeral 4 requires three more supporting techniques for

Fig. 5.8 Think of working a detonated device the same as putting together a jigsaw puzzle

Table 5.1 Analysis Guide for Explosives

Categories 1 and 2	Categories 3	Categories 4
Infrared spectroscopy (IR)	Gas chromatography (GC)	Burn test
Gas chromatography/mass spectrometry (GC/MS)	Gas chromatography thermal energy analyzer (GC-TEA)	Flame test
Energy dispersive X-ray analyzer (EDX)	Liquid chromatography (LC)	Color Spot test
Liquid chromatography/mass spectrometry (LC/MS)	Liquid chromatography thermal energy analyzer (LC-TEA)	Melting point
Raman spectroscopy	Ion chromatography (IC)	

identification. Some caveats can come into play when using these guidelines. When identifying ions, two techniques per ion are required. Some category 3 techniques lend themselves to being counted twice. For example, chromatographic techniques may be counted as two distinct Category 3 methodologies when different stationary and/or mobile phases are employed. Polarized light microscopy (PLM) may be counted as two distinct Category 3 methodologies when two different identification tests are done, such as examination of the physical/optical properties plus a microcrystalline test.

For any analytical technique to be considered of value, the test must be considered "positive." Although "negative" tests provide useful information for ruling out the presence of a particular family of explosives, these results have limited value toward establishing the identification of an explosive substance.

If we look at the following flowchart, we can see a basic scheme of analysis that uses a layered approach using almost all forms or types of explosive materials (Table 5.2).

5.2.1.1 Preliminary Tests

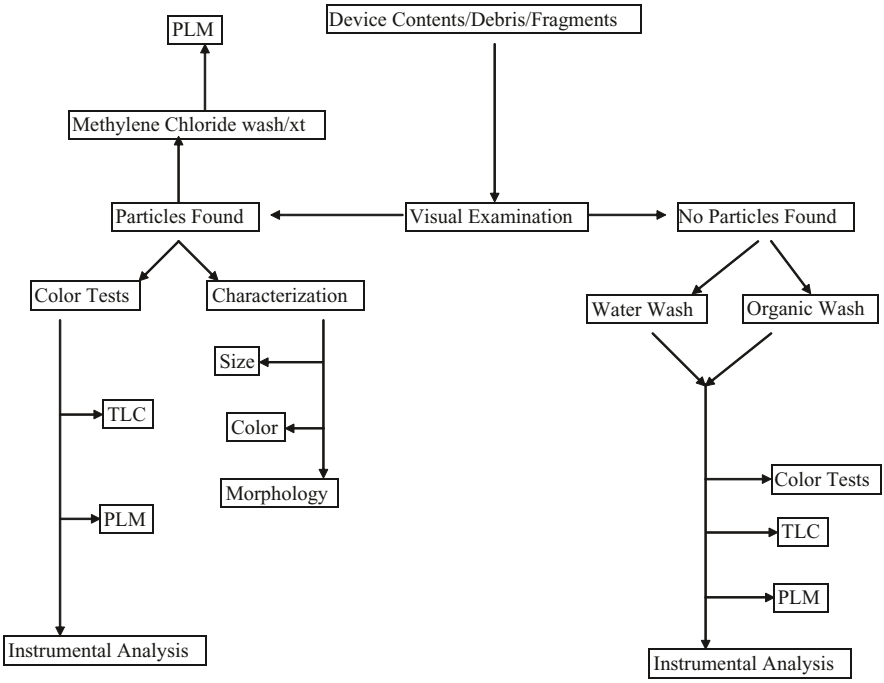
The first step in analysis is a simple presumptive color test. Regardless of whether the explosive is inorganic or organic based, these color tests will start the analyst down the road to identification. The most widely used color test is the diphenylamine color test. It gives a dark blue color with both organic and inorganic nitrates as well as chlorates (Fig. 5.9).

Some color tests can be used to differentiate between organic and inorganic explosives. The antazoline test reacts with inorganic nitrates while methanolic KOH (potassium hydroxide) gives good color reactions with organic explosives. Whichever color test color test is used, they are still presumptive tests (Figs. 5.10 and 5.11).

5.2.1.2 Confirmatory Tests

Once the preliminary color tests have been done, the next step depends upon whether or not intact particles are found. If particles are present, analysis can begin immediately. If no particles are found, a series of washes are done on the debris or

Table 5.2



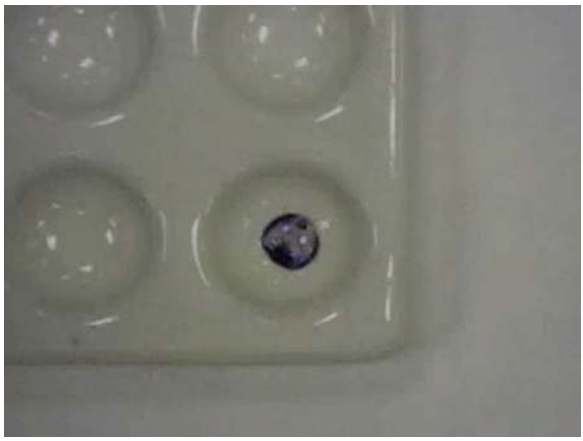


Fig. 5.9 The diphenylamine color test gives a dark blue color with both organic and inorganic nitrates as well as chlorates

fragments to recover any residues present. A water wash is done for inorganic explosives, while an organic solvent is used for organic explosive residues.

Regardless of whether traditional instrumental analysis or PLM is chosen as the confirming technique, the analysis is entering the final phase.

Fig. 5.10 The antazoline test reacts with inorganic nitrates

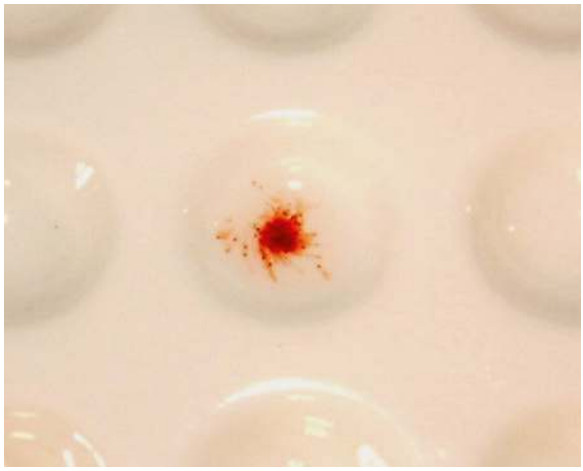


Fig. 5.11 Methanolic KOH (potassium hydroxide) gives good color reactions with organic explosives

If there are no intact particles present ion the bombing debris, any fragments or the actual soil from the crater can be rinsed to capture any residues that might be present. They are rinsed with an organic solvent first and then with water. By using both an organic solvent and then water, organic and inorganic explosive residues may both be recovered. Once residues have been recovered, there are any numbers of ways to analyze them. Explosive analysis has been performed in forensic labs for quite a while. To identify explosives, some lab personnel use PLM while others prefer an all-instrumental approach (Figs. 5.12 and 5.13).

Shown above are two examples of the different types of equipment that can be used to analyze both unconsumed explosives and explosive residues. Although both methodologies are considered conclusive, the way the data is obtained varies

Fig. 5.12 Polarized light microscope (PLM)

Fig. 5.13 Gas chromatograph/mass spectrometer (GC/MS)

greatly. The PLM gives data that must be examined visually and relies on a highly trained individual to make the determination of what it means. It will conclusively identify both organic and inorganic explosives (Figs. 5.14 and 5.15).

Fig. 5.14 Organic explosives using the polarized light microscope

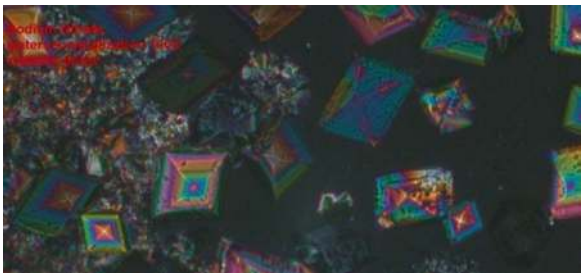


Fig. 5.15 Inorganic explosives using the polarized light microscope

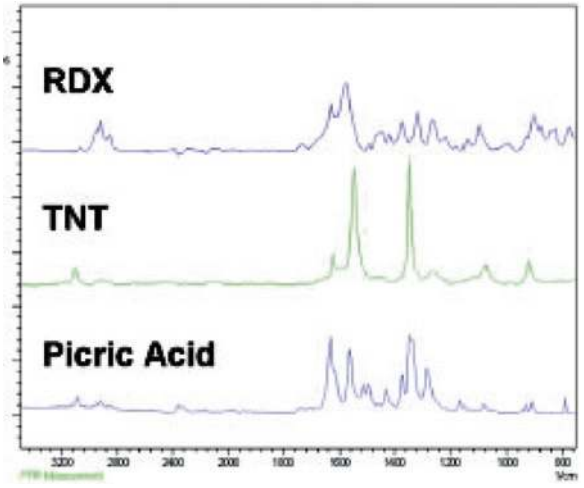


Fig. 5.16 Data in the form of infrared (heat radiation absorbance/transmittance)

Instrumental analysis gives a different type of data. These data types are referred to as spectral data or spectrums. This data may be in the form of infrared (heat radiation absorbance/transmittance) or data that show the actual molecular make-up of a compound such as mass spectral information. Just as with PLM, both organic and inorganic explosives can be identified (Figs. 5.16 and 5.17).

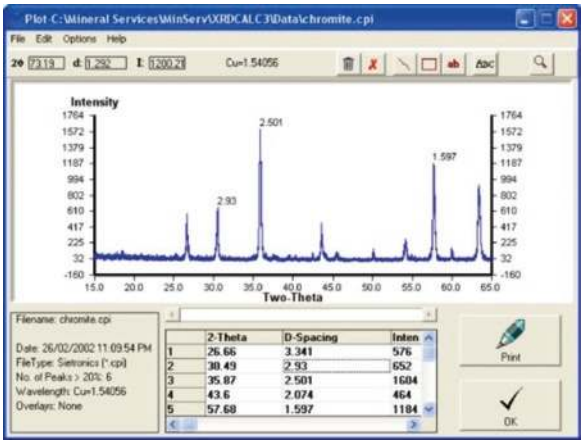


Fig. 5.17 Data that show the actual molecular make-up of a compound, such as mass spectral information

5.2.2 Fire Debris Analysis

Fire debris or arson analysis has been done for years. Initially ignitable liquids were extracted from fire debris by steam distillation. As time progressed, new and more efficient methodologies were developed. Currently most labs utilize a method referred to as passive absorption/elution. This is entails placing an absorbent material sensitized to organics inside a container of fire debris. As the container temperature is raised, any ignitable liquids will volatize and be absorbed by the absorbent inside of the can. The material is then rinsed with another organic solvent that extracts any absorbed ignitable liquids out of the absorbent material. This sample can then be run by either of two methods: gas chromatography or gas chromatography/mass spectrometry. The main difference between the two techniques is the difference in the detectors that are used to identify the compounds as they elute from the gas chromatograph.

5.2.2.1 Gas Chromatography (GC)

A gas chromatograph utilizes the amount of time that a compound takes to reach the end of a column and be detected. This means that although rare, two compounds could come off of the column at the same location, and the analyst would be unable to differentiate between them. This method was the standard method of analysis back in the 1980s and is still in use in many laboratories within the United States today. Data obtained was compared with a classification system developed in the late 1970s/early 1980s by the Bureau of Alcohol, Tobacco and Firearms.

- Class 1: Light petroleum distillates. Distillates in the range of C4 (butane) to C12 (dodecane) with a major alkane peak less than C9. Examples include many cigarette lighter fluids.
- Class 2: Gasoline. All brands and grades of automotive gasoline.
- Class 3: Medium petroleum distillates. Distillates in the range C8 (octane) to C12 (dodecane). Examples include some mineral spirits and charcoal starters.
- Class 4: Kerosene. Distillates in the range of C9 (nonane) to C16 (hexadecane). Examples include home heating oils.
- Class 5: Heavy petroleum distillates. Distillates in the range of C8 (octane) to C23 (tricosane). Examples include diesel fuel.

Using GC methodology, everything was classified as a petroleum distillate. This methodology did not work well for synthetic compounds and other types of naturally occurring materials that could be used as an accelerant.

5.2.2.2 Gas Chromatography/Mass Spectroscopy (GC/MS)

If we look at the GC/MS, as it is called, the GC is being used again to separate the compounds, but the Mass Spectrometer is the detector in this case. It does more than simply look at the amount of time it takes a compound to come off the column. It causes each compound to fragment. Each compound will fragment the same basic way time after time. Because of this, we can classify the compounds by the way they fragment, making it a much more definitive type of identification (Fig. 5.18).

The American Society for Testing and Materials (ASTM) developed a new classification system that utilized all the information that could be obtained by GC/MS analysis. It is called ATSM 1387-95, and all ignitable liquids are separated into six classes and five subclasses as follows:

- Class 1: Light petroleum distillates. Distillates in the range of C4 (butane) to C12 (dodecane) with a major alkane peak less than C9. Examples include many cigarette lighter fluids.
- Class 2: Gasoline. All brands and grades of automotive gasoline.

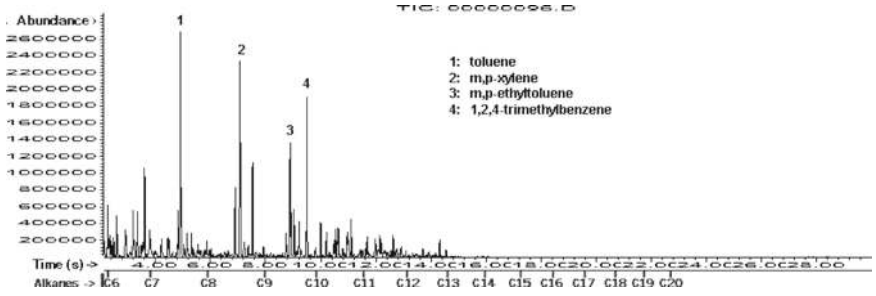


Fig. 5.18 Gas chromatography/mass spectrometer (GC/MS) graph

- Class 3: Medium petroleum distillates. Distillates in the range C8 (octane) to C12 (dodecane). Examples include some mineral spirits and charcoal starters.
- Class 4: Kerosene. Distillates in the range of C9 (nonane) to C16 (hexadecane). Examples include home heating oils.
- Class 5: Heavy petroleum distillates. Distillates in the range of C8 (octane) to C23 (tricosane). Examples include diesel fuel.
- Class 0: Miscellaneous compounds. This class encompasses all non-distillate products except for automotive gasoline. The miscellaneous class is subdivided into five sub-classes.
    - Class 0.1: Oxygenated solvents. Single-component and blended products that contain an oxygenated component. Examples include many lacquer thinners.
    - Class 0.2: Isoparaffinic products. Products comprised solely of branched chained alkanes (isoparaffins). Examples include many odorless paint thinners and charcoal starters.
    - Class 0.3: n-Alkane products. Products comprised solely of normal alkanes. Examples include candle oils.
    - Class 0.4: Aromatic products. Products comprised of aromatic compounds. Examples include some specialty cleaning solvents and insecticide vehicles.
    - Class 0.5: Naphthenic-paraffinic products. Products comprised of cyclic and branched chained alkanes. Examples include some odorless lamp oils, charcoal starters, and specialty solvents.

This new classification system is much better and allows almost every type of ignitable liquid to be classified.

In recent times, ASTM has come up with another newer identification guideline (ASTM E 1618-01). It is as follows (Table 5.3):

This new classification scheme combines the original distillate scheme with the original ASTM multilevel scheme. It combines the best of each into an easily explainable format.

5.3 Reports and Court

Once the analysis is done, a report must be written no matter what type of analysis has been done or what the results. Reporting procedures vary from agency to agency. Many have a standardized form that can be used. A fire debris report may read something like the following:

- Analysis conducted on item(s) # disclosed the presence of a flammable/combustible liquid(s) from the medium petroleum distillate class (MPD) class. The following are some examples of this class: paint thinners, some types of charcoal starters, mineral spirits, and cleaning napthas.
- Analysis conducted on item(s) # disclosed the presence of a flammable/combustible liquid(s) from the miscellaneous class. This class includes isoparaffins, alcohols, terpenes/turpentine, single component solvents (benzene, pentane, xylene, etc.), and specially formulated mixtures of alkanes or aromatics.

Table 5.3 Newest Ignitable Liquid Classification scheme

Class	Light range	Medium range	Heavy range
Gasoline	Fresh gasoline is typically in the light to medium range		
Petroleum distillates	Some cigarette lighter fluids Some camping fuels	Some charcoal starters Some paint thinners Some mineral spirits	Kerosene Diesel fuel Some charcoal starters
Isoparaffinic products	Aviation gasoline Specialty solvents	Some charcoal starters Some paint thinners Some copier toners	Some commercial specialty solvents
Aromatic products	Some paint and varnish removers Some automotive parts cleaners Xylene-based products Toluene-based products	Some automotive parts cleaners Specialty cleaning solvents Some insecticide vehicles Some lamp oils	Some insecticide vehicles Industrial cleaning solvents
Naphthenic/ paraffinic products	Cyclohexane-based solvents	Some charcoal starters Some insecticide vehicles Some lamp oils	Some insecticide vehicles Some lamp oils Some industrial solvents
Normal alkane products	Solvents Pentane, hexane, heptane	Some candle oils Some copier toners	Some candle oils Carbonless forms Some copier toners
De-aromatized distillates	Some camping fuels	Some charcoal starters Some paint thinners	Some charcoal starters
Oxygenated solvents	Alcohols Ketones Some lacquer thinners Fuel additives Surface preparation solvents	Some lacquer thinners Some industrial solvents metal cleaners/ deglossers	
Miscellaneous	Single-component products Some blended products Some enamel reducers	Turpentine products Some blended products Various specialty products	Some blended products Various specialty products

- No flammable/combustible liquid(s) were detected in item(s) #. This does not preclude the possibility that those types of liquids were present at an earlier time.
- Analysis conducted on item(s) # was inconclusive at this time.

An explosives report may look like this:

- Results of analysis disclosed the presence of potassium nitrate on the pipe fragments.
- Potassium nitrate is a major component of gunpowder. When confined and ignited in a pipe, gunpowder will produce an explosion. This type of improvised explosive device (IED) is capable of causing serious injury and/or death.
- Results of analysis disclosed large square fragments of a galvanized 1-in. diameter pipe. Physical characteristics determined that these fragments were part of a pipe bomb filled with a low explosive/explosive compound and ignited. Some types of low explosives commonly used in IEDs are gunpowder, flashpowder, or potassium chlorate/sugar. This type of IED is capable of causing serious injury and/or death.
- Analysis on the debris did not detect the presence of an explosive/explosive residue or any fragments/components of an IED.

All of the above are merely examples how reports could read. A report must clearly state the results. It may be necessary to describe how the results were achieved, and what they actually mean. It is also very helpful to the investigator to give examples of what a class may contain, such as a MPD in arson analysis.

Once the report is generated, it may or may not have to be explained in court. Many times the report itself will be entered as evidence and the analyst who generated it will not have to testify, although this may change with the recent court rulings. In the hundreds of bombing and arson cases I have worked during the last thirty years, there have been very few times have I ever actually testified, probably in less than 25 cases. In most situations, the report is not attacked so much as is the chain of custody. However, in today's contamination-conscious legal system, laboratory procedures are coming under more and more scrutiny.

5.4 Educational Concerns

Since the "Hollywood" effect has occurred, there have been hundreds of "forensic science" programs popping up all over the country. Most are substandard, in my opinion, and really do not offer a true forensic degree. Understand my lack of enthusiasm for these programs because very few of them have anyone involved in either developing their curriculum or even teaching the curriculum who has any real experience in forensic science. In how many other fields do those who have done, teach? Do they use interns to teach doctors? Or do they use doctors who have years of practical experience to pass their knowledge along? Those who have actually done the work should be the ones to teach the new people coming into the field. From my past experiences in education at the university level, I have found that, in most cases, those teaching the classes may be technically competent but they had

no clue in solving the problems that occur when dealing with real evidentiary issues. Our educational institutions are producing technicians, not scientists any more, or at least it seems that way. A technician follows directions. A scientist searches for answers, solving problems as they occur. This has been a reoccurring discussion that many of us in forensic science have had over the last several years, which has culminated in the Forensic Science Education Programs Accreditation Commission (FEPAC).

Some of this has been brought on by the drive for standardization of crime labs and accreditation. As pointed out in the recent National Academy of Science report, this can be a good thing; however, it can also stymie efforts to produce the best possible results by creating too many roadblocks in the path of the scientist trying to do the work. Somehow, a balance must be achieved in order for forensic science to continue to flourish as it has in the past.

5.5 Questions

1. An alcohol is considered:

   (a) An oxygenated solvent
   (b) A paraffinic product
   (c) A distillate
   (d) A naphthenic product

2. Both micro-taggants and chemical taggants have been used to help in the recovery of high explosives.

   (a) True
   (b) false

3. TWGFEX is located at

   (a) FBI
   (b) ATF
   (c) NCFS
   (d) NFSTC

4. The most current ignitable liquid identification/classification guideline is ASTM E 1618–01.

   (a) True
   (b) False

5. The diphenylamine color test gives a blue color as a positive reaction for:

   (a) Sulfur
   (b) Perchlorates
   (c) Nitrates
   (d) Nothing

6. A burn test is considered to be a Class 3 test.

   (a) True
   (b) False

7. An IR will give limited structural data.

   (a) True
   (b) False

8. How many tests must be done to identify an inorganic explosive by PLM?

   (a) 1
   (b) 2
   (c) 3
   (d) 4

9. Contamination can occur both at the scene as well as the lab or evidence locker.

   (a) True
   (b) False

10. More agencies offer fire debris analysis than explosive analysis.

    (a) True
    (b) False

5.6 About the Author

James Crippin started in 1977 and is still currently active in the field of forensic science. From August 1978 to August of 1984, Mr. Crippin served as forensic chemist with the Missouri State Highway Patrol system. In August of 1984, he was promoted to laboratory supervisor of the Saint Joseph, Missouri Troop H laboratory. During his tenure with the Missouri State Highway Patrol, Mr. Crippin was responsible for working all of the explosive incidents in the state of Missouri. Mr. Crippin resigned from the Missouri State Highway Patrol in August of 1988 and became a commissioned agent with the Colorado Bureau of Investigation.

In February of 2002, Mr. Crippin resigned from the Colorado Bureau of Investigation to form the Western Forensic Law Enforcement Training Center (WFLETC) and serve as the Director. In February of 2003, the United States Congress funded this concept as the newest crime lab in the state of Colorado. In 2007, funding ended and Mr. Crippin took WFLETC private to provide training both in this country and internationally.

Mr. Crippin is a member of or has served in office for nine different professional organizations, including the Midwestern Association of Forensic Scientists and the Southwestern Association of Forensic Scientists, and is past chairman of the Technical Working Group for Fire and Explosions. He has presented several

briefings on terrorism and IEDs to NorthCom and NORAD and has recently been designated a National Security Asset in these areas by Northern Command. He is also part of the United States State Department Bureau of Diplomatic Security training program. Mr. Crippin has taught more than 70 classes in various areas of forensic analysis or Homeland Defense areas. Mr. Crippin has also presented 25 papers and had eight articles published in professional journals. He is currently under contract with the National Center for Forensic Science and the National Institute of Justice to help write four on-line delivery classes in Explosives Analysis, Post-Blast Investigation, and CBRNE (chemical, biological, radiological, nuclear, explosive).

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Chapter 6
Fingerprints

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Contents

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Fingerprint identification has been a valuable tool of law enforcement in the United States since around the beginning of the twentieth century. Indeed, it has been a valuable tool whenever there was a need for positive identification as in both natural and man-made disasters. Many books have been written about fingerprint identification, more specifically, friction ridge identification. This chapter will discuss several topics regarding fingerprint identification; hopefully, it will give some insight into the profession and some of the challenges facing fingerprint experts. The reliability of fingerprint evidence has been universally accepted for many years. In fingerprint training, emphasis was placed on the physical ability to compare friction ridge details, process evidence for latent prints, have a good knowledge of the history of fingerprints, and providing credible testimony in court. When the fingerprint expert presented testimony well, spoke to the jury with confidence, and used photographic aids to demonstrate how they effected the identification, quite often there were no questions from the defense. Things have changed over the past several years. One of the greatest challenges to fingerprint experts today stems from the numerous attacks on the methodology used to reach conclusions. Most fingerprint examiners were well trained in establishing fingerprint identifications but were not skilled in explaining the process that led to their conclusions. The attacks come in the form of what has become known as the Daubert Motion. A Daubert Motion is a motion raised before or during trial for the purpose of excluding certain evidence from being introduced.

6.1 A Brief History of Fingerprint Identification

1686 – Marcello Malpighi, Professor of Anatomy at the University of Bologna. He made use of a newly discovered instrument, the microscope, and noted "certain elevated ridges" describing "divers figures" on the palmer surfaces. He perceived them to be "drawn out into loops and spirals" at the ends of the fingers. As far as is known, he did no further study.

1823 – John Evangelist Purkinje, Professor of Anatomy at the University of Breslau: Published a thesis in which he commented upon the diversity of ridge patterns, "especially on the last phalanx of each finger" and evolved a vague differentiation of these patterns into nine varieties.

1858 – Sir William James Herschel, British Chief Administrative Officer for the Hooghly District, Bengal, India: Began the first known official use of fingerprints on a large scale. He required natives to affix their fingerprints

as well as their signatures to contracts. As familiarity with fingerprints grew, their individuality must have become evident to him, because in 1877, Herschel introduced the use of fingerprints in several departments at Hooghly and also submitted a report asking permission to extend the practice as a means of identification of prisoners as well as parties to civil contracts. This permission was not forthcoming, but Herschel, within his own province, applied the system extensively. At about the same time, Dr. Henry Faulds, of Tsukiji Hospital in Tokyo, Japan, began his observations of fingerprints.

1880 – The English scientific journal, Nature, published an article by Dr. Faulds, discussing his studies and making suggestions as to the future possibilities of the fingerprint science. His ideas are remarkable for their anticipation of present-day practices. He recommended the use of a thin film of printers ink as a transfer medium, just as is generally used today. Faulds is credited with making one of the earliest latent fingerprint identifications.

1882 – The year in which the first authenticated record of official use of fingerprints in the United States appeared. Mr. Gilbert Thompson of the United States Geological Survey, while in charge of a field project in New Mexico, used his own fingerprint on commissary orders to prevent their forgery.

1891 – Marked the first installation of fingerprint files as an official means of criminal identification. Juan Vucetich, an Argentinean Police official, based his system on the patterns typed by Sir Francis Galton. At first, it was used in conjunction with the Bertillon system of identification by body measurements, which it gradually replaced. The Vucetich System is the basis of those systems presently used in most Spanish-speaking countries and a number of other countries as well. Vucetich also claimed the first official criminal identification by means of fingerprints left at the scene of a crime.

1892 – La Plata, Argentina, a woman named Rojas, who had murdered her two sons and had cut her own throat, blamed the attacks on a neighbor. Bloody fingerprints on a doorpost were identified by Vucetich as those of the woman herself and led to her confession.

1901 – Marked the official introduction of fingerprinting for criminal identification in England and Wales. The system employed was also developed from Galton's observations and was devised by Mr., later Sir, Edward Richard Henry, then Inspector-General of Police in Bengal, and later Commissioner of London's Metropolitan Police. Henry simplified fingerprint classification and made it applicable to police identification. His system and that devised by Vucetich form the basis of all modern ten-finger fingerprint identification systems. The basic Henry system, with modifications and extensions, is used by most English-speaking countries of the world.

1902 – The first known systematic use of fingerprints in the United States was begun with the establishment of the practice of fingerprinting by the New York Civil Service Commission to prevent applicants from having better qualified persons take their tests for them. Dr. Henry P. DeForest, an American pioneer in the fingerprint science, installed the system in December 1902.

1903 – Is claimed by the New York State prison system as the date of the first practical, systematic use of fingerprints in the United States for the identification of criminals. On June 5, 1903, the fingerprint system was officially adopted.

1904 – Acceptance of the fingerprint system accelerated when the United States Penitentiary at Leavenworth, Kansas, and the St. Louis, Missouri, Police Department both established fingerprint bureaus.

1905 – Adoption of a fingerprint system for the United States Army. Installation was completed the following year, marking its first official military use in the United States. The first official use by the navy was begun 2 years later by the Bureau of Navigation, followed the next year by the Marine Corps. (History of Fingerprint Identification, open-source material FBI Department of Justice.)

late 1960s – Advent of fingerprint computers. Today, modern automated fingerprint identification systems (AFIS-->) are in use throughout the world. The Henry system in use throughout the United States for longer than 100 years has virtually been replaced by AFIS.

6.2 An Introduction to the Henry System: Primary Classification

Although the Henry System is not in use to the extent that it once was, and many examiners are not trained in its use because it has been replaced by AFIS, it is something with which anyone working as a Latent Fingerprint Examiner/Expert should be familiar.

The Henry System is based on an alphanumeric formula and consists of six parts: Key, Major, Primary, Secondary, Sub-Secondary, and Final. There are three basic fingerprint patterns: Loop, Arch, and Whorl (Figs. 6.1–6.3).

Approximately 60% of fingerprints fall into the loop category; 35% fall into the whorl category and 5% fall into the arch category. From these three basic patterns, there are two types of arches; plain and tented; two types of loops, radial and ulnar; and four types of whorls, plain, central pocket loop, double loop, and accidental (Figs. 6.4 and 6.5).

The primary, which is the main component of the classification formula, is derived from the number of whorl patterns appearing on the fingerprint card and their location. The classification formula is divided by a line, which separates the numerator (upper part) from the denominator (lower part) (Fig. 6.6).

In calculating the primary, finger blocks numbered 1 and 2 have a value of 16, finger blocks numbered 3 and 4 have a value of 8, finger blocks numbered 5 and 6 have a value of 4, finger blocks numbered 7 and 8 have a value of 2, and finger blocks numbered 9 and 10 have a value of 1. An arbitrary 1 is always added to the total in both the numerator and denominator. For purposes of calculating the primary, the even-numbered blocks make up the numerator and the odd-numbered blocks make

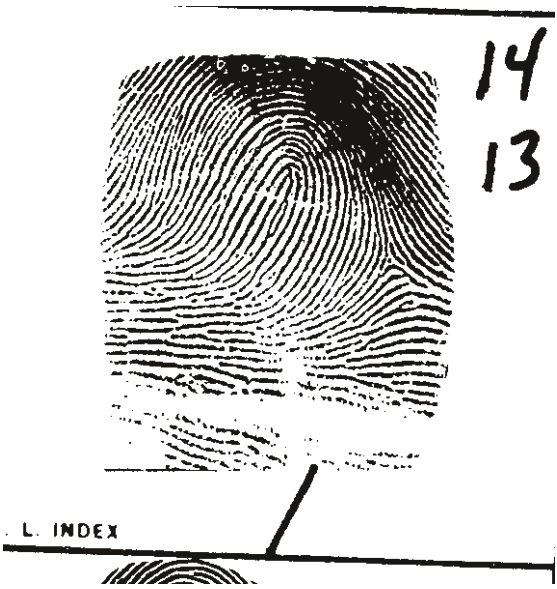

Fig. 6.1 Loop pattern

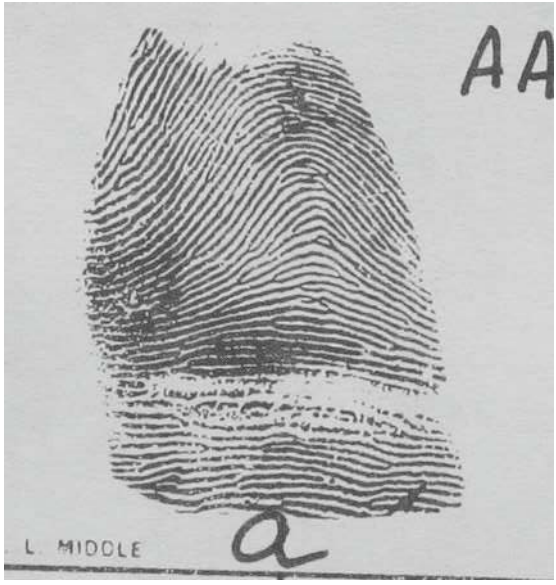

Fig. 6.2 Arch pattern

up the denominator. Beginning with the number 1 finger block, note the location of any whorls; if a whorl is present count that finger block with the assigned value. Example: If no whorls are present in any of the finger blocks, the total for both

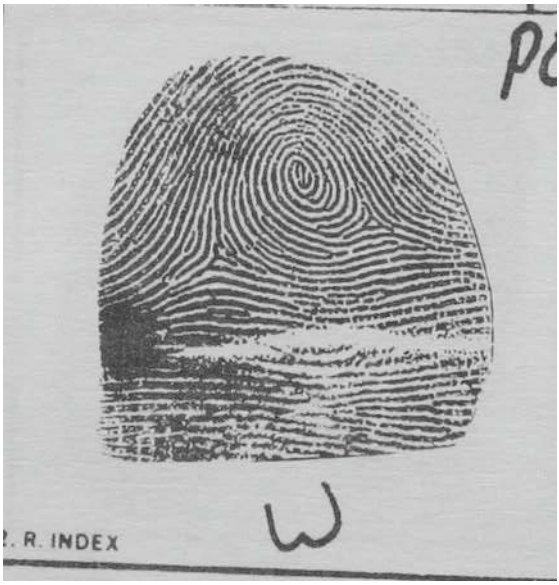

Fig. 6.3 Whorl pattern

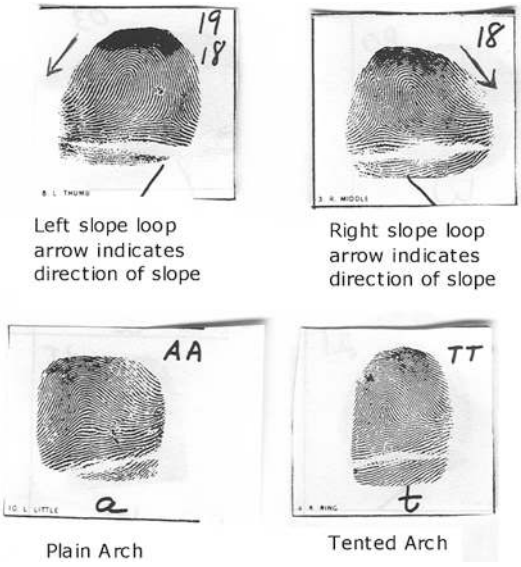

Fig. 6.4 Examples of the loop pattern. Note how the slope of the loop is indicated. The left slope loop is a loop in the #6 finger block on the fingerprint card. The Henry classification would be ulnar loop. A fingerprint sloping in the same direction on the right hand would be called a radial loop. The right slope loop pictured is from the right hand and is an ulnar loop. A loop sloping in the same direction on the left hand would be a radial loop. Also pictured here are the plain and tented arch patterns

numerator and denominator is 0: by adding the arbitrary 1, each would have a value of 1 and the primary classification for that fingerprint card would be 1/1 (1 over 1) (Fig. 6.7).

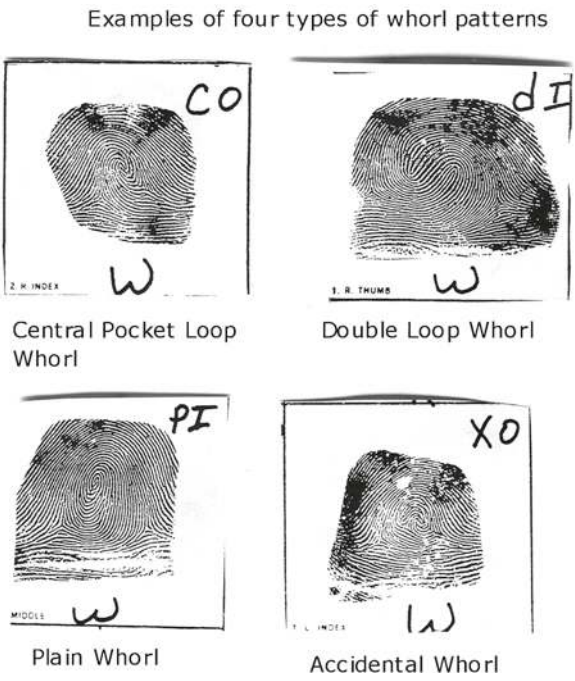

Fig. 6.5 Examples of the four types of whorls: Central Pocket Loop Whorl, Double Loop Whorl, Plain Whorl, and Accidental Whorl

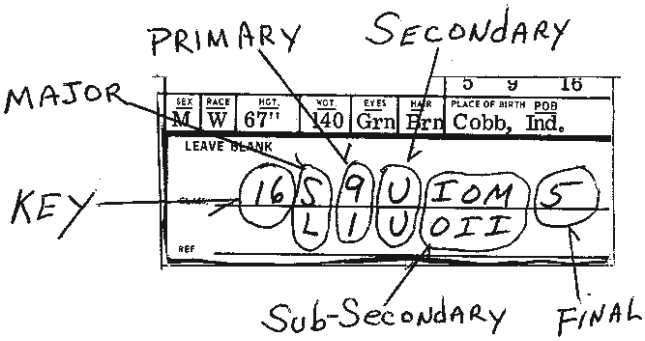

Fig. 6.6 The classification formula with the six parts *circled*. In this particular classification formula, the primary is 9/1 (9 over 1); which means that there is a whorl present in the #4 finger block and no other whorls appearing elsewhere

6.2.1 Example

If there are whorls in the #1 finger block and the #4 finger block, begin counting the denominator (odd finger blocks); #1 has a whorl, so the value of that block is 16. Because there are no other whorls in the other odd-number blocks, the denominator

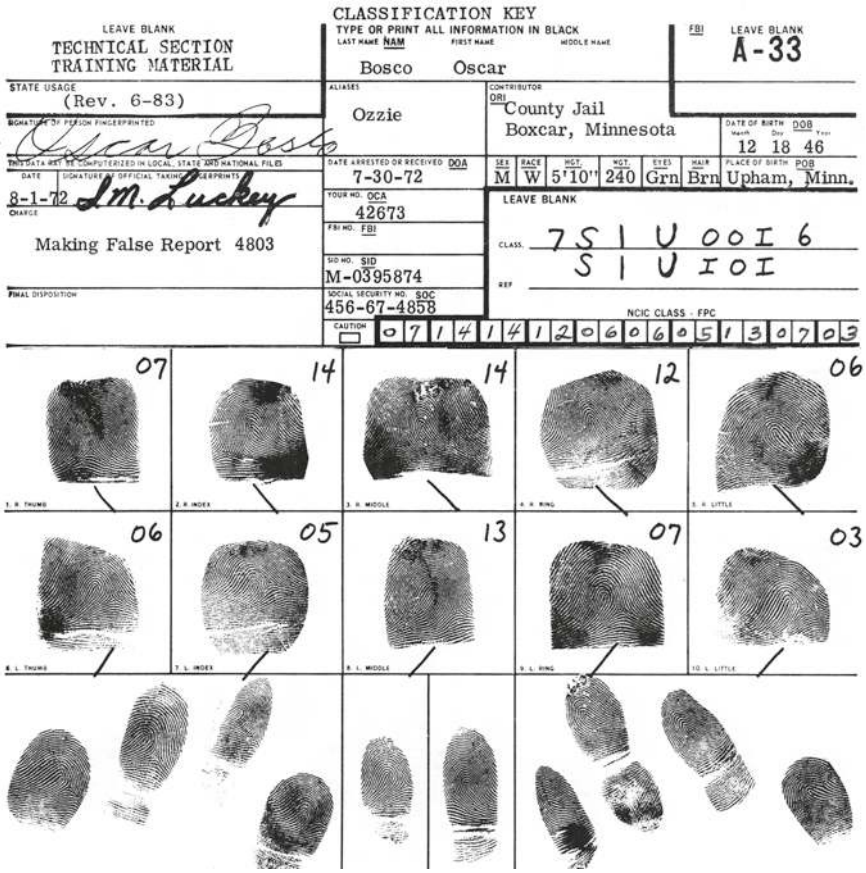

Fig. 6.7 1/1 (1 over 1) Primary classification

has a value of 16 plus the arbitrary 1 for a total of 17 (Fig. 6.8a). Now look at the even-number finger blocks; the only whorl appears in the #4 finger block, this has a value of 8; adding the arbitrary 1 for a total of 9 for the numerator. The primary classification will be 9/17 (9 over 17). There are 1,024 total possible primary classifications starting from 1/1 (1 over 1) to 32/32 (32 over 32). The FBI has available a fingerprint training manual and the Science of Fingerprints Manual, both of which go into great detail about the Henry System. The books Scott's Fingerprint Mechanics (Walter Scott and Robert Olsen) and Friction Ridge Skin (James F. Cowger) are also good sources of information for learning the Henry Classification. It should be noted that classification is distinctly different from identification. The classification system is designed for an orderly filing and retrieval of 10-print fingerprint cards. There are thousands of possible classification formulas that the various 10-print fingerprint cards will fall into. The formula is a result of interpretation of the class characteristics; that is, the fingerprint patterns, not the identifying minutia within the pattern. Because there are billions of fingerprints that are classified into

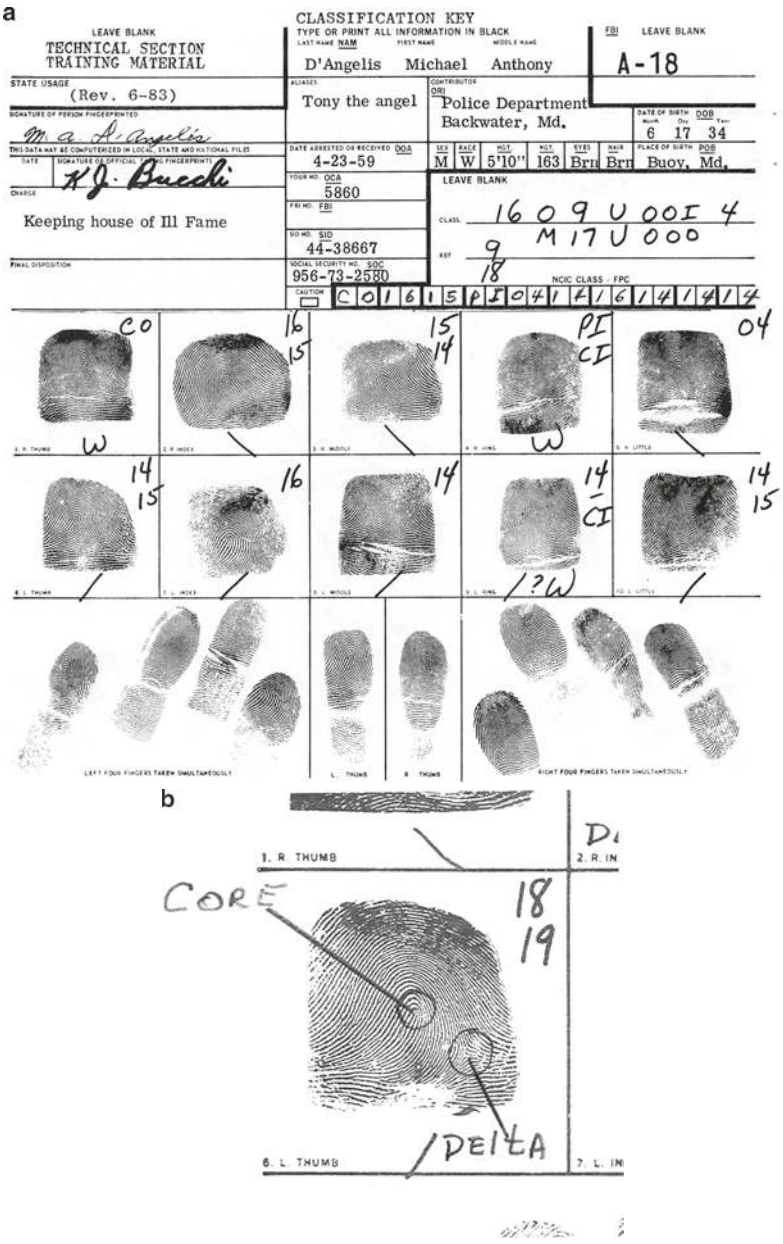

Fig. 6.8 (**a**) Fingerprint card showing whorls in the #1 and #4 finger blocks, making the primary 9/17. Note that the loop pattern in the #9 finger could also be interpreted as a whorl pattern; this would now make the primary 9/18, as shown on the reference line underneath the classification formula. The NCIC formula appears underneath the Henry classification formula. (**b**) An ulnar loop in the #6 finger block with a ridge count of 18. The circled areas depict the delta and core.

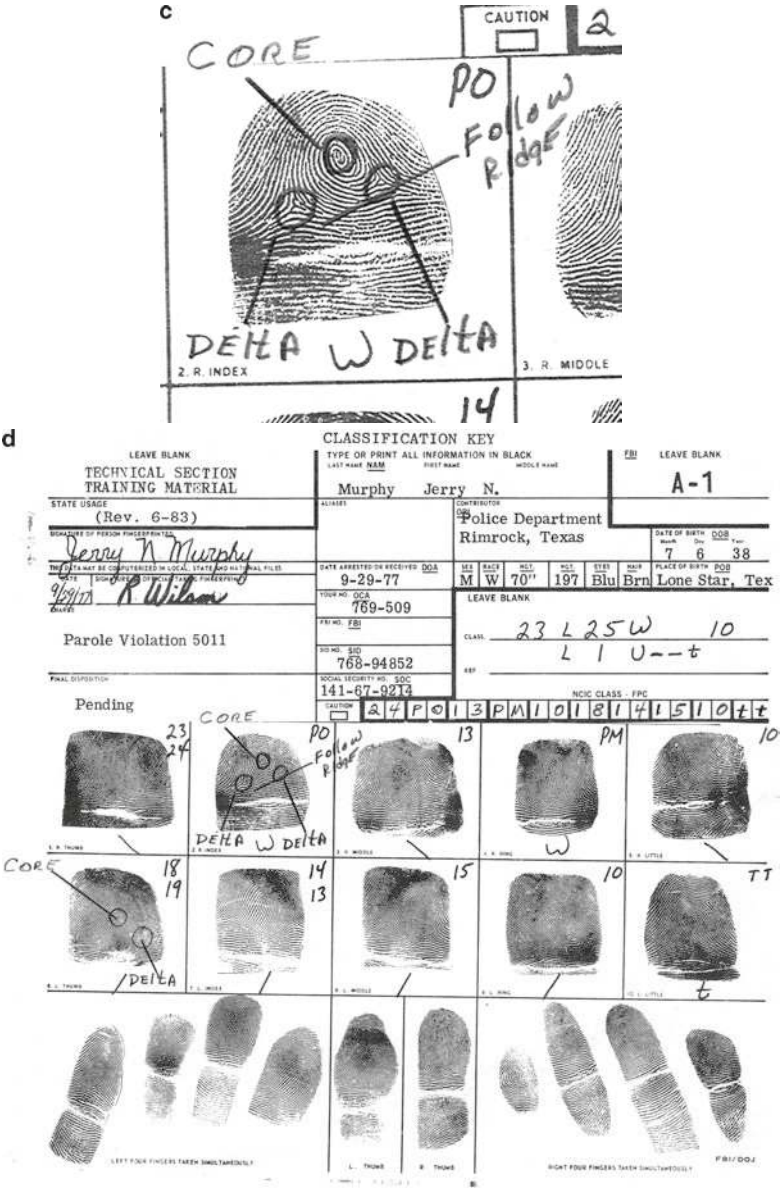

Fig. 6.8 (Continued) (**c**) A whorl pattern in the #2 finger block with a ridge tracing of "O" or outer. The circles depict the two deltas and one core and the ridge being traced or followed from left to right delta. (**d**) The fingerprint card bearing the completed Henry and NCIC classifications. The --t on the classification line indicates that there is a tented arch in the #10 finger block. This is one of the variations of the Henry classification, the "t" takes the place of the sub-secondary

thousands of classification formulas, it stands to reason that there will be many fingerprint cards that will have the same exact or at least very similar fingerprint classifications. The classification formula allows a fingerprint examiner to narrow the search in a large file of fingerprint cards to a manageable amount.

6.2.2 Example

As mentioned earlier, there are 1,024 possible primary combinations. (This is just one part of the classification formula.) If you are searching a fingerprint card that has a primary classification of 1/1 (1 over 1); you have already excluded 1,023 other possibilities of where that card is located. Once you have located the fingerprint cards within the parameter of the classification you are searching, you then begin the detailed examination looking more closely at the minutia to determine whether there is a fingerprint card on file bearing the same fingerprints as the card you are searching. The classification system allows for referencing, which means that there could be possibly more than one interpretation for a particular fingerprint. Also, pressure and inking may vary during the recording process and allowances have to be made for some of these variances. The Henry System has been and still is a very effective way of filing and searching of 10-print fingerprint cards. More detailed information on the Henry System of fingerprint classification is listed in the reference section of this chapter.

6.3 Ridge Counting and Tracing

In the Henry classification system, ulnar loops have a numerical value and whorls have an alpha value. These values are as a result of counting ridges between delta and core of the loops and tracing from delta to delta on whorls. Loops have one delta and core and whorls typically have two deltas and one or more cores. Plain arches, tented arches, and radial loops are simply designated by the appropriate letters “a,” “t,” or “r.” The numerical value for ulnar loops is acquired by counting the ridges between the delta and core and the tracing for whorls is acquired by tracing from left delta to right delta. Depending on where the tracing leads you, the value could be “inner,” “meeting,” or “outer.”

Figure 6.8b shows an ulnar loop with a ridge count of 18, counting ridges in a direct line from the delta to the core.

Figure 6.8c shows a whorl with a ridge tracing of “O” or outer. Figure 6.8d shows a fingerprint card with the completed Henry and NCIC fingerprint classifications. Note the tented arch pattern in the #10 finger block and how it is designated on the classification line. There are many variables and rules pertaining to the Henry classification, far too many to discuss fully in this chapter. Please see the recommended reading in the reference section to learn more about the Henry system.

Fig. 6.9 Basic tools of the fingerprint examiner. Depicted here are three examples of adjustable low-power magnifying glasses and a tool called a ridge counter. The ridge counter aids the examiner in locating minutiae or identifying features that make up the friction ridge impression

6.4 Basic Tools of the Fingerprint Examiner

The fingerprint examiner has many tools and aids from which to choose. However, the very basic instrument that you will find in any fingerprint laboratory is the adjustable low-power magnifying glass and a tool called a ridge counter, which is a pen-like device that is used by the examiner to locate and/or refer to minutiae when performing side-by-side comparisons using the magnifying glass. These magnifying glasses come in various shapes and sizes, and many examiners use several types, depending on the evidence being examined (Fig. 6.9).

6.5 NCIC Fingerprint Classification

The National Crime Information Center (NCIC) fingerprint classification system was established many years ago to assist law enforcement in tentatively identifying wanted criminals. This was certainly not a positive means of identification, but could be of assistance in helping to establish tentative identity especially when, for example, law enforcement officials were communicating over some distance by telephone and were trying to piece together information about a person whom they suspected as being wanted. Whenever information concerning an individual was reported to the NCIC, the person's NCIC fingerprint classification was included. This classification is distinctly different from the Henry classification system. A brief description of the system is as

follows: It is an alphanumeric system, which is written or typed out in a series of twenty blocks. The ten fingerprint blocks on a standard FBI fingerprint card consist of two rows of five fingers each. The top row is for the right hand and the bottom row is for the left hand. The top row is numbered from left to right one (1) through five (5) and the bottom row numbered six (6) through ten (10). The twenty blocks of the NCIC classification are all in a single row and represent the fingers in sequential order from finger #1 through finger #10. Twenty blocks are used because the alphanumeric value given each finger will require two boxes. The order would represent the fingers thus: right thumb, right index, right middle, right ring, right little, left thumb, left index, left middle, left ring and left little. Refer back to Figs. 6.7 and 6.8 and note the NCIC classification formula under the Henry Classification formula. A plain arch pattern is designated AA; a tented arch pattern is designated TT; an ulnar loop is designated by its ridge count; if the count is less than ten, a 0 is used as the first character; a radial loop is designated by the ridge count plus 50 (a 5-count radial loop, for example, will have a value of 55); the unusually high ridge count immediately is recognized as being a radial loop as opposed to an ulnar loop; a whorl is designated by the type of whorl plus the tracing. Plain whorl is P, central pocket loop whorl is C, double loop whorl is d or D, and an accidental whorl is X. Missing/amputated fingers are designated XX and completely scarred or mutilated patterns are designated SR. Example of an NCIC classification: On an fingerprint card that has the following finger values: #1 Finger Central Pocket Loop Whorl w/outer tracing; #2 finger Ulnar Loop W/16 ridge counts; #3 finger Ulnar Loop W/15 ridge counts; #4 finger Plain Whorl W/Inner Tracing; #5 finger Ulnar Loop W/04 ridge counts; #6 finger Ulnar Loop W/14 ridge counts; #7 finger Ulnar Loop W/16 ridge counts; #8 finger Ulnar Loop W/14 ridge counts #9 Ulnar loop W/14 ridge counts; #10 finger Ulnar Loop W/14 ridge counts; the NCIC Classification is CO1615PI041416141414. Refer back to Fig. 6.8. Note both the Henry classification and the NCIC classification. Notice also the reference line (Ref). This indicates that the #9 fingerprint, although classified as an ulnar loop, could also possibly be interpreted as a Central Pocket Loop Whorl. This would change the primary classification to 9/18 (9 over 18). By referencing such as this, the fingerprint card would then be searched in all appropriate areas of the fingerprint file.

6.6 Properly Recording a Set of Inked Fingerprints

The equipment required for properly recording a set of inked fingerprints could be very basic. At the very least, you will need a roller, black printers ink, and a cardholder with an inking slab (Fig. 6.10).

Using the proper amount of ink to achieve the best results will come with a little practice. The standard fingerprint card is designed for the ten fingers to be rolled, in sequence, in the ten finger blocks provided on the upper part of the card and for simultaneous impressions of the four fingers of each hand and the right and left thumb prints to be recorded on the bottom portion of the card (Fig. 6.11).

Each finger is rolled on the inking plate making sure to record the entire first joint of the finger from one side to the other. This is referred to as rolling “nail to nail.” It is vital to roll the finger fully from one side to the other and include the crease at

Fig. 6.10 Basic portable fingerprint taking kit

the first joint of the finger. This insures you have captured the entire first joint of the finger, which is the area of the finger used to obtain the classification formula. When the rolled impressions are completed, it is time to record the simultaneous impressions. Taking the subject's hands, record the right four fingers on the right lower side of the card and the left four fingers on the left side of the card in the spaces provided; and then record the both thumb prints in the proper blocks. As mentioned, the fingers must be recorded in the proper sequence. The four fingers taken simultaneously of the both hands allow you to check to make sure that all fingers are recorded in the proper finger blocks. This is the primary reason for recording these fingers simultaneously. A number of books explain in detail the proper recording of inked prints. You will find information on these books in the reference section of this chapter.

6.7 Live-Scan Fingerprinting

Many agencies are now using what is referred to as live-scan fingerprint equipment. Several different manufacturers supply this type of equipment. The fingerprints are recorded via an electronic scanning device and no inking of the fingers is required. The fingers are rolled over a glass plate, nail to nail, as in the regular inking method, and the impression is recorded digitally on a computer. The image is readily seen on a computer screen and the operator or fingerprint taker has the opportunity to view the image and delete the image and redo the process or accept and move on to the next finger. Live scan equipment has the ability to check the sequence of the

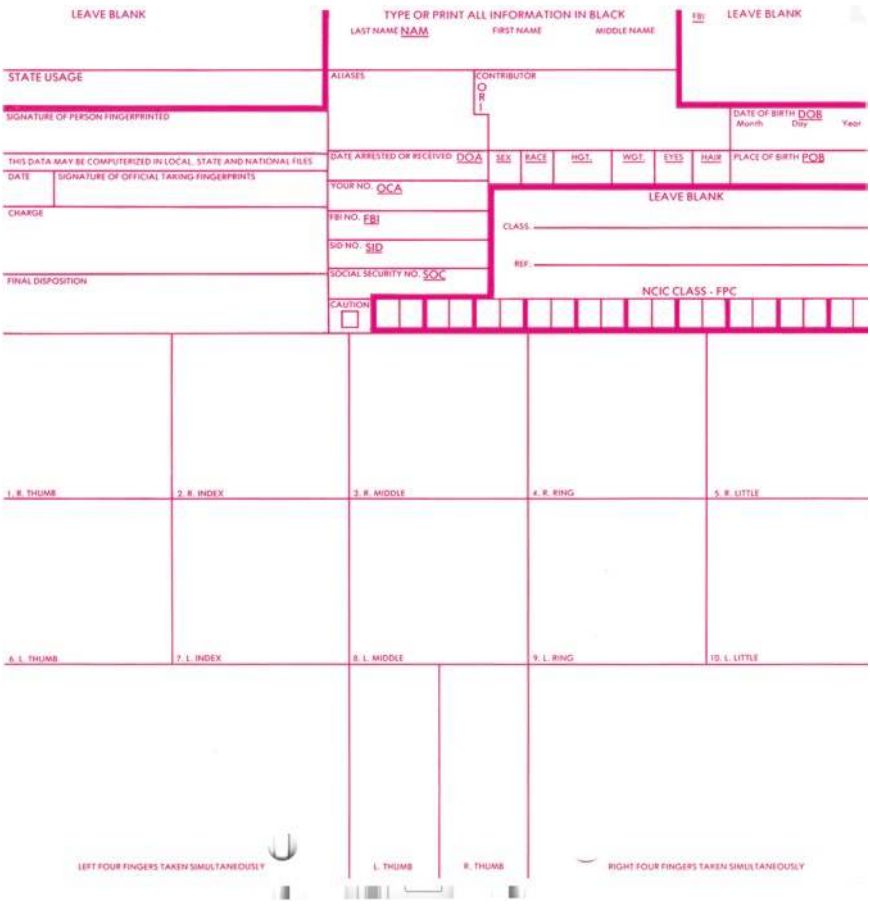

Fig. 6.11 Standard 8 × 8-inch fingerprint card

fingers by automatically checking the rolled impressions with the simultaneous impressions. Once the images are captured, they may be sent electronically to be searched through an automated system (AFIS) and the FBI IAFIS. Hard copies of the fingerprint cards can be printed if necessary. Please refer to the reference section for locations of more information on live-scan fingerprint equipment.

6.8 ACE-V Methodology

David Ashbaugh, in his book Quantitative–Qualitative Friction Ridge Analysis, explains that there are four parts to friction ridge identification methodology: Analysis, Comparison, Evaluation, and Verification. This methodology is now

being taught to latent fingerprint examiners throughout the modern world. ACE-V is the acronym now used to describe the methodology. In his book, Ashbaugh goes into much greater detail of this process and the book is highly recommended reading for both novice and experienced fingerprint examiners.

6.8.1 Analysis

In the analysis of the unknown print, the examiner begins the process of analyzing everything about the questioned mark including the substrate, matrix, clarity, amount of friction ridge detail present, and anything that might raise questions concerning the print.

6.8.2 Comparison

After a complete examination of the unknown, the examiner begins the comparison process with the known prints. The examiner thoroughly examines the friction ridge detail. This is done in a systematic way by a side-by-side comparison of all of the available friction ridge detail.

6.8.3 Evaluation

Upon completion of the comparison process, the ultimate decision of the examiner is to eliminate the donor of the known prints or to identify the donor of the known prints as the source of the questioned print. In other words: to individualize.

6.8.4 Verification

Verification is a form of peer review. The verifier follows the same steps as the original examiner in their process to individualize.

6.9 Areas of Concern During the Identification Process

Fatigue and pressure are factors that may affect the identification process. Preconceived notions about the evidence, especially if coupled with peer pressure, can cause undue stress on the latent print examiner.

6.9.1 Peer Pressure

In a case involving a stolen and forged treasury check, a palm print was developed under the signature that was consistent with what is sometimes called the "writers palm": that portion of the palm that comes in contact with the document when someone is writing. The document examiner positively identified subject A as the writer, but the latent fingerprint examiner eliminated subject A as the source of the palm print. The investigator was insistent that bank photos show subject A signing and cashing the check; he was positively identified by the bank clerk and the document examiner positively identified him as the author. Further investigation revealed that a second subject who originally was going to do the crime placed his palm on the check to sign it, but changed his mind at the last minute; turning the check over to subject A. The only identifiable latent print developed on the check was subsequently identified as belonging to the second subject.

6.9.2 Other Pressures

Pressure comes in many forms: from overzealous investigators who "know they have the right guy, they only need one print to prove it"; colleagues who ask "Everyone else can see it why can't you?"; to department heads who question whether you are a "team player."

On the left is a fully recorded fingerprint and on the right is a partial print (Fig. 6.12). Is there sufficient detail in the partial print to individualize? Do you see

Fig. 6.12 Examine both prints. Could they be from the same source?

similarity between the partial print and the fully recorded print? Could undue pressure and/or not following correct methodology cause you to render an incorrect opinion? Look at Fig. 6.13.

Both are the same prints as in Fig. 6.12; however, the print on the right shows more friction ridge detail. They are not the same. Can you see the where they differ? Proper orientation is also a factor in the comparison process. Look at the rolled

Fig. 6.13 Same prints as Fig. 6.12; however, the print on the right shows more detail. These prints are clearly from different fingers

Fig. 6.14 Rolled fingerprint

fingerprint depicted in Fig. 6.14. Compare the partial print (tri-radius area) depicted in Fig. 6.15.

Is the orientation correct? Look at the same partial print depicted in Fig. 6.16 with a different orientation.

Distortion and scarring are other factors that can sometimes cause difficulty in determining individualization. Friction skin is composed of two layers; the dermis (inner layer) and the epidermis (outer layer). When an area of friction skin is damaged, the result might be temporary or permanent. If just the epidermis is affected, the damage will be temporary. If the dermis is damaged, the result will be a permanent scar, which will remain constant when healed. Permanent scars can present unique problems to the fingerprint examiner. Examine the figures below. Both are photos of the same print before and after scarring. A print with scarring to this extent could easily be overlooked (Figs. 6.17 and 6.18).

Fig. 6.15 Tri-radius (Delta area) extreme right delta of Fig. 6.14. Is the orientation correct?

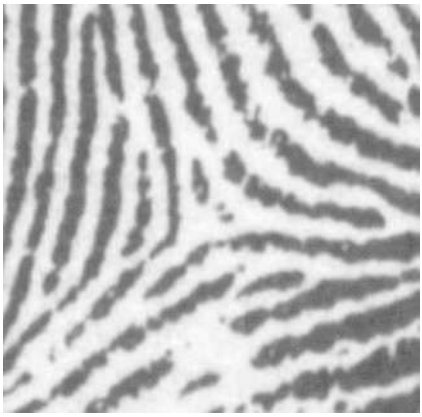

Fig. 6.16 Tri-radius area in correct orientation

Fig. 6.17 Normal fingerprint before scarring

Fig. 6.18 Same fingerprint as Fig. 6.17; however, scarring has changed the appearance completely

6.10 Theory and Hypothesis

The ACE-V methodology is scientific. Friction Ridge Skin is unique and permanent; Friction Skin can be individualized. This hypothesis has been tested by longer than 100 years of study and experiment. Analyze the unknown; compare the unknown with the known exemplars; evaluate and form your opinion/conclusion; present for peer review (verify); prepare to defend your conclusions in court.

6.11 Evidence

6.11.1 Forged and/or Falsified Evidence

Forgery or falsification of fingerprint evidence is not a new phenomenon. It is not something that has been talked about a great deal in the past. Most of the incidents have been the falsification of fingerprint evidence; however, there have been some cases involving the actual forgery of fingerprints. It is useful to know as much as you can about what has happened in the past so you can deal effectively with any such incidents in the future. Fortunately, these incidents are few and far between (Figs. 6.19 and 6.20).

Fig. 6.19 Rubber glove with Friction ridges glued to the fingertips

Fig. 6.20 Enlarged area of fingers on rubber glove showing ridge detail

A person could wear this glove and theoretically leave these forged fingerprints at the scene of a crime simply by rubbing the latex prints on an oily part of the body and touching various objects at the scene (Figs. 6.21 and 6.22).

On the left is a silicone cast of a finger; made to be used like a rubber stamp; latent prints are made from the cast by rubbing the cast on an oily part of the body and "stamping" the print on a surface shows a forged fingerprint made from silicone and glued onto a handle to be used like a rubber stamp. The prints were made by rubbing the silicone finger on an oily part of the body and "stamping" the prints on a smooth surface. The prints were subsequently developed using black magnetic powder.

Fig. 6.21 Silicone cast of a finger. Note the friction ridge detail. First, a silicone mold was made, then the mold was used to produce the silicone finger

Fig. 6.22 Silicone finger glued on a wood holder and used like a rubber stamp. The prints were the result of rubbing the silicone finger on an oily part of the body and "stamping" the prints on a smooth surface. The prints were developed using black magnetic powder with a magnetic applicator

6.11.1.1 Case One

In the late 1960s, there was a case in South Florida of a man accused of a crime involving explosives. The fingerprint laboratory developed the accused palm prints on a box containing dynamite. Just before trial time, the accused claimed that his prints were forged on the box and he proceeded to attempt to prove his theory by showing that fingerprints/palm prints could be forged. He produced etched metal plates and rubber casts of his hands and fingers. He allowed the police laboratory to experiment with the items. After extensive examination, the fingerprint examiner testified at trial that although the accused was able to in fact forge his own prints, the print on the dynamite box was a latent print from his hand and not a forgery made from his or any other forged material. The man was convicted. Examination of all of the evidence took a great deal of time. Many impressions were made using all the supplied forged samples and all were examined. Nothing came close to the naturally deposited palm print on the box (Figs. 6.23–6.27).

As one can readily see from these examples; it is quite possible for a person with the proper skill to forge his own prints; however, forging the prints of someone else presents quite different problems. You most likely would want to acquire the prints of someone without them being aware of it. Although not impossible, it can be difficult, especially to obtain good prints. That is why most of the cases of this type involve falsifying the evidence rather that actually forging the fingerprint. It should be noted that forging someone's fingerprints is just the first step in attempting manufacture this type of evidence. One not only needs the skill and knowledge to accomplish the forgery, but then has to have the skill to be able to "plant" the evidence at the scene in such a way as to not be detected as forgeries. Rubber stamps,

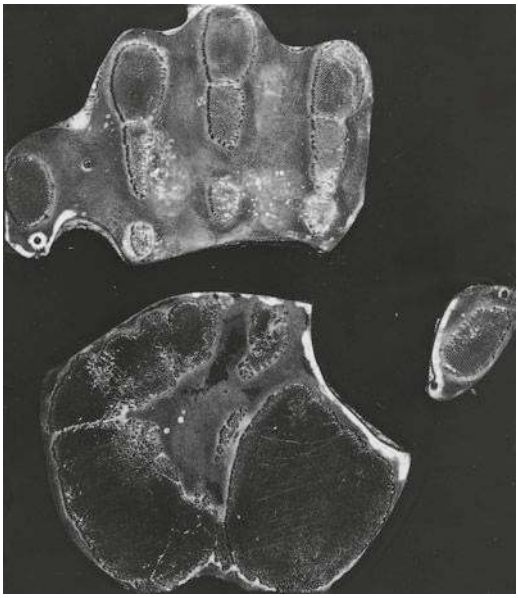

Fig. 6.23 Etched metal plate of right palm print

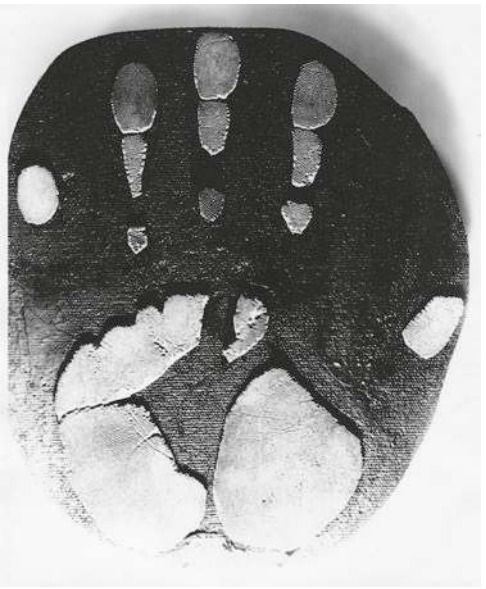

Fig. 6.24 Rubber cast of right palm print

Fig. 6.25 Original inked palm print of the accused

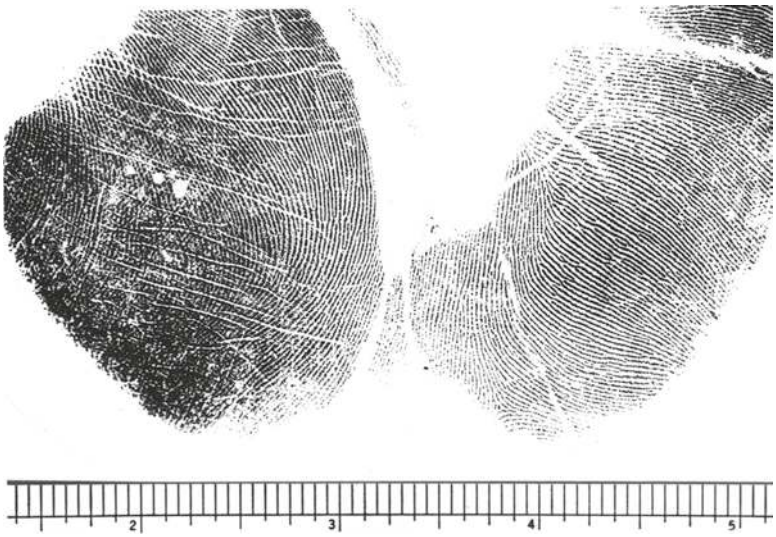

Fig. 6.26 Inked impression from rubber cast

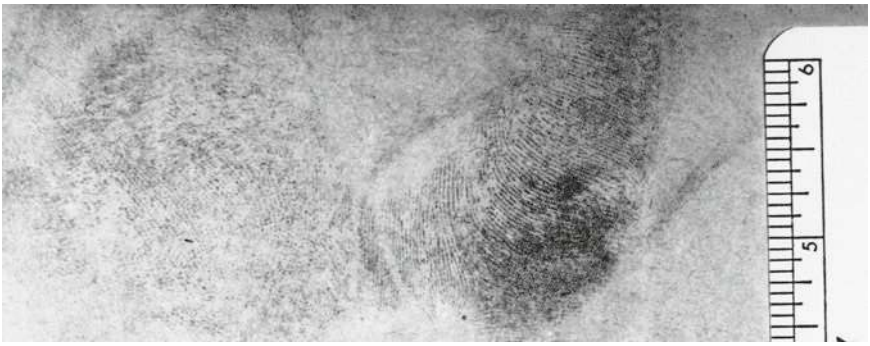

Fig. 6.27 Latent palm print developed by ninhydrin on the box of dynamite

casts, plates, etc., most often leave minute traces behind, which tend to suggest that the print was not naturally deposited. Unfortunately, there have been several cases involving unscrupulous people who, for whatever reason, have manipulated evidence involving latent prints.

6.11.1.2 Case Two

One prime example of this involved a crime scene officer lifting a print from an original inked fingerprint card and marking the lifted print as coming from the scene of a crime. He presented the evidence along with the subject's fingerprint card for

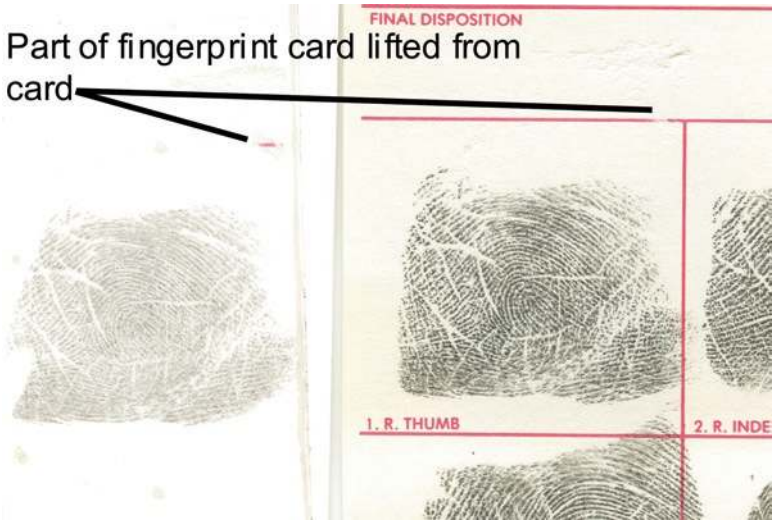

Fig. 6.28 Example of an attempt to lift a fingerprint from an inked fingerprint card. Note the removal of part of the card along with the print. There are several "red flags" regarding these prints. Do you see anything that would arouse suspicion?

comparison. Fortunately, when the evidence was presented to the fingerprint examiner it became immediately apparent where the print had come from (Fig. 6.28).

There are several "red flags" present on this lift and on the fingerprint card. Not all are visible in this photograph. Note the part of the fingerprint card that was removed by the lifting tape indicated by the two lines. This is just one example of an area of concern between these two prints. The fact that the "latent" print is fully rolled is something that rarely if ever occurs. Can you notice anything else that might arouse your suspicions?

6.11.2 Evidence Processing

In order to process evidence for latent prints, it is important to understand what causes a latent print in the first place. What exactly is a latent print? In teaching a class of experienced latent print examiners, I posed a simple question. "You all have stated that you are fingerprint experts, please tell me what is a fingerprint." What started as a simple question evoked a number of different responses. Some had difficulty explaining what a fingerprint was. Friction ridges, which make up the palmer surface of the hand and the soles of the feet, contain pores, or openings, which exude perspiration. When these ridges come in contact with an object, they might leave an impression or outline of those ridges on that object; this impression or outline, usually invisible to the naked eye and requiring some form of development to make it visible, is referred to as the latent print. This impression is also referred to as the

crime scene mark or print; the unknown print or the questioned print. The latent print is usually not a complete print and it is usually left unknowingly or unintentionally. An inked print is the recording of the friction ridges of the fingers, palms, or feet sometimes by using black printers ink; sometimes recorded electronically via the use of live-scan fingerprinting equipment or any of various other methods. The fingers, for example, are rolled in a thin layer of ink then rolled onto the fingerprint card in the appropriate finger block, thereby leaving an impression in ink. So, in simple terms, "what is a fingerprint?" A fingerprint is an impression of the friction ridges that are present on person's fingers. Latent print processing of any item begins with a thorough visual inspection. Various surfaces require specific methodology in order to obtain proper results. Generally, when the friction ridges come in contact with an object, it is the moisture from the pores coating the ridges that is left behind. This moisture can be extremely delicate and all items must be handled with extreme care. On non-porous surfaces, such as glass and metal, the latent print, in the form of moisture, is resting on the surface and can be easily destroyed. One method of making this print visible is to apply fingerprint powder with an acceptable fingerprint brush. Several different powders and brushes are available to the fingerprint examiner. Lightly brushing the object, the powder will adhere to the moisture and the print will become visible. This print can then be photographed and "lifted" by the use of lifting tape. Once lifted from the surface, the print is placed on a lift card with a contrasting color to the powder that was used. The lift card will then be marked as to where and when the print was recovered. This is the simplest form of latent print processing and has been in use for many years. Latent prints on paper require a different approach. When the moisture from the hands or fingers comes in contact with paper, in time, the moisture will be absorbed into the paper. Proper development requires methodology other than the application of fingerprint powder in order to make the print visible. Various chemical methods are normally used for treatment of paper. One chemical process that has been used for many years is called the ninhydrin process. Ninhydrin is a chemical that reacts with the amino acids that are present in the perspiration. The paper being examined can be sprayed with or dipped into a solution of ninhydrin, allowed to dry, and subjected to humidified heat. Latent prints will begin to develop and will appear purplish in color. These latent prints must then be photographed immediately because the developed prints may fade in time. The "dusting" process and the ninhydrin process are two processes that are very effective in the development of latent prints. These were the mainstay processes and indeed still are for many laboratories, especially the smaller labs, throughout the world. There are, however, guidelines discussing the various steps and recommended procedures for development of latent prints. Over the past few years, many of the larger laboratories have employed fingerprint specialists and research chemists who are continually developing new methodology and improving established methodology. Processing evidence must be done sequentially. Some items require multiple processing and some processes will negate subsequent processing. Suggested processing for a non-porous item might include the following sequential examination: visual inspection, examination by laser or some alternative light source, cyanoacrylate fuming, laser (alternate light source), cyanoacrylate dye, laser

(alternate light source), vacuum metal deposition, powder. A note worth mentioning: a laser is a very expensive piece of equipment and is not affordable to many smaller departments. The vacuum metal deposition process (VMD) is a very effective process for developing latent prints on non-porous surfaces; however, this is another very expensive piece of equipment not available to many smaller departments. VMD is the same process that coats mirrors. An item is placed in a sealed chamber, which is then brought to vacuum. A small amount of metal, several different metals might be used, placed in the chamber is superheated to the melting point and the resulting "residue" deposited on the object being examined. The fingerprint deposit becomes visible when the deposited metal adheres to the surface around the print. In simple terms, this explains the process; however, as stated above, the equipment involved for this process is very expensive. So where does this leave the examiner who has limited resources? There are two choices: to make do with what is at your disposal or to send the evidence to a fully equipped laboratory, if one is available to you. It is important to note that the various processing guides are suggested best practices to obtain optimal results. However, ultimately, it is the decision of the latent print expert to determine the best method for examining a given piece of evidence. Keep in mind that you will have to defend your decisions in court, so be prepared to explain why you decided to process a particular item in a particular way.

6.11.3 Handling Evidence

As mentioned previously, a latent print on an object is easily destroyed if not handled properly. It is important to note that wearing gloves when handling evidence does not protect the latent print from being rubbed off the surface. It is unfortunate that some uninformed persons think: "as long as I have gloves on I can do no harm." Wearing gloves usually assures you that you will not leave your fingerprints on the item but it does not prevent you from destroying valuable evidence because of mishandling. Oftentimes, on television or in movies, you will see a detective wearing gloves handling crime scene evidence, such as a firearm or a knife, or wrapping items up in a handkerchief and placing it in his/her pocket. Unnecessary handling should be avoided. And, of course, you will also see "investigators" using a pen to pick up a handgun by inserting the pen in the barrel. Admittedly, the pen will most likely not be a problem regarding fingerprints, but firearms examination is another story.

6.12 Courtroom Testimony

When a latent fingerprint specialist is called to testify in court to their findings regarding the examination of evidence involving fingerprints (friction ridges), they are called as an expert witness. An expert witness differs from a lay witness because

an expert is allowed to express an opinion based on their examination of the evidence. As mentioned earlier in this chapter, an expert in fingerprint identification must be knowledgeable in all aspects of friction ridge identification. When notification of trial is received, every effort should be made to engage in a pre-trial conference with the prosecuting attorney. It is important that both the prosecutor and fingerprint expert understand how the direct questioning will proceed to provide for an orderly presentation of the expert's qualifications and the introduction of the evidence. At some point during the direct questioning and prior to the expert rendering his opinion concerning their examination of the evidence, the prosecutor will proffer the fingerprint examiner as an expert in fingerprint identification. The trial judge will be the person who decides whether the fingerprint examiner will be allowed to testify at trial as an expert witness. The defense has the right to ask the judge to "voir dire" the witness. Voir dire is a French term meaning, "to see to speak." It is used as a means for determining the competence of a witness. Voir dire is used mainly for the purpose of questioning prospective jurors but is very often used to question expert witnesses. During voir dire, any questions about fingerprint identification might arise. This is why a fingerprint expert must be well informed in all areas of fingerprint identification. A fingerprint examiner must not only possess the skills necessary to examine evidence for latent prints – develop, preserve, interpret, and identify friction ridge details, but must be able to articulate findings in court. The courtroom is where all of the fingerprint examiner's expertise will be put to the test.

6.12.1 Daubert Motion

In 1993, the Supreme Court introduced a new rule concerning the admissibility of scientific expert testimony. The case was entitled Daubert v. Merrell Dow Pharmaceuticals. In general terms, attorneys have the right to invoke a Daubert Motion to bring into question the validity of the testimony that will be given by the expert fingerprint witness. The main purpose of the motion is to question the methodology used and bring into question error rate, general acceptance, peer review, etc. Basically, the motion is filed to keep the fingerprint evidence from being introduced at trial. The trial judge will listen to arguments from both sides regarding the validity of the scientific principles involved in the individualization of friction ridge skin. The defense can elicit the testimony of experts to refute the scientific process. There have been numerous Daubert hearings held over the past several years and, to date, the fingerprint science has been upheld. A Daubert Motion may be filed at any time before or during a trial and a fingerprint examiner must be ready to defend their opinion regarding the examination of evidence and the scientific process that led to their conclusion. There has been much written about the Daubert opinion/motion, especially as it relates to friction ridge testimony. Sources for some of this information are listed in the reference section.

6.13 Certification

The International Association for Identification (IAI) is the certifying body for fingerprint examiners, both 10-print and latent print. The certification program for latent print examiners began in the late 1970s. It was decided that certification would be a step forward for the latent print community. Many attorneys are aware of the certification program and, as a result, they usually ask about certification on the witness stand. It is most beneficial for you as an expert witness to be able to testify that you are certified; in other words, that you have been tested and met the requirements of your peers in the fingerprint community. The process for someone to be certified, either in 10-print identification or latent print identification, is fully explained on the web site of the IAI at theiai.org.

6.13.1 Latent Print Examiner

Generally the requirements for latent print examiner are that you must be of good moral character and high integrity; and you must have high ethical and professional standards. You must have at least a minimal amount of formal training. Educational requirements are: a bachelor's degree plus 2 years of experience, an associate degree plus 3 years of experience, or 4 years of full-time experience as a latent print examiner. There are certain documents that you are required to submit along with your application.

The certification process involves being tested in several topics as follows: comparison of latent prints with inked prints; pattern interpretation; true and false and multiple choice questions; and courtroom presentation. The questions in the test include pattern interpretation, history, and latent prints. This is a timed test. I think it important to note here that a person should be well informed and trained in every aspect of the field of latent print identification. The IAI will provide a list of suggested reading material that relates to all of the questions included in the test. The IAI web site lists the entire process and provides contact names and numbers for additional information.

6.13.2 10-Print Examiner

The requirements for 10-print certification are that you must be a person of good moral character and high integrity, and you must have high ethical and professional standards. You must have a minimal amount of board-approved training in the pertinent subject matter and training in courtroom testimony. You must have at least two years of full-time experience in recording, classifying, filing, and searching 10-print fingerprint cards. Educational requirements are: an associate's degree or at least

sixty semester hours of college credit; or experience can be substituted for college at a rate of one year of experience for one year of college. The testing process consists of five parts and is a timed examination. Part one consists of comparisons of a specified number of single impressions to 10-print fingerprint cards. Part two consists of pattern recognition and interpretation and questions. Pattern recognition will involve knowledge of the Integrated Automated Fingerprint Identification System (IAFIS), which is the FBI AFIS; knowledge of the Henry system of fingerprint classification and the National Crime Information Center (NCIC) classification system. Questions will include topics in classification, history, permanence and uniqueness of fingerprints, pattern interpretation, AFIS, live-scan, and ridgeology. Part three is a technical examination that tests your ability to evaluate 10-print records accurately. Part four involves court testimony. If you had previously testified in court regarding 10-print records, you will be required to submit documentation to that effect. If not, you will be required to participate in being tested before the certification board. This is what is covered in part five of the requirements. The board will set up a 1-h time for you to participate in a form of moot court. All of these requirements and procedures are explained in greater detail on the IAI web site.

6.14 Ethics

Ethics is a critical component of the certification process. As part of the application for certification, you must certify that you meet certain ethical standards. The code of ethical conduct is listed on the web site of the IAI and in essence states that it is the duty of a latent print examiner to serve the best interests of justice; use sound judgment in your examinations; and evaluate and interpret your findings based on your experience and knowledge. Unfortunately, there have been violations of ethics on a few rare occasions, which gave cause for certain latent fingerprint examiners to not be allowed to testify in court. Defense attorneys have the right to inquire as to your past conduct and you are required to inform the prosecutor in a case that you may be called to testify as to any potential problem involving unethical conduct. In examining evidence of a crime, the ultimate goal is to eventually present your findings in court. If you are unable to do that, you cannot fulfill your responsibility as latent print examiner.

6.15 Laboratory Accreditation

Most police agencies in the United States have a crime laboratory, or some facility that is called a crime laboratory. Some are very limited in scope and others are very extensive. Many of the smaller agencies, usually small cities or towns, have one-person operations. A single person might be the investigating officer, crime scene technician, and fingerprint examiner. Larger state and federal agencies have most if

not all of the forensic disciplines represented and possess the latest equipment available. For many years, agencies operated in various ways in dealing with evidence control, contamination of evidence, transporting of evidence, chain of custody, etc. Some agencies were very good at handling evidence and others were sorely lacking. It was recognized that the need for standardization in evidence control, quality assurance, and testing was imperative. The American Society of Crime Laboratory Directors (ASCLD) was formed in 1974. The participants consisted of laboratory directors of a number of crime laboratories from around the United States. Out of a series of meetings over the next few years, the Laboratory Accreditation Board was formed as a separate organization, and, in 1982, ASCLD/LAB began accepting applications for laboratory accreditation. The accreditation process is a long process. Accredited laboratories have the benefit of knowing that they meet and maintain the highest standards for evidence control, quality assurance, and testing. More and more laboratories are seeking accreditation. As of November 2008, 350 crime laboratories were accredited by ASCLD/LAB. Complete information about ASCLD/LAB accreditation can be found on the ASCLD/LAB web site at ascld-lab.org. The history of ASCLD and ASCLD/LAB can be found at http://www.ascld-lab.org/dual/aslabdualhistory.html.

6.16 Frequently Asked Questions About Latent Prints

6.16.1 What is a Latent Print?

The word latent has several possible meanings; among them are hidden, invisible, and undeveloped. Latent print examiners usually refer to the crime scene print as the latent print. It is the unknown or questioned print usually left unknowingly and randomly by someone. It normally requires some form of development to make it visible to the naked eye.

6.16.2 Can You Tell What Hand Made the Latent Print?

You cannot always tell what hand made a particular latent print. In the Henry classification system, for example, we know that an ulnar loop slopes to the right in the right hand and to the left in the left hand and radial loops flow opposite. However, when a single latent print is developed at a crime scene, you may know that it is a loop pattern, however, you cannot say ulnar or radial because you cannot be sure from which hand it came. So, latent print examiners use the terminology right slope loop and left slope loop. Sometimes you will develop multiple latent prints or a complete handprint showing the fingers and palms,

which will indicate from which hand it came. Sometimes you will develop multiple latent prints on an item that might indicate that it was handled in a particular way by a particular hand; a thumbprint might be developed on one side and one or more fingers developed on the opposite side. Many of these factors have to be taken into consideration when examining evidence and/or latent prints developed from a piece of evidence.

6.16.3 Can You Tell the Age of a Latent Print?

You cannot scientifically tell the age of a latent print that is developed on an item. This question has come up in court time and time again. "Do you know when my client touched this item?" "No, I can only say that at some point in time his finger came in contact with the item and left that mark." There have been cases where known items were cleaned at a particular time prior to an incident and that might make it likely that the latent print in question was left at some point after the cleaning.

6.16.4 Does Someone Always Leave a Fingerprint on an Item That He Touches?

This question also comes up in court. The answer is no, but with an explanation. There is something called the Locard principle that basically says any contact between two physical bodies will result in an exchange of material. There might well be some trace left each time the finger contacts an object; however, you may not always be able to develop an impression with sufficient detail to even be sure that it is a fingerprint, let alone develop an impression that can be individualized.

6.16.5 Can You Develop Latent Prints on an Item That Has Been in Water?

You can develop prints on many different items that may have been subjected to water soaking. Investigators are constantly asking latent fingerprint examiners "is it worth it to process certain evidence because it has been wet or left outdoors for a long period of time." The answer is yes you can develop latent prints on this type of evidence. Most latent print examiners will tell you "you don't know until you try." A case in point: Several years ago, manufacturers of counterfeit currency, in order to get rid of their printing press and other counterfeit paraphernalia, dumped everything in a canal in South Florida. After a period of time, the water receded enough for part of the equipment to be visible in the water. After retrieving the items from the canal and drying them over several days, numerous fingerprints were developed through the use of fingerprint powder and several subjects were eventually identified.

6.16.6 How Long Will Fingerprints Remain on an Item?

Fingerprints have been known to last for many years on various items. There are a great many variables that affect a fingerprint that has been left on an object. Because the residue that causes a latent print is mostly water, additional handling of the object, climate, storage, and other factors all have something to do with how long a print will last. There are reported cases of latent prints being developed on paper after more than twenty years. No one can say for sure how long a latent print can remain on an item.

6.17 Questions

1. Why do you think that fingerprint identification has been relied upon for longer than 100 years as a positive means of personal identification?
2. Do twins have the same fingerprints?
3. Can a person's fingerprints be destroyed?
4. If you touch something, is it safe to assume that you will leave a fingerprint on that object?
5. Are humans the only mammals that have fingerprints?
6. In fingerprint identification, what is the difference between classification and identification?
7. Because it is possible that every case a fingerprint examiner handles is a potential court case, at what point should you start thinking about preparing for court?
8. If you have identified/individualized a fragmentary latent print that was developed with fingerprint powder using a standard inked fingerprint card as the known exemplar and are asked in court: "are the two prints identical"; how would you respond?
9. If two latent prints are developed, one over the top of the other, is it possible to identify one or both of the prints?
10. What or who is an expert witness?

6.18 About the Author

Carmine Artone is a Certified Latent Print Examiner. He began his career with the Federal Bureau of Investigation Identification Division in 1956. He received his initial training in Fingerprint Identification at the FBI and subsequently worked in the FBI Identification Division for approximately 6 years. Upon leaving the FBI, he was employed by the Miami Dade Police Department (formerly Dade County Sheriff's Office) where he worked as a Fingerprint Examiner from 1963 to 1970. During that period of time, he spent a year assigned to the Mobile Crime Laboratory. Upon leaving Miami in 1970, he was employed by the United States Secret Service

as a Latent Print Examiner and subsequently retired as Branch Chief of the Identification and Research Branch, Forensic Services Division, in April, 2000. Since retirement, he has remained active in fingerprint identification by teaching fingerprint identification abroad in several countries for agencies of the United States Government.

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Chapter 7
Legal Issues Concerning Expert Evidence and Testimony

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Contents

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7.1 The Nature and Purpose of Expert Opinion Evidence

7.1.1 Scope of the Chapter

The use of scientific evidence and expert opinion testimony in pretrial proceedings and at trial has increasingly become the focus of the courts, lawyers, and legislators in recent years. This increased focus can be attributed to a convergence of factors, including (1) the ever-evolving capability and sophistication of the scientific methods and technological tools that can be brought to bear on legal disputes, (2) United States Supreme Court decisions refining the legal standards for admitting expert testimony, (3) the efforts of professional legal educators and scholars who have devoted an increasing amount of written and classroom work on the use of scientific evidence at trial, and (4) the portrayal of forensic specialists in the popular media. The result is that there is an increased willingness, and even demand, by courts and jurors alike to hear expert testimony from scientific experts in criminal and civil legal proceedings [1].

The material in this chapter provides the forensic science professional with a frame of reference in dealing with attorneys, judges, juries, and the court system. Because the subject matter of this chapter is so broad in scope, no attempt will be made to cover it exhaustively. By highlighting the basics, however, the chapter will serve as a useful adjunct to subsequent parts of this volume dealing with specific fields of expertise. The scientist who studies this chapter will have a general understanding of the law related to scientific evidence, and will be able to identify areas warranting close attention when they are encountered in the laboratory.

7.1.2 Theory of Admissibility of Expert Testimony

The general rule of evidence is that a witness may testify only to facts known personally. When a person testifies to a fact that can be perceived by the senses, he or she must have actually observed that fact. A lay witness can make inferences, however, and state them in the form of an opinion based upon what was observed, as long as the opinion is not based upon scientific, technical, or other specialized knowledge that is within the scope of Rule 702 [2]. Consequently, ordinary observers are allowed to give their opinions on such matters as identity of persons, color of objects, distances, and speed of vehicles [3].

Over the course of history, however, the courts have encountered issues that require analysis and explanation by persons having scientific or specialized knowledge or experience. This situation, associated with the expanding horizons of the sciences and technology, led to the evidentiary use of expert testimony at trial.

The scope of expert opinion testimony in civil and criminal trials has expanded to include any subject relevant to issues that may be disputed at trial, so long as the factual inference about which the expert will venture an opinion is distinctly related to a generally accepted science, profession, business, or occupation whose workings are beyond the experience of the lay person. The expert must be shown to the court to possess such knowledge, skill, experience, training, or education in the relevant field of endeavor to reasonably assure the court that the proffered opinion or inference will assist the judge or jury to understand the evidence or determine a fact at issue.

The testimony of the expert must also be the product of reliable principles and methods that the expert reliably applied to the facts of the case [4]. Finally, there must be a showing that the expert maintained primary control over the analysis, examination, observation, or experiment, and that any instrument or process used as an intermediate is equally trustworthy and reliable. The issue, of course, must be a proper one for expert opinion testimony. The principal consideration is whether or not the opinion of the expert will assist the trier of fact (i.e., the judge or jury). If the subject of inquiry is one within the range of ordinary intelligence and observation, expert opinion evidence is unnecessary to prove or disprove the matter and is inadmissible.

The basis of the opinion testimony of the expert is allowed if it is of a type reasonably relied on by experts in the particular field in forming opinions or inferences upon the subject. Under the Federal Rules of Evidence, at least, the facts or data that the expert relied upon do not need to be admissible in order for the opinion to be admissible. However, if any of the facts or data are inadmissible, they will not be made known to the jury unless the judge finds that the probative value of the inadmissible evidence substantially outweighs their prejudicial effect in helping the jury to evaluate the expert's opinion [5].

Experts are employed (1) to assist the attorney in understanding the complexities involved in proving a fact and/or (2) to assist the attorney in preparing the cross-examination of the adversary's expert, and/or (3) to present a report to the attorney, and (4) when the results are favorable to the employing party, to testify at trial concerning that opinion and the basis for it.

The fact question put to an expert may be so objective that any expert with competent training who performed the examination with requisite skill would give the same opinion. On the other hand, the fact issue may be one upon which two qualified, competent experts may subjectively disagree, even though their examinations meet all recognized standards and show precisely the same objective results. For example, psychiatry is a discipline where experts of unquestioned integrity often differ in their interpretations of diagnostic observations. Divergent approaches or schools of thought may result in a conflicting resolution of a particular issue. The less subjective an interpretation is, the more acceptance and credence it will receive from the judge or jury.

7.1.3 Tests of Admissibility

Most courts decide the issue of the admissibility of certain types of opinion evidence on the basis of precedent. An evidential question arises when an attempt is made to deduce expert opinion from a test that has not yet received widespread scientific recognition or acceptance in a discipline or profession. The courts have dealt with this problem by fashioning a variety of admissibility standards [6], some of which will be discussed within this chapter.

7.1.3.1 The Pre-Frye Period of the Common Law

While courts have admitted the opinion evidence of experts for several centuries, the development of a theoretical basis for doing so is less than a century old. During the 1800s, courts did not rely on any doctrinal statement to decide whether proffered expert evidence was logically and legally relevant, but there were some serious restrictions placed on what experts were permitted to state in court. Experts had to base their testimony only on admissible, admitted evidence presented in open court; the question for the expert had to be couched in a hypothetical question that took into account all pertinent facts. Further, neither experts nor lay witnesses could testify to an ultimate issue in the case, and an expert's conclusions had to be stated to a reasonable degree of professional probability in the expert's field [7].

7.1.3.2 The Frye Rule: "Expert Testimony in Search of a Rationale"

In 1923, a court attempted to offer a more structured test by which to make the admissibility decision when confronted with a novel kind of expertise. Its criterion has come to be known as the "Frye" test, or also the "general acceptance" test and draws from the frequently quoted language of the Frye case, which dealt with the inadmissibility of "lie detector" test results:

> Just when a scientific principle or discovery crosses the line between the experimental and demonstrable stages is difficult to define. Somewhere in this twilight zone the evidential force of the principle must be recognized, and while courts will go a long way in admitting expert testimony deduced from a well-recognized scientific principle or discovery, the thing from which the deduction is made must be sufficiently established to have gained general acceptance in the particular field in which it belongs [8].

The sweeping principle enunciated in Frye, for which the court cited no authority, initially was given scant attention by other courts. In civil cases, Frye would not be cited as a guiding principle until 1984, and was mentioned in less than half a dozen civil cases [9]. In criminal cases, by contrast, Frye became the polestar to guide the admission of test results from dozens of widely varied techniques that poured out of the growing number of crime laboratories in the 1970s [10].

While the Frye test supposedly represents a conservative approach to admitting evidence based on newly developed scientific applications [11], an approach deemed desirable because jurors are easily overawed by conclusions voiced in court by articulate experts with impressive credentials, actual experience has shown that "general acceptance" under Frye does not necessarily result in establishing the "reliability" of the test used. For example, in Frye, the court said that the "field" that was generally to accept the new polygraph in order to assure admissibility of the test results was one composed of the combined fields of physiology and psychology. Neither of these fields has as yet embraced the polygraph. Instead, an entirely new field of polygraphy has evolved.

Some forms of expert testimony are easily classified as to the field in which they belong [12], but many are not as easily categorized. New developments made by imaginative professionals in a field may be considered radical by their more conservative colleagues, who reject the new developments regardless of their worth [13]. On the other hand, professionals in a novel area sharing a common goal may develop a technique that furthers their professional aims and they may "generally accept" it regardless of its scientific validity, sometimes despite strong scientific denial of its underlying premises. In the first case, admissibility may be denied to a reliable and scientifically provable technique because the logical "field" in which it belongs refuses generally to accept it; in the other, admissibility may easily follow because a test is accepted in a field that was newly created for the express purpose of generally advocating its reliability [14]. Also, many lawyers lack scientific acumen to deal with complex issues grounded in one of the sciences [15].

7.1.3.3 The Federal Rules of Evidence Emerge

After the passage in 1975 of the Federal Rules of Evidence, questions were raised by many courts on whether the Frye concept of "general acceptance" within a discipline remained a viable one. State and federal court decisions were divided into at least three groups on that issue: (1) jurisdictions holding that the Federal Rules (or its state evidence rule equivalents) had replaced Frye v. United States and that the Federal Rules' more flexible "relevancy" test permits use of scientific evidence that is not "generally accepted;" (2) jurisdictions maintaining that Frye survived the enactment of the Federal Rules of Evidence and is complementary of Rule 702; and (3) jurisdictions neither adopting Frye's general acceptance test nor possessing a rule comparable to Federal Rule 702.

Federal courts began to adopt a liberal posture in regard to admitting expert evidence. A let-it-all-in attitude on the one hand caused a cry to be heard in other quarters that "junk science" was flooding the courtrooms [16]. Despite the liberalizing trend toward admissibility of anything that might even marginally aid the jury's understanding, some federal courts left the Frye rule in place, while being ambivalent as to when it ought to be applied.

7.1.3.4 Daubert Interprets Federal Rule of Evidence 702

In its 1993 opinion in Daubert v. Merrell Dow Pharmaceuticals [17], the United States Supreme Court concluded that the Frye rule was replaced by the enactment of the Federal Rules of Evidence, and held that expert testimony would no longer be inadmissible merely because it has not gained general acceptance in the scientific field in which it belongs.

The Supreme Court relegated Frye to history as far as federal civil and criminal trials are concerned, stating that "a rigid general acceptance requirement would be at odds with the liberal thrust of the Federal Rules and their general approach to relaxing the traditional barriers to opinion testimony." In its decision, the Court mandated that in the future, instead of proof of general acceptance, proof that establishes the "scientific reliability" of expert opinion evidence be produced. It set up the following mechanism for that determination:

> Faced with a proffer of expert scientific testimony, then, the trial judge must determine at the outset, pursuant to Rule 104(a), whether the expert is proposing to testify to (1) scientific knowledge that (2) will assist the trier of fact to understand or determine a fact in issue. This entails a preliminary assessment of whether the reasoning or methodology underlying the testimony is scientifically valid and of whether that reasoning or methodology properly can be applied to the facts in issue [18].

To assist the trial court in making the legal decision on admissibility of proffered expert opinion testimony, the Court further suggested that the trial judge examine the following factors: (1) whether the type of evidence can be and has been tested by a scientific methodology; (2) whether the underlying theory or technique has been subjected to peer review and has been published in the professional literature, although specifically stating that peer review and publication are not a sine qua non of admissibility; (3) how reliable the results are in terms of a potential error rate; and finally (4) "general acceptance" can yet have a bearing on the inquiry. A "reliability assessment does not require, although it does permit, explicit identification of a relevant scientific community and an express determination of a particular degree of acceptance within that community" [19]. The Supreme Court stressed that the new test is a flexible one, wherein not one factor is determinative, and expressed a confidence – not necessarily shared by many commentators – that the trial judges are able to fulfill this gatekeeping role.

While Daubert decided the admissibility principle for federal cases only, civil as well as criminal, the ruling has had a great impact in states that have evidence codes based upon the Federal Rules of Evidence, and even on states that had previously followed the general acceptance rule of Frye in the absence of specific evidence rules or statutes similar to the federal rules. Some of these developments will be chronicled below.

Establishing "scientific reliability" under Daubert has proved to be no easier task than establishing "general acceptance" under Frye [20]. Proving scientific reliability on the stand may at times call for resources in manpower and insight on the part of the attorney opposing admission of the evidence that is not typical of the trial bar. As a result, courts frequently are not aware of deficiencies in the

reliability and replicability of novel test results. In the course of ordinary trial procedure, reliability of a technique and its general acceptance in the proper discipline is shown through expert testimony. It is not always the case, however, that both adversaries will have access to expert assistance at trial, due to a disparity in resources or tactical decisions made by the lawyers in advance of trial. As a result, the court, in making the legal decision of whether proffered evidence is scientifically reliable [21], often will have only the one side's expert's assessment of the soundness of the procedures before it. Also, while most forensic scientists, whether prosecution or defense oriented in their practice, honestly believe that they are objective in their scientific inquiries, practicing lawyers, judges, and even candid experts realize that once the battle is joined and they have connected to one of the litigants in the courtroom, it becomes impossible to be totally "impartial." Many of the deficiencies in our fact-finding process on scientific issues are inherent in the adversarial system and result from factors other than the test for admissibility that a jurisdiction may use.

Courts soon disagreed as to the applicability of Daubert to a diverse number of issues. Perhaps the principal one was whether a Daubert-like approach was also appropriate when a particular form of expert testimony was not clearly grounded in science, or its scientific underpinnings were disputed. The distinction between expert testimony based on science as opposed to technical knowledge, observational specialty, or applied science is not easy to make. Perhaps it was for that reason that some state courts suggested avoiding the Daubert quandary by applying the decision's factors only to "novel" scientific evidence. In doing so, inevitably, courts began to differ with other tribunals in determining whether a given field of expertise was "science" [22] or even whether it was "novel" [23].

7.1.3.5 Daubert Broadened in Kumho Tire v. Carmichael: Other Decisions

The debate about these post-Daubert uncertainties was settled in 1999 when the United States Supreme Court handed down its decision in Kumho Tire Co., Ltd. v. Carmichael [24], another civil case. The Court stated unequivocally that Daubert's gatekeeper function for the trial judge applied also to non-scientific experts, whose testimony might be either of a technical nature, or based on "other specialized knowledge" under Rule 702. The Court did reiterate in Kumho Tire the Daubert admonition that its "factors" to determine evidentiary reliability constituted a flexible guideline only and not a definitive checklist [25]. Thus, the Court recognized that, for some professions, there might well be other criteria by which reliability could be examined more appropriately.

In the aftermath of Kumho Tire, the argument whether a profession is based on "scientific knowledge" or merely experience-based non-science has become irrelevant. When a challenge is mounted, all expert opinions are to be scrutinized by the court for their inherent reliability. As is customary whenever a new decision is announced, differing interpretations on its scope abound [26].

Since "gate keeping" is now required under Rule 702, whether the expert evidence is deemed "scientific" or "other," Daubert/Kumho Tire challenges to prosecution-offered forensic testimony have been and continue to be brought in many cases, among the most notable ones being the professions of forensic document examination, friction ridge impression (fingerprint and palm print identification) evidence, bite mark comparisons, firearms and tool mark examinations, and others.

7.1.4 Expert Opinion in the States: Other Concerns and Considerations

The United States Supreme Court opinions discussed in this section apply only in federal civil and criminal trials because they interpret the meaning of Federal Rule of Evidence 702. Many of the states that have evidence rules patterned after Federal Rule 702 have decided to follow Daubert. A sizeable number of Frye states, however, have chosen to retain Frye. Some states adopted a hybrid approach [27]. Even in the states that have remained true to Frye, the decisions of the United States Supreme Court interpreting Rule 702 are having a great impact, not always on the decision of admissibility, but certainly as a way of evaluating the probative value of the evidence. Furthermore, even true Frye states are reinterpreting the "general acceptance" standard as one that requires perhaps more proof of reliability than merely acceptance by the users of the test.

7.1.5 Judicial Notice of Underlying Science's Reliability

Some scientific techniques and tests have become so thoroughly recognized by courts as to receive "judicial notice" of their reliability, which means that those courts will from now on accept that those techniques and tests meet the standards of Daubert/Kumho Tire, and it is not necessary for a party wishing to use those techniques and tests to present evidence of their reliability. DNA analysis and fingerprint evidence are prime examples of this almost blanket acceptance.

At the other end of the spectrum are such tests as those involving so-called "truth-serum," the use of hypnosis or psychological stress evaluation of the voice to ascertain the truthfulness of a person's assertions. There is very little support for the reliability of these techniques as a means for making such a determination. In between these two extremes is the polygraph ("lie-detector") technique. A number of specialists in the field credit it with a high degree of reliability and advocate judicial approval of test results, but opposing views are held by a substantial number of psychiatrists, psychologists, and other professed evaluators. Up to the present time, admissibility of test results has generally been denied.

7.2 Discovery and Disclosure in Criminal Cases

7.2.1 The General Purpose and Nature of Disclosure and Discovery

In recent years, there have been many statutes, court rules, and case decisions involving pretrial disclosure and discovery in criminal cases. This is partially the result of a trend toward accepting, in criminal matters, the general purposes of disclosure and discovery in civil actions: preventing surprise at trial; narrowing the issues to be tried; and speeding the administration of justice by encouraging settlement (e.g., plea bargaining) of those cases where both sides know the strength or weakness of the evidence. Pretrial discovery also provides a means whereby defense counsel is able to equalize the imbalance of resources available to the state [28].

The discovery of scientific information is, in one sense, merely a part of the total discovery of a party's case and the same general purposes apply. However, special considerations arise with regard to expert discovery. The major reason given for expert discovery in criminal and civil actions is the need for the opposing attorney to be adequately prepared for cross-examination. The cross-examining lawyer often needs to have technical knowledge of the particular scientific field to put the expert's conclusions to a meaningful test. This is different from the cross-examination of a lay witness (e.g., eyewitness), where the lawyer may draw from his or her own personal knowledge of the common fallibilities of sense perception and memory. This section focuses first upon some statutes and court rules regarding expert criminal discovery. Thereafter, discovery in civil cases will be discussed.

7.2.1.1 Informal Disclosure by the Prosecution

Until recently, informal discovery of the prosecution's evidence was encouraged as a means of circumventing the severe restrictions placed on pretrial discovery by the rules then in effect [29]. The need for such informal procedures has been lessened, however, by the liberalization of the federal and state criminal discovery rules. Today, informal discovery is common [30]. Depending upon defense counsel's working relationship with the prosecutors involved in a case, it is sometimes possible to obtain a considerable amount of discovery without resorting to formal discovery practice. In essence, the informal technique entails a conference call with the prosecutor, coupled with a defense request that the prosecutor reveal the contents of his file. This informal procedure may be in lieu of or as an adjunct to the filing of formal motions for discovery.

7.2.2 Laws of Disclosure

7.2.2.1 Federal Due Process Obligations

Generally, a criminal defendant has a Fifth Amendment due process right, which requires the prosecution to disclose material exculpatory evidence [31]. The issue as to what disclosures fall within the requirement was clarified by the Court in its opinion in United States v. Agurs, which explained that there are three standards for determining whether evidence is "material," and therefore required to be disclosed to the defendant, depending on the factual circumstances of the particular case [32].

The first circumstance is where undisclosed evidence demonstrates that the prosecution's case includes perjured testimony and the prosecution knew or should have known of the perjury. In such cases, the conviction will be set aside "if there is any reasonable likelihood that the false testimony could have affected the judgment of the jury" [33].

The second situation where disclosure of "material" information is constitutionally required is where such evidence is favorable to the accused and the prosecution suppresses it after a request for disclosure by the defense. This was the holding of Brady v. Maryland [34], in which the United States Supreme Court held the suppression of such information to be a violation of the defendant's right to due process, irrespective of the good faith of the prosecution. In this type of case, where there has been suppression of specifically requested material, Agurs characterized the evidence to be material if it might have affected the outcome had it not been suppressed [35].

In the third situation, "if the omitted evidence creates a reasonable doubt that did not otherwise exist," [36] then the evidence is material and must be disclosed regardless of whether the defendant made a request for such evidence. Where reasonable doubt exists, failure of the prosecution to disclose the material information constitutes constitutional error, and grounds for overturning a conviction on appeal.

There are, then, three relevant constitutional standards defining "material" evidence that must be disclosed on due process grounds: (1) strict materiality in false evidence cases (i.e., false evidence is material if it could have affected the case result); (2) specifically requested evidence that might have affected the outcome; and (3) evidence that would create a reasonable doubt as to the defendant's guilt even where there has been no request or merely a general request for exculpatory evidence [37].

7.2.2.2 Pretrial Discovery in Federal and State Courts

The term "pretrial discovery" is used by lawyers and the courts to refer to a variety of procedures used by the parties to criminal or civil litigation to obtain factual information from their adversaries or non-parties prior to trial. These procedures include, generally, such things as written interrogatories, demands or subpoenas for documents or other tangible things, and depositions. An underlying purpose of

these discovery procedures is to reduce the likelihood of surprise at trial, allow the parties an opportunity to gather evidence in support of their claims and defenses, and assist in trial preparation.

It should be noted that there is little procedural variation among those jurisdictions that have enacted statutes or adopted court rules dealing specifically with expert discovery. Rules or statutes provide for the release of tangible evidence held by one party so as to allow the opposing party to engage his own expert to test the evidence [38]. These systems are designed to allow disclosure of specific scientific information, including experts' reports.

The emphasis of the following analysis will be on the discovery provisions concerning disclosure of reports of examinations and tests by experts. This emphasis is appropriate since there is greater variation among these provisions, and also because discovery of the results reached by the opponent's expert from testing tangible evidence is often more helpful than the tangible evidence by itself.

7.2.2.3 Discovery in Federal Criminal Cases

Currently, pretrial discovery in federal criminal cases is covered by Rule 16 of the Federal Rules of Criminal Procedure. Rule 16 has two separate provisions covering discovery of experts retained by the defendant and those experts retained or employed by the prosecution [39].

The provision for defendant's discovery of expert information from the prosecution is contained in Rule 16(a)(1)(D) [40]. Under this provision, discovery is activated by the "request" of the defendant. An amendment to Rule 16 in 1993 inserted subparagraph (G) and requires the government, upon defendant's request, to disclose "a written summary of [expert witness] testimony that the government intends to use" in its case, describing "the witnesses' opinions, the bases and reasons for those opinions, and the witness's qualifications" [41]. A request is most often made and complied with without the involvement of the judge. However, in the case of a dispute over discovery, either party may make a motion to the court for an order denying, restricting, or deferring discovery or inspection. Rule 16 grants courts the power to regulate discovery.

Once the defendant makes a request, the rule provides that the government shall permit the defendant to inspect or copy the results of reports of medical or scientific tests [42]. However, for the rule to apply, the expert information must be in the control of the government, the prosecution must know of its existence, and the information requested by the defendant must be material to the preparation of their defense or it must be intended to be introduced at the trial by the prosecution [43]. The final restriction is intended to prevent the defendant from conducting a "fishing expedition" through the voluminous reports of the government. It also protects the work efforts of the advisor-expert from disclosure, thus encouraging full case investigations by the prosecution. Of course, the defendant will eventually receive expert information from the prosecution that is material and favorable to the defense under the Brady (exculpatory evidence) rationale, even if the expert is not expected to

testify [44]. Nevertheless, neutral or other information not favorable to the defense, and that is not intended to be introduced, is not discoverable.

Fed. Rule 16(b)(1)(B) contains a provision permitting the prosecution to discover the defense's expert information [45]. Corresponding to the duty imposed upon the government to disclose, upon request by the defense, information about its expert witness' opinions, the bases and reasons for such opinions, and the experts' qualifications, the rule also imposes a like duty of disclosure upon the defense in paragraph Rule 16(b)(1)(C). These provisions are nearly identical to those for discovery by the defense except that they contain a reciprocity clause. That is, the prosecution can discover the expert information of the defense only if the defendant first requests disclosure of similar information from the government [46]. If the defendant has triggered Subdivision (b)(1)(B), the prosecution may request the information it desires. However, the reports or test results that are sought must be within the control of the defense and there must be the intention to introduce such evidence at trial. Also, the prosecution may seek only the results or reports of medical or scientific tests that were made in connection with the case, thus prohibiting possible oppression by a prosecutor requesting irrelevant expert information. But the prosecution may also discover information that was prepared by a person whom the defense intends to call as a witness, and this applies even though the reports or results themselves are not intended to be introduced as evidence. It is sufficient that they relate to the expert's testimony.

At first glance, this latter provision appears to grant the prosecutor an additional right that the defense does not have. However, it is evident that this merely involves the ability of the government to cross-examine defense witnesses, which is also provided to the defense through its ability to discover information that is "material to preparing the defense" in Subdivision (a)(1)(E).

It is important to note that Rule 16 removes any possible work product claim to prevent discovery of expert information. Work product is the writings, notes, memoranda, reports of conversations with the client or witness, research, and confidential materials that an attorney has developed while representing a client, particularly in preparation for trial. Generally, "work product" may not be demanded or subpoenaed by the opposing party, as are documents, letters by and from third parties and other evidence, because the work product reflects the confidential strategy, tactics, and theories to be employed by the attorney. Rule 16 exempts expert information from protection as "work product," presumably as a result of logic similar to that applied in the civil discovery rules: expert information is evidence in itself and is not merely an evaluation of evidence. The report of a coroner or medical examiner, or of a firearm or fingerprint expert, can be crucial to linking or not linking the accused person to the crime. Overriding public policy considerations call for allowing the court to receive this information, and the strong public interest in ascertaining the truth in criminal matters is evidenced by the tone of Rule 16.

"Discovery" under Rule 16 is more aptly termed "disclosure" because, once certain conditions are met, specified information must be disclosed. This difference from the discovery methods in civil cases is further emphasized by the absence of provisions for depositions or other discovery methods in addition to what is required to be disclosed [47].

7.2.2.4 American Bar Association Standards

Before discussing various state provisions, it is important to recognize that the American Bar Association Recommended Standards for Criminal Discovery [48], together with Federal Rule 16, have formed the models for many revisions in state criminal discovery rules.

As with the federal rules, the Standards have provisions relating to the discovery of expert information by both the defendant and the prosecution. Also, as with the federal rules, "discovery" is not as accurate a description as "disclosure" for the purpose and scope of Standards.

7.2.2.5 Discovery Rules of the States

From the foregoing discussion of the ABA Standards and Federal Rule 16, it is evident that these general models have three main elements: (1) whether or not disclosure of expert information is available only upon motion and court order (the motion element); (2) whether or not there is a need for reciprocity – no prosecution discovery unless the defendant seeks similar discovery (the reciprocity element); and (3) whether or not the opposing party must intend to introduce the expert information at trial before it can be discovered (the intent element). The states have dealt with these elements in different ways, with some states' provisions being patterned after Fed. Rule 16 [49], others patterned after the pre-1974 version of federal discovery rules [50], and yet others patterned after the ABA Standards [51]. The states also place different burdens on the prosecution and defense.

7.3 Discovery and Disclosure in Civil Cases

7.3.1 General Considerations

Since the adoption by the Supreme Court of the Federal Rules of Civil Procedure in 1937 [52], and throughout its amendments, discovery has become an important part of the civil litigation process. It replaced pleadings as the primary means by which parties learned of some factual information and formulated issues in the case. When it comes to discovery of experts, and information held by them, two opposing views have traditionally been advocated. The first view is that which favors liberal discovery, leading to a narrowing of the triable issues prior to trial and the avoidance of surprise at the trial. The opposing view regards the retention and consultation of experts by an attorney as part of a professional and competent pretrial preparation that should be kept confidential; to do otherwise would be to reward the incompetent and less resourceful advocate. Adherents of this latter view suggest various rationales for prohibiting discovery of information in the possession of the expert: (1) an expert who is consulted in preparation of trial gains

knowledge about the case that should be covered by the attorney–client privilege; (2) even if the expert's knowledge is not within the evidentiary privilege, it should nevertheless come under the "work product" rule; and (3) to permit an opponent to discover information collected at great expense and with considerable resourcefulness is unjust.

The modern view, exemplified by the Federal Rules of Civil Procedure provisions on discovery, have taken the position favoring discovery, and have sought to prevent abuses and exploitation by provisions permitting the courts to issue protective orders and direct the demanding attorneys to make payment of fees and expenses to the party retaining the expert. In 1993, the discovery rules were further amended to require voluntary disclosures about experts and others without a prior demand at a very early stage in the pre-trial period. Most state discovery rules are patterned upon the federal rules [53]. For that reason, only the federal rules will be covered here.

7.3.2 Scope of Expert Witness Discovery in Civil Cases Under Federal Rule 26

Significant and massive changes in Federal Rule 26 and other Rules of Civil Procedure have occurred over the years. To summarize the most important aspect of federal civil discovery, litigants must disclose to their opponent, without being asked to do so, a variety of types of essential information about pending litigation. The rule continues to deal with experts who are expected to be called as witnesses differently from those who are merely consulted for assistance in preparing the case. If the purpose of discovery is to prevent surprise and promote effective pre-trial preparation, then lawyers need access to the experts who will be witnesses at the earliest possible opportunity. It is for that reason that, under Rule 26, a party is now required to disclose the substance of the anticipated testimony of an expert at an early stage.

When a witness has been retained in anticipation of litigation but is not expected to testify as a witness for the retaining party, such as a consulting expert, discovery can be had only upon showing a special need. An exception is made for Rule 35 physical and mental examinations of persons. Rule 26 does not address the expert witness who only has participated in the transaction that is the subject of the litigation. Such an expert would be treated as an ordinary (non-expert) witness.

7.3.2.1 Discovery Based on the Expert's Role

It is clear from the provisions discussed in the previous section that, considering the impact of Rule 26 on experts, discovery rights depend upon the role the experts have played in the case prior to the request for discovery. An expert's involvement in litigation may be characterized as falling into one of four different categories: (1) experts who are expected to be called as witnesses by the opposing party; (2) so-called consulting experts who are not expected to testify at trial; (3) experts who are informally

consulted prior to trial but not formally retained; and (4) experts who obtained information about the case independent or pre-trial preparation by a litigant [54].

7.3.2.2 Experts to Be Called as Witnesses

Experts retained by a party who are expected to testify as expert witnesses are compelled to reveal the nature of their anticipated testimony, and much other information about them, in the pre-trial voluntary disclosure process. This includes testimony about the facts known or made known to the expert, his or her opinions, and a summary of the grounds for each opinion. Furthermore, the attorney retaining them must also furnish to the opponent the list of cases in which the experts have testified during the last 4 years and the qualifications of the experts. The purpose of the 1993 amendments was to get this most crucial information disclosed at the earliest possible stage. Further discovery as it existed before the 1993 changes, such as by interrogatories, may also be had. Under the old rule, discovery by interrogatories was often considered to reveal only the bare-bones of what a litigant would like to know, and its effectiveness was called into question [55].

Rule 26(b)(4)(A) represents the potential second step of the discovery process. Discovery through depositions and motions to compel production is also permitted. Under the pre-1993 rule, there certainly seemed to be a trend toward allowing additional discovery by deposition, although scant case law exists on the issue, since discovery orders are ordinarily not appealable until final judgment.

Information such as the expert's report and data relied upon by the expert must now be voluntarily disclosed by each litigant under Rule 26. The materials utilized by the experts in arriving at their opinions, whether forming the basis of their opinion or rejected by them, should also be included in the information turned over to the opponent.

7.3.2.3 Non-Witness Consulting Experts

Disclosure of information and discovery from an expert who was retained solely as a consultant to assist in the preparation of the trial, including the possible cross-examination of an opposing expert, is far more restricted than that allowed for experts to be called as witnesses. Here, no voluntary disclosure is required and discovery is permitted only if certain conditions are met. First, the demanding party must show exceptional circumstances demonstrating that the demanding party cannot discover the facts or information by other means in a practical way [56]. The courts will have to flesh out the types of exceptional circumstances that would require the granting of additional discovery privileges. Among the exceptional circumstances that may warrant discovery are those: (1) where the only known expert in the field has been retained by the opposing party; (2) where the expert retained by the opposing side has made an investigation that now, due to a change in the circumstances, can no longer be duplicated by a different expert, as where an analysis has consumed the substance

to be analyzed, or materially altered it; and (3) where the information is available through effective discovery but only by the expenditure of excessive time and money and where a significant delay of the trial would be caused.

Rule 26 does not specifically address whether a litigant may discover the name of an expert who has been retained or specially employed but who will not be called as a witness at trial. In deciding the pre-1993 rule, courts have differed in their approach to the issue. In one case, the court held that the identity of a non-witness retained expert was discoverable without showing "exceptional circumstances" [57]. By contrast, another court required a showing of exceptional circumstances even to discover the names and identities of experts [58]. The former rule is clearly the better one, when one considers that it may be difficult to conduct effective discretionary discovery of non-witness experts without knowing even their existence.

It may at times be difficult to determine whether an expert will be a testifying expert or a consulting expert. An expert may have been initially retained by an attorney who planned to call that expert as a witness, but the opinion rendered by the expert makes it undesirable to call the expert as a witness at trial, and therefore the witness is used as a consultant. The states do not have a uniform answer to the question of which rule applies in this instance. Some may argue that the conclusion reached by such an expert, as well as the data reviewed, ought to be privileged from discovery, because to do otherwise would be to discourage lawyers from seeking to gain as much information about a pending case as they can gather. However, if the expert had formed an opinion on the case or has knowledge of the facts of the case, prior to being retained, such opinions and facts would not be shielded from disclosure under Rule 26. Furthermore, an expert may sometimes straddle both categories, so that some of the facts and opinions are discoverable, and other aspects are not [59].

7.3.2.4 Experts Informally Consulted But Not Retained

It is not uncommon for attorneys to telephone an expert and ask off-the-cuff questions on some aspect of a pending case. Sometimes, these conversations result in the expert being retained, which then would put the expert in one of the two categories already discussed. At other times, however, the conversation will not result in a retainer, even though the expert has been told some of the essential facts of the case. Rule 26 does not address the discovery of experts informally consulted but not retained. However, the advisory committee note to the pre-1993 version of Rule 26 suggested that Rule 26(b)(4)(B) "precludes discovery against experts who are informally consulted in preparation for trial, but not retained or specially employed" [60]. Committee notes to subsequent amendments to the rule do not provide further guidance.

7.3.2.5 Experts Who Obtained Independent Information

If an expert gained information about the pending case prior to being retained by a party, whether as part of the expert's regular employment and not in anticipation of

litigation or by being a participant or witness to an occurrence that becomes the focus of later litigation, such knowledge will not be shielded from discovery [61]. The expert, here, will be treated as any ordinary witness would be, for purposes of discovery, and discovery of any information possessed should be freely allowed.

7.3.3 2006 E-Discovery Amendments and ESI (Electronically Stored Information)

The most recent amendments to the Federal Rules of Civil Procedure that went into effect in 2006 were designed to accommodate the growing importance and all-pervasive nature of electronic data storage and its impact on the discovery process. They do not specifically apply to expert witnesses. The amended rules became effective on 1 Dec 2006.

The main consequences of the pervasiveness of e-Discovery will be that lawyers and their clients are now required to work closely together in retrieving the many types of data that are covered under ESI, including email, IM (instant messaging), word processing files in various operating systems, spreadsheets, database records, voice messages, digital photos, videotapes, surveillance camera records, as well as web pages and their servers. Furthermore, ESI also covers the devices that generate data, be it desktop computers, laptop computers, PDAs, cell phones, back-up tapes, and various types of digital storage devices.

Rather than claiming ignorance and relying solely on the word of their clients, lawyers will have to actively seek to find out where ESI is being kept, and in what format(s). Discovery of the future is not going to be in folders, files, or even boxes of printed material. Rather, it will take the form of "gigabytes upon gigabytes of information that might be relevant to a case" [62]. Experts are indirectly affected by these provisions inasmuch as they may work for large laboratories or organizations wherein electronic data storage is already the norm.

7.4 The Expert at Trial

7.4.1 Qualifying Procedures

An expert is permitted to testify not only to facts but also to the expert's opinions and conclusions drawn from the facts. Before an expert witness testifies, it must be demonstrated by proof that the witness is qualified from observation, study, or actual experience to speak as an expert [63].

Before the expert testifies, the expert's knowledge and experience should be tested by questions producing answers by which the trial judge may determine the witness' competency. This discretionary judgment is made after the court has heard the witness' qualifications. The scope of this discretion is quite broad. Nevertheless, even

after the trial judge rules that the witness is competent to testify as an expert, the trier of fact (jury or judge) may weigh credentials against the witness' credibility.

It has been suggested that trial judges typically permit any witness who is shown to have had some experience or background in a field of specialty to qualify as an expert, suggesting that any weaknesses in the competence may be brought out on cross-examination [64].

The court must determine whether a proffered witness is qualified to testify as an expert, and that determination will not be overturned except for an abuse of discretion [65]. Federal Rule of Evidence 702 states that a witness may qualify as an expert on the basis of knowledge, skill, training, experience, or education. An expert witness must possess only one of these traits for the judge to find the expert qualified to give an opinion. In making this evaluation, the judge may consider the expert's educational background, work experience, publications, awards, teaching, speaking or other professional engagements, prior expert-witness testimony, and membership in professional associations.

Often, the expert may have to educate the attorney proffering the expert regarding the significance of particular experience, achievements, and certifications to ensure that they are appropriately emphasized to the judge. An expert must be prepared to explain board certification and licensure requirements to the judge in detail.

7.4.2 Experience as an Expert Witness

Experience and training are often more significant than academic background and are accorded more weight by jurors [66]. However, experience as an expert witness, standing alone, does not qualify someone as an expert in later cases. For example, in Bogosian v. Mercedes-Benz of North America Inc., [67] the court rejected the opinion of a witness who had testified as an expert 126 times. Another court noted that, "it would be absurd to conclude that one can become an expert by accumulating experience in testifying" [68]. Conversely, a lack of previous experience as an expert witness does not disqualify one from testifying as an expert [69].

7.4.3 Education and Training

An expert may be qualified based on academic credentials, including the expert's undergraduate, graduate, and postgraduate work. An expert's academic credentials should only be issued by accredited educational institutions and programs [70].

An expert should continuously perform research and publish in the expert's field, preferably in peer-reviewed publications. Teaching experience is another of the qualifications that judges will evaluate: all forms of teaching – regular, specialty, guest lecturing, visiting professorships, continuing education, and short courses – weigh in as credentials. An expert should also keep up-to-date with developments in the expert's field by reading the current literature, enrolling in continuing education seminars, joining professional societies, and attending professional meetings.

7.4.4 Membership in Professional Associations

A study published by the U.S. Department of Justice in 1987 found that jurors perceived those experts who belonged to professional associations to be more credible than other experts, and presumed experts would belong to such groups [71]. It is therefore important for an expert to remain active and participate in professional societies; the expert's credibility is diminished if the expert has not recently attended a professional meeting. Professional associations that only require annual dues payment to become a member are not as prestigious as associations that are joined by special invitation only, by approval of special referees, or by passing an examination. Thus, an expert should be selective about which professional associations to join [72].

7.4.5 Increased Scrutiny of Experts

Experts have come under increased scrutiny for either fabricating or inflating their qualifications [73]. In addition to perjury prosecutions for false qualifications [74], some jurisdictions will also prosecute for academic fraud. For example, in Florida, a person who misrepresents association with, or academic standing at, a postsecondary educational institution is guilty of a first-degree misdemeanor [75]. Courts have also overturned convictions where the experts testified outside their field of expertise [76].

Once the witness' qualifications have been accepted by the court, direct examination on the substance of his investigation commences. The witness should first specify the data considered, and the examinations made, after which the expert testifies to the opinion. The weight to be given to the expert's substantive testimony is determined by the trier of fact, which may be the judge or jury, depending on whether the trial is a bench (judge-only) trial or a jury trial [77].

7.5 Legal Impediments to Expert Testimony

7.5.1 Hearsay

A hearsay question arises when the expert bases the opinion on information given to the expert by someone else. Hearsay evidence is defined as testimony or written evidence of a statement made out of court, which is offered as evidence in court to prove the truth of the matter in the out-of-court statement. Courts will generally refuse to admit such evidence because the person making the statement (the "declarant") is not present to testify in court, and to be subject to cross examination in order to test the declarant's credibility. As a general principle of law, all hearsay evidence is inadmissible unless the hearsay falls within one of the long list of recognized exceptions to the hearsay rule – exceptions that have been carved out because of necessity or because the hearsay was uttered under circumstances which have some guarantee of trustworthiness. For example, Rule 803(6), exempts from exclusion as hearsay any records of

regularly conducted activity that may be contained in memoranda or reports kept in the regular course of a business, institution, association, profession, occupation, or calling of any kind.

Federal Rule 703 specifically provides that an expert may give opinion testimony based on facts and data, including reports by others, even though this information may be inadmissible, provided the information is "of a type reasonably relied upon by experts in the particular field in forming opinions or inferences upon the subject." Opinions based on information received from others not present in court would normally be inadmissible under the rules prohibiting hearsay testimony, but the federal rules of evidence chose to focus on the reliability of such information as accepted within a professional discipline.

A slightly different situation is presented when the expert formulates an opinion derived from the operations of technicians working under the expert's orders. The hearsay rules are frequently adjusted to allow an expert under whose control and supervision a test is made to testify at trial and to give an expert opinion based on the factual results of the test, even though the test was actually conducted by another.

As indicated above, under Rule 703 of the Federal Rules of Evidence, an expert may base the opinion upon facts or data "perceived by or made known… at or before the hearing. If of a type reasonably relied upon by experts in the particular field in forming opinions or inferences upon the subject, the facts or data need not be admissible in evidence" [78]. This would seem to justify use of hearsay by the expert in reaching the opinion, as long as others in the field do likewise. It could apply to reports of investigators, laboratory analyses, and information from other persons peripherally involved with crime detection. Although the evidentiary rule that states an expert witness is entitled to render an opinion based on inadmissible evidence when the facts and data are of a type reasonably relied upon by experts [79], the witness should not be permitted to serve merely as a conduit for the introduction of otherwise inadmissible evidence, or to parrot the corroborative opinions solicited from non-testifying colleagues.

Expert opinion may be predicated on the facts contained in hospital records properly admitted in evidence under state business or hospital records statutes. For example, a medical examiner may testify to their own conclusion formed on the basis of an autopsy conducted under their supervision and control.

7.6 Proof of Chain of Custody of Tangible Evidence

The chain of custody rule provides that the party seeking to introduce into evidence the results of an expert analysis has the burden of proving that the specimen or object analyzed was, in fact, derived or taken from the particular person or place alleged. This proof, which is of particular importance in criminal cases, is customarily established by testimony that traces the location and custody of the specimen from the time it was secured by law enforcement officers or agents of the state until it is offered in evidence. The chain of custody includes (1) the initial possession of the specimen or object by an officer, (2) the journey to

the laboratory, (3) the method of storage at the laboratory prior to analysis, and (4) the retention, whenever feasible, of the unused portion of the specimen or the object after analysis and up to the time of trial. It must also be established, as a prerequisite to admissibility of the evidence specimens, that they were in fact the same ones taken from the place or person in question, so that not only unbroken possession, but also the original source, can be established with certainty [80].

Chain of custody is an essential requirement of proof in any case involving such materials as bullets, cartridge cases and weapons, fingerprints, hair, stained clothing, drugs, and blood specimens. In most cases, the chain of custody can be sufficiently proven by the testimony of the investigator who secured the specimen or object and the analyst who examined it. The investigator's conduct reflects that he or she took the exhibit, identified it, and placed it in a sealed container that was also marked for identification, and that the exhibit remained in the witness' custody until placed in the mail or in the laboratory receptacle such as a lock box. The expert proceeds to remove the specimen or object from the mail or laboratory receptacle and to analyze it. Tangible objects that are not consumed in the analysis are marked for identification by the analyst and secured until the time of trial so that they will be admissible in addition to the testimony concerning the analysis. For example, in the case of blood specimens from a D.W.I. suspect, there must be legal proof that the specimen taken by a physician, nurse, or laboratory technician was the same specimen analyzed by the expert.

Whenever a break exists in the chain of custody of a specimen that was linked by scientific analysis to the defendant in an inculpatory fashion, it will be reversible error to admit the opinion testimony that is based upon the analysis [81]. It is important to determine in each case whether the break affects the possible validity of the expert's findings. However, the practicalities of proof may not require a party offering certain evidence to negate the remotest possibility of substitution or alteration; all that need be established is a reasonable certainty that there has been no substitution, alteration, or tampering with the specimen [82].

7.7 Ethical Considerations

7.7.1 The Expert's Ethical Obligations

Experts must take care to be familiar with the ethical constraints placed upon the expert's behavior by the ethics codes of certifying bodies or professional associations [83]. For example, members of the American Academy of Forensic Sciences (AAFS) are prohibited from making material misrepresentations of their education or of the data upon which their professional opinions are based [84]. If an AAFS member is found to have violated the code, an ethics committee may impose sanctions, such as censure, suspension, or expulsion from the organization [85].

Some courts have sanctioned experts for their unethical behavior. In Schmidt v. Ford Motor Co. [86], the court banned the plaintiff's accident reconstruction expert

from testifying in federal court in Colorado because he had conveyed intentionally misleading information in depositions and informal conversations with the defense expert. The expert also concealed his knowledge from the defendant that one of the plaintiffs had tampered with the evidence.

7.7.2 Attorneys' Ethics in Dealing with Experts

Attorneys' ethical obligations are contained in each state's Rules of Professional Conduct or Code of Professional Responsibility. While no specific rule deals directly with attorneys and expert witnesses, some of the American Bar Association Model Rules of Professional Conduct are applicable. The Model Rules have been adopted by every state except Maine and California [87]. Some of the model rules that impact attorneys' use of expert witnesses are the following:

Rule 3.3 (Candor Toward the Tribunal) requires the attorney to investigate the background of expert witnesses to avoid putting on perjurious testimony regarding their credentials.

Rule 3.8 (Special Responsibilities of a Prosecutor) specifies that the prosecutor's role as a "minister of justice" requires the making of timely disclosure of evidence or information that will negate evidence of guilt or mitigate guilt. Therefore, if fraud is uncovered relating to the expert's acts of knowledge, it must be disclosed.

Rule 5.3 (Responsibilities Regarding Nonlawyer Assistants) applies to experts as well as paralegals, and extends to situations where the lawyer is in essence ratifying the unethical conduct of the expert.

Rule 8.3 (Reporting Professional Misconduct) requires the prosecutor to report unethical conduct of other attorneys. Therefore, if the opposing party's counsel knowingly uses an expert discovered to be a fraud, counsel is obligated to report the other lawyer to the grievance committee. If counsel does not report, they themselves are in violation of the rule.

Rule 8.4 (a)-(d)(Misconduct) states that it is professional misconduct to violate the Model Rules, commit a criminal act that reflects adversely on a lawyer's honesty, trustworthiness, or fitness; engage in conduct involving dishonesty, fraud, deceit, or misrepresentation; or engage in conduct that is prejudicial to the administration of justice.

Additionally, an attorney shall not fabricate evidence or counsel or assist a witness to testify falsely or offer an inducement to a witness that is prohibited by law or make frivolous discovery requests or fail to make a reasonably diligent effort to comply with a legally proper discovery request [88]. A lawyer shall not make false statements of material fact or law to a third person, such as an expert witness [89].

Model Rules 1.1 (Competence) and 1.3 (Diligence) require an attorney to seek out expert services, if needed by the client. Failure by a defense counsel in a criminal case to obtain the services of expert witnesses may later be deemed by courts to have resulted in the ineffective assistance of counsel [90].

A lawyer may not promise an expert a fee contingent on the outcome of the case [91], nor may an attorney share fees with an expert [92]. An attorney has been held

to have an ethical obligation to pay an expert's fees unless he gives an express disclaimer or responsibility [93].

It should also be noted that Rule 11 of the Federal Rules of Civil Procedure provides for sanctions to punish filing of a false and misleading pleading. Courts have held that failure to disclose a contrary expert opinion alone is an insufficient basis for imposing Rule 11 sanctions [94].

The American Bar Association standards relating to the Administration of Criminal Justice also set forth standards for prosecutors [95] and defense counsel [96] to follow when working with expert witnesses in criminal trials. The standards provide that the attorney should respect the expert's independence, not dictate the formation of the expert's opinion, and that paying excessive or contingent fees is unprofessional.

7.8 Liability of the Expert Witness for Malpractice

7.8.1 Expert Malpractice: A Problem of National Scope

A cause of action designed to hold expert witnesses, doctors, and lawyers, responsible for their negligent professional behavior [97] has been driven by the recognition that expert negligence is not uncommon [98]. High-profile incidents have revealed failures in the application of some of the most well-established scientific techniques, such as fingerprint identification [99] and DNA testing [100]. Other investigations have demonstrated that pathologists faked hundreds of autopsies [101] or committed grievous errors [102] in determining cause of death.

At present, the law does little to regulate the quality of expert testimony [103]. Non-tort solutions offered by the scientific and legal communities to curb expert abuses include: capping expert witness fees [104]; pre-screening experts; using only court-appointed experts [105]; adhering to strict ethics codes [106]; instituting peer review [107]; and establishing a science court [108]. Additionally, it has been suggested that fraudulent experts be prosecuted [109].

The conventional wisdom long held that the principal safeguard against errant expert testimony is the opportunity for adversarial cross-examination [110]. In reality, however, most lawyers do a woefully inadequate job in cross-examining experts [111], due to a general reluctance to challenge experts in their own fields and improper trial preparation [112]. Finally, the vast majority of civil and criminal cases are settled or plea bargained prior to trial, so that the expert may never be subjected to rigorous questioning during the adversary process.

To date, none of the non-tort solutions offered to curb expert abuses have succeeded in accomplishing their goal. While attempts at self-regulation and court supervision may provide some deterrence, they do not compensate individuals harmed by negligent experts. This lack of effective solutions to expert negligence or intentional professional misconduct has led to the area of expert malpractice tort law.

7.8.2 Expert Malpractice

The last two decades have seen a substantial increase in the number of tort actions against experts and their employers. The four elements of an expert malpractice claim are: (1) the existence of a duty owed to the plaintiff arising out of the relationship between the expert and the plaintiff; (2) a negligent act or omission by the expert in breach of that duty; (3) causation; and (4) damages [113].

The premise of the cause of action is that, first, expert witnesses owe a duty to their clients. However, the duty does not end there. Expert witnesses also owe a duty to any foreseeable plaintiff who may be affected by the expert's conduct and who are likely to suffer damages due to a negligently rendered opinion. These duties are based upon their professional knowledge and skills and are similar to the duties owed by a doctor to a patient and a lawyer to a client. In this way, the specter of malpractice encourages experts to be careful, accurate, and compliant with "quality control" measures.

The standard of care for a forensic scientist is that of the reasonably prudent practitioner in the relevant scientific field [114]. Standards of professional practice and ethical codes help define the standard of care, and most disciplines within the forensic sciences have adopted such standards.

In order to prevail, a plaintiff must prove that the expert did not adhere to the standard of a reasonably prudent expert in rendering an opinion, conducting an examination, or giving testimony. Ordinarily, an independent evaluation by a disinterested expert in the same field will be required to determine whether an expert deviated from the required standard of care.

A crucial element of the tort of malpractice is causation. Causation tests whether the defendant's actions were in fact connected to the plaintiff's injury, and whether the connection was close enough to allow compensation to the injured party. In some cases, it will be readily apparent that an expert's testimony alone "caused" the wrong. This is especially true when the expert evidence is the only determinative evidence presented in the litigation [115]. Studies have demonstrated that, despite jury instructions to the contrary, jurors give expert testimony greater weight than other evidence [116]. Thus, it is clear that financial injury to a potential plaintiff, or conviction and incarceration of a potentially innocent individual who is prosecuted on the basis of an expert's opinion evidence [117], are reasonably foreseeable consequences of expert negligence or intentional misconduct.

When a plaintiff proves that an expert has committed malpractice, the measure of damages that may be awarded include, though are not limited to: (1) the difference between a full verdict of proven loss and the reduced verdict resulting from the expert's testimony; (2) the difference between a full settlement and the reduced settlement that resulted from the expert's misconduct; (3) the cost of the expert's investigation; and (4) the attorneys' fees for responding to the expert's testimony and in proving the misconduct [118].

Although traditionally experts were afforded absolute immunity in trial testimony and reparation, expert witness malpractice causes of action are gaining momentum

[119]. Courts in New Jersey [120], Connecticut [121], Texas [122], California [123], Pennsylvania [124], Massachusetts [125], Louisiana [126], Vermont [127], and Missouri [128] are among the growing number of jurisdictions that have allowed plaintiffs to sue experts for malpractice. This trend may induce defendants to settle cases even when the jurisdiction has yet to recognize the cause of action [129].

Despite this trend, some jurisdictions continue to adhere to a policy of absolute immunity for expert witnesses [130]. Although witness immunity is an exception to the general rules of liability, and is traditionally extremely narrow in scope, a few courts have nevertheless shielded experts from civil liability for ordinary negligence by reasoning that (1) negligent mistakes or inaccuracies do not constitute perjury, or (2) testimony and reports provided to courts are privileged [131]. Other courts have held that the expert witness who gives opinion evidence is the court's witness, and therefore enjoys immunity against all post-trial damage claims whether sued by a party or non-party to the action [132]. Such limitations are increasingly rare, however, and no court shields erring expert witnesses from perjury charges for willful deceptions, or from damage actions where the expert's conduct involved intentional or grossly negligent conduct.

There is a compelling argument to be made against expert immunity. First, the doctrine of immunity was not created to bar a suit against a professional who negligently performs services [133]. Moreover, when an expert is accused of malpractice, the real complaint is not with the testimony provided in court, but rather with the negligently produced out-of-court work product. By testifying, the expert merely publishes his negligence to the court. Absolute immunity should not be afforded to experts, who are neither judges nor their adjuncts, but merely third-party participants in litigation. And the courts, the legal profession, and the forensic disciplines recognize that the trend is firmly toward permitting claims for damages resulting from negligent expert testimony.

Concerns that the proliferation of expert malpractice suits will have a chilling effect on the supply of willing forensic experts are misplaced. While the emergence of such a cause of action may chase the habitually negligent or incompetent expert from the field, this is, of course, a salutary by-product of the legal trend. Any additional impact on the supply of experts, or in the fees charged for their services, is not so compelling as to justify a public policy against recognizing the cause of action.

The interests of our system of justice in expert accountability and the full and accurate development of evidence in civil and criminal litigation are not served by protecting the incompetent or dishonest expert. The justice system as a whole benefits when such causes of actions are permitted, and the forensic sciences should enjoy greater respect and admiration when it is known that their members are accountable for their misdeeds.

7.9 Questions

1. What is the court's principal concern in determining whether expert testimony is appropriate on a given issue at trial?

2. What is the main distinction between the test for the admissibility of expert testimony set forth in *Frye* on the one hand, and the Supreme Court's subsequent decisions in *Daubert* and *Kuhmo Tire* on the other hand?
3. What is "pretrial discovery?" Does it apply to expert witness opinions in criminal cases? Civil cases?
4. What factors may a court consider in determining whether a particular witness qualifies as an "expert" who may testify at trial?
5. What is "hearsay?" Is it ever admissible at trial?
6. What is "chain of custody?"
7. What are the possible consequences to an expert who materially misrepresents his or her credentials to the court?
8. What rules govern attorneys' ethics in dealing with expert witnesses?
9. May an expert be sued for malpractice? Under what circumstances?

7.10 About the Authors

Professor Carol Henderson received her J.D. degree from The National Law Center, George Washington University in 1980. Prior to receiving her J.D., she worked for the Federal Bureau of Prisons and the Department of Justice Criminal Division. She began her legal career as an Assistant United States Attorney in Washington, D.C.

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87. *See*, http://www.abanet.org/cpr/mrpc/alpha_states.html, last visited on December 18, 2008.
88. Model Rules of Professional Conduct, Rule 3.4 (2004).
89. *Id*. at Rule 4.1.
90. *See*, *e.g.*, Wilkins *v. State*, 146 P.3d 709 (Kan.App. 2006).
91. *Dupree v. Malpractice Research, Inc.*, 179 Mich.App. 254, 445 N.W.2d 498 (1989).
92. *See*, Model Rules of Professional Conduct, Rule 5.4(a)(2004).
93. *Copp v. Breskin*, 56 Wash.App. 229, 782 P.2d 1104 (1989).
94. *Schering Corp. v. Vitarine Pharmaceuticals, Inc.*, 889 F.2d 490 (3d Cir. 1989).
95. Standard 3–3.3, ABA Standards for Criminal Justice, 3d ed. (2006).
96. Standard 4–4.4, ABA Standards for Criminal Justice, 3d ed. (2006).
97. Randall K. Hanson, *Witness Immunity Under Attack: Disarming "Hired Guns*," 31 Wake Forest L. Rev. 497, 508–509 (1996)(reviewing arguments in support of and in opposition to witness immunity for experts); *see also* Carol Henderson Garcia, *Expert Witness Malpractice: A Solution to the Problem of the Negligent Expert Witness*, 12 Miss. C. L. Rev. 39 (1991).
98. Craig M. Cooley, *Reforming the Forensic Science Community to Avert the Ultimate Injustice*, 15 Stan. L. & Policy Rev. 381, 395–396 (2004)(listing 21 recent exonerations where the underlying conviction was based on inaccurate or completely false testimony by forensic examiners); *see also* Paul C. Giannelli, *Fabricated Reports*, 16 Crim. Just. 49, 49 (2002) (discussing some of the recent "experts" who consistently fabricated reports and testimonies to achieve a particular bias).
99. *See* Robert B. Stacey, *A Report on the Erroneous Fingerprint Individualization in the Madrid Train Bombing Case*, 54 J. Forensic Identification 706 (2004); Steven T. Wax & Christopher J. Schatz, *A Multitude of Errors: The Brandon Mayfield Case*, Champion Mag. at 6 (Sept./Oct. 2004).
100. *Murray v. State*, 692 So.2d 157, 159 (Fla. 1997)(finding that State's expert "affirmatively misled" the trial court as to the general acceptance or reliability of PCR DNA methodology); *see also* Nick Madigan, *Houston's Troubled DNA Crime Lab Faces Growing Scrutiny*, N.Y. Times, Feb. 9, 2003, at I20 (Detailing the results of an audit of the police DNA lab that found a number of problems with its methods; in response to the audit, the district attorney ordered a review of all convictions based on the lab's DNA analysis).
101. Richard L. Fricker, *Pathologist's Plea Adds to Turmoil*, 79 ABA J. 24, 24 (Mar. 1993); *see also* Richard L. Fricker, *Reasonable Doubts*, 79 ABA J. 39, 44 (Dec. 1993)(the pathologist was reported to have a "reputation for providing the type of forensic evidence prosecutors needed," though his conclusions were later deemed "impossible" by qualified reviewing medical examiners).
102. Jon Nordheimer, *In New Jersey Slip-Ups Show Autopsy System Deficiencies*, N.Y. Times, Oct. 20, 1993 at A1 (This article describes a number of flawed autopsies by county medical examiners in two different New Jersey counties, including one case where a pathologist described bullet entrance and exit wounds, and its track through the brain, where it was later established that death was due to "blunt force injury" and that no evidence of a bullet wound existed, and a second case where a medical examiner concluded that a woman had died from alcohol poisoning and exposure, when a later autopsy established the woman had been strangled and raped).
103. Peterson & John E. Murdock, *Forensic Science Ethics: Developing an Integrated System of Support and Enforcement*, 34 J. Forensic Sci. 749 (1989); *see also Austin v. American Assn. of Neurological Surgeons*, 253 F.3d 967, 973 (7th Cir. 2001)("[I]t is well known that expert witnesses are often paid very handsome fees, and common sense suggests that a financial stake can influence an expert's testimony, especially when the testimony is technical and esoteric and hence difficult to refute in terms intelligible to judges and jurors. More policing of expert witnesses is required, not less").
104. Iowa Code Ann. § 622.72 (West 2006).
105. *See*, Oliver C. Schroeder & Theodore R. LeBlang, *Court Appointed Experts*, 1 Forensic Sci., 18–1, 18–1 through 18–20 (Cyril Wecht, Ed. Matthew Bender, N.Y. 2000)(explaining the role of the court-appointed expert; the statutory authorization for the court-appointed expert; the procedure for the appointment of the expert; the methods to discover the court-appointed

expert's opinion; the weight accorded to the court-appointed expert's testimony; the use of court-appointed experts in civil and criminal trials; and finally, the constitutional issues related to appointing an expert); *but see* Catherine T. Struve, *Doctors, the Adversary System, and Procedural Reform in Medical Liability Litigation*, 72 Fordham L. Rev. 943 (March 2004)(discussing a 1998 survey that indicated that in litigation involving complicated technical or scientific testimony only 16% of federal judges used court-appointed experts).

106. Code of Ethics of the California Association of Criminalists, 2006.
107. Terry Carter, *M.D. with a Mission: a Physician Battles against Colleagues He Considers Rogue Expert Witnesses*, 90 ABA J. 40, 42 (Aug. 2004)(advocating peer review in the courtroom for medical expert witnesses).
108. *See Twenty-Five Year Retrospective on the Science Court: A Symposium*, 4 Risk 95–188 (1993)(containing a series of articles by advocates and detractors of the science court, including one by its "inventor"); *see also* Sven Timmerbeil, *The Role of Expert Witnesses in German and U.S. Civil Litigation*, 9 Annual Surv. Intl. & Comp. L. 163, 170 (Spring 2003) (discussing several proposals, including the science court, that addressed the concern that hired experts hindered the truth-seeking process of courts).
109. *In re Investig. of W. Va. St. Police Crime Lab*, 438 S.E.2d at 509; *see also* Jane Harper, *West Virginia Court Wants Forensics Expert Prosecuted*, Houston Post (July 17, 1994) at A22.
110. *See, e.g., Trower v. Jones*, 520 N.E.2d 297 (Ill. 1988).
111. Kevin M. Dowd, 14 N. Eng. J. On Crim. & Civ. Confinement. 169, 171 (1988)(reviewing Patrick A. Anderson & L. Thomas Winfree, *Expert Witnesses: Criminologist in the Courtroom* (1987)); *Convicted by Juries, Exonerated by Science: Cases Studies in the Use of DNA Evidence to Establish Innocence After Trial*, NIJ Research Report (June 1996) (Arguing that even improved science will not remedy the problem of inadequate legal counsel; of twenty-eight cases addressed in the study, had defense counsel sought the opinion of a competent expert or simply reviewed the case notes of the state's expert witnesses prior to trial, then the inconsistencies and inadequacies of these flawed testimonies could have been brought to light during the trial)(Available at http://www.ncjrs.org/txtfiles/dnaevid.txt (last visited on February 13, 2008)).
112. Frank E. Haddad, *Admissibility of Expert Testimony*, 1 Forensic Sciences n. 36 at 1–21 and 1–23 (Cyril Wecht, Ed., Matthew Bender, N.Y. 1996)(stressing that the keys to an effective cross examination are (1) preparation and (2) becoming knowledgeable in the particular field).
113. *Prosser and Keeton on Torts* § 30 at 164–165 (W. Page Keeton, Dan B. Dobbs, Robert E. Keeton & David G. Owen, eds. 5th ed. 1984); Dan B. Dobbs, *The Law of Torts* §114, at 269 (West 2000); *see also* Kathleen L. Daerr-Bannon, *Cause of Action for Negligence or Malpractice of Expert Witness*, 17 Causes of Action 2d 263 (2003)(adding that in a malpractice case against a friendly expert, the plaintiff must also prove that witness immunity is not applicable to the facts to avoid dismissal).
114. *See, e.g.*, *LLMD of Michigan, Inc. v. Jackson-Cross Co.*, 740 A.2d 186, 191 (Pa. 1999)("[t]he judicial process will be enhanced only by requiring that an expert witness render services to the degree of care, skill and proficiency commonly exercised by the ordinarily skillful, careful and prudent members of their profession"); *see also* Leslie R. Masterson, *Witness Immunity or Malpractice Liability for Professionals Hired as Experts?*, 17 Rev. Litig. 393, 393 (1998).
115. Richard S. Frank, *The Essential Commitment for a Forensic Scientist*, 32 J. Forensic Sci. 5 (1987)("[t]he impact of the forensic scientist's conclusions affords no room for error, because such an error may be the direct cause of an injustice").
116. Kurt Ludwig & Gary Fontaine, *Effect of Witnesses' Expertness and Manner of Delivery of Testimony on Verdicts of Simulated Jurors*, 42 Psychol. Rep. 955 (1978). There are many cases that express concern that the special aura of reliability and credibility that surrounds an expert witness will cause the jury to neglect their fact-finding role. *See, e.g., State v. Johnson*, 681 N.W.2d 901, 906 (Wis. 2001); *State v. Ward*, 138 S.W.3d 245, 270 (Tenn. Crim. App. 2003); *Franco v. State*, 25 S.W.3d 26, 29 (Tex. App. 2000).
117. Courts have awarded plaintiffs damages for illegal confinement due to legal malpractice, rejecting the argument that estimating the value of a person's loss of liberty is speculative.

See, e.g., Geddie v. St. Paul Fire and Marine Ins. Co., 354 So. 2d 718 (La. App. 1978); *Holliday v. Jones*, 264 Cal. Rptr. 448 (Cal. App. 4 Dist. 1989)(awarding damages for emotional distress as a result of wrongful incarceration due to professional malpractice); *In re Investig. of W. Va. St. Police Crime Lab*, 438 S.E.2d at 509 (underlying civil suit settled for the state's $1 million insurance policy limit); *see also*, *Restatement (Third) of the Law Governing Lawyers: Liability for Professional Negligence and Breach of Fiduciary Duty* § 53 cmt. (g) (2000)("emotional distress damages are… ordinarily recoverable when misconduct causes a client's imprisonment").

118. Mark Hansen, *Experts are Liable, Too*, 86 ABA J. 17, 17 (Nov. 2000).
119. *Davis v. Wallace*, 565 S.E.2d 386, 389–90 (W. Va. 2002).
120. *Levine v. Wiss & Co.*, 478 A.2d 397, 399 (N.J. 1984)(denying a court-appointed expert witness immunity); *contra* Laurie S. Weiss, *Expert Witness Malpractice Actions: Emerging Trend or Aberration?*, 15 (2) Pract. Litig. 27, 37 (March 2004)(discussing cases from other jurisdictions that recognize witness immunity if the expert was appointed by the court).
121. *Pollock v. Pahjabi*, 781 A.2d 518 (Conn. Super. Ct. 2000).
122. *James v. Brown*, 637 S.W.2d 914 (Tex. 1982).
123. *Mattco Forge, Inc. v. Arthur Young & Co.*, 60 Cal. Rptr. 2d 780 (Cal. App. 2 Dist. 1997).
124. *LLMD of Michigan, Inc. v. Jackson-Cross Co.*, 740 A.2d at 191.
125. *Boyes-Bogie v. Horvitz*, 14 Mass. L. Rptr. 208 (Mass. Super. 2001).
126. *Marrogi v. A.A. Mathews*, 805 So. 2d 1118 (La. 2002).
127. *Politi v. Tyler*, 751 A.2d 788 (Vt. 2000).
128. *Murphy v. A.A. Mathews*, 841 S.W.2d 671 (Mo. 1992).
129. *See, e.g.*, Don DeBenedictis, *Off-Target Opinions*, 80 ABA J. 76, 76 (Nov. 1994)(Hospital and national drug laboratory settled on the eve of trial for undisclosed sums for misdiagnosing toxins in a baby's blood, which had resulted in the mother's murder conviction and imprisonment); *In re Investig. of W. Va. St. Police Crime Lab*, *supra*.
130. *Bruce v. Byrne-Stevens & Assoc. Engineers, Inc.*, 776 P.2d 666 (Wash. 1989); *see also* Weiss, 15(2) Pract. Litig. N. 217 at 30–31 (listing Washington as the only state where witness immunity still controls "friendly" experts and providing a detailed description of the *Bruce* decision); *Diehl v. Danuloff*, 618 N.W.2d 83 (Mich. App. 2000)(court-appointed expert enjoys quasi-judicial immunity as "an arm of the trial court"); *Otero v. Warnick*, 614 N.W.2d 177 (Mich. App. 2000)(holding that forensic odontologist for county medical examiner was not liable to a former criminal defendant because (1) as an employee of the medical examiner, the expert owed no duty to criminal defendants in performing his official duties, and (2) expert's testimony at trial was absolutely privileged provided it was relevant, material, and pertinent to the issue being tried).
131. Michael J. Saks, *Prevalence and Impact of Ethical Problems in Forensic Science*, 34 J. Forensic Sci. 772 (1989) (containing a summary of some cases involving litigation against expert witnesses).
132. *Bailey v. Rogers*, 631 S.W.2d 784 (Tex. App. 3 Dist. 1982); *compare Mattco Forge, Inc. v. Arthur Young & Co.*, 6 Cal. Rptr. 2d 781 (Cal. App. 2 Dist. 1992), *on appeal after remand*, 45 Cal. Rptr. 2d 581 (Cal. App. 2 Dist. 1995), *on subsequent appeal*, 60 Cal. Rptr. 2d 780 (Cal. App. 2 Dist. 1997)(holding that the California Civil Code's litigation privilege does not protect a negligent expert witness from liability to the party who hired the witness, though it would still shield experts that are court appointed, and would also shield expert witnesses from suit by opposing parties); *Murphy*, 841 S.W.2d at 679 (also holding that under Missouri law, privilege does not protect a negligent expert witness from liability to the party who hired the witness, though it would still shield experts that are court appointed, and would also shield expert witnesses from suit by opposing parties); *Marrogi*, 805 So. 2d at 1132 (broadening the scope of expert witness malpractice to include not only pretrial litigation services but also the expert's actual testimony during trial).
133. *Murphy*, 841 S.W.2d at 679 (holding that the policy behind witness immunity is not advanced by offering immunity for incompetent experts retained by a party to perform professional services including trial testimony); *Marrogi*, 805 So. 2d at 1132 (same).

Chapter 8
Digital Evidence

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Contents

8.1 Introduction

Since the advent of the microprocessor, affordable storage devices, and networks, more of our daily lives are being recorded in the ones and zeros of the digital world. Thus, it is not surprising that when crimes and torts are committed, there is often evidence of probative value stored or transmitted in digital form. This, in fact, is the definition of digital evidence according to the Scientific Working Group on Digital Evidence (SWGDE) [1]. This digital evidence can be probative in virtually any

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criminal or civil matter. As a result of this, it appears digital evidence will likely become the predominant form of evidence in the twenty-first century.

Digital evidence (DE) can be found in an ever-increasing number of places in a bewildering number of formats. It may be useful to define a brief taxonomy of digital evidence at this point in history. Doubtless, this will change and evolve over time but will serve to provide a framework for the further discussion of the science.

In the definition of DE, we refer to information stored or transmitted in digital form. Thus, information is converted to ones and zeros (digital form) and placed into one of two states: static (stored) or dynamic (transmitted). One of the key advantages of the digital world is the simple transition from one state to another. Information does not have to be translated between states. This easy transmission allows us to easily move and replicate information and so it is not unusual for the same information to change between states numerous times between the creation of the information and its recipient.

A document written using word processing software is initially created by digital signals emanating from the keyboard and stored temporarily in the computer's random access memory (RAM). When the document is saved, it is transferred from the computer's RAM to the hard drive or other storage device as a file. This file can then be sent via email to another person who, using their email software, opens the email, saves the file to their hard drive, and subsequently reads the document by opening it in their word processing program. It can be converted into printed form by sending the file to a printer.

We can see from this example that the information goes through a number of transitions in what is otherwise a simple process. While the transitions may not require the conversion of the data, per se, the data may be manipulated in different ways, such as compression and encryption, along its journey. When the data is initially encoded into digital form or recreated in human-readable form, it is interpreted by the operating system and applications present in the destination computer. Many of these manipulations may leave additional probative information called "meta data," or "information about information."

From a forensic perspective, each location in which the information appears, in either state, is a potential location for evidence. Even the fact that a transition took place may provide probative information!

The forensic examination or analysis of static data is often called computer forensics, media forensics, or media analysis. The most common form of forensic examination and analysis of dynamic data is called network forensics. Because computers, including mobile devices such as phones and "netbooks" (small, lightweight, network-connected computers), are converging with the network, the larger term "digital forensics" has become the overarching term.

Digital evidence is latent in the same way that latent fingerprints, and firearms and tool mark evidence are latent. Latent evidence is not visible to the naked eye, and it requires careful handling and specialized training to efficiently and effectively preserve. It is easily altered, damaged, or destroyed. When processed by qualified examiners using hardware and software, information that is valuable to legal

proceedings can be obtained. Failure to adequately preserve the original evidence can render it unusable by the prosecution or the defense. Improper examination, review, or analysis by unqualified persons can yield inaccurate or misleading results and opinions.

Because it takes qualified examiners using high-tech equipment to process, it often requires expert testimony to make both the process and the results understandable to the judge or jury.

Collectively, these characteristics suggest that the examination of this type of evidence is a forensic process that should be performed by qualified forensic personnel, ideally in a forensic laboratory setting.

8.2 Types of Evidence Examined

The examination of computers and their associated storage devices, such as hard drives, floppy disks, and optical disks, are the most obvious form of digital evidence. However, they are by no means the sole sources. Digital evidence can be found embedded in or attached to a wide variety of devices, such as PDAs, music players, cameras, watches, Global Positioning System devices, mobile phones, fax machines, and security access devices. Many new credit cards come with an embedded computer chip, and, as a result, are often called "smart cards." New devices are invented nearly every day and each generation of devices is faster and has more storage capacity. The available storage in a single device often exceeds the capacity of large libraries. This trend, first articulated by Moore [2] in the 1960s, recognized that the density of semiconductors, which are the building blocks of computer chips, would double every 18 months. This increase would similarly translate to digital storage; the size of storage devices has been following a similar curve [3] (Fig. 8.1).

Static data is not the only source of probative information. The data that is transmitted over both wired and wireless networks can be intercepted. In the dynamic arena, there is a similar variety of physical media, such as coaxial and braided wires, fiber optic cable, infrared, and radio frequency carriers, that conduct signals formed into "packets." These packets are constructed in an ever-increasing number of formats designed for various purposes.

As we move further into the twenty-first century, technology is being used in a variety of ways undreamt of a decade ago. Much of our latest technology is designed to be used collectively and collaboratively utilizing communication and web-based applications. Web-based technologies, such as Really Simple Syndication (RSS), which allows for subscribers to be notified of updated web information, blogs (electronic diaries hosted online), wikis (collaboratively edited web pages such as Wikipedia), social networks such as Facebook, and "mash-ups" such as iGoogle, allow for the storage of a tremendous volume of potential evidence. Linking a suspect to data can become a substantial problem that requires well-qualified investigators with equally qualified forensic examiners [4, 5].

Fig. 8.1 Digital storage devices

8.3 Forensic Evidence Processing

The nature of digital evidence is such that it possesses special challenges for admissibility in court. To effectively respond to these challenges, proper forensic processing must be followed. The process consists of four distinct but related activities; collection, examination, analysis, and reporting [6].

Collection (acquisition and preservation) starts with the request for a search warrant and includes identifying evidentiary items and proper collection, documentation, packaging, storage, and delivery. Search warrants for electronic storage devices typically focus on two primary sources of information [7]:

- Electronic storage device search warrant
  - Search and seizure of hardware, software, documentation, user notes, and storage media to include floppy disks, CDs, DVDs, and removable storage devices.
  - Examination of search and seizure of data.
- Service provider search warrant
  - Service records, billing records, subscriber records, etc.
  - Request for information from service providers such as utility companies, financial institutions, telephone or cable companies, etc.

After the scene has been secured, restrict access to the area, preserve potential fingerprint evidence, and identify potential digital evidence. Do not turn any electronic devices on or off. Turning a device off could activate a "lock out" feature such as disk encryption and turning a device on could alter the evidence. In some cases, information in RAM can be crucial and must be captured when the system is "live." Document the scene by taking photographs, making a diagram, or recording the location and condition of electronic devices. The information on the visual display should also be documented because it may provide useful during the examination or analysis activities.

Electronic devices must be handled in such a manner to preserve their physical integrity as well as the electronic data they contain. Whenever possible, only personnel trained in the collection of digital evidence should be allowed to collect the evidence in compliance with agency policy. All actions taken should not add, change, or destroy data stored on any electronic device. Since electronic devices are sensitive to temperature, humidity, physical shock, static electricity, and magnetic sources, special care must be taken while packaging, transporting, and storing electronic devices. Do not transport or store any electronic device near a radio transmitter, speaker magnets, or heated vehicle seats.

Evidence must be secured in such a way as to protect from loss or contamination and to provide visible evidence if the container or seal were damaged or altered. This can be achieved by placing the items in a static-free transparent bag and sealing the opening or by placing the items in a box and sealing the openings with evidence tape or stickers.

8.3.1 Planning the Examination

Digital evidence is unique in the forensic science arena. Due to the variety of sources, types, and volume of digital evidence, it is necessary to apply adequate planning at each stage of the process from acquisition to testimony. This planning has both an investigative component and a technical component. Neither the investigator nor the examiner alone usually has sufficient information or knowledge to conduct a thorough and efficient collection and examination. As a result, the forensic examination requires teamwork between the examiner and the investigator.

Examination is the first phase in the process that makes digital evidence available to the court. This phase consists of several definable steps. Like most forms of evidence, it must first be collected. Because it is found in such a wide variety of places, in such large quantities, some means of limiting the intake is required by both the law and practicality. This is both an investigative issue that seeks to identify where probative evidence is likely to be found and a technical issue of how that evidence can be effectively and efficiently collected. Like most crime scenes, the investigator is responsible for all activities conducted. Even when the investigator is well trained in the collection and preservation of evidence, they may benefit from

either consultation with forensic examiners or the participation of a forensic examiner on scene where the evidentiary environment is complex.

Due to the ease in creating a digital duplicate of the original evidence, the acknowledged best practice [8] is to create one or more duplicates of the original either by creation of duplicate media or of creating a file containing a bit-for-bit copy of the original. The digital duplicate of the original evidence is used to conduct the forensic examination to preserve the integrity of the original evidence.

Once the evidence has been acquired and preserved, the next step is the forensic examination. This step is the sole responsibility of the examiner; however, it is not possible to conduct an effective and efficient examination without substantial participation by the investigator. Because there is so much evidence and it can be looked at in so many ways, there must be a clear set of goals and criteria to limit the examination. These goals and criteria must be established in concert with the investigator prior to the commencement of the actual examination. The examiner then needs to convert these goals and criteria into a set of forensic questions that can be answered by the examination proper [9].

Using these forensic questions, the examiner designs an examination process that will effectively and efficiently meet these requirements. In most cases, this will begin by a thorough documentation of the physical and logical structure of the original digital evidence. The next step is often to recover data that is deleted, damaged, or hidden. In an effort to minimize the amount of data to be analyzed, a data reduction process is usually applied. This can take the form of comparing file or packet signatures with known, non-pertinent data, eliminating duplicates, filtering files and packets by format or headers, and applying string searches. The goal of this step is to include all pertinent information while minimizing the non-pertinent information.

Following the documentation and data reduction steps, the examiner reviews the forensic questions, goals, and criteria to determine if the information produced from the examination meets the stated goals and criteria. If the goals of the examination include examining the data to answer questions concerning the source or methods used to store, alter, or delete the data or if there are questions concerning the order in which activities occurred, then the examiner will conduct further examination to answer these questions.

8.3.2 Analysis

The documentation, data recovery, data reduction, and extraction that comprise the examination phase are focused on the characteristics of the data in the technical context. Analysis is the evaluation and organization of the information provided from the examination in the investigative context. This phase is largely the providence of the investigator and/or the investigative analyst assigned to the case or the program. They will determine if the material is pertinent, the level of confidence in the material and where the information “fits” in the investigative context. The forensic examiner often

plays an advisory role in this phase by assisting the investigative team with determining alternative scenarios that would account for the data and advice concerning the degree of reliability of the data about the data, referred to as metadata.

8.3.3 Reporting

Once all of the goals have been met, the examiner produces a report of the examination, which, accompanied by the information exported from the examination, is provided to the investigator.

The final report of examination must contain enough detail to allow another competent examiner to reproduce the same extracted results. All activities from receipt of the evidence to its return to the submitter must be documented. Each step executed in preparing the evidence for examination, such as making and working from a duplicate of the original evidence to the software utilized and the results obtained must be accurately and clearly presented in the report. It should be noted that the report does not contain every detail of the examination. The examiner's notes, taken concurrently in electronic form during the examination are designed to provide these details. Many forensic tools produce step-by-step logs and exported file capabilities and are sometimes referred to as "reports" within the software, and provide a very handy way to make the material identified in the examination accessible by "point and click," but these are really supplemental to, and not a substitute for, the Examination Report.

The goal of the forensic process is to provide knowledge that will assist in the investigation. The ability to communicate the distilled results of the digital evidence process is called the presentation phase. The actual presentations may take the form of written reports, oral presentations, or testimony. It is important that the forensic examiner be able to communicate to a jury with limited technical knowledge, not only the process that was utilized in the particular examination, but the underlying science and technology that allows the examiner to make factual and opinion statements. It is also important to be able to clarify the difference in roles between the examiner, the analyst, and the investigator. If all have done their part and communicated with each other, then the judge, jury, or customer gains as complete and truthful a picture as is possible (Fig. 8.2).

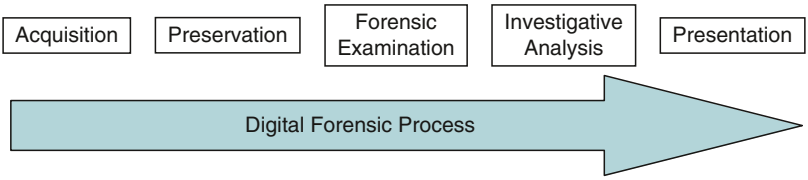

Fig. 8.2 Digital forensic process

8.4 Quality Assurance

If evidence and laboratory tests are mishandled or improperly analyzed; if the scientific evidence carries a false sense of significance; or if there is bias, incompetence, or a lack of adequate internal controls for the evidence introduced by forensic scientists and their laboratories, the jury or court can be misled and this could lead to wrongful conviction or exoneration. If juries lose confidence in the reliability of forensic testimony, valid evidence might be discounted and some innocent persons might be convicted or guilty individuals acquitted [10].

A digital evidence laboratory should have as one of its goals to provide high-quality results through the use of accurate, reliable, reproducible, and legally defensible procedures. This is accomplished through documented activities that assure that quality control procedures are in place and are being properly administered. The quality management system defines and documents the organizational structure, responsibilities, procedures, processes, and resources for implementing an effective program. The success of a quality system depends on the commitment of management and active participation by each member of the laboratory. The personnel responsible must be clearly designated and have access to highest level of management responsible for approving policy. Ideally, a quality assurance manager should be selected who has mastered the technical requirements of digital evidence collection and examination and is not currently performing case work. More commonly, a member of the staff assumes quality assurance as a collateral duty.

It is well known that serious deficiencies can occur when insufficient attention is given to the quality of the work product. Applying the necessary controls to assure high-quality results is no simple matter. It requires not only a thorough knowledge of the laboratory's mission but the commitment to excellence by the management and operating staff. This commitment may be based in part on the need or desire for accreditation. To achieve this level of performance, the laboratory will find it necessary to operate under a quality assurance system that requires extensive documentation of its procedures.

Since 2003, the American Society of Crime Laboratory Directors/Laboratory Accreditation Board (ASCLD/LAB) has recognized digital evidence as an forensic discipline and currently both Legacy and ISO 17025 accreditation are available to both traditional multidisciplinary forensic laboratories and dedicated digital forensic laboratories conducting digital evidence examinations [11]. The American Academy of Forensic Sciences also recognized the importance of digital evidence by establishing a new section called "Digital and Multimedia Sciences Section." The American Academy of Forensic Sciences is a multi-disciplinary professional organization that provides leadership to advance science and its application to the legal system. The objectives of the American Academy are to promote education, foster research, improve practice, and encourage collaboration in the forensic sciences.

8.4.1 Establishing a Program

Once management decides to financially and administratively establish a quality assurance program, a plan must be written to document all of the requirements of the program. Although there is no generally accepted plan to establishing a program, many of the principles are applicable to most programs. It is critical to the success of the program to have the entire staff involved in developing and implementing the program. Top management is responsible for committing resources, establishing policy, assigning responsibilities, and overall accountability for the program. Supervisors must seek consensus approval from the operating personnel as the plan is developed, obtain cooperation of the staff in assuring success of the program, and supervise implementation of changes to the plan. Operating personnel provide technical input and advise management when changes must be made to the plan based on daily operations. The quality assurance manager monitors the program, recommends changes, evaluates maintenance records, conducts quality audits, and assists in problem resolution.

8.4.2 The Quality Assurance Manual

This manual identifies the policies, organizational objectives, functional activities, and quality activities designed to achieve the quality goals of the program. The manual must be flexible enough to accommodate changes in methodology, technology, and personnel. It must be reviewed periodically to maintain its relevance and to assure compliance. In addition to the general quality assurance principles, such as competency and proficiency testing, personnel, training, safety and health, evidence control, report writing, deviations, and deficiencies; digital evidence laboratories must address the uniqueness of digital evidence when developing controls. Of primary importance is the use of validated software to conduct examinations. Off-the-shelf software and in-house developed software should not be used until properly validated and the results of the validation documented.

The use of standards and controls for digital evidence laboratories is substantially different than those used in other forensic disciplines. Digital evidence examiners do not compare unknown evidence with known reference materials obtained from a reliable source. Additionally, digital evidence examiners cannot run known material in parallel with the unknown evidence. These differences do not negate the need to run digital evidence controls; however, the process is different from other forensic disciplines and will vary from laboratory to laboratory.

8.5 Technology: Existing and on the Horizon

The current technology utilized in digital forensics is a combination of hardware and software tools that are designed to perform each of the functions described in the examination process. As each new technology appears in the market place, the forensic practitioner must acquire the tools required to deal with this new technology, so, in a very real sense, this discipline is driven by the market.

In the acquisition phase, the forensic practitioner must have the hardware that will allow for connection to the storage media or transmission media utilized by the original evidence. In many situations, existing software collection tools can be used. If they cannot, they will either have to be modified or new tools developed. The tools used in the documentation step of the examination phase must be updated to correctly interpret new file systems and packet structures. Likewise, data recovery and data reduction tools must be "aware" of the evolving technologies.

Currently, examiners typically utilize top-of-the-line desktop computers with a complex array of data inputs and removable storage. The average cost to set up a digital evidence laboratory is $25,000 per workstation. Network-attached storage devices (NAS) are becoming commonplace tools for allowing the processing, in an automatic fashion, of a number of pieces of evidence in either parallel or sequence. Storage-attached networks (SAN), an even more complex and expensive technology, are being explored to further reduce the time required to process evidence.

Forensic software is also going through an evolutionary process. The software tools first used in conducting examinations were products that were produced by manufacturers of hardware, operating systems and network operating systems to troubleshoot their products. Software tools followed, often written by forensic practitioners, to perform specific steps, or even sub-steps, in the forensic process. These tools became more numerous and complex over time and evolved into the complex graphical user interface tools that are the backbone of current practice. In the static evidence arena, tools such as EnCase [12], the Sleuth Kit [13], and Forensic Tool Kit [14] are most commonly utilized. In the dynamic data area, tools such as WireShark [15], OnmiPeek [16], and DCS-1000 [17] are utilized.

Moore's law and society's insatiable demand for more information will serve to continuously push the capabilities of forensic examiners. Whenever and wherever new technology appears, the digital evidence forensic specialist will have to acquire, preserve, examine, analyze, and present digital evidence. Likewise, each new technology will be examined to see if it can be applied to perform these tasks better, faster, and cheaper.

8.6 Computer Databases Available

One of the applications of new technology has significantly assisted the data reduction step in the forensic examination phase. A mathematical algorithm can be applied to files, packets, messages, or even complete storage devices, which creates

a unique value for that data. The algorithm is designed such that any alteration, of even one bit, will change the resulting value of the algorithm called a "hash." This hashing methodology allows for the authentication of original evidence and verification that the original evidence has not been tampered with to a mathematical precision. When applied to single files, it allows the confirmation of files as identical if their hash value is the same. The National Institute of Science and Technology (NIST) developed and published, with the assistance of the digital forensic community, a reference of known file hashes for commercial software [18]. By utilizing this database in the data reduction step of the forensic examination phase, a very high percentage of files can be eliminated from consideration because they have been positively identified as being part of a commercial software product and therefore not unique to the examination at hand.

8.7 Uses and Limitations of Procedures

As we have seen, the fact that a series of ones and zeros exists either on a physical piece of media or in a data stream must be evaluated in several different contexts. The operating system, network protocol, file system, application, and location, all contribute to the "truth," which is the technical meaning of the data. That is then overlaid by investigative contexts such as who are the creator and/or recipient of the data, what is the time sequence and is the data pertinent to the current investigative questions. Clearly, this lends itself to opportunities for misinterpretation and error.

Examiners, analysts, and investigators must rigorously evaluate their conclusions and ensure that the "truth" as presented is clearly identified within a context and that the limitations of that context are stated. Professional ethics demand that when there is any doubt as to the accuracy of the result or the interpretation of the results, that that doubt be clearly stated. "Professional Ethics" refers to those principles that are intended to define the rights and responsibilities of scientists in their relationship with each other and with other parties, including employers, research subjects, clients, students, and others [19].

The need for ethics in the digital evidence discipline is no different than the requirements for other forensic disciplines. The results of digital evidence examinations may be pivotal in determining a person's guilt or innocence. It is equally important that examiners maintain the highest standards of ethics when generating criminal investigative information or when involved in civil matters.

Ethical issues begin at the evidence collection site and persist until the evidence is destroyed. Because digital evidence is latent, it can easily be altered, damaged, or destroyed by improper handling. The person collecting digital evidence must be able to recognize items that may contain potential digital evidence and ensure proper handling. The devices discussed earlier in this chapter may be contraband, fruits of the crime, a tool of the offence, or merely a storage device containing evidence of a crime. Agency SOPs, statutory requirements, and best practices must be followed whenever possible and deviation policies must be followed when

exceptional situations are encountered. In the field and in the laboratory, personnel must be aware of the conditions of the warrant and ensure that all conditions are satisfied.

Every examiner shall refrain from providing any material misrepresentation of education, training, experience, or area of expertise. Examiners must reveal any conflict of interest; resist any pressure from attorneys, investigators, or superiors in the acquisition of evidence, preparing reports, and during the presentation of testimony. Should an examiner uncover evidence that was not requested by the investigator, is within the scope of the search warrant, and is of probative value, that information must appear in the report of findings. Examiners must be unbiased and conduct their examinations in a professional manner designed to discover the truth of the matter at hand independent of external influence.

8.8 Questions

1. What is digital evidence?
2. Why is digital evidence considered latent?
3. What are six items that may contain digital evidence?
4. What are the four steps of the forensic evidence process?
5. After the scene has been secured, what is the first action to be taken?
6. Who is responsible for all activities at the scene of digital evidence collection?
7. Why is a digital duplicate of digital evidence produced?
8. What is metadata?
9. What is the goal of the forensic process?
10. What is "hash"?
11. How will "Web 2.0" technologies impact digital forensics?
12. What bodies have recognized digital forensics as a scientific discipline?

8.9 About the Authors

Robert Bianchi retired as the director of the DEA Special Testing and Research laboratory after 34 years of Federal service. During his tenure with DEA from 1996 to 2000, the responsibility for DEAs computer forensic program was assigned to Mr. Bianchi.

Bianchi Consulting was created in July 2000 to assist the law enforcement community establish a coordinated computer forensic program and prepare for accreditation by the American Society of Crime Laboratory Directors/Laboratory Accreditation Board. In conjunction with FBI personnel, he developed a training program for RCFL and FBI Computer Response Team quality managers. He also acted as liaison between RCFL, the forensic community, and the Scientific Working Group for Digital Evidence.

Mr. Bianchi organized and moderated digital evidence workshops at the American Academy of Forensic Sciences, the American Society of Crime Laboratory Directors, the California Association of Criminalists, and the Mid-Atlantic Association of Forensic Scientists meetings.

He is a former Board member of the American Society of Crime Laboratory Directors (ASCLD), chairs the ASCLD Awards committee, and is an ASCLD/LAB-trained inspector. Mr. Bianchi is a Fellow of the American Academy of Forensic Sciences and retired emeritus member of ASCLD.

Mark Pollitt served more than thirty years in the US Government: longer than ten years as a military officer in the Marine Corps and Coast Guard and then another twenty years as a Special Agent of the Federal Bureau of Investigation. In addition to conducting criminal and national security investigations for more than thirteen years, he supervised online investigations, was the Chief of the FBI's computer forensic unit (CART), and was the Director of the Regional Computer Forensic Laboratory Program.

After retiring, he founded his own consulting firm and taught as adjunct faculty at a number of institutions including Johns Hopkins, Syracuse, Polytechnic, and Norwich Universities. He joined the University of Central Florida as a full-time faculty member in 2006, transferring to Daytona State College in 2010, where he teaches information security and digital forensics. He has served in leadership roles in a number of national and international organizations involving digital forensics, and has lectured around the world.

Mr. Pollitt is a graduate of Cornell University, Syracuse University, the Information Resources Management College, National Defense University, and has done postgraduate work in forensic science at George Washington University. He is currently working on a PhD in Texts and Technology.

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Chapter 9
Firearms and Toolmarks

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Contents

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9.1 Introduction

The field of firearms identification is typically associated with toolmark identification in the context of two related but different entities. In reality, much of firearms identification entails a specific area of toolmark identification. By definition, a toolmark results from the contact of one surface with another, the harder of which is the "tool." Thus, in the case of a firearm and a bullet, the firearm (the interior of the barrel) is the tool that produces toolmarks on the surface of the bullet as it moves through the barrel upon discharge of the firearm. Likewise, the examination of firing pin impressions, magazine marks, extractor marks, ejector marks, breech face marks, and chamber marks on fired cartridge cases all constitute toolmark examinations.

The fact that firearms identification also involves examinations other than "toolmarks," accounts for the distinction between the two disciplines. The analysis of gunpowder patterns on clothing, the determination of cartridge case ejection patterns, the measurement of trigger pull, or establishing bullet trajectory are examples. Likewise, weapons function testing, shot pellet pattern testing, and serial number restoration are additional "non-toolmark comparison" aspects of firearms identification.

Firearms identification is often referred to as "forensic ballistics" or just "ballistics." This is a misnomer, however, because ballistics is limited to the study of projectile behavior. Ballistics, in the true sense, includes three different aspects, interior ballistics (bullet behavior within the confines of the barrel), exterior ballistics (bullet behavior upon exiting the barrel), and terminal ballistics (bullet behavior upon impacting a target). Wound ballistics is a specialized area of terminal ballistics relating to the behavior of bullets striking human or animal targets.

Toolmark examination, on the other hand, is limited to the determination of whether or not a toolmark was made by a particular tool. Tools commonly examined and compared with questioned (evidence) toolmarks include pliers, saws, screwdrivers, pry bars, hammers, chisels, and the like.

Toolmarks are of two different types, impressed and striated. Impressed toolmarks result when a tool leaves an impression on another surface. An example would be the result of a blow from a hammer on soft wood.

Striated toolmarks are the result of a combination of force and motion. The example of a gun barrel producing a toolmark on a bullet illustrates the production of striated toolmarks. A cut in metal with a pair of shears is another example. The striations that are produced are often visible only under magnification (e.g., with a microscope).

The basis for the identification of a particular tool as having produced a certain toolmark lies in the fact that random, unique marks are present that only that tool could have left. In order to be able to properly evaluate firearm/toolmark evidence, an examiner must have extensive training and knowledge about manufacturing techniques of firearms and tools. This is required so that the examiner can distinguish between what are random, unique marks or "individual characteristics" and what are merely "class characteristics" or "subclass characteristics."

Class characteristics are those characteristics exhibited by an entire group or class of tools. An example would be the width of the blade of a particular brand of screwdriver or the cross-sectional diameter of a gun barrel (caliber) of a certain brand and model firearm.

Subclass characteristics are produced incidental to manufacture and can change over time. Thus, only certain members (a subset) of a class or group will exhibit them. An example would be tools made using a mold or die having some defect that carries over to the tool. Once the die/mold wears, such that the defect disappears, or the die/mold is replaced, the subclass characteristic does not appear on subsequently manufactured tools.

Individual characteristics are unique to a particular tool (to the exclusion of all similar tools). They are accidental or random characteristics that provide a basis for individualization. Individual characteristic may be produced in manufacture and/or through use (wear).

As an example of class, sub-class, and individual characteristics, one can simply look at a US one-cent coin (penny). Pennies, as a collective group, constitute a class of coins. Thus, all pennies display the same general class characteristics such as shape, size, thickness, and composition, as well as the general design features (i.e., the bust of Abraham Lincoln, etc.).

Upon closer inspection of several pennies, one notes that the dates on them may be different. There also may be a letter below the date, such as "D" (for The Denver Mint). We can, therefore, separate pennies into smaller groups (sub-classes), such as all pennies with the date stamp of 2001 or all with the stamp 2008 along with a "D." Finally, with even closer examination, we are likely to see nicks, scrapes, or other random markings on the surfaces that represent individual characteristics not exactly duplicated on any other penny. This is analogous to the kinds of characteristics that the firearm and toolmark examiner looks for and uses to compare questioned marks with those known to have been made by a particular tool.

The actual comparison, and ultimate identification, of individual characteristics is a combination of quantitative and qualitative evaluation of the surface contours present. Identification is the result of the examiner determining that "sufficient agreement" exists in the surface contours of a test toolmark and an evidence toolmark.

After decades of court acceptance, challenges to the scientific validity of toolmark examination have been made. The basis for the challenges lies in the lack of clearly articulated criteria for identification (e.g., a specific number/quality of marks). Various studies have been undertaken in an effort to resolve this apparent shortcoming. Further discussion of criteria for identification appears in a following section.

9.2 Types of Firearms

The broadest category of firearms includes two types, handguns and long guns. Handguns are designed to be fired while held in the hand and long guns are designed to be fired from the shoulder.

Handguns include revolvers and pistols, examples of which appear in Figs. 9.1 and 9.2. Pistols are either semi-automatic (auto-loading) or fully automatic (machine pistol). The difference being a semi-automatic requires that the trigger be pulled for each shot, while a fully automatic continues to fire until all its ammunition is expended following an initial pull of the trigger. Pistols use magazines, sometimes erroneously referred to as "clips," to feed cartridges into their actions. Revolvers rely upon a rotating cylinder to hold cartridges and place them into a firing position.

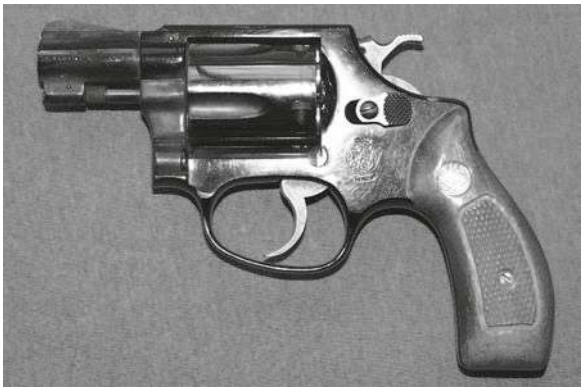

Fig. 9.1 Revolver

Fig. 9.2 Pistol

Revolvers are classed as either single action or double action. Single action means that the hammer must be manually cocked in order to fire the weapon. Double action means the hammer will be cocked as the trigger is pulled and while simultaneously rotating the cylinder.

Pistol actions function in stripping a cartridge from the magazine, seating it in the chamber, firing the cartridge, extracting the fired cartridge case, and ejecting it from the weapon. Each of these events potentially leaves identifiable toolmarks on the cartridge case.

Long guns include rifles, shotguns, machine guns, and submachine guns. Rifles and shotguns can have a variety of actions, including bolt action, lever action, and semi-automatic. Submachine guns and machine guns are capable of fully automatic fire. The difference between machine guns and submachine guns is that machine guns fire rifle cartridges and submachine guns fire pistol cartridges. A typical rifle and shotgun are shown in Figs. 9.3 and 9.4.

Handguns and long guns, with the exception of most shotguns, have spiral grooves cut or formed into the interior surface of the barrel. These grooves are designed to impart a spin to the bullet as it moves down the barrel upon discharge of the weapon. This spin stabilizes the bullet in flight to improve accuracy and increase the effective range. The areas between the barrel grooves are known as "lands." There are an equal number of lands and grooves in a gun barrel. The number of lands/grooves typically ranges from 2 to 16. The lands/grooves in a gun

Fig. 9.3 Rifle

Fig. 9.4 Shotgun

Fig. 9.5 Lands/grooves

barrel are illustrated in the cut-away seen in Fig. 9.5. The configuration of the lands and grooves of a gun barrel are best described as a helix. Various methods of creating the barrel grooves (rifling) are used. Traditional methods involve cutting using hooks, carbide buttons or broaches, while methods that are more recent rely on hammer forging (polygonal rifling) or electrochemical etching.

The direction of twist of the lands and grooves may be either clockwise (right) or counter-clockwise (left); however, most weapons have a right twist. The number and widths of lands/grooves, the direction of twist, and the degree of twist are among the class characteristics of a given make and model of weapon.

The degree of twist is the rate at which the rifling creates bullet spin per unit length. Common rates of twist for small arms would be 1 in 12 or 1 in 14. This means the number of bullet revolutions per inch of barrel length 1 turn in 12 in. vs. 1 turn in 14 in. (even though the barrel may not actually be that long). As seen in the cut-away barrel in Fig. 9.5, the helical orientation of the lands and grooves is pretty subtle and nothing like a corkscrew configuration. It must be understood that the bullet is moving very rapidly and would not be able to engage rifling that had anything more than the slight rotation illustrated.

The cross-sectional dimension from land to land is the caliber of a weapon, and represents another class characteristic. People sometimes confuse caliber with cartridge designation. For example, 9-mm Luger, 38 special, and 357 magnum are designations for specific cartridge configurations. The calibers of the weapons that fire these cartridges are all essentially the same, however. Caliber determination is illustrated in Fig. 9.6.

Shotguns, on the other hand, are usually smooth bore (without lands/grooves). Because spherical pellets are most often fired, spin stabilization, and, hence, rifling, is unnecessary. Shotguns may also be used to fire “slugs” (single, large projectiles), in which case, spin stabilization is desirable. This may be accomplished by having spiral grooves cast into the body of the slug itself. There are also shotguns with true rifling in the barrels.

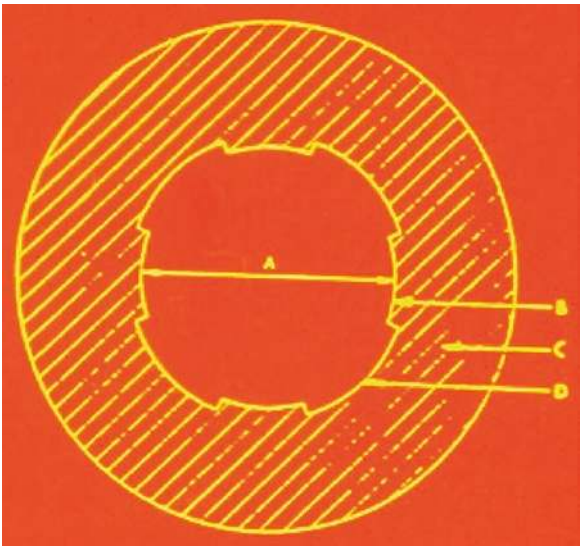

Fig. 9.6 Caliber determination (A – caliber, B – land, C – barrel, D – groove)

Rather than by caliber, most shotgun barrels are distinguished according to "gauge." Commonly encountered gauges include 12, 16, 20, and 28. The gauge designation is a holdover from old English terminologies. Gauge represents the number of lead shot of a particular diameter to the pound. Thus, a 12-gauge shotgun barrel has a diameter such that 12 lead shot of that same diameter would weigh 1 lb. Because a 16-gauge shotgun represents a barrel diameter equivalent to 16 shot to the pound, a 12-gauge shotgun has a greater diameter than a 16-gauge, which is greater than a 20-gauge, and so on. Exceptions are 410 shotguns, in that they are actually designated by caliber (0.410-in. diameter), rather than gauge.

Shotgun pellets leave the barrel in a cylindrical column that gradually begins to spread into a conical pattern. Various constrictions can be built into the muzzle end of the barrel of shotguns. The purpose of these constrictions, or "chokes," is to increase the distance from the muzzle that pellet spread begins. Chokes range from "full choke" to "cylinder bore" (no constriction at all). In between are modified, improved, and improved–modified. In general, the greater the choke, the greater the distance of pellet travel before spreading occurs.

At muzzle-to-target distances of approximately two feet, most shotguns firing standard loads typically produce a singe hole. At approximately 3 feet, the margins of the hole show a ragged or scalloped effect as the pellets start to move apart. At approximately four feet, signs of pellet spread first appear as individual pellet holes around the main, central hole. This is illustrated in Fig. 9.7.

A rough approximation of shotgun muzzle to target distance can be made by measuring the overall pellet spread and allowing one yard of muzzle to target distance for each inch of pellet spread. This is useful for providing a starting point at a crime scene to begin looking for other evidence of shooter presence, such as

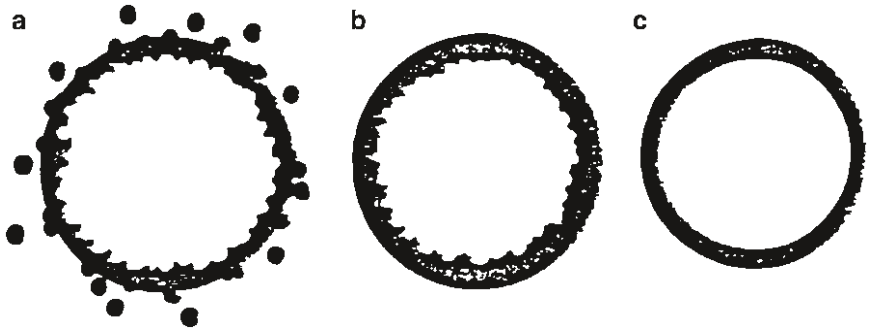

Fig. 9.7 Typical shotgun impacts at (**a**) 2 ft, (**b**) 3 ft, and (**c**) 4 ft

ejected shot shells, footwear impressions, and/or cigarette butts. Different chokes, barrel length, shot shell components (i.e., shot cup design), and shot size can and do affect the pellet pattern diameter. This requires that actual test firing be conducted using the same weapon and shot shells like those used in the shooting incident.

This writer had the privilege of teaching a shooting incident reconstruction class at the Drug Enforcement Administration (DEA) Academy in Quantico, Virginia several years ago. While at the academy, DEA firearms instructors shared some experimental results regarding shotgun pellet patterns obtained using eight-pellet 00 buckshot loads rather than the standard nine-pellet rounds. The removal of one pellet from a standard round drastically reduced the downrange pellet spread. This round is now available to law enforcement agencies through Federal Ammunition Company. A further modification by Federal to the traditional 00 buckshot load has been the incorporation of a thick-wall shot cup. This combination is known as the Federal Tactical eight-pellet 00 buckshot round.

9.3 Ammunition Components

Small arms ammunition is divided into two categories, cartridges and shot shells. Cartridges consist of a metallic case containing a priming mixture in the base, a powder charge (gunpowder) in the body, and a bullet seated in the mouth. The priming mixture is either found in the annular rim of the cartridge case (rim fire) or encased in a metal cup seated in the center of the base (center fire). Figures 9.8 and 9.9 illustrate rim fire and center fire cartridges. Modern rim fire ammunition is mostly 22 caliber, although 17 caliber is rapidly gaining popularity. All modern larger caliber metallic cartridges are center fire.

Modern priming mixtures have typically consisted of compounds of lead, barium, and antimony. The presence of lead, barium, and antimony on the hands is then used to state that a suspect either fired a weapon, handled a weapon, or was in close proximity to a weapon that was fired. The environmental concerns about lead

Fig. 9.8 A 22 rim fire cartridge (phantom view – image courtesy of RCBS Corporation)

Fig. 9.9 Typical center fire cartridge (phantom view – image courtesy of RCBS Corporation)

Fig. 9.10 Hollow-point bullet (expanded due to impact with a target)

have resulted in the introduction of "lead-free" primers. Lead-free ammunition also includes copper bullets or lead bullets fully encased in nylon or copper. Other elements, such as zinc and titanium, are used in the priming mixture and are tested for in the event lead-free ammunition was used in a shooting.

Bullet designs vary greatly depending on their designated use. Round-nose or flat-nose lead bullets are most often used for target practice. Hunting bullets and bullets for law enforcement/personal protection typically consist of an inner lead core and either a partial or total covering (jacket) of copper or brass. This jacketed design allows for controlled expansion upon impacting a target. This results in maximum tissue destruction and maximum likelihood for incapacitation. Maximum expansion is achieved through the so-called hollow-point design, in which the bullets have a cavity in the nose (Fig. 9.10). A myriad of various shapes and designs of bullets are available. The fact that there are so many different designs can assist the examiner in identifying a particular source.

From a forensic standpoint, the hollow-point bullet is most desirable. This is because intermediary target material tends to accumulate in the hollow-point cavity. This material can be recovered by the examiner and used to establish a "history" of

Fig. 9.11 Bullet with imbedded pulverized glass

the bullet path. Figure 9.11 shows a bullet with pulverized glass embedded in the nose, indicative of the bullet having passed through a windshield prior to its final impact into the victim in this particular case.

Gunpowder consists of several different shapes and formulations, depending on its intended use. It takes more gunpowder to push a bullet out of a long barrel than a short barrel. Ammunition manufacturers must take into consideration all possible weapons in which their ammunition might be used. For that reason, they incorporate more than enough gunpowder to do the job. This is good news for the firearms examiner because it means that, at close range, there will likely be unburned or partially burned gunpowder spewed out the end of the barrel. The presence of this gunpowder can be determined through examination/testing and used to estimate the distance of the shot.

The shape or morphology of gunpowder particles designed for small arms ammunition includes spherical (ball powder), flattened ball, disk or flake, and cylindrical. Two different chemical formulations are used. Single-base powders use nitrocellulose. Double-base powders use nitrocellulose in combination with nitroglycerine. Various stabilizers, plasticizers, and anti-static agents are also usually present.

The chemical composition and morphology of the gunpowder particles can be determined and compared with gunpowder found in ammunition confiscated from shooting suspects. The examiner can then make a determination as to whether the suspect's ammunition is consistent or inconsistent with the evidence.

Shot shells consist of a paper or plastic tube with a brass base and center primer. Shot shells constructed entirely of plastic are also manufactured. The shot or pellets are separated from the powder charge by a paper or plastic wad. Some shot shell designs incorporate the wad with a plastic cup that contains the shot and is known as a shot cup. A typical shot shell is shown in Fig. 9.12. At close range (less than approximately 10 feet), the shot cup/wad is often found inside the wound. The characteristics of the shot cup/wad can provide the examiner with information as to the gauge and manufacturer.

Fig. 9.12 Typical nine-pellet 00 buckshot load (shot shell was cut in half to remove the contents – clockwise from top, center pellets and buffer, shot cup, gunpowder, two halves of shot shell)

Fig. 9.13 Shot shell buffer (scale in mm)

Shotgun pellets are designated as either birdshot or buckshot. The shot is made of either lead, steel, bismuth, or tungsten (non-lead shot is required for environmental concerns in some areas of the country). Lead shot is of three general types, soft shot (pure lead), hard shot (hardened with antimony), and plated shot (plated with copper). Shotgun pellets range in size from 0.05-in. (No. 12 birdshot) to 0.36-in. diameter (000 buckshot), the specific size being designated by number. Shot shells can contain two different shot sizes (duplex loads) or three different shot sizes (triples loads), although most contain only one size.

Shot shells, particularly buckshot loads, often contain polypropylene or polyethylene particles known as buffer. Buffer may also be present in slug rounds. This is illustrated in Fig. 9.13. The presence of buffer material on the clothing or body assists the examiner in determining the shot distance because the buffer material

will only travel a limited, determinable distance. Because buffer material varies in composition and morphology (shape), the examiner is able to make some determination as to the source (manufacturer and specific load).

9.4 Manufacturing Processes

The firearm/toolmark examiner must have knowledge of manufacturing processes for firearms and tools in order to properly assess the significance of marks that are present on ammunition components and other surfaces. Without knowing how a firearm or tool was made, the examiner might erroneously conclude that a class or subclass characteristic was an individual characteristic.

Early manufacturing techniques relied heavily on hand production and hand finishing. Interchangeable parts were a concept that had not yet arrived. The individuality that was inherent in the firearms and tools that resulted was an examiner's dream.

Modern manufacturing techniques have resulted in closer tolerances as well as parts interchangeability. Computer-controlled machine tools have taken much of the hand work out of the manufacturing processes. On the surface, the demise of individuality would seem to be the inevitable, if not desired, outcome. In spite of all the mechanization, however, individuality is still alive and well.

Hand finishing, in the form of grinding and polishing, is still used in the manufacture of most firearms and tools. Even automated machining processes involve the use of bits, blades, grinders, and other tools, the surfaces of which are subject to wear and, hence, change. As these surfaces come into contact with the firearms parts or tool parts, they leave random, unique manufacturing marks. The result is that modern firearms and tools can and do produce unique, random marks that can be used to effect positive identification. It is just more incumbent upon the examiner to become familiar with the admittedly less common sources of individuality.

9.5 Types of Examinations Conducted

The firearm/toolmark examiner is capable of answering a wide range of questions through the examination of evidence recovered at a crime scene in addition to "Did this tool make this mark?" These questions include:

Did this weapon fire the bullet/cartridge case/shot shell recovered?
Did this weapon chamber the cartridge/shot shell?
What type of weapon could have fired the recovered bullet/cartridge case/shot shell (no gun recovered)?
Was the bullet/cartridge case/shot shell recovered fired from the same weapon as that used in other crimes?
What was the approximate muzzle to target distance of the shot?
What was the direction of the ricochet mark/crease?
Is the firearm functional?

Is the firearm capable of accidental firing (mechanical malfunction)?
How does the firearm eject fired cartridge cases/shot shells?
What was the serial number on this defaced weapon?

Additionally, many firearm/toolmark examiners are trained and experienced in the reconstruction of shooting incidents. Reconstruction involves determining positions of shooters and victims, sequence of shots and other aspects relating to how shootings took place. This frequently involves other disciplines as well as firearms/toolmarks (i.e., footwear/tire tread evidence, bloodstain pattern analysis, latent prints, trace evidence, and DNA).

9.6 Planning and Carrying Out the Examination

Unlike the examiners portrayed on popular television dramas, firearm/toolmark examiners usually have evidence come to them by way of the investigators who collected it rather than being at the scene themselves. Some examiners, however, are actively involved in crime scene analysis/reconstruction and collect evidence at the scene themselves. This activity is usually restricted to major crimes, due to manpower considerations and the heavy workload most crime labs have.

Typically, there will be a lead detective (case officer) in charge of the crime scene, who has the responsibility of seeing that all appropriate evidence is collected and transported to the crime lab for examination and testing. An Evidence Submittal Sheet and a Request for Analysis form accompany the evidence and help maintain a record of where the evidence has been from the point of collection until it is presented in court and to give direction to the examiner. The record of evidence transmission/receipt is known as the chain of custody.

Since the examiner is the expert who is most familiar with laboratory capabilities and limitations, it is important that the Request for Analysis be critically evaluated. If, in the examiner's opinion, additional and/or different tests are more appropriate, this must be communicated to the case officer. Blindly following the Request for Analysis without considering the possibility of other testing does a disservice and is unprofessional. Examiners are sometimes tempted to do so by the pressures of heavy caseloads and the subsequent motivation of not wanting to "create any extra work." Given the fact that lives are often hanging in the balance and depend on the outcome of the laboratory examinations, this attitude can simply not be tolerated.

9.7 Equipment and Tools

9.7.1 Microscopes

The firearm/toolmark examiner primarily uses two different types of microscopes on a regular basis. The first is the stereomicroscope. This microscope sits on the worktable and is usually mounted on a boom or arm extending from a stand. It usually

Fig. 9.14 Comparison microscope (image courtesy of James Gannalo, Det. NYPD ret.)

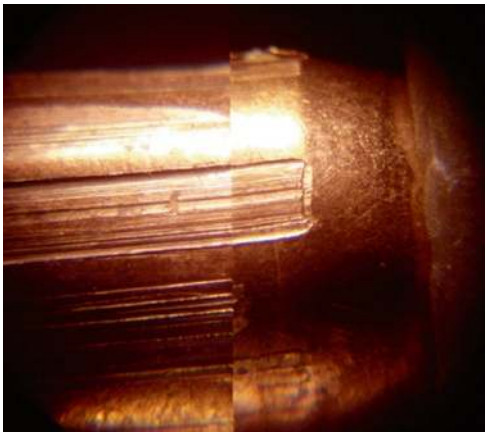

Fig. 9.15 View through the comparison microscope

has zoom capabilities for magnification from approximately 3× to approximately 10×. Initial examinations of weapons, ammunition components, tools, and objects with toolmarks on them are done with the stereomicroscope. The relatively low power gives lots of working room so that the examiner can manipulate various cumbersome objects into the field of view.

The workhorse of the firearm/toolmark section is the forensic comparison microscope (Fig. 9.14). This is actually two microscopes that are connected via an optical bridge so that as one looks through the eyepieces, both stages are visible via a split screen. In this way, evidence toolmarks on a surface can be compared directly with test toolmarks on a similar surface. A typical view is illustrated in Fig. 9.15, where the split image indicates that two different surfaces are being compared.

Forensic comparison microscopes have special holders that fit on the stages so that a wide variety of evidence items can be examined (e.g., bullets, cartridge cases, shot shells, tools, firearms/parts). Creative fixtures must sometimes be fabricated by the examiner in order to get a desired part under the microscope.

Comparison microscopes are fitted with multiple objectives so that a range of magnification is available to the examiner. A maximum of approximately 40× magnification is typically adequate for firearm/toolmark examination.

The comparison microscope is usually fitted with a video imaging system for use in training and for case documentation purposes. Digital images showing the specific areas of identification provide visual support for the examiner's written notes and conclusions. An argument against photographing identifications has been made on the basis that photographs do not fully represent what the examiner sees because they are only two-dimensional (2D) when the actual toolmarks are three-dimensional (3D).

While this may be true to some degree, such images are useful for refreshing the examiner's memory of the comparison at a later date and for allowing a defense expert to see the basis for the identification. Of course, some toolmarks have no perceptible depth and, thus, the argument is completely lost in those cases.

9.7.2 Measuring Tools

Firearm/toolmark examiners use a number of different measuring tools in the process of examining evidence. Dial calipers allow accurate measurements of thicknesses and depths to one-thousandth of an inch (Fig. 9.16). Micrometers are also used to measure thicknesses and are accurate to one-thousandth of an inch as well (Fig. 9.17). Such measurements come into play with firearms and ammunition components in particular where various comparisons of size are being made.

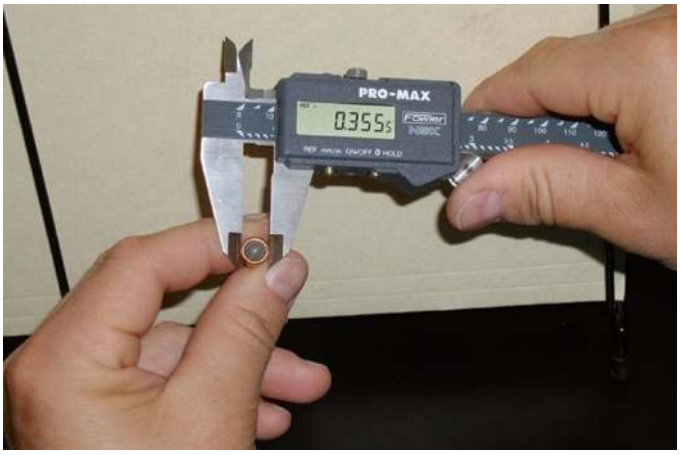

Fig. 9.16 Dial calipers (image courtesy of James Gannalo, Det. NYPD ret)

Fig. 9.17 Micrometer (image courtesy of RCBS Corporation)

Trigger pull weights, scales, and/or electronic measuring devices are used in the testing and evaluation of functionality of firearms. Extremely light or extremely heavy trigger pulls can be a factor in whether a shooting was intentional or not.

9.7.3 Water Trap

In order to have test bullets for comparison with evidence bullets, the examiner must have a bullet trap that is capable of catching/preserving fired bullets. Water traps typically consist of large (approximately 30 × 48 × 96 in.), stainless steel boxes with a pipe attached to one end into which to fire. Filter systems for both the air and the water help keep the working environment safe.

9.7.4 Reference Collections

In examining weapons, ammunition, and tools, there are frequent needs for exemplars. With regard to weapons, it is sometimes necessary to have parts available so that an evidence weapon received with a broken part might be test fired anyway by replacing the part. Ammunition of known origin assists the examiner in identifying various ammunition components submitted for examination. Having reference bolt cutters, saws, pliers, screwdrivers, and other tools can provide information as to the presence of class, sub-class, and individual characteristics.

9.8 Case Example

The following example illustrates the basic process of evidence examination for a firearms case. In this example, we will assume there has been a shooting incident in which a person has one superficial wound to the arm with the bullet entering, exiting, and lodging in a wall. The fatal shot strikes the victim in the chest, first passing through the shirt. A weapon is found at the scene.

9.8.1 Evidence Receipt

The firearm/toolmark examiner first receives the Evidence Submission/Request for Analysis form that alerts the firearm/toolmark examiner to the evidence submission. A typical excerpt from this type form appears below.

9.8.2 Evidence Submission

Items submitted

38-caliber Smith & Wesson model 36 snub-nose revolver, serial number K37653
Three live rounds (2 R-P, 1 W-W) and two fired cartridge cases from item 1 (1 R-P, 1 W-W)
Bullet recovered from the NW bedroom wall at the crime scene
Bullet recovered at autopsy (removed from victim's chest)
Black T-shirt from victim with apparent bullet hole in chest

9.8.3 Request for Analysis

Examine the weapon for latent fingerprints. Compare the weapon with the bullet from the scene and the bullet from the victim. Examine the victim's shirt for gunshot residue and determine the shot distance.

9.8.4 General Evidence Examination

The examiner begins by checking out the evidence from the property and evidence unit where the case officer or crime scene investigator had submitted it. The evidence is then taken into the examiner's work area, where examination of the evidence commences and a worksheet is begun. The stereomicroscope and measuring tools are used.

9.8.5 Evidence Examination Worksheet

Item 1–Tape-sealed paper sack bearing the initials "AMP" and the ID #3296, containing a black steel Smith & Wesson 38 special model 36 revolver, s/n K37653, five shot.
Visual exam – No blood or other trace evidence observed in/on weapon; two prominent cylinder flares (chamber under hammer, one to immediate left); cylinder rotates clockwise, five lands/grooves (right twist).
Super-glued weapon – no identifiable prints obtained.

Fig. 9.18 Revolver cylinder flares

Trigger pull 11–12 lb (double action) 6–7 lb (single action).
Test fired 6× using lab ammunition (R-P semi-jacketed hollow point, 120 grain, 3×; and W-W round nose lead, 3×).
Weapon functions normally marked "EEH" (Edward E. Hueske) under left grip.

The evidence examination worksheet shows that no trace evidence was present on the weapon as received. It is important to make this determination prior to conducting any sort of testing to avoid loss or contamination.

It was noted that there were "two prominent cylinder flares." Cylinder flares are deposits of soot that appear on the cylinder face around the margins of chambers in which cartridges have been discharged. Each successively produced flare overlaps the previous such that the sequence of shots can be determined (Fig. 9.18).

In this example, the clockwise rotation direction of the cylinder and the location of cylinder flares under and to the left of the hammer indicate that the cylinder has been rotated from its original position. Were this not the case, the cylinder flares would be under and to the right of the hammer or the cylinder flare under the hammer would overlap the one to the left.

The first step the examiner takes is to determine whether or not one of the investigators is responsible for the cylinder rotation. Often times, investigators cannot resist the urge to open the cylinder of a revolver found at the scene. Without realizing it, they rotate the cylinder as they open it and then close it back.

In the event that an officer is not responsible, it must be assumed that the cylinder was rotated between the firing of the first and second shots. Because two bullets were recovered, one from the scene and one from the victim, the question is which was fired first? The answer is found by using the crime scene investigator's notation as to which chamber had the "R-P" cartridge case (Remington–Peters) and which had the "W-W." Since the bullet designs will be different (see Fig. 9.19 for example),

Fig. 9.19 Two different bullet designs

it will be possible to determine which was fired first (e.g., if the W-W cartridge case is to the left of the R-P, it was fired first).

Once those observations are made, the weapon is tested for the presence of latent fingerprints using the technique of superglue (cyanacrylate ester) fuming. No "identifiable prints" means there may have been a few friction ridges and/or smudges, but no potentially identifiable fingerprints. In the authors' experience, *identifiable* fingerprints are found on firearms in less than approximately 10% of the cases. However, statistics compiled by the Boston Police Department following implementation of on-scene processing (rather than packaging and transporting firearms to the crime lab for processing) show a success rate of approximately 30%. The increase is doubtless a result of minimizing the handling and eliminating storage prior to processing.

The worksheet indicates that the trigger pull was determined in both single-action and double-action mode. This is done to test for the possibility of an extremely light pull ("hair trigger"). Trigger pulls below 1–1.5 lb are considered dangerous and can contribute to unintentional firing. In this example, the trigger pulls are within the range expected for a weapon of this type. Trigger pull may be determined either by hanging special weights from the trigger or by using a spring scale or electronic tester.

The worksheet entry regarding test firing indicates that three each of two different brands of ammunition were fired in the weapon. This was done because these same two different brands of ammunition were fired in the weapon during the incident under investigation. It is imperative that the examiner duplicate the actual conditions of the crime as nearly as possible when carrying out tests such as these. This is because different brands of ammunition can have different bullet and cartridge case compositions. Different compositions can mean different degrees of hardness and that can affect how the various markings (rifling, breech face, etc.) will be imparted.

The firing of three test rounds is done to allow the examiner to inter-compare the tests so that reproducibility of markings can be established. This will help the examiner in examining the evidence bullets and cartridge cases by knowing what markings to expect and to look for. In this example, the weapon was recovered at the crime scene and, being a revolver, did not eject the fired cartridge cases, but retained them in the cylinder. In spite of what would seem obvious, the examiner cannot assume anything and must compare the fired cartridge cases to known test fires to verify their source.

9.8.6 Cartridge Case Comparison

Test-fired cartridge cases are obtained by firing the weapon into a water trap, which will yield bullets with markings but no distortion. The examiner begins the cartridge case comparison by inter-comparing the test cartridge cases. This is followed by a comparison of the evidence cartridge cases to the tests. This is all done using the comparison microscope.

Comparison	Result
Test fires T1, T2, T3	T1 identified to T2/T3 by firing pin impressions and breech face marks
Test to 2a	2a identified to T2 by breech face marks
Test to 2b	2b identified to T1 by firing pin impression

Note: both cartridge cases received with “AMP” engraved in mouth

The cartridge case examination worksheet indicates that all three test fired cartridge cases were identified to one another on the basis of firing pin impressions and breech face marks. Either of these is sufficient for positive identification. Both the firing pins and the breech faces of weapons receive unique, random marks during manufacture and through use (wear). These, in turn, may be impressed upon the cartridge cases, as in this example.

Breech face marks result from the expansion of the cartridge case back against the breech face upon discharge. This expansion can also produce chamber marks along the sides of the case.

Firing pin impressions in the outer area of the base of rim fire cartridges and in the primer of center fire cartridges result when the firing pin impacts these areas during discharge. The shape and size of firing pins constitute class characteristics only. The tiny gouges, scrapes, and other random markings produced by manufacture/wear must be present for identification.

It is possible for a cartridge to be inserted and/or cycled through a weapon but not fired. Thus, the presence of magazine marks, extractor marks, and ejector marks do not necessarily indicate firing. On the other hand, breech face marks, firing pin impressions, and chamber marks can only result from firing and, therefore, positively confirm firing (Fig. 9.20).

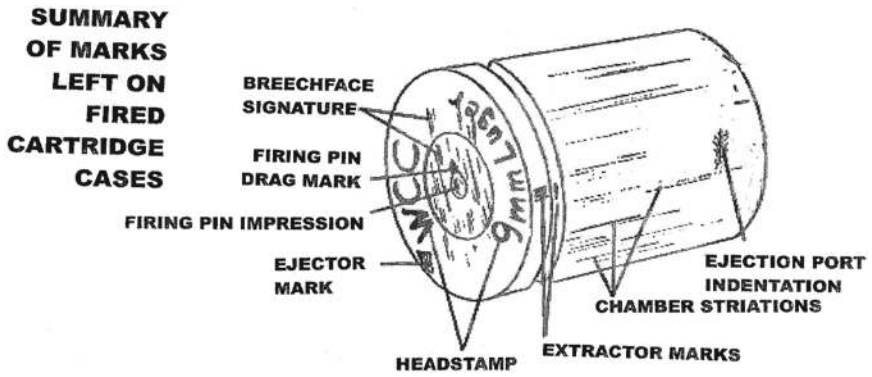

Fig. 9.20 Cartridge case markings that are possible

Table 9.1 Cartridge case examination worksheet

Item	Headstamp	Type	Case	Primer
2a	W-W	38 spl	Nickel	Nickel
2b	R-P	38 spl	Brass	Nickel

The worksheet reflects that evidence cartridge case 2a was identified to test T2 and evidence cartridge case 2b was identified to Test T1. Because all three test cartridge cases were inter-compared and identified, this is fine. The net result is that it was confirmed that 2a and 2b were fired from the same weapon, albeit having been proven indirectly. This process is summarized as:

T1 and T2 were matched.

Then T2 was matched to 2a, and 2b was matched to T1.

Therefore, 2a matches 2b.

The two evidence bullets will, of course, have to be compared with test fires as well. The fact that the weapon was fired twice and two bullets were recovered might also appear to make it obvious that this is the responsible weapon. Once again, however, the examiner must verify this. There is always the possibility that the weapon/ammunition was altered in some way or that another weapon and or other ammunition components were used (Table 9.1).

9.8.7 Bullet Comparison

Test-fired bullets are recovered from the water trap they were fired into. The bullet comparison follows in the same manner as the cartridge case comparison in that the test fires are inter-compared first and then the comparison of the evidence items to the test is conducted using a comparison microscope.

A sample bullet examination worksheet for this example appears below:

In the comparison of the bullets, both evidence bullets were identified to the same test bullet (T1). It was noted that there were two areas of correspondence and

Comparison	Result
Test fires T1, T2, T3	T1 identified to T2/T3 by two areas of 6+ consecutive/striae near base
Test to 3	Three identified to T1
Test to 4	Four identified to T1
Comments	Dried blood in nose of item 4 removed and placed in paper packet for exam by DNA unit
	Both bullets received with "AMP" engraved on nose

Table 9.2 Bullet examination worksheet

Item	Caliber	L/G #	WT (grains)	Twist	Type	Trace evidence
3	0.357	5	158	Right	RN lead	No
4	0.357	5	125	Right	SJHP	Blood

that these areas were near the base of the bullet. Both of the two areas were noted to consist of more than six consecutive striations (striae) each.

Note the significance of two areas of more than six consecutive striae is discussed in the section on criteria for identification that follows (Table 9.2).

9.8.8 Gunshot Residue Testing

In this case example, there was a black T-shirt with a bullet hole in the chest. The examiner begins with visual and microscopic (stereomicroscope) examination of the shirt, noting the presence of gunpowder, blood, and any other trace evidence of potential value. The sample worksheet for this part of the examination appears below.

9.8.9 Gunshot Residue Examination Worksheet

Item – Black T-shirt.
Markings – "AMP" on tag as received; marked "EEH" on back of tag.
Visual exam – Round hole in chest 16 in. from right side, 12 in. below neck band; apparent soot/powder residue; small amount of apparent blood on inside around hole (soaked through).
Microscopic exam – no tearing/burning/melting/soot around hole margins observed; powder particles (disk) visible with a diameter of approximately 4 in.
Griess test – Pattern of nitrites detected with a diameter of approximately 4 in.
Rhodizonate test – No vaporous/particulate lead detected.

The gunshot residue examination results for this example revealed that an intermediate range shot was involved. This is based on there being a 4-in. pattern of gunpowder particles around the hole in the chest of the T-shirt but no tearing, burning, melting, or soot. At contact or near contact distance, little or no powder particles would be found (since they go into the wound) and the muzzle blast would cause burning and/or melting of fibers and deposit soot. Distance shots, on the other hand, would not deposit gunpowder particles.

The next step for the examiner is to use the weapon and ammunition like that in evidence to establish test patterns that duplicate the 4-in. powder pattern found on the front of the T-shirt. Because there are two possible brands of cartridges (W-W and R-P), the examiner has to refer to the evidence submission form and utilize his ammunition reference collection to verify which brand produced the bullet hole in the T-shirt (and, of course, the wound).

Once a determination of which type ammunition was used has been made, the examiner acquires several rounds of that ammunition and proceeds to the shooting range to conduct test firings. Test shots are fired at measured distances into white cotton twill squares. In this example, the examiner would probably begin by firing at 24 inches and then moving in or out depending on the result obtained. Six-inch increments are usually used. Once a pattern similar to the evidence is obtained, an additional shot is made at that same distance for confirmation. Finally, a swatch of the actual evidence garment is used for final confirmation firing.

The reason for using the actual material is that gunpowder particles can behave differently upon striking various different surfaces. For example, a powder particle might bounce off a tightly woven nylon fabric while, at the same distance, it might adhere to a woolen sweater. An example of the gunshot residue testing report is shown below.

9.8.10 Gunshot Residue Examination Report

The area around a hole in the chest of the item 5 T-shirt was examined microscopically and processed chemically for the presence of gunshot residue (gunpowder and primer residues). A pattern of gunpowder particles was obtained.

Using the item 1 revolver and ammunition like that in item 4, a similar pattern was obtained at a distance of 12–18 inches.

These results mean that the fatal shot was probably fired at a distance of 12–18 inches, (muzzle to garment). The chemical tests used consist of the Griess test (a chemical color reaction for nitrites) and the sodium rhodizonate test (a chemical color reaction for lead). Nitrites result from partial burning of gunpowder (nitrates). Lead originates from the priming mixture (lead styphnate/lead azide) and/or lead bullets.

Ultimately the examiner writes a final report in which all the findings are articulated. This report is provided to both the case officer and the prosecutor (district attorney, county attorney, etc.). An abbreviated version of the final report for this example appears below.

9.8.11 Report of Scientific Examination

The item 1 revolver was examined for the presence of latent fingerprints but no identifiable prints were found.
The item 1 revolver was test fired and found to be in working order.
The item 3 bullet (from the crime scene) and the item 4 bullet (recovered at autopsy) were both identified as having been fired from the item 1 revolver.
The item 5 T-shirt was found to have a bullet hole in the chest that testing indicates was fired from a distance of approximately 12–18 inches.

The bullets and cartridge cases were entered into National Integrated Ballistics Identification Network (NIBIN) and no hits were obtained.

In this example case, the firearms examiner was able to provide useful evidence that would assist the lead investigator in reconstructing the shooting. The examination results provided information as to sequence of shots and the distance from which the fatal shot was fired.

9.9 Databases

A number of useful databases have been established and are available to the firearm/toolmark examiner. Probably the most significant is the NIBIN. This system contains a database of bullet rifling marks and cartridge case base markings (firing pin impressions and breech face marks). The system is networked with law enforcement agencies throughout the US and is administered by the Bureau of Alcohol, Tobacco and Firearms (ATF).

The ATF provides equipment to the agencies, who agree to support the program with staffing and resources. According to the ATF, more than 6,200 “hits” have been logged to date. This means bullets/cartridge cases entered into the system that have been found to match other bullets/cartridge cases already in the system (i.e., fired from the same gun).

Many agencies, such as NYPD, assign individuals to do nothing but enter bullet/cartridge case data from weapons seized on the street into the database. It is here that so-called cold hits are generated. This system, although time consuming itself, still saves thousands of hours of manual searching that would have to take place when a bullet or cartridge case need to be searched against previous submissions.

Other useful databases include trigger pull data and general rifling characteristics. The general rifling characteristics, along with the incorporated cartridge case markings file, allow the examiner to predict possible weapons that could have fired bullets/cartridge cases.

Future possibilities include the entering of bullet/cartridge case markings data from new weapons through cooperative agreements with firearm manufacturers. This would be similar to having a fingerprint file for all individuals from birth.

9.10 Criteria for Identification

Examiners are sometimes reluctant to present images of comparisons at trial for fear of opening the door for defense attacks where less than obvious agreement between striae exist or where there is even apparent disagreement.

These arguments can be overcome by simply pointing out that there will never be 100% agreement in these marks. Jerry Miller and Michael McLean put it like this in their article "Criteria for Identification of Toolmarks" that appeared in the *AFTE Journal* in 1998 "Nothing duplicated in nature has been reportedly found to be exactly the same, and man has not been able to produce things exactly alike" [1].

The Association of Firearm and Toolmark Examiners (AFTE) allows for "opinions of common origin to be made when the unique surface contours of two toolmarks are in sufficient agreement" [2]. The definition of "sufficient agreement" varies somewhat depending on who is asked to define it. A big part of the answer lies in the examiner having looked at a large number of toolmarks, particularly known non-matches (toolmarks known to have been made by different tools).

Studies of the number of consecutive matching striae have been conducted. Biasotti and Murdock have proposed a "conservative criteria for identification as

> In three dimensional toolmarks when at least three each, or one group of six consecutive matching striae appear in the same relative position in an evidence toolmark compared to a test toolmark
>
> In two dimensional toolmarks when at least two groups of at least five each, or one group of eight consecutive matching striae are in agreement" [3].

There is ongoing study and debate on this subject. The lack of universally accepted criteria for identification has fostered the legal challenges to toolmark identification that have arisen [4]. The problem of articulating criteria for identification lies in the fact that comparisons must take into account not only the quantitative aspect (number of consecutive matching striae) but also the quality of the match. Exactly how to define "quality of match" is somewhat more difficult than establishing the minimum number of consecutive striae for an identification.

While there may continue to be legal challenges to the scientific validity of toolmark evidence, in the author's opinion, the proof of the validity lies in the results of studies such as a study he participated in a number of years ago involving consecutively manufactured pistol barrels. The greatest chance for carry-over of toolmarks is clearly going to be found in the manufacturing process, where the same machine/operator/tool/stock are used to produce items one after another.

Thus, a group of consecutively manufactured pistol barrels was obtained. The purpose of the test was to see if bullets fired through the barrels could be distinguished from one another and, more importantly, that the bullets could be identified to the specific barrel that fired them. The bottom line was that the bullets were both distinguishable from one another and identifiable to the barrel that fired them [5].

9.11 Comparing Screwdrivers, Pliers, and Other Hand Tools

The underlying principle in comparing two objects is that "like must be compared to like" or, to coin an old cliché, "you can't compare apples with oranges." In other words, if a toolmark was left on a piece of copper sheet, the test toolmark should also be made on copper sheet and not lead or zinc.

While similar principles are used to compare all different types of toolmarks, there are inherent differences that must be considered. For example, a common pair of shears has four different surfaces, two sides on each blade, that could produce toolmarks. Thus, directionality/orientation becomes an issue. If a test cut is made holding the shears opposite to the direction the evidence cut was made, the toolmarks produced will not be in the same relative orientation.

Comparison of hand tools begins with a stereomicroscope examination of the tool surfaces for the presence of tiny bits of material (metal, plastic, wood, etc.) from the item that was cut/drilled/sawed/scratched/gouged/indented. If this material is found, the tool can be related to it, even if the toolmarks cannot provide positive identification.

Test toolmarks are produced and evaluated for class, sub-class, and individual characteristics. This may require obtaining exemplar tools for examination/comparison. The exemplar tools should be new and unused. As already mentioned, test toolmarks should be made in/on the same material as the evidence. It is possible, however, to make useful test toolmarks in other media, such as lead rod or sheet, and use these to establish reproducibility [6].

Usually three test impressions are made and inter-compared for reproducibility. Once the examiner has established that the tool makes reproducible marks, comparison of the test marks to the evidence marks begins. This an oversimplification, however, because different angles, positions, degrees of force, and other factors can affect the toolmarks produced. The examiner must consider all of these factors and may have to make numerous test marks in an effort to duplicate the conditions under which the evidence marks were produced.

In some instances, the examiner may make silicone casts of a test toolmark in one medium and the evidence toolmark in another medium and compare the casts to one another. In this way, apples are compared to apples, albeit with a backdoor approach [7].

9.12 Serial Number Restoration

The restoration of obliterated serial numbers is typically part of the responsibilities of the firearm/toolmark examiner. Stolen items that bear serial numbers, such as firearms, motorcycles, tractors, etc., often have their serial numbers defaced or removed in an effort to avoid identification.

Fig. 9.21 Example of serial number restoration (*left* – before restoration, *right* – after) (photographs courtesy of Det. James Gannalo, NYPD ret)

When the serial number is stamped into metal, disruption of the crystalline structure occurs. This disruption extends below the actual impression of the number. When the number is ground off, but not excessively, there is a reasonable chance that the number can be restored through chemical etching. This is because the compressed area of the metal reacts at a different rate than the surrounding area when subjected to chemical etching. The "before" and "after" is illustrated (Fig. 9.21).

The first step in any serial number restoration process is to polish the surface where the serial number obliteration has taken place. This is done using fine sandpaper and/or polishing wheels. The purpose is to allow as much contrast as possible between the compressed and uncompressed areas.

Different chemical etching solutions are used depending on the metal (e.g., steel, aluminum, or zinc alloy). The process can be speeded up through the use of electrical current because the etching process is actually an electrochemical process in which electrons are being transferred as the metal is etched. The examiner must be careful, however, because over-etching can totally destroy the serial number remnants.

Some success has been achieved by heating defaced metal surfaces with a torch until red hot and then observing the cooling process. The principle is the same, in that the compressed area cools at a different rate than the uncompressed area, allowing visualization of the serial number.

Another method relies on differences in magnetic properties of compressed vs. uncompressed steel. This is the same technique used by metallurgists to locate defects in steel objects and is known as magnafluxing. Finely divided iron filings (magnaflux) in an oil suspension are placed on the surface under examination after an electromagnetic field has first been applied. The filings collect in the compressed area of the serial number.

Another technique that has been used involves an ultrasonic bath. The ultrasound technique produces etching much like the chemical process.

Serial numbers in plastics can be restored by using organic solvents, such as chloroform, to cause swelling. Again, the difference in rate of reaction between compressed and uncompressed areas allows visualization.

If the serial number has been too deeply ground away or drilled out, nothing can be done to restore the number. Likewise, serial numbers that are lightly stamped or merely engraved offer little hope for restoration when defaced.

9.13 The Future

The future of firearm/toolmark examination is directly tied to the technology of the firearms and tools that are being and will be devised. As the technology of these items changes, the methodologies used in their identification and comparison must also change. Firearms are already being developed that use electronic ignition rather than conventional firing pin/primer mechanisms. This eliminates the firing pin impression aspect of firearms identification. Caseless cartridges have been around since before the Civil War, but there is renewed interest in them. Obviously the markings typically utilized (extractor, ejector, breech face, firing pin, and chamber) are not available if there is no cartridge case. Alternative means of identification will have to be developed.

The most probable changes on the horizon for firearm/toolmark examination will likely involve increased automation. A possible consideration would be the use of topographical analysis of toolmarks and automated comparison. In this way, the quality and the quantity of the marks could be related. The quality would be based on the degree of contour match of the marks (test vs. evidence), whereas the quantity would be evaluated as is already being done (number of consecutive striae). A combined "degree of match" might then be derived.

A push has been underway for a number of years for certification of firearm/toolmark examiners through the AFTE. In the future, universal endorsement of AFTE certification may become a reality.

9.14 Updates

9.14.1 Comparative Lead Analysis

There are approximately 25 million bullets produced every day throughout the world. When bullets are used in crimes, the ability to relate bullets to a particular source would be very valuable. For nearly forty years, the FBI has purported that it is possible to associate bullets produced in a particular batch (lot) by analyzing the lead in bullets as to total elemental composition. While the primary component is lead, there are numerous possible additional metallic components including tin, antimony, and copper.

However, a fairly recent study (2005), has refuted the elemental uniqueness claim for bullet lead batches causing the FBI to shut down its comparative bullet lead analysis (CBLA) program.

Former FBI metallurgist William Tobin researched the validity of CBLA and found very little support for its validity. Refineries where bullet lead is produced use recycled car batteries to make the lead. As many as 34 million bullets can come out of each batch. Tobin found that the various constituent elements are not found uniformly throughout the lead. They clump and cluster together in a process known as segregation. The elemental composition can, therefore, be different for bullets produced from the same batch of lead.

Unfortunately, since the 1980s, CBLA has been testified to by the FBI in approximately 500 trials. Those persons convicted in cases where CBLA was involved now have bases for petitioning the court for new trials. The subsequent cost to tax payers could be tremendous.

9.14.2 Firearms Identification

Recently, firearms identification has come under attack due to the lack of specific identification criteria. The 1993 Supreme Court decision in *Daubert v. Merrell DowPharmaceutical* states that an expert witness's testimony must be grounded in solid, verifiable science. The perceived problem with firearms identification is its reliance on pattern recognition. There are no generally accepted criteria for identification. All examiners use their own judgment, based upon their experience and training.

Recent scrutiny by the courts and within the discipline itself has led to a number of ongoing studies that seek to establish universally accepted criteria for identification. In 2006, Benjamin Bachrach conducted a federally funded study to prove that firearms examination is an exact science. Using computer technology and 3D imaging, the computer generates a score that shows the degree of a match between two bullets based upon topographical analysis of the bullet striations. This eliminates the human element of subjectivity. The conclusion of this study was that pattern recognition is, in fact, a viable methodology for bullet comparison. Although not specifically addressed, cartridge case identifications are considered to be equally appropriate.

9.15 Case Study

The reconstruction of a shooting incident is most complicated when there are multiple shooters and those shooters are moving about during the incident. In a recent case this writer reconstructed for the prosecution, three officers were involved in a shootout involving a member of the Aryan Brotherhood prison gang. Unfortunately,

one of the officers received a fatal shot to the head during the shootout. The incident took place inside a mobile home and both of the officers and the suspect moved about during the shooting.

The officers were attempting to arrest the suspect on parole violation charges and had received information that the suspect was staying at the mobile home. One of the officers, wearing a city utility worker shirt and hardhat, knocked on the door while the other officers remained out of sight. When a woman answered the front door, the officer announced that he was a police officer and inquired as to whether the suspect was inside. The woman replied that the suspect was not there. The officer then asked for permission to come inside and search. According to the officer, the woman readily agreed, stating in a rather loud voice "The police are here and want to come in and look around" (there was a man just inside seated on a sofa who the officer recognized was not the suspect). At this point, the other two officers appeared in response to the first officer's radio alert, one on foot and the other pulling up in front of the mobile home in his squad car.

The three officers then entered the mobile home through the front (north) door, one of them going to the left (east) toward the back bedroom and the other two approaching a partly closed door across the hallway from the front door. According to the surviving officer, upon pushing the door open, he saw a hand extending from behind the partially closed closet door inside. At that point, a warning was called out as the two officers drew their pistols and fired shots as the suspect moved from the closet to the foot of a mattress on the floor in the southwest corner firing shots back toward them. The surviving officer stated that he rolled to his left onto the living room floor and fired multiple shots while down on the floor.

The other officer originally at the bedroom doorway moved down the hallway to the west, firing through the wall as he moved. The suspect inside the bedroom began firing through the wall into the hallway where the officer was. Realizing that he was not in a good tactical position, the officer made a heroic decision and moved back to the east to attempt to engage the suspect from the doorway. Unfortunately, when the officer moved into the doorway, the suspect moved out across the mattress, firing several shots, one of which struck the officer in the forehead. The officer collapsed in the living room just beyond the doorway to the bedroom and the north entry door.

When the shooting had commenced, the third officer had come back to the kitchen (adjacent to and east of the living room) and joined the firefight, firing from a tactical stance through the wall separating the living room from the bedroom. After the officer was mortally wounded by the suspect, the suspect jumped out the bedroom window, cutting himself as he fled the scene. The suspect broke into another nearby mobile home and took the owner hostage as police officers responded to the call "Officer down." A standoff ensued that ultimately resulted in the suspect surrendering to authorities without harming the hostage. The suspect had a superficial gunshot wound under his chin in addition to some minor glass cuts. The injured officer was transported to an area hospital where he was put on life support. After several days, in a very emotional moment, the family was forced to make the difficult decision to take the well-liked, highly respected officer off life support.

With the passing of the officer, the suspect was charged with capital murder, indicted, and a trial date was set. Following the initial scene examination and evidence documentation/collection, the district attorney's office purchased the mobile home and had it moved it to a secure location for further examination and evaluation. This somewhat unprecedented move turned out to be tantamount in being able to carry out the reconstruction of this very complex shooting incident. No less than ten visits were made to the mobile home by this writer in the course of reconstructing the shooting.

The defense effort was focused on two premises, a case of mistaken identity on the part of the defendant (i.e., he did not know it was the police) and a lack of intentional, directed fire on the part of the defendant (i.e., "wildly firing about in response to incoming fire"). Accordingly, the reconstruction of the shooting had to address these specific issues in addition to the general aspects that are typically addressed in any shooting reconstruction.

In addressing whether the defendant knew it was the police, the only meaningful aspect of the reconstruction that could be done was to establish what opportunities the defendant might have had for recognizing the officers as such. The initial announcement by the woman that the police were entering would seem to be an area that could be utilized to establish potential recognition. The problem, however, was there was no way to quantify the volume of the announcement or what the defendant might have been able to hear. This was further exacerbated by the presence of a window unit air conditioner that was running at the time of the incident but there was no way to determine what setting the air conditioner fan was on (it had not been documented). As this writer testified to at trial under cross-examination, there were simply too many variables to carry out any meaningful testing in this regard.

More significant as to the potential for recognition of police presence was the police cruiser parked in front of the residence and the police insignias worn by the officers that stood in the bedroom door as they confronted the defendant. A crime scene photograph taken from within the bedroom where the defendant was positioned clearly demonstrates the defendant at least had an opportunity to have seen the police cruiser from inside the bedroom if he had peered through a partially open bedroom door (Fig. 9.22).

In order to address the question of recognition of police insignia, a reenactment was conducted. This reenactment was conducted in the mobile home using the surviving officer and a stand-in for the deceased officer of the same stature, both individuals wearing attire like that worn during the incident. As can be seen in Fig. 9.23, it is readily apparent that both officers presented opportunities for visual recognition of their identities as police officers.

A secondary aspect of the defense theory had to do with the allegation that because the defendant had "snitched out" another member of the Aryan Brotherhood while in prison, they had put out a contract on the defendant and the defendant thought the police officers were members of the Aryan Brotherhood coming to get him. Since both officers standing in the doorway were Hispanic and the Aryan Brotherhood admits Caucasians only, that notion did not seem very plausible.

The question of whether the defendant was directing his fire or "wildly" firing in self-defense was addressed through the placement of trajectory rods in the bullet

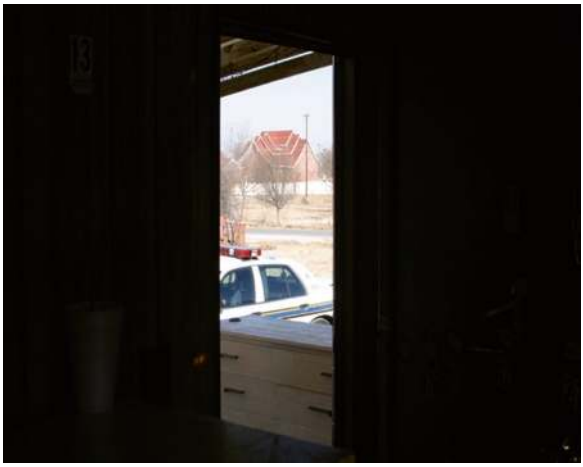

Fig. 9.22 View from inside bedroom out through front door

Fig. 9.23 Reenactment with officers' badges and other insignia clearly visible from inside the bedroom

holes coming from within the bedroom. By so doing and documenting the results with appropriate photographs, it was shown that there were obvious similarities to the trajectories of the defendant's shots and a number of shots, including the fatal shot, were directed toward the doorway. One such view is shown in Fig. 9.24.

A rather unusual aspect of the case that greatly facilitated a more traditional aspect of reconstructing the shooting (i.e., who fired which shots) was the fact that all three officers were firing different caliber weapons, one a 45 caliber, the second

Fig. 9.24 Trajectory rod placed into bullet hole above doorway into the bedroom

a 40 caliber, and the third a 9 mm. Thus, it was fairly easy to relate the initial entry holes to the responsible caliber weapon and, hence, the officer who fired the shots. The placement of trajectory rods again was used to substantiate the officers' statements as to their firing positions (Fig. 9.25).

The defendant was convicted of capital murder and sentenced to life without parole. The reconstruction of the shooting played a key role in the prosecution's case. Shooting incident reconstruction is a specialized discipline that transcends the traditional duties of firearm and toolmark examination. Unfortunately, in today's era of specialization, it is less likely that there will be opportunities for cross-training in other disciplines as existed a number of years ago. Specifically, training in trace evidence, footwear/tire tread evidence, bloodstain pattern analysis, and gunshot residue analysis is required in addition to firearms and toolmark identification.

The field of firearms/toolmark identification itself, like other disciplines of forensic science, has a basis in physical science. Physics and chemistry are related to just about everything that the firearms examiner does from conducting examinations, carrying out muzzle-to-target distance determinations, and doing serial number restorations. Accordingly, someone seeking to prepare themselves academically for a career in firearms/toolmark identification would be wise to take as many science classes as possible, if not acquire a degree in physical science.

Fig. 9.25 Trajectory rods placed into bullet holes fired by two officers into wall between the living room and bedroom

Firearms/toolmark identification is a discipline that requires great attention to detail, perseverance, and an inquiring mind. Each case presents new challenges and hurdles, making it an ideal profession for the individual who does not like the same old routine day in and day out.

Glossary

Annular rim	The outer circumference of the cartridge case base (location of priming mixture in rim fire cartridges).
Antimony sulfide	A component of most priming mixtures that acts as a fuel.
Ballistics	The study of projectile motion, often confused with firearms identification.
Barium nitrate	A component of most priming mixtures that acts as an oxidizer.
Bird shot	A general term for any shot smaller than buckshot.

Bolt action	A firearm in which the breech is always in line with the bore and manually reciprocates to load, unload, and cock (two principle types rotating and straight pull).
Bore	The interior of a barrel forward of the chamber.
Breech face	That part of the breech block or bolt that is against the base of the cartridge case or shot shell during firing.
Broach	Rifling cutter that cuts all the grooves simultaneously.
Buckshot	Lead pellets ranging in diameter from 0.02 to 0.36 in. and normally fired in shotguns.
Bullet	The projectile portion of a cartridge.
Bullet jacket	Metallic covering over bullet core.
Caliber	The cross-sectional diameter of the barrel from land to land.
Calipers	A device consisting of two moveable jaws or legs used to measure distance, thickness, or width.
Cartridge	Ammunition component consisting of a cartridge case, bullet, powder charge (propellant), and primer.
Cartridge case	The container for all the other components of a cartridge.
Center fire	Cartridge with the primer in the center of the base (head).
Chamber	The rear part of the barrel bore that has been machined for a specific cartridge (revolver cylinders are multi-chambered).
Chamber marks	Individual characteristics imparted to the chamber walls during machining.
Choke	Constriction in the muzzle end of a shotgun barrel.
Class characteristics	Those characteristics exhibited by an entire class or group.
Clip	A separate device for magazine reloading.
Cock	To place a firing mechanism under spring tension.
Disk powder	An extruded form of gunpowder that is cut into small disks.
Double action	A single pull of the trigger cocks and releases the hammer.
Ejection	The expulsion of a fired cartridge case or shot shell.
Ejector marks	Marks left on the base (head) of a cartridge case or shot shell by the ejector during the process of ejection.
Etch	To produce corrosive action on metal.

Falling block	A single-shot lever action mechanism in which the breech block slides vertically or nearly vertically down as the lever is worked.
Firing pin	That part of a firearm mechanism that strikes the primer and initiates ignition.
Firing pin impression	The impression left by the firing pin upon impact with the primer.
Function testing	The examination of a firearm for operability and firing capability.
General rifling	The number, width, and direction of twist of rifling grooves.
Griess test	Chemical test for nitrites used to detect gunpowder residue around bullet holes.
Grooves	Helical grooves in the interior of the barrel to impart spin on the bullet.
Gunshot residue	Gunpowder and primer residue resulting from discharge.
Hammer	That part of the firing pin that imparts energy to the firing pin.
Hammer forging	Process of forming the interior/exterior of a barrel by hammering.
Individual characteristics	Accidental, random marks used to identify toolmarks.
Lead azide	Chemical compound used in most priming mixtures.
Lever action	Type of firearms action that utilizes a lever to move the breech mechanism.
Micrometer	Precision measuring device used to measure small distances/thickness.
Nitrocellulose powder	A smokeless propellant whose principle ingredient is nitrocellulose.
Nitroglycerin	A high explosive and component of double-based gunpowder.
Pellet	Common term for small, spherical shot used in shot shells.
Polygonal rifling	Rifling with rounded edges instead of the usual square edges.
Powder stippling	The result of powder particles striking the skin and imbedding and/or leaving a burn or bruise.
Primer	Shock-sensitive explosive mixture that initiates burning of the propellant.
Propellant	The powder charge inside a shot shell or cartridge case.
Slug	Single projectile for a shotgun.
Sodium rhodizonate	Chemical test for lead.

Toolmark, impression	The result of a tool pressed against another surface with enough force to leave and impression.
Toolmark, striated	A mark produced with a combination of force and motion.

9.16 Questions

1. How are toolmarks produced on the surface of a bullet?
2. What are the "non-toolmark comparison" aspects of firearms identification?
3. What are the three aspects of ballistics?
4. What are the two types of toolmarks?
5. What is the difference between a semi-automatic weapon and a fully automatic weapon?
6. What is the area between the barrel grooves called?
7. How is the caliber of a weapon determined?
8. True or false: Firearms identification was developed in the 1800s.
9. What are the two main types of microscopes used in firearm/toolmark examinations?
10. What compounds do most primers consist of?
11. What is the best technique to use when testing for primer (GSR) residue?
12. What is the most significant database used by firearm/toolmark examiners?
13. What is the underlying principle when comparing two objects?
14. How many test impressions are made and inter-compared for reproducibility?
15. What is the first step in any serial number restoration process?
16. How can you speed up the process of chemical etching?
17. The field of firearms/toolmark identification, like other disciplines of forensic science, has a basis in science.
18. What is the Griess test?
19. Sodium rhodizonate is a chemical test for what?
20. What are ejector marks?

9.17 About the Author

Edward Hueske has 39 years experience as a forensic scientist. He has authored two books and 35 technical papers. Mr. Hueske is a member of several professional societies and has served in various capacities in those organizations. He currently serves as the Criminalistics Program Coordinator at the University of North Texas and teaches criminalistics and crime scene investigation at both the undergrad and graduate levels.

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Chapter 10
Forensic Odontology: Teeth and Their Secrets

Helena Soomer Lincoln, DDS, PhD

Contents

10.1 Introduction

As a child, I always liked to play puzzle games. It took me time and lots of patience, looking, matching, and looking again, to get that big and complete picture, but the effort was well worth it. Forensic science is like that. By working with these "puzzle pieces" – the pieces of evidence from a crime scene – the "big picture" almost

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always results. The resulting picture is a provable reconstruction of what happened, how it happened, and most importantly, who did it. A team of forensic specialists does this reconstruction work. They work together at the crime scene to recover, document, collect, and transport the resulting evidence to the crime laboratory for further analysis. Each expert has special skills in his or her area of expertise. The forensic odontologists on these teams are dentists who have such special skills in the areas of clinical dentistry, forensic medicine, and police investigation. They analyze any dental evidence, make forensic conclusions, and testify in court to support their conclusions. Forensic odontologists often play an essential role in identifying either victims of disasters or victims and suspects of individual crimes. They analyze abuse cases, involving injuries to teeth.and oro-facial structures as well as bite marks. They thereby assist the legal authorities in solving crimes and bringing criminals to justice. Forensic odontologists have other roles as well. For example, their activities may include assisting in archaeological expeditions to estimate the age or health status of skeletal remains. Age can also be estimated on a living person based on radiographs. Age can even be estimated in assessing bite marks and injuries to the teeth and facial structures for plaintiffs in civil and criminal cases.

10.2 Who is the Forensic Odontologist?

The forensic odontologist is first and foremost a highly trained clinical dentist, familiar with tooth development, anatomy, disease pathology, and oral and maxillofacial surgery and restoration. The forensic odontologist combines this specialized clinical knowledge with additional investigative skills. For example, the odontologist is trained in collecting evidence and working closely with police investigators and the medical examiner, while remaining independent. For example, the forensic odontologist must keep an open mind and investigate all options even if the police or general public have formed hypotheses. The experienced forensic odontologist must be familiar with the standards for evidence recovery, documentation, and analysis, such as the International Criminal Police Organization (Interpol) standards for victim identification. Thus, forensic odontology crosses the disciplines of clinical dentistry, forensic medicine, and police investigation.

10.3 What is Dental Evidence?

Dental evidence may include such diverse items as a bite mark impression, the entire dentition of a victim, or just a single fragment of a tooth found at a crime scene. Dental evidence also includes the antemortem, or historical evidence of dental treatment, such as clinical patient records, whether written or electronic, including textual records, diagrams, clinical photos, and X-rays. Because teeth are the hardest materials of the human body and strongly resist postmortem changes and adverse environmental conditions such as fire, water immersion, or explosion,

dental evidence is often available in crime cases, even "cold cases." Consequently, forensic odontologists play a vital role in investigations.

For example, our team was once called to the scene of a murder where we found a fractured tooth in a pool of blood next to a murdered man. The forensic odontologist immediately recognized the unique morphological features of this tooth fragment and identified it as the upper left second molar. However, the victim had his second molar, and indeed all 32 of his teeth, in place. The odontologist surmised that the tooth probably belonged to the assailant, who must have been injured severely to lose such a large and firmly rooted tooth so deep in the mouth. Therefore, all emergency medical facilities in the region were alerted to be on the lookout for a recent traumatic facial injury. In fact, one hospital had just received a patient who had sustained a gunshot wound to his face. He claimed to have been wounded while cleaning his gun. Our forensic team rushed to the hospital and asked for his panoramic mouth X-ray. The X-ray revealed that, in addition to his other facial injuries from the gunshot, the patient was freshly missing a second molar – consistent with the tooth we found at the crime scene. The patient tried to escape from the hospital after receiving first aid, but was arrested at the door for suspicion of murder. In this case, the forensic odontologist quickly identified the criminal, who would have otherwise escaped early capture. The type of identification procedure described herein is "comparative identification," which consists of the forensic comparison of a person's known dental data (the panoramic mouth X-ray in this case) and the dental evidence found at the crime scene. The result is a determination of whether the dental evidence came from the known person (the suspect in this case). This example shows how the forensic odontologist can play a crucial role in a breaking crime scene investigation.

10.4 Scope of Forensic Odontology

Forensic odontology is broadly applicable to criminal investigation, disaster recovery, and civil law cases. Identification of unknown persons is a main focus of forensic odontology. However, forensic odontologists also participate in a wide variety of activities, including scientific research and even in the investigation of ancient civilizations and peoples.

10.4.1 Identification Work

Identification is one cornerstone of forensic odontology. Whether it involves estimating the age of an illegal immigrant detained in a terrorism investigation without documents, matching victim remains to antemortem records in a mass disaster, or identifying a single crime victim, forensic odontologists spend most of their time trying to answer identity questions: Who is the victim with the dental bridge and a missing molar? Who is the criminal who left that bite mark? How old is that detained terrorist?

10.4.2 Age Estimation

Age estimation helped solve a recent European case where a man was tortured and then murdered in a brutal fashion: his hands were tied and he had received multiple flesh wounds before finally dying. After the murder, the criminal tried to hide the crime by burning the victim. As a result, the victim was unrecognizable: the outer layers – hair, skin, and clothing – were completely burned away. However, the teeth were preserved because they are the hardest and most resistant parts of the body. This victim had shining white teeth, which led the policemen and forensic pathologist in attendance to agree that he must have been young. Fortunately, the forensic odontologist was also in attendance and recognized that the "nice white teeth" were in fact artificial – covered by expensive porcelain veneer. The rear teeth were worn and had moderate periodontal disease. Dental age estimation by the forensic odontologist provided a completely different victim profile: this man was in his fifties and was likely someone wealthy enough to have this expensive veneer work done.

In this investigation, the forensic odontologist correctly recognized and correlated a variety of inter-related factors: the normal dental anatomy, the presence of subtle blended restorations, and the age-related pathology and wear patterns. This technique is called "reconstructive postmortem dental profiling." With reconstructive profiling, dental evidence collected from the body is used to determine the victim's profile, including factors such as approximate chronological age, social status (e.g., expensive restorations imply wealth), smoking and dietary habits, and even sex, race, and country of origin.

Dental age estimation is a common dental forensic procedure. It can be done upon intact teeth, as demonstrated in the preceding case, or even more precisely by sectioning the teeth and examining them microscopically. The microscopic exam typically assesses features such as the amount of secondary dentine (a reparative tissue), increased root transparency, root resorption, and the amount of cementum around the root – all of which increase directly with age. The gross appearance of the wear patterns and other microscopic findings are all directly related to a person's age. Several formulae have been derived to calculate age based on these observations and measurements [1–6]. The application of reliable dental age estimation techniques [7], as well as assessment of other associated dental features, permit the police to narrow their search among missing persons and, therefore, identify murder or disaster victims more quickly and effectively [8].

10.4.3 Disaster Victim Identification

Forensic odontologists are crucial team members when investigating small- and large-scale disasters. Dental identification, along with fingerprint and DNA identification, is considered a primary method of identification because it is quick, highly accurate, cost-effective, and can be done on site in most cases. In contrast to other

techniques, such as DNA identification, it requires only minimal equipment and logistical support. Typical requirements include electrical power, X-ray equipment, and a computer-assisted identification program, such as WinID or Interpol Disaster Victim Identification (DVI), when large amounts of victim data are involved. DNA analysis is a powerful adjunct technique as well, but it is not possible in all cases. For example, just as antemortem dental records may be missing, antemortem DNA samples may not be available. In some other cases, the postmortem DNA may be degraded or contaminated, such as in the case of the fractured tooth mentioned earlier, where the DNA-rich pulp has been exposed to and contaminated with an unknown blood source. However, as that case also showed, the anatomy of the same tooth fragment may be all that is needed to provide an immediately available and crucial clue that can result in an arrest. DNA, fingerprint (also footprint), and dental identification are the primary identification methods. DNA analysis requires considerable time, often weeks or even months, because multiple postmortem samples and antemortem reference samples must be processed [9]. In many cases, DNA, fingerprint, and dental identification complement and confirm each other. For more information, please see the guidelines for disaster victim identification teams, http://www.interpol.int/Public/DisasterVictim/guide/default.asp [10].

10.4.3.1 Mass Disasters

The South East Asia Tsunami of December 2004

On 26 Dec 2004, a seaquake of 9.0 on the Richter scale, with its epicenter off the coast of Sumatra, caused a devastating tidal wave that led to the death of more than 230,000 persons in at least eight countries (Indonesia/Sumatra, Sri Lanka, India, Thailand, Myanmar, the Maldives, Malaysia, and Bangladesh). In the Phuket area of Thailand alone, there were 3,600 victims, many of whom were tourists and foreigners from 38 different countries, including 552 Germans, 543 Swedes, 178 Finns, 150 Great Britons, and 111 Swiss nationals. Of the Phuket victims, 2,679 were successfully identified, 1,105 by dental status alone and 346 in combination with dental status and other methods. Consequently, dental identification was used in 1,451 (54.16%) of the cases [11]. Sweden is known for its high level of standardized dental record keeping, and so had better results than some other countries. The Swedish identification effort was led by Swedish officials, including forensic odontologist Dr. Irena Dawidson. Of 543 Swedish citizens lost, 528 were found and identified. Of these, 70% were identified by dental comparison of antemortem and postmortem records, and 10% by a combination of methods (e.g., family identification of the corpse, photographs, identifying marks, DNA) that included dental comparison [12]. DNA identification was less used initially because of the badly decomposed state of many of the corpses and because the investigators did not initially agree on which DNA methodology and what DNA reference laboratories were to be used. Later, when dental methods, fingerprinting, and other identifying characteristics had been exhausted, DNA analysis was more frequently used among

the remaining victims. In the end, DNA analysis accounted for approximately 20% of total identifications of the Western victims, and an especially large proportion of the children younger than the age of 5 years, who understandably had little restorative work that could allow unique identification. Approximately 600 presumably Western corpses remained unidentified in Thailand by the summer of 2006 and were buried when investigations ceased [12].

September 11th Attacks

The notorious terrorist attacks on 11 Sep 2001 included the World Trade Center in New York City. At this location, 2,752 deaths were recorded [10]. The victims virtually all received severe trauma and therefore more than 19,900 body parts were recovered. Approximately 1,435 victims have been positively identified. The main methods of identification were DNA (more than 700 cases), dental (more than 500), and fingerprints (approximately 200). In addition, dental identification contributed in a total of 78% of the cases where some other means of identification was conclusive [10]. A dental contribution to identification typically meant that there were no discrepancies between antemortem and postmortem dental data, but that the dental data alone was not sufficient by itself for positive identification. For example, the dental identification was deemed to contribute if antemortem dental information was not unique (e.g., could match several victims, as might be the case if only textual dental records were available and no dental X-rays were available). Another example of dental identification being contributory was when the antemortem dental data was relatively complete but there was only limited amount of postmortem information (e.g., only a small piece of jaw or just one tooth). Dental identification was able to play such an important role in the September 11th disaster in part because antemortem dental records in the United States were, generally, highly complete and readily available.

In order to handle the huge amount of data, forensic odontologists working on the September 11th disaster used a computerized dental identification system called WinID. WinID is a database that stores antemortem and postmortem dental information about physical descriptors, pathological injuries, and anthropologic findings. These findings are used to match missing persons to the unidentified victims [13]. WinID is one of several available forensic dental computer systems. For example, Interpol offers another computerized identification system that is used in Europe called the DVI system. Unlike WinID, DVI not only has dental identification capabilities, but also is a general-purpose forensic tool to store and match other data, such as information about the victim's overall physical description, autopsy findings, personal belongings, DNA profile, etc. Computerized systems have become increasingly important in mass disasters, wherein dozens, hundreds, or even thousands of potential antemortem data sets must be matched to postmortem data sets.

Although September 11th is particularly memorable because of the human and economic scale, other mass disasters occur with dismaying frequency. Although airline crashes come to mind most readily, wartime crimes, such as those in Kosovo

[14] in the mid 1990s, ship or ferry disasters, and natural disasters are also significant. Airline and other transportation disasters are particularly notorious and difficult to deal with, perhaps because of their unexpected occurrence and frequently multinational implications. The severe trauma these victims often undergo also presents particular challenges to forensic teams.

SAS 686 Crash, Milan, Italy

On 8 Oct 2001, at Linate Airport in Milan, Italy, an SAS MD-87 airplane with 110 crewmembers and passengers on board was ready to take off. It was cleared to reposition itself onto the active runway, but simultaneously a Cessna Citation II jet with two pilots and two passengers on board was taking off on the same runway. Seconds later, these two airplanes collided and crashed into an airport baggage hangar, causing the death of four additional victims among the ground staff. The planes caught fire and large pieces of airplane wreckage and multiple body parts flew into the air. Fire fighters and rescue crews rushed to the scene, but no one had survived. The accident claimed a total of 118 victims of nine nationalities [15].

Following this accident, DVI teams from the respective countries involved began work. Some "home" teams stayed in the passengers' countries of origin and collected antemortem data, whereas other teams arrived on site to collect postmortem data. Using passenger lists from the airline, the odontologists back in the home countries worked in pairs (checking each other's work) in order to collect and enter all available antemortem dental data from dental records into the Interpol DVI system. The on-site teams simultaneously entered the postmortem data into the same system. The DVI software allowed the team members to match the antemortem and postmortem data and produce possible matches. I was in Copenhagen at the time and joined the Danish DVI home team in collecting antemortem data.

This multinational disaster in Milan involving nine different countries demonstrated several important points. First, forensic odontologists must be familiar with different countries' dental record-keeping systems (including legal standards). Dental record-keeping standards in different countries vary widely, far beyond the obvious language differences. Some countries, such as Sweden, have elaborate clinical documentation requirements, whereas other countries have no particular requirements beyond legal minimum standards for billing [16]. Second, dental conventions and standards used in the dental record also vary widely. For example, European dental records refer to the right lower third molar as tooth number 48, but, in the United States, it is called tooth number 32. Forensic odontologists must be aware of these different standards and the various terminology systems used. Third, the Milan disaster also indicates the need for forensic odontologists to reach agreement on international standards to collect antemortem and postmortem information, such as the Interpol DVI system and WinID that were previously described. The Interpol DVI system is particularly useful because it serves to integrate the victims' dental, pathological, anthropological attributes (e.g., clothing, documents, jewelry), and personal information. Systems such as Interpol DVI and WinID allow the evidence to be combined and

viewed in a single system. Both systems also permit remote, on-line collaboration by antemortem "home" teams that are physically separated from the on-site teams.

Scandinavian Star Ferry Fire

The Scandinavian Star was a European ferry that in 1990 experienced a disastrous arson-caused fire at sea, resulting in 158 deaths. Many victims could not be visually identified because they were burned beyond recognition. A team of forensic investigators, including forensic odontologists, was called up to secure evidence for identification. In this case, the fire was so intense and long lasting that some remains were partly ashed, and even the teeth (that usually resist fire) had started to degrade. Because the remains were so fragile, it was crucially important that the odontologists were able to work on site in order to preserve the dental evidence (e.g., by spraying the remaining teeth with fixatives). Otherwise, as the evidence was recovered, documented, and packed for transportation, it might well have been accidentally destroyed. The four forensic dental teams involved in the Scandinavian Star accident were based at Institute of Forensic Medicine at the University of Oslo in Norway. These teams used the Interpol DVI forms in their work and all victims were positively identified within 17 days. Dental identity was positively established in 107 cases (68% of the total victims) [17]. In cases such as these, dental identification has proven to be extremely effective and reliable.

10.4.3.2 Interpol's Role in Mass Disasters

Interpol is a global organization of 187 countries whose mission is to prevent and combat international crime and to assist in international mass disasters. I have interned at Interpol headquarters, located in Lyon, France. Interpol sets standards and also identifies, coordinates, and assists national and international forensic teams. The agency provides member countries with necessary resources such as the computerized Interpol DVI system. Interpol also sponsors symposia and meetings for DVI teams where the latest forensic techniques are presented. In summary, Interpol provides a support network for the forensic experts in different countries, so that they can work together more effectively.

In addition to its work assisting DVI teams, Interpol maintains and publishes databases that help governments find missing persons and identify unknown victims. Interpol also provides a network of secure computer databases that are accessible to member countries' law enforcement agencies. These databases include data concerning criminal intelligence information (e.g., trends in international crimes), the modus operandi of various criminal and terrorist networks, and information about a variety of police support activities. Interpol's databases and reference collections also encompass comprehensive examples of genuine and fraudulent travel documents (i.e., passports) and currency forgery examples. Finally, Interpol provides a conduit to disseminate information about fugitives and missing persons.

Interpol staff members are top-level experts in various areas of policing and forensic sciences. Forensic odontologists and forensic teams should take advantage of Interpol's resources, particularly in the case of disasters or crimes involving international participants. It is important that all law enforcement agencies, including forensic teams, work together in an effort to create a safer world.

10.5 Police Cases

Although mass disasters are prominent news stories, the daily work of forensic odontologists involves assisting in the solution of everyday police cases. Suppose, for example, that an elderly person lives alone and one day his neighbor calls the police because he has not seen the elderly person for many days. Then the police and forensic pathologist would go to the house and perhaps find a partly decomposed body in bed. In this case, the identity may still be in question, and then the forensic odontologist would be called to verify the person's identity based upon his dental records. This type of work is the bread and butter of forensic odontology. Although this might be termed an ordinary case, the forensic odontologist also becomes involved with fascinating and even notorious criminal cases.

10.5.1 The Case of an Ambitious Surgeon

In one case in which I participated, a well-known female surgeon from a prestigious hospital was suspected of murder. She had an unambitious husband who had lost his job, was known to abuse alcohol, and was reportedly violent. One day she reported her husband was missing. Police started an intensive search. A black garbage bag was found near the victim's home that contained an upper human torso. Soon afterwards, another bag was found containing the lower torso. Body parts kept turning up in a gruesome fashion: a week later legs and arms were found and, finally, the head. These body parts were unusual in that they were precisely cut, as if in a medical amputation. In order to verify the victim's identity, the forensic odontologist examined the teeth and compared the findings to the missing man's dental record. Every detail matched, and the missing husband was therefore quickly identified. The wife was later found guilty in this case.

10.5.2 The Case of a Missing Teen

Sometimes an unusual dental injury or condition can provide the crucial clue needed to establish identity. I participated in one case involving a missing teenage girl who had disappeared without a trace after a birthday party. One year later, some

skeletonized remains were found, but they were badly eroded because the remains were in a gravel pit. The teeth were the only remains in good condition because (as previously mentioned) teeth are the most resistant tissues in the human body. Some of these particular teeth were stained in a characteristic pattern – a horizontal, gray line in the enamel – consistent with childhood exposure to tetracycline, an antibiotic normally not given to children. Indeed, medical records showed that the missing girl had accidentally received tetracycline when she was approximately seven years of age. The stains in the skeletal teeth were in those permanent teeth that would have developed at approximately age seven years. This case shows that teeth may have particular characteristics, such as discoloration owing to antibiotics, which provide relatively unique and important dental evidence that can solve the case.

10.5.3 The Case of the Pink Teeth

Another example of unusually colored teeth was the result of a postmortem cause, not antemortem damage. This was the "case of the pink teeth." Townspeople came across a grisly find on a nice spring day when the sun was shining and the resulting snowmelt uncovered a corpse on the bank of a local river. Police were called to the scene and uncovered a partially skeletonized body with shoes and jacket still on. The male corpse was brought to the morgue for autopsy, where it was found that one of the most remarkable features was that the teeth were pink. The jacket included a wallet and driver's license, indicating that the corpse was that of a taxi driver who had been missing since the previous fall. Therefore, although identification was not in question, the mechanism of death was. The body was partly skeletonized and there was no obvious bullet wound or trauma. However, the pink teeth strongly suggested a death by strangulation. The phenomenon of pink teeth is typically produced by engorgement of the pulp and dentin of the tooth with blood. This can occur when venous pressure in the head is raised, such as during strangulation or choking. When this happens, the erythrocytes (red blood cells) are released into the tooth's pulp and dentin. Development of this appearance takes a long time after death, as the erythrocytes must decay, and a wet environment aids the decay process. These factors were both present in this case [18]. The presence of the pink teeth led the forensic pathologist to more closely examine the hyoid bone ("Adam's apple"), which was fractured in a manner consistent with strangulation. The suspect – a late evening passenger – finally confessed that he had strangled the driver from behind in order to take the last of that day's fares.

10.6 Injury Analysis

Another cornerstone of forensic odontology is the analysis of injuries. These include bite marks on a victim or perpetrator, other injuries that imply a biting mechanism, or facial injuries in criminal, civil, or malpractice cases. For example,

who committed that sexual assault and bit the victim? Did the victim bite back, and, in that case, do the suspect's injuries match the victim's teeth? Was someone's dental injury really caused by that bar fight, or was it pre-existing? These are the sorts of injury questions forensic odontologists answer.

10.6.1 Bite Marks

One unique branch of forensic dentistry attempts to match a victim's bite mark to the unique dentition of a suspect. These cases are not uncommon. For example, one case involved a young woman who had just left a party and was on her way home. She matched the profile for being a good target: walking alone on a quiet street, distracted by using her cell phone, had long hair that was easy to grab, and was wearing high heels (making it hard to run away). She was later found sexually assaulted and murdered, and a severe and distinctive bite mark was found on one breast. The mark was particularly distinctive because it was an indented, three-dimensional mark. That showed that the bite had been inflicted around the time of death even shortly after death. If the woman had been alive for even a short time afterwards, the normal reaction of live tissue would have caused the mark to become raised. The finding of the three-dimensional bite mark is significant because it tells us that the person who bit the woman was present and in physical contact with the woman at the time of her death and most likely also responsible for the death. In this case, the forensic odontologist who examined this mark matched it to the unique misalignment of the suspect's teeth. The suspect was subsequently arrested, convicted, and sentenced to life imprisonment.

Recently, the reliability and validity of bite mark identification in criminal proceedings has been seriously questioned. Bite mark evidence is variably employed around the world. It is little used in Europe, frequently used in South Africa, and has been variably used in the United States, with notable recent controversy. In a landmark report, entitled Strengthening Forensic Science in the United States: A Path Forward [19], the National Academy of Sciences performed a comprehensive analysis of forensic science methods and results in the United States. The National Academy determined, among their many findings, that bite mark analysis cannot provide conclusive identification of suspects. For example, the report cites the fact that bite mark impressions and photographs are usually compared with one or more suspects' teeth, but not to non-suspects' teeth. As a consequence of this practice, there is no scientific evidence to indicate what percentage of the non-suspect population could have made a similar bite mark (i.e., the likelihood of a "false-positive" identification). Furthermore, victim bite marks are often only partial, and these marks change over time due to skin elasticity, swelling, inflammation, and healing. It is therefore not too surprising that there is no scientific evidence that different forensic experts, or the same expert over a period of time, can consistently make reproducible, bite mark based, identifications. The American Board of Forensic Odontology has provided guidelines for bite mark comparisons terminology and methods. However, as the National Academy report points out, there are no

requirements that the guidelines be used in providing evidences in courts, and serious doubts as to whether the general approach of bite mark analyses meets the Daubert precedent [20] for scientific reliability.

10.6.2 Facial and Dental Injuries in Civil or Criminal Trauma

Dental injuries occur relatively frequently in family disputes, brawls, and gang fights. The forensic odontologist is sometimes called to determine how the dental injury happened (the trauma mechanism) and what damage was incurred. The forensic odontologist provides evidence that may show who is to blame for the injury, so that a court may subsequently rule who is to pay the costs of the treatment and suffering. For example, in one case I have seen, a man claimed that his front teeth were kicked out in a recent fight. He attempted to get compensation for his injuries from his alleged assailant. However, our examination showed that this "victim" had severe periodontal disease that likely explained the missing teeth, and dental X-rays showed that the bone around the teeth had long been healed. In this case, the claim was clearly fraudulent, although that fact would not necessarily be obvious to a lay jury or even to a treating physician. Forensic odontologists are frequently called on to validate assault cases or civil lawsuits for trauma or injury, and they can often provide conclusive testimony.

10.6.3 Malpractice Cases

Forensic odontologists also take part in malpractice cases. These cases often involve some long-term treatment that has had a poor result. For example, an orthodontic treatment may result in undesirable alignment of the teeth. Malpractice cases can also result from a failure to diagnose. For example, the treating dentist may fail to recognize a cavity. If that cavity then gets bigger and reaches pulp chamber, the tooth often requires root canal treatment and an extensive crown, instead of just a simple filling. In these cases, the patient may ask for compensation and the forensic odontologist may be asked to provide evidence.

10.6.4 Anthropology and Archaeology

Anthropology is also an important field in forensic odontology – and one with surprising applications to criminal cases as well. There was a news report indicating that three sets of fetal remains were discovered in an attic during remodeling. Were these children stillborn, or born alive and then murdered? The forensic odontologist may be called on to provide that answer, and they may do it using the same anthropological techniques used to assess the age and health status of ancient children.

Forensic odontologists may work in collaboration with archeologists to examine persons who are long dead, such as ancient peoples whose remains are uncovered in archeological digs. For example, I have been involved in several anthropological projects involving investigation of skeletal remains of the Middle Helladic period (approximately 2000–1700 BC). These projects involved ancient peoples from the Lerna and Asine areas of ancient Greece, nearby present day Nauplion, Greece. I worked closely with both archaeologists and anthropologists to estimate the age and health of ancient individuals based on their dental remains [21]. In the Asine and Lerna studies, the main focus was on children and even fetuses. The death rate was high among young children and infants in ancient Greece. In this study, a subject's health and nutritional status was estimated by examining the extent of dental enamel hypoplasias. Hypoplasias are visible both grossly (when severe) and microscopically. These lesions indicate a reduction in enamel growth, usually resulting from severe illness or malnutrition, which are conditions of great concern to anthropologists.

The anthropologist in this study also wished to determine whether the infant skeletons represented live births or stillbirths. Many infants in the Middle Helladic period were probably stillborn. I was able to estimate whether a fetus had been born alive or was stillborn by determining the presence or absence of the "neonatal line." The neonatal line is similar to an enamel hypoplasia, but represents the changes in dental growth that occur acutely at birth instead of changes related to illness later in childhood. Thus, infants who are stillborn lack the neonatal line because they have not undergone the birth process. The presence or absence of the line is determined by microscopic examination of a sectioned tooth. Such a technique has obvious applications in criminal cases, as indicated in the attic example.

10.7 How to Become a Forensic Odontologist

Few degree programs in forensic odontology exist, so formal education is not always easy to obtain. After obtaining my dental degree, I took a PhD in forensic medicine with a specialization in forensic odontology. The program, based at the University of Helsinki and University of Tartu, included a set of courses in forensic pathology, death investigation skills, causes of death, and other fields in addition to the dental forensic science. The dental forensic sciences studied included dental anthropology, embryology, and dental development. I also attended special seminars and courses, such as those offered by the United States Armed Forces Institute of Pathology in Maryland and the Karolinska Institute in Sweden. To some degree, forensic odontologists must often put together their own curriculum by combining courses and materials from different institutions. The aspiring forensic odontologist is also well advised to join the American Academy of Forensic Sciences' Odontology Section and participate at the annual meetings and continuing education activities.

Of course, the very first step to become a forensic odontologist is to go to dental school and become a qualified dentist. Many forensic odontologists are part-time clinical dentists and, even if they eventually give up clinical practice, they will still need to have excellent clinical knowledge. Subsequent training may involve a formal program, but at a minimum has to include investigative skills and a thorough grounding in forensic pathology. The best way to achieve the investigation skills is to work on an active, multidisciplinary forensic team. Being involved in actual casework and training with criminalists, police investigators, and medical examiners is an essential activity. Because no forensic case is routine, the odontologist must be trained to a very high standard. In many cases, someone's life is at stake when a forensic examination is performed: a suspect may be convicted or exonerated depending on the forensic evidence. For example, if the suspect's teeth could not have left the bite mark that was observed on the victim's skin, then the suspect could be exonerated. Likewise, based on neonatal line analysis, the forensic odontologist may find that a baby whose body was found discarded was in fact a murder victim, not an unfortunate stillbirth. Small and seemingly unimportant pieces of evidence are almost always worth investigating and so the forensic odontologist must be patient and painstaking in their work. Sometimes, as the first case in this chapter has indicated, even a small tooth fragment can provide the missing piece that unlocks a forensic puzzle.

The next step in becoming a forensic odontologist is to gain an advanced degree if possible and to pursue board eligibility in forensic odontology. As indicated previously, very few advanced degree programs are available. However, there are a number of continuing education courses and short courses that can prepare a forensic odontologist short of a full doctoral degree. For example, the laboratory of Dr. David Senn at the University of Texas at San Antonio offers several such courses (Ref. http://www.utforensic.org/fellowship.asp). The American Board of Forensic Odontologists does board certification. However, the certification standard is very rigorous and maintaining currency is difficult for forensic odontologists who are not full time. This may explain why only a minority of forensic odontologists actually achieves board certification through the American Board of Forensic Odontologists. One recent study found that highly trained (not necessarily board certified, however), as opposed to medium- and low-trained forensic odontologists, achieved significantly higher identification accuracy [22]. This finding strongly emphasizes the critical role of training and recurrent education for forensic odontologists. One cannot emphasize enough how important it is to join a recognized, multidisciplinary forensic team to acquire this training and experience.

10.8 Conclusions

Forensic odontology is an exciting field that can combine one's interests in clinical dentistry and criminal investigation. In this exciting field, forensic odontologists may often have the chance to "pull the rabbit out of the hat" and supply the missing

piece to a forensic puzzle by means of their detailed knowledge of dentistry, forensic medicine, and criminal investigation.

Forensic odontologists start as highly trained clinical dentists, familiar with tooth development, oral anatomy, disease pathology, and dental surgery and restoration. They combine this specialized clinical knowledge with additional criminal investigative skills in such areas as evidence recovery, documentation, and analysis. This unique combination of clinical and forensic skills makes them uniquely skilled to investigate criminal cases when dental evidence is relevant. Most forensic odontologists participate as part of a wider multidisciplinary forensic team that includes criminalists, police officers, forensic pathologists, and other specialists. Legal cases may quite often turn to the evidence that forensic odontologists are able to interpret. Forensic odontologists often investigate questions of identity in single cases, determine the age of unknown persons living and dead, and analyze facial and dental injury patterns. They almost always play a critical role in mass disaster victim identification, such as the September 11th tragedy. They even play essential roles in purely scientific work, such as forensic anthropology and archeology.

Someone who wants to become a forensic odontologist must first successfully complete dental school and then combine their clinical qualifications with an interest in forensic and criminal matters. Additional training required beyond dental school may consist of attending short-term courses or obtaining an advanced degree in forensic medicine. Most important, the forensic odontologist should join and actively participate in a multidisciplinary forensic team. This teamwork helps to train and keep the forensic odontologist sharp. In this exciting field, forensic odontologists often have the chance to supply the crucial missing piece of a criminal or forensic puzzle that has eluded others.

10.9 Questions

1. Name at least three other professional disciplines with which Forensic Odontologists must be familiar.
2. List at least four items that can be called dental evidence.
3. What sort of academic and practical or experiential qualifications should a forensic odontologist have?
4. What is the main focus – the bread and butter – in the work of a forensic odontologist?
5. What is reconstructive postmortem dental profiling?
6. How were the victims from the Asian Tsunami disaster of 2004 identified?
7. List at least three “primary” means of forensic identification.
8. List at least three “secondary” means of identification.
9. How can one train to become a Forensic Odontologist?
10. What is the dental neonatal line and how is it useful to the forensic odontologist?

10.10 About the Author

Helena Soomer Lincoln D.D.S., Ph.D. was born in Tallinn, Estonia, and trained in Dentistry at the University of Tartu (1996) and in Forensic Medicine at the Universities of Tartu and Helsinki (2003). As part of her Ph.D. training, Dr. Soomer Lincoln worked at the Karolinska Insitute (Sweden), the University of Oslo, University of Copenhagen, Scotland Yard (London, U.K.), the Organization for Security and Cooperation in Europe (OSCE), the International Red Cross representing Eastern Europe and Scandanavia (Geneva, Switzerland), and Interpol (Lyon, France).

Dr. Soomer Lincoln is a Fellow of the American Academy of Forensic Sciences, Odontology Section, admitted in 2004. Dr. Soomer Lincoln has several academic publications dealing with the reliability and reproducibility of forensic science methods. After completing three years as an instructor at the University of Utah School of Medicine, Department of Neurobiology and Anatomy, Dr. Soomer Lincoln re-entered dental school in 2008 at the University of Michigan in order to obtain a North American clinical degree and subsequent U.S. licensure. She graduated from the University of Michigan school of Dentistry in 2010 and is currently a general practice resident at the University of Michigan Hospital Dentistry.

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Chapter 11
Forensic Pathology and the Investigation of Death

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Contents

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11.1 The Origins of Death Investigation

When death occurs suddenly and unexpectedly or by violent means, society looks to public authorities for answers and accountability. The need to understand why death occurs appears to be universal, and our history contains many references of society's attempts to comprehend this never-ending mystery. In the Middle Ages, under the Emperor Charlemagne (ca. 806), death investigation became formalized in legal and administrative documents known as the capitularies of Charlemagne. The capitularies mandated that "proofs as clear as day" be brought forth to explain crimes of a serious nature. Officials in Charlemagne's time were required to seek out opinions from medical practitioners in cases of physical injury, infant death, and suspected suicide [1].

In Italy around the middle of the thirteenth century, medical consultants were appointed to the courts to assist the legal profession in carrying out death investigation. In Bologna, around 1300, the first medicolegal autopsies were performed when the state ordered postmortem examinations in cases involving suspected homicide and suicide. In addition, postmortems were performed on criminals executed by judicial decree [2].

Between 1241 and 1253, Chinese Commissioner of Justice, Tung Tzu, advanced death investigation practices with the publication of an instructional textbook titled, "*Record on the Washing Away* (*of*) *Wrongs*," also known as "*Collected Cases of Injustice Rectified.*" Tzu's extensive work spans five volumes and explains many critical procedures that later became standard practice in medicolegal death investigation. The first volume describes the inspection of bodies and injuries. A second volume contains notes and methods on postmortem examination. The third, fourth, and fifth volumes hold forth on the appearance of the bodies showing various causes of death. Tzu's seminal work was translated into English in 1855 by the British scholar W.A. Harland, M.D. [3].

The beginning of death investigation in the United States dates back to the English coroner's office, a post that drew more on the skills of a tax collector and record keeper than a death investigator trained in science and medicine.

The office of the coroner was officially established in England in 1194, during the reign of Richard I. Under King Richard, the royal treasury was awash in debt, due in part to the funding of the Crusades. To replenish the king's wealth, the crown confiscated private property and personal belongings from individuals who died and from those were responsible for bringing about unnatural death. It was the coroner's job to record information surrounding these events. If a horse and cart ran over a man with death resulting, the coroner prepared his report, recording the circumstances of death and documenting – for the benefit of the crown – the value

of the horse and cart. These official reports, known as "pleas of the crown" or "coroner's rolls," provided the legal evidence justices relied upon as they rode the county circuit hearing cases and dispensing the king's justice. Today, some 460 of these early coroner's rolls remain in the Public Records Office in London [4].

To ensure accurate reporting in cases involving unnatural death, British coroners were required to visit the scene and view the body, taking note of any signs of violence and the types of wounds present. Coroners also convened official inquests, summoning witnesses and local townspeople in advance of ruling on an official cause of death.

However, the British coroner system, unlike some European death-investigation protocols in place at the time, did not require coroners to apply scientific-based inquiry or medical knowledge to their death investigation. Thus, when the British arrived in America in the 1600s, they brought with them their unscientific coroner system. The British system continued in the United States well into the 1800s, when Massachusetts and Maryland first advanced the idea of having trained medical physicians conduct medical death investigations. By 1860, Maryland required a physician be present at a coroner's inquest. And, in 1877, Massachusetts replaced coroners with medical examiners who were trained as licensed physicians [5].

However, it was not until 1928 that the National Academy of Science National Research Council's Committee on Medical Legal Problems recommended the development of medicolegal institutes, where medical examiners would affiliate with hospitals and universities [6]. In 1954, the National Conference of Commissioners on Uniform State Laws issued the Model Post-Mortem Examinations Act, advocating "greater competence be assured in determining causes of death … (recommending) each state should set up an Office headed by a trained pathologist …" Unfortunately, these recommendations have yet to be implemented [7]. As a result, as of 2004, death investigation in the United States remains a jumble of more than 2,000 separate death investigation jurisdictions and systems.

Yet there is hope for reform. A February 2009 report from The National Academy of Sciences publication titled, "Strengthening Forensic Science in the United States," revisited some of the National Conference of Commissioners' recommendations posed over a quarter century ago. In the February report, the authors advocate establishing a medical examiner system with proper medical examiner staffing, equipment, administration, education, and training, with the aim of eventually eliminating the existing coroner system. Authors of the study also support research education and forensic pathology training in collaboration with medical universities (Recommendation 11) [8].

11.2 Investigating and Documenting Deaths in the United States

Every known death in the United States is documented and recorded. Each year nearly 2.5 million deaths occur in the United States, according to data published by the Centers for Disease Control and Prevention [9]. The documentation

process begins by initiating an official document called the death certificate. Completing the death certificate is a collaborative effort, usually involving the decedent's next of kin, the funeral director, and a medical doctor. The next of kin confirms the decedent's name, age, and place of birth, as well as other biographical data, such as employment and veteran's status. The funeral director documents body preparation for embalming or cremation. In addition, the funeral director notes final disposition of the body, which may be a cemetery, a vault, or a medical facility in the case of anatomic donation. However, it is a medical doctor who is solely responsible for investigating the reason for the death and documenting the circumstances under which it occurred. A generic death certificate is found in the Appendix.

Authority for signing the death certificate rests with the medical examiner, the coroner, or with other physicians associated with the decedent. The decedent's primary care physician or attending doctor at the time of death may sign the death certificate. Both primary care and attending physicians also may certify their patient's cause of death when the death is the result of a known disease process. However, when the death is sudden or unexpected, or involves injuries or possible unnatural circumstances, determining the cause of death becomes the sole province of the medical examiner or coroner.

11.2.1 Reportable Deaths

Determining which deaths are reported to the medical examiner or coroner's offices for investigation depends on the applicable laws in the city, county, or state where the deaths occur. Reporting requirements also differ when the death occurs on federal land or on Indian reservations. While there is some variation in death-reporting requirements across jurisdictions, all jurisdictions have standardized rulings requiring a medicolegal death investigation in any death that is sudden, unexpected, unexplained, or involves injury. Deaths in these categories may include those caused by natural disease processes previously unrecognized or undiagnosed, or in cases in which the decedent's attending physician cannot properly certify the cause of death (Table 11.1).

The majority of deaths reported to the medical examiner or coroner's office are referrals from attending physicians in hospitals or from police. However, other individuals, such as states' attorneys general, or other medical personnel trained in jurisdiction reporting requirements, also initiate cases. In addition, relatives of the deceased who suspect foul play or medical error, as well as funeral directors who discover suspicious marks on a body, have the right – and obligation – to report cases to the medical examiner's office. In general, anyone with knowledge of a possible unnatural death may notify the medical examiner's or coroner's office for assistance.

Table 11.1 Reportable deaths investigated by a medical examiner's office

Disease that develops following injury
After or during anesthesia or a therapeutic, diagnostic, or surgical procedure
Infant/newborn death without medical attendance
Job-related injury or death while at work
Persons in custody: jails/holding cells/prisons/state mental institutions
Injury or violence
Environmental exposures
Body whose identity is unknown
Death while in apparent good health
Deaths unattended by physician
Death due to neglect
Death when the body is be cremated
Death in any unusual, unnatural, or suspicious circumstances
Public places (parks, buildings, aircraft, or ships in jurisdiction)
Suspected contagious disease or agent
Alcohol/drugs/poisons/chemicals
Suspected human anatomic parts
In-hospital deaths that are unexpected or involve injury
Deaths within 24h after admission to hospitals or other healthcare facilities; all death-on-arrivals (DOAs) at all healthcare facilities
Organ or tissue donation is desired by the individual or family

11.2.2 Outcomes of Reported Cases

Once deaths are reported, the medical examiner or coroner initiates a case review that results in one of the following determinations: (a) the case from the jurisdiction is accepted and the decedent is brought to the medical examiner's office for further examination; (b) a death *in absentia* investigation, whereby the case comes under legal jurisdiction but does not require the body to be transported to the medical examiner office for examination; and (c) the case does not fall into the medical examiner or coroner's jurisdiction and will be transferred to the decedent's doctor, in which instance, the referral may be designated "no case" or "declined case" [10].

A typical case where no further investigation is warranted would involve the death of an elderly person who expires at home from a known natural disease capable of causing death. In such situations, law enforcement and scene investigators must confirm that no suspicious circumstances existed at the death scene. Once this is established, the medical examiner may then permit the primary care physician to complete the death certificate, allowing the body to be transported directly to the funeral home.

Unlike the natural death case noted in the example above, the *in absentia* case may involve a non-natural death. However, in this instance, the death must show no evidence of suspected criminal involvement or foul play. Adequate information about the decedent's condition must be obtained to allow the medical examiner to

determine the cause of death to a reasonable degree of medical certainty without performing a postmortem examination. *In absentia* cases almost always involve victims who are hospitalized for a period of time or have extensive and well-documented medical histories. Here, the medical examiner relies on the decedent's hospital records, rather than a body examination to determine the cause of death.

In instances where the jurisdiction accepts the case, the medical examiner takes custody of the body, conducts a death scene investigation, and performs a body examination to determine the cause and manner of death. At the conclusion of the investigation and examination, the medical examiner completes the death certificate.

The funeral director files all completed death certificates with the bureau of vital statistics in the jurisdiction, with copies made available to the family and other official agencies. Although death certificates are legal documents, they are subject to change. Physicians signing the death certificate base their opinions on information available at the time of their investigation. Should additional information come to light after the physician signs the death certificate, a reinvestigation and possible change to the cause and/or manner of death may be justified. Forms to amend or change the death certificate are available at vital statistics offices.

The most common reason for amending a death certificate is a cause of death determination initially listed as "pending." This designation indicates that the cause of death remained unclear after the postmortem exam and associated testing and scene investigation. In such cases, further medical testing may be warranted to analyze body fluids for drugs or poisons, or for tissue analysis. Testing may take weeks or months to complete.

11.2.3 Uses of the Death Certificate

The death certificate is an important legal document used by many agencies and families as the basis for filing insurance claims and estate settlements. It is also widely used in the criminal justice system and frequently introduced as evidence in the courts. However, death certificates also play a lesser known but equally important role in providing government agencies with critical data used to identify and monitor a broad range of health and safety issues. Often, such concerns as environmental and occupational safety, consumer product safety, medical errors, deficiencies in medical care monitoring, detection of emerging infectious disease, and acts of bioterrorism, first appear when noted on the death certificate completed by the medical examiner.

Yet for all the hard work medical examiners and coroners invest in death investigation, some portion of those efforts can be compromised by the lack of standardization among the nation's 2,342 jurisdictions [11].

11.3 The Cause and Manner of Death

The cause and manner of death are opinions based on a reasonable degree of medical certainty that indicate what had caused the body to cease functioning (the cause of death), and what events or circumstance were present when the death occurred (manner of death).

The medical examiner must obtain as much information as possible about the decedent before rendering an opinion on the cause and manner of death. These determinations are based on several factors, not the autopsy alone. Four general components comprise the forensic pathologist's death investigation: (1) scene investigation, (2) forensic autopsy and laboratory testing, (3) police reports and witness statements, and (4) medical history and hospital records.

Medical examiners arrive at cause and manner of death determinations by seeking answers to what is traditionally known as "The Six Questions of Forensic Pathology": (1) Who was the victim?, (2) When did the death and/or injuries occur?, (3) Where was the scene; what were the circumstances?, (4) What injuries are present?, (5) Which injuries are significant?, and (6) Why and how were the injuries produced? [12].

Determination (sometimes called certification) of cause and manner of death can be a straightforward matter, but, at other times, making the correct determination can require the careful evaluation of a host of complex and competing issues. The medical examiner must have a thorough grounding in general medical training, as well as appropriate training and experience in forensic pathology. Additionally, the medical examiner must be proficient in forming opinions based on available information, applying the scientific method and sound reasoning. Pressure may be brought to bear on the medical examiner because his or her opinion is at odds with prevailing political sentiment or media speculation. Despite these sometimes intense pressures, forensic pathologists must be able to confidently – and accurately – voice their findings to the public.

11.3.1 Cause of Death

In the broadest sense, the cause of death is defined as the disease or injury that brought about a person's death. Specifically, the cause of death is the injury, disease, or combination of the two that begins the train of physiological disturbances, either brief or prolonged, which produce the fatal termination.

Although initially appearing clear-cut, the cause of death is actually composed of several parts: the mechanism of death, the immediate cause of death, and the proximate cause of death. The medical examiner, therefore, must apply scientific and medical knowledge, along with thoughtful analysis of each of these elements, to establish a cause of death diagnosis [13].

11.3.1.1 Proximate Cause

The proximate cause of death is the primary or underlying injury or disease that ultimately leads to death. Understanding the existence and the correct identification of the proximate cause of death is critical to understanding situations where a delay exists between the initiating disease or injury and the ultimate death of the person.

The proximate cause of death can be identified by its linkage to the actual death by a series of foreseeable events. For example, a victim dies of wound infection and sepsis several weeks after receiving a stab wound. Although the infection caused the body to stop functioning (the immediate cause of death, see below), the proximate cause of death is the stab wound. The correct identification of the proximate cause of death may initiate a police investigation into an event occurring years before, such as when the victim of a gunshot wound dies of complications of that injury many years later. The death, now ruled a homicide, will cause the police to open a homicide investigation.

A criterion for assessing the existence of and validity of a proximate cause of death is whether the individual recovered to a similar baseline of health and functioning experienced prior to the proposed proximate event. A documented chain of foreseeable events, unbroken by recovery or substantive intervening cause, must exist between the proximate event and the eventual patient death.

11.3.1.2 Immediate Cause of Death

The immediate cause of death is the injury or disease that caused the body to stop functioning at a particular place and moment in time. It is the sequelae that develop from the proximate cause of death. In many medical examiner cases, the time between the onset of disease or injury and the death of the individual is very short or even simultaneous with the event, thus combining the proximate and immediate causes of death into one term. Such cases typically involve instances in which an individual collapses and dies from a massive myocardial infarction (heart attack), or a death from brain injuries minutes after the victim experiences severe blunt force trauma from an automobile accident, or during emergency surgery for treatment of gunshot wounds.

11.3.1.3 Mechanism of Death

The mechanism of death is the physiologic or biochemical disturbance that is incompatible with life. This mechanism of death is initiated by the proximate and immediate causes of death. However, the mechanism of death itself is not a cause of death. The mechanism is not etiologically specific and gives little information about what actually caused the death. For example, death from the terminal mechanism

of cardiac arrhythmia can be the result of many true causes of death, such as myocardial infarction, brain injury, or prescription drug overdose. The terminal mechanism of exsanguinations (bleeding to death) can occur because of a gastric ulcer or a stab wound in the chest.

11.3.2 Analysis of Cases

These different components that comprise the full cause of death are best illustrated by case example. Consider the case of a 33-year-old woman who had been confined to a wheelchair for ten years. When she failed to appear at work, her coworkers checking on her wellbeing found her slumped in her wheelchair unresponsive in her living room. Because the death was sudden and unexpected, the medical examiner assumed jurisdiction and a medicolegal death investigation was conducted. The cause of death was revealed on postmortem examination: massive bilateral pulmonary emboli were present in the right and left branches of the main pulmonary artery. Examination of the deep veins of the leg revealed some residual thrombus present. Thus, the immediate cause of death was pulmonary embolism. The pulmonary embolism caused the body to stop functioning at that particular time. The exact physiology of death, or mechanism, caused by a massive pulmonary embolism is acute heart failure. The event that initiated the series of events that led to her death was a spinal cord injury, which confined her to a wheelchair, a condition from which she never recovered. This non-ambulatory status caused the venous thrombosis to develop in her legs, which then dislodged and traveled (embolized) to the pulmonary artery. The spinal cord injury was caused by a gunshot wound to her spine that occurred during an attempted robbery. Thus, based on this information, the full cause of death statement is acute heart failure (mechanism) due to pulmonary embolism (immediate cause of death) due to immobilization from spinal cord injuries from a gunshot wound (proximate cause of death). The manner of death is classified as homicide.

In another example, consider the case of an individual hospitalized for several weeks due to a head injury. Due to the prolonged hospital stay and decreased level of consciousness, pneumonia developed. Pneumonia then caused respiratory failure (the mechanism) and death. Attributing the cause of death solely to pneumonia (the disease that caused the death at that particular time), misses the important fact that the pneumonia developed as a consequence of the head injury. Pneumonia is a natural manner of death, however, when correctly linked to the proximate cause, the manner is accident or homicide, depending on the circumstances of the head injury.

In many cases where the injury or disease causes a sudden, rapid death in a single episode, the mechanism and immediate and proximate causes, may be combined into one single term on the death certificate. This would be the case in a fatal gunshot wound to the head where the time between the initiating event and the demise is essentially instantaneous. The cause of death can be listed simply as gunshot wound of the head, or brain injuries and skull fractures due to gunshot

wound of the head. Without an in-depth understanding of the components of the cause of death, it is easy to see how cause of death can be mislabeled.

11.3.3 Manner of Death

In addition to the cause of death, the forensic pathologist must determine the manner of death. The manner of death is a one-word description of the circumstances under which the death occurred. This opinion reflects the totality of the information that has been gathered in the investigation, and includes not only the autopsy but police reports, witness statements, scene investigation, and medical records. It is based on all available information pertaining to the circumstances of the death.

There are five general distinctions for manner of death: natural, accident, homicide, suicide, and undetermined. Some jurisdictions recognize a sixth manner of death, that of therapeutic complication [14]. As in the case of the cause of death, the manner of death may also be listed as pending, when further investigation or testing is warranted. A death certificate, even with cause and manner pending, acts as a legal document that certifies the death of the person and allows burial of the body to take place. After completion of testing and investigation, the manner can then be "unended" to one of the five manners of death.

The manner of death is certified as natural when the death results solely from the progression of a disease with no intervening outside events.

Deaths due to the influence of a hostile external environment are termed accident when they involve the contribution of an element from outside the body. Examples of hostile external environments include water, in the case of a drowning death, or a moving motor vehicle in the case of an automobile–pedestrian fatality. Accidental deaths may involve some degree of negligence but fall short of suicidal or homicide intent.

When death is intentionally self-inflicted, it is classified as suicide. The designation of suicide means that the medical examiner's investigation has shown clear evidence that the individual intended to take his/her own life, and that the act itself required deliberate steps (i.e., was self-inflicted).

A homicide is a death that has resulted from the deliberate action (or in some cases non-action, such as neglect) of another. The decision to initiate criminal proceedings, however, is up to the prosecuting attorney and/or grand jury. Sometimes the dividing line between accident and homicide may be a gray zone and is only resolved in the legal arena by assessing the level of intent and/or premeditation.

The manner of "undetermined" means that the medical examiner, after exhausting all available sources, still has inadequate information to substantially support natural, suicide, accident, or homicide as a manner of death.

Because all sudden or unexpected deaths in hospitals or during the medical, surgical, or diagnostic procedures are reported to the medical examiner's office, the medical examiner may become involved in the investigation of deaths due to

alleged medical malpractice. The medical examiner is a specialist in forensic pathology and usually not qualified to comment on a particular standard of care except in extraordinary circumstances. The medical examiner does, however, have a role to play in providing important information in malpractice ligation. In the legal system, there are three requirements for a plaintiff to prevail in a malpractice case. The first is to prove that the doctor owed duty to the plaintiff; second, that the doctor breeched this duty by failing to adhere to the standard of care; and, third, that the breach of duty caused injury to the patient. The information provided by the forensic pathologist usually speaks to the third requirement of how the injury and/or death of the patient arose [15].

Death while under medical care, however, does not necessarily mean unsatisfactory or negligent medical care: because all diagnostic and therapeutic procedures have risks. Because it is possible for any type of medical care to contribute to or be directly responsible for the death of a patient, it is important that medical negligence be differentiated from recognized complications of medical and surgical procedures and treatments. The manner of death, therapeutic complication, is used by medical examiners in some jurisdictions (currently New York and Massachusetts) to indicate the manner of death in such circumstances.

11.4 The Autopsy or Postmortem Examination

Autopsy, which literally means, "to see for oneself," is an important investigative tool that aids pathologists in establishing the cause and manor of death. Also referred to as the postmortem examination, the medical procedure allows pathologists to see internal organs and tissue to determine what caused the human body to cease functioning. Summing up the role autopsies plays in death investigation, Sir William Osler, considered by some the father of modern medicine, notes, "To investigate the cause of death, to examine carefully the condition of organs after such changes have gone in them as to render existence impossible and to apply the knowledge to the prevention and treatment of disease is one of the highest objects of the Physician …" [16].

As we shall see in greater detail below, pathologists perform three types of postmortem exams: a hospital-based autopsy, a private autopsy, and a medicolegal autopsy. Hospital-based and private autopsies are conducted only in cases that do not fall under the jurisdiction of the medical examiner [17]. Of course, all medicolegal autopsies fall under the purview of the medical examiner.

11.4.1 The Hospital Autopsy

The hospital autopsy procedure is reserved for hospital patients who die a natural death after receiving care in a hospital. Because patients have been receiving

medical attention at the facility, hospital staff is well acquainted with the patients' health conditions detailed in medical records. After review of the decedent's chart, hospital physicians may wish to perform a postmortem examination, but, to do so, they must obtain permission from the patient's family. The family may deny the autopsy procedure completely or place restrictions on areas of the body that can be examined.

In the hospital setting, an autopsy is done to evaluate the effects of prior medical treatment and to determine the severity and extent of a known disease entity. The hospital autopsy correlates the patient's clinical signs, symptoms, and diagnostic test results with the actual findings in the body (i.e., a clinicopathologic correlation). The autopsy also supports medical education and contributes to medical research on disease and treatments.

After conducting the hospital autopsy, the pathologist then communicates the results to the treating physician, first through a list of provisional anatomic diagnoses, then by the final autopsy report. Unlike the medicolegal autopsy, the hospital autopsy is not performed to determine the cause and manner of death per se; instead, it is undertaken to elucidate the disease process. The patient's doctor usually completes the death certificate immediately after the death, a time obviously prior to the autopsy results. The hospital autopsy report is the last entry in the patient's medical chart.

The rate of hospital autopsies has steadily declined since the mid 1970s. On average, 60 or fewer autopsies are performed at hospitals each year. Medical examiner autopsies, on the other hand, are usually performed daily, sometimes resulting in hundreds or even thousands of postmortem examinations per year, depending on jurisdiction.

11.4.2 The Private Autopsy

In certain cases, families engage a pathologist to perform a private autopsy to address issues important to the family. Such concerns, while of interest to family members, do not warrant the medical examiner's attention. Typically, a family member or representative, usually an attorney, arranges for the service with payment for the examination made directly to the physician performing the autopsy.

11.4.3 The Forensic or Medicolegal Autopsy

Finally, the forensic or medicolegal autopsy is conducted by a medical examiner or coroner in cases relating to death from injury or when the death is unexpected. These deaths, occurring in the hospital setting or elsewhere in the jurisdiction, are investigated in accordance with local, county, and state laws designed to protect the public interest. Medicolegal autopsies do not require consent from next of kin.

The forensic autopsy considers a broader range of causes of death than those pursued in hospital autopsies. These autopsies include deaths from non-natural as well as natural causes. The forensic autopsy is usually a thorough examination of the entire body. This means all body cavities will be opened and all organs will be examined and described. Tissue samples will be taken for microscopic study, and body fluids and tissues retained for toxicologic evaluation. Toxicologic analysis is rarely done in the hospital autopsy.

In addition to the diagnosis of disease or injury, the forensic autopsy is conducted to preserve trace evidence and identify unknown persons.

The external examination of the body in a forensic autopsy is extremely important and detailed. This is in contrast to the external examination performed in the hospital autopsy, which is often cursory. Examination of clothing for defects and foreign material is an important part of a forensic autopsy. (Clothing is not examined in a hospital autopsy.) The external examination in a forensic autopsy is concerned with the collection of trace evidence, as well as the interpretation of minute findings on the body with detailed descriptions and measurements of injuries.

The external examination includes a search for any foreign substances or secretions on the body. For example, attention is paid to the condition of the fingernails and any associated material, such as skin fragments or fibers that may link a suspect to a homicide. If a sexual assault is suspected, additional evidence may be collected, consisting of pulled and combed pubic hair, pulled scalp hair, and oral, vaginal, and rectal swabs and smears.

When forensic pathologists preserve specimens obtained from the external examination or autopsy, these items must be subject to strict accountability and control. Accordingly, the pathologist initiates a chain of custody document that accounts for any transfer and receipt of materials. Any potential specimens that stray from the custody chain are at risk of being compromised and subsequently ruled inadmissible in the courts. Also important to retain and analyze as potentially contributing to the cause of death are items such as cardiac pacemakers, medication pumps, child apnea monitors, or scuba diving equipment.

In the case of an unknown decedent or a non-visually identifiable decedent, an oral autopsy may take place where the upper and lower dentition is removed for detailed charting and X-ray. The results are then compared with antemortem dental records. Procedures to identify victims in mass fatality incidents such as transportation accidents or catastrophic natural events include not only dental comparisons, but DNA analysis, fingerprints, and full-body X-rays.

Toxicology is not a part of the hospital autopsy procedure, but it is routine procedure in forensic cases. Indeed, any suspicion of a drug-induced death in the hospital must be reported to the local medical examiner. The routine specimens taken for toxicologic evaluation in forensic cases include blood from the heart and blood from a peripheral vessel such as femoral, bile, urine, gastric contents, and vitreous humor. For unusual cases where particular drugs or toxins are suspected, specimens may include nasal swabs, excised intravenous-injection sites, sequestered hematomas, and other tissue such as liver, brain, lung, adipose tissue, skeletal muscle, and kidney.

A blood sample or dried-blood drop on a blood-specimen card is often retained in the event that DNA analysis or genetic studies are required. For example, most medical examiner offices send a dried-blood specimen card from all infant cases to specialized laboratories to look for inborn errors of metabolism. The vitreous fluid of the eye can be sampled for evaluation of the electrolyte status of the deceased in addition to being used for toxicology. Finally, body fluids and tissues may be sent to microbiology laboratories to culture for detection of infecting viruses, bacteria, or fungi.

The forensic pathologist applies specialized autopsy techniques to answer specific questions that are not required in a hospital autopsy [18]. For example, examination of the sphenoid sinus in the base of the skull for the presence of fluid can provide information important to the diagnosis of suspected drowning. Discovering infection in the inner ears by opening the petrous bones is important in pediatric cases. The tongue and posterior oropharynx are always closely examined. Abnormalities there may reveal evidence of seizure activity or suffocation by airway blockage. A layer-by-layer dissection of the neck including musculature, vessels, hyoid bone, larynx, and airway structures is done if there is suspicion of application of force to the neck as in manual strangulation. A posterior neck dissection including vertebral artery dissection is essential in some motor vehicle accidents, falls, and assaults. Special techniques can detect pneumothorax and air or gas embolism. Specialized examination of the extremities includes evaluation of the deep veins of the leg for evidence of thrombosis or the dissection of the bony skeletal of the lower extremities in cases of pedestrian fatalities to better visualize bumper fractures. In pediatric cases of suspected shaking, special dissections allow for assessment of the back of the eye for retinal hemorrhages and the optic nerve for nerve sheath hemorrhages.

Artifacts due to postmortem changes (i.e., damage and changes occurring after death) must be recognized as such by the forensic pathologist and not misinterpreted or misdiagnosed as injuries or disease processes. These include the postmortem changes of rigor mortis (stiffening of the body), livor mortis (settling of the blood according to gravitational forces), algor mortis (cooling of the body), as well as decomposition of changes of autolysis and putrefaction. Changes also occur to the body as a result of exposure to a hostile environment. This may include animal and insect activity, or exposure to fire or submersion in water for prolonged periods of time. Emergency medical and resuscitation efforts can also produce injuries and introduce artifacts to the body unrelated to the cause of death.

Even in cases where the cause of death is obvious and unquestioned, such as multiple gunshot wounds, a full postmortem examination helps reconstruct the circumstances of death and supports the investigation by police. Information from the forensic autopsy helps the forensic pathologist and law enforcement officials understand the relationship of the dead body to other evidence at the scene, such as blood stain patterns, recovered bullets, and the veracity of witness statements.

Establishing the exact nature of internal injuries from the medicolegal autopsy can determine whether any purposeful activity could be carried out by the individual after injury. It also can determine the time to incapacitation or the time to

unconsciousness and death. For example, if a victim of a fatal gunshot wound to the neck was shown to have transected the spinal column at autopsy, the victim would not be expected to run several blocks after being shot. Police can used this type of information to assess the truth of eyewitness reports. In other cases, study and documentation of injury patterns can place individuals in specific positions as occupants of motor vehicles, fix the positions of pedestrians when struck, or determine how safety devices may have failed or were circumvented in workplace fatalities.

The final work product of the forensic pathologic examination is the postmortem examination report. This is usually much more detailed than a hospital autopsy report. It is divided into multiple sections: external examination; evidence of injury; evidence of medical therapy; procedures and specimens; laboratory report results; final diagnoses; cause, manner, and circumstances of death; and a final narrative case summary. The forensic autopsy report is usually a confidential document available to only legal next-of-kin, law enforcement, and treating physicians. However, in some jurisdictions, it is more freely available to other interested parties under public information and freedom of information statutes.

It is important to remember that, although seemingly rather intrusive, the autopsy is a medical procedure carried out by professionals who take great care in preserving the dignity of the decedent throughout the entire examination. As the last doctor to attend to the decedent, forensic pathologists perform their final duties ensuring that surgical incisions do not alter the decedent's appearance or preclude open casket viewing at the funeral home. With such care, survivors are better able to come to terms with their loss and begin the grieving process.

11.5 The Medical Examiner's Office

11.5.1 Definitions

Forensic pathologists who investigate deaths for city, county, and state governments are called medical examiners. They perform their work, not in hospitals, but in medical examiner offices in the jurisdictions in which they serve. The term "medical examiner" can sometimes prompt confusion, as it is also used to identify others besides the forensic pathologist who conducts death investigation. State boards that license medical professionals, for example, are sometimes referred to as the Board of Medical Examiners. And the term "independent medical examiner" can describe a physician who performs physicals for insurance companies.

The distinction between "medical examiner" and "coroner" is also misunderstood. Many regard "medical examiner" and "coroner" as synonymous terms, but they are in fact quite different. Most coroners are elected officials who, as part of their duties, may be called upon to certify a death that has occurred in their jurisdiction. Coroners may hold inquests to interview witnesses to determine how a person

has died. However, coroners are not usually physicians, and, in many cases, they lack professional medical training. To compensate, coroners hire pathologists to conduct autopsies and to furnish postmortem reports for completing death certificates.

In some jurisdictions, another elected official, the justice of the peace, performs similar duties to the coroner. In actual practice, the justice of the peace certifies only a small number of deaths each year. These elected officials in most instances receive only a smattering of death investigation training. And, like the coroner, they rely on the forensic pathologist to conduct postmortems and provide associated reporting for the death certificate. An important distinction separating these individuals from medical examiners is that the latter are appointed by governing bodies or search committees; they are not elected officials. Because of this, medical examiners generally remain free of political pressure that could influence their rulings. However, coroners and justices of the peace, because of their elected status, may be subject to the influence of politically motivated officials or civilian powerbrokers who desire to manipulate facts in an investigation.

Coroner systems work best when the appointed coroner is a forensic pathologist, or when the coroner contracts and works closely with a properly trained forensic pathologist. Only then can there be assurance that the coroner system will work in the public's best interest.

11.5.2 Components of a Medical Examiner's Office

Establishing a medical examiner's office is a costly endeavor involving an array of specialized equipment. A properly equipped office will include: (1) the physical plant including plumbing, ventilation, biological waste treatment, and security, (2) equipment for X-ray, microscopic examination, photography, body transport, and communication, and (3) highly trained staff to handle the caseload.

Funding for the medical examiner's office comes from city, county, or state budgets, but securing these resources is never easy task. In today's troubled economy, medical examiners may find themselves in competition with other agencies and programs, competing for what seem to be an ever-shrinking piece of the budgetary pie. Compounding this is that many politicians and administrations are inclined to focus scarce resources on the needs of the living, neglecting all but the bare essentials at the medical examiner office. However, when this happens, there is often a hidden cost that is not always measured in dollars and cents. Autopsy backlogs may occur that delay criminal justice proceedings or prevent grieving families from coming to terms with an unexpected death. And vital steps in preventing the spread of contagious disease can be delayed if adequate resources are not in place to detect them. Of all issues facing medical examiners today, the budgetary component is perhaps the most daunting.

11.5.2.1 Staff

Even with adequate funding, the medical examiner's office would cease to function if it were not for the dedication and service of a highly trained staff. At the top of this list is the chief medical examiner, who provides the leadership and vision that keeps the organization operating smoothly and efficiently. The chief medical examiner is an experienced, board-certified forensic pathologist who also has a thorough understanding of organizational structure and policy. The chief has many roles to fill, but perhaps none more important than securing adequate manpower to meet a never-ending workload.

Manpower requirements at the medical examiner's office include a component of key individuals who take charge of scene investigations, complete autopsies, conduct laboratory testing, and those who oversee cases to their successful conclusion.

Working under the chief, one or more deputy chief medical examiners assist in overall day-to-day case management and in forensic investigations. Deputies should also be experienced and board certified in forensic pathology. Deputies stand in for the chief medical examiner in his or her absence.

Appearing under deputies on the organizational chart are the assistant medical examiners. Assistants perform the daily postmortem examinations with oversight from the chief and deputy medical examiner. Assistants should have board certification in forensic pathology or be eligible to obtain it. Below this hierarchy are a number of other key positions and areas that come into play during the course of the medicolegal death investigation.

Because the medical examiner cannot respond to every death scene, the scene investigator is dispatched on their behalf. Often referred to as the "eyes and ears" of the medical examiner, these first responders make a general forensic inspection of the body, making note of any pertinent scene evidence that will help the initial police investigation and later assist the forensic pathologist in correlating autopsy results with scene conditions. In addition, scene investigators take custody of the body, and assume control of the decease's personal property, along with any pertinent scene evidence possibly related to the death. Scene investigators also arrange transportation for the deceased to the medical examiner's office.

Scene investigators may have varied backgrounds in law enforcement, emergency response, nursing, or criminal justice. In the past, medicolegal scene investigators received only on-the-job training. However, as forensic science has become more demanding, so has the need to have formalized training for death scene investigators. Today, scene investigators may enroll in training programs and apply for certification to the American Board of Medicolegal Death Investigators. Their performance measures have been set in the NIJ document, Death Investigation: A Guide for the Scene Investigator [19].

The autopsy assistant is the individual who assists the medical examiner in the performance of the autopsy. Because these individuals perform so many tasks, in the past they have been referred to as *dieners*, the German word for "servant." Typically, autopsy assistants have received on-the-job training and may have some background in mortuary or other health sciences. They often

help the doctor with specialized or difficult dissections, weigh organs, assist with photography, prepare the body for the funeral director after autopsy, and maintain the mortuary physical plant and surgical equipment. They do not perform the autopsy itself.

Autopsy assistants often have other responsibilities outside the autopsy suite. These may include transporting the decedent from the scene or health care institution to the medical examiner's office. Besides this, autopsy assistants are well versed in chain-of-custody procedures governing the receipt and authorized release of the body and personal effects to the funeral director. Many medical examiners have noted that it would be extremely difficult for any office to run without the autopsy assistant.

Photography plays an important role of the medical examiner's office and is much more sophisticated than the non-digital photography of the past. Ideally, the forensic photographer has received formal training in field with experience in digital images, videography, and criminal justice. Precise and accurate documentation is essential, and an independent in-house photographer allows the medical examiner's office to maintain autonomy from law enforcement in the death investigation process. Depending on the size of the office and budgetary constraints, these duties may be carried out by the medicolegal death investigator, the autopsy assistant, or the medical examiner.

The medical transcriptionist and medical records clerk are often overlooked as an essential component of the medical examiner office. They play vital roles in recording, organizing, storing, and retrieving medicolegal death investigation records. Medical examiner records can be voluminous, containing not only autopsy reports but volumes of hospital records and police reports as well. Medical examiner records are kept indefinitely because they may be subject to review in legal proceedings or in other matters years after a death investigation is completed. Voice-recognition software and template formats can help medical transcriptionists streamline report preparation and rapid retrieval.

Modern medical examiner offices also need business and administrative personnel to handle many routine day-to-day transactions. A busy office will process repeated requests for autopsy records from attorneys, courts, and insurance companies, along with requests for assistance from bereaved families. Human resources staff is needed to handle employee record management, hiring/firing and other employee matters. Depending on the size of the office, human resources may cover other duties, such as payroll and scheduling.

A growing number of medical examiner offices have a forensic toxicology laboratory on site.

Having the lab in-house facilitates a close and productive interaction between the forensic pathologist and the toxicologist working on difficult cases. Smaller offices typically out-source this service because of the high costs associated with laboratory development. In-house histology, X-ray facilities, and associated staff are also desired. When conducted off site, these functions are expensive, logistically difficult to manage, and invariably slow the pace of the death investigation.

Medical examiners investigate cases in a variety of circumstances, running the gamut from death after complex congenital heart disease surgery to skeletonized remains. With such variation, it is helpful to have specialized consultants available to help make the medical examiner's job easier and more efficient. The most commonly requested consultants are cardiovascular pathologists, neuropathologists (specialists in the brain and central nervous system), forensic anthropologists, pediatric pathologists, and forensic odontologists (dentists). These individuals are highly specialized and may be available on a regional basis, depending on the location of the medical examiner's office.

11.5.2.2 Office Accreditation

The National Association of Medical Examiners (NAME) has developed voluntary accreditation standards for medical examiner offices that set forth minimum resources that are required to provide adequate death investigation for a particular jurisdiction [20]. These standards document policies and procedures that are in place, as well as evaluate available resources of staffing and equipment. Knowledge of these standards can help an office justify requests for additional equipment, staff, or other resources. The quality of the professional work product, however, rests with the chief medical examiner and his or her staff. The tremendous variation in death investigation systems in the United States, marginal available resources, and entrenched local traditions impede the development and implementation of standardized best practices in medicolegal death investigation.

11.6 Selected Topics in Forensic Pathology

The forensic pathologist must have a complete and current knowledge of the pathology and physiology of natural disease processes based on his or her training in general medicine and anatomic pathology. In addition, the forensic pathologist must understand the pathology of sudden unexpected death due to natural causes that are unfamiliar to the hospital-based pathologist. These include such topics as sudden death from cardiovascular disease, sudden physiologic-type death, and sudden infant death syndrome (SIDS). Forensic fellowship training provides the specialized knowledge to pursue investigations of unnatural and traumatic death.

Topics in trauma pathology include firearms injuries; blunt force injuries; cutting, stabbing, and chopping wounds; motor vehicle injuries; asphyxia; drowning; electrocution; lightning; thermal and environmental injuries; and alcohol- and drug-induced deaths. Postmortem changes and artifacts must also be understood to avoid errors in diagnosis.

Basic understanding of the pathology of firearm injuries as well as blunt and sharp force trauma are fundamental elements in trauma pathology. These basic patterns are applied to understand complex traumatic deaths such as motor vehicle

injuries, and pediatric accidental and non-accidental injuries (i.e., child abuse) and asphyxia. The reader is referred to textbooks to expand on these and other topics in forensic pathology [21–23].

11.6.1 Firearms Injury

The pathology of firearms injury is concerned with so-called terminal ballistics or the effect of a projectile on the body. The damage caused to the body by projectile is a direct result of the concept of the conservation of energy. A moving object, whether it is a bullet, a motor vehicle, or a baseball bat possesses a certain amount of kinetic energy. The kinetic energy (KE) is directly proportional (or equal to) one-half times the mass times the velocity squared.

$$KE = 1/2\ MV^2$$

Although the mass of a bullet is a quite small, the velocity is large, ranging from 300 to 3,000 feet/second depending on the ammunition and type of weapon. Because the velocity term in the kinetic energy equation is squared, a bullet possesses a tremendous amount of kinetic energy, all of which must be transferred to the tissues of the body (if the projectile is retained therein). When a bullet enters the body, it produces two types of injury, known as cavitations. The first is called a permanent cavitation, which corresponds in size to the dimension of the bullet itself. The second type is much more devastating. This so-called temporary cavitation is produced by a shock wave of energy absorbed by the tissue causing a cylindrical area of damage surrounding the permanent cavity that is much greater than the size of the bullet (Fig. 11.1).

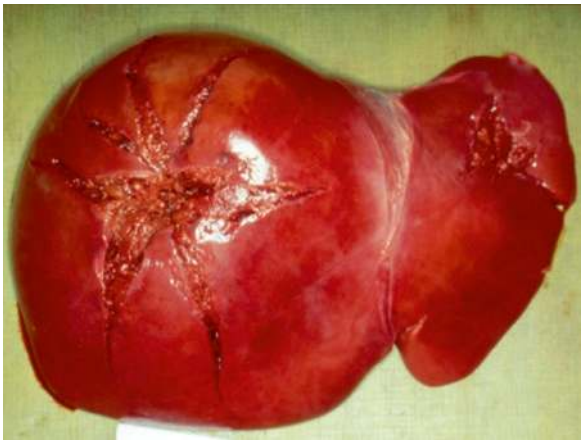


Fig. 11.1 Gunshot wound of liver demonstrating permanent cavity (central defect caused by bullet itself) and temporary cavity (tearing caused by transfer of kinetic energy to tissue). The bullet has also passed through the left lobe of the liver – smaller lobe on the right of the panel

The forensic pathologist must document three basic findings when examining a gunshot wound victim: (a) Identification of the entrance and exit wounds, (b) Estimation of the range of fire (or the distance between the body and the muzzle of the gun), and (c) Documentation of the internal damage by the projectile passing through the body.

Because the skin is elastic, the nose of the bullet first compresses, then stretches, and finally punctures the skin as the bullet enters the body. Because the skin is stretched over the nose of the bullet prior to the skin being perforated, the sides of the bullet scrape the skin causing abrasion around the circumference of the margin of the entrance wound. This scraping, known as marginal abrasion, is a characteristic that defines a gunshot entrance wound. As an aside, it can be observed, based on this mechanism of stretching of the skin, that an entrance hole will not exactly reflect the size (or caliber) of the bullet. When a bullet exits the body through the skin, the skin is pushed outward prior to its perforation, and there is no marginal abrasion. An exit wound can appear slit-like, even resembling a stab wound, and may show strands of tissue protruding from it or may be more irregular. The exit wound can be either smaller or larger in size than the entrance wound. Obviously, there is no exit wound if the bullet is retained in the body.

Once the entrance and exit wounds have been identified, then the range of fire can be determined by examining the characteristics of the entrance wound and the skin around it. The skin around the entrance wound (or the clothing over the wound) is witness to the materials that have left the muzzle of the gun. In addition to the bullet, other materials leave the barrel of the gun after a shot is fired. These are flame and hot gases, smoke (or soot), and gunpowder (both burns and burning), which travel different distances from the muzzle. Based on the presence or absence of the deposition of these materials on the target, the range of fire can be classified into four divisions: contact (sometimes subdivided into tight contact and near or loose contact), close range, intermediate range, and distant.

To produce a contact wound, the muzzle of the gun is pressed tightly in against the body surface. Due to the flame and gas exiting the muzzle, the wound edges may be scorched. The gas expanding underneath the skin causes tearing around the wound, so-called stellate or star-like wound. The stellate pattern is particularly characteristic of a contact wound where skin is supported by underlying bone, such as in contact wounds of the temple. Soot and gunpowder particles are driven into the wound tract. Because of the expansion of gases under the skin, the skin is pressed back onto the muzzle of the gun often leaving a muzzle imprint on the skin surrounding the entrance hole (Fig. 11.2a).

In a near or loose contact wound, some soot may escape and blacken the surrounding skin. In a close range wound, soot will be present on the skin but no – or very little – gunpowder will be present. Because soot is a fine particulate material, it rests on the surface of the skin (Fig. 11.2b) and can be wiped or washed off. As a general rule, soot can be found on the skin when the muzzle is within 6–10 in. of the target. When the muzzle-to-skin distance is greater than 2–2.5 ft, the soot-type smoky material will not reach the skin; only burned and burning grains of gunpowder will impact the skin. These are classified as intermediate range wounds. The grains of gunpowder impacting the skin actually embed themselves under the skin

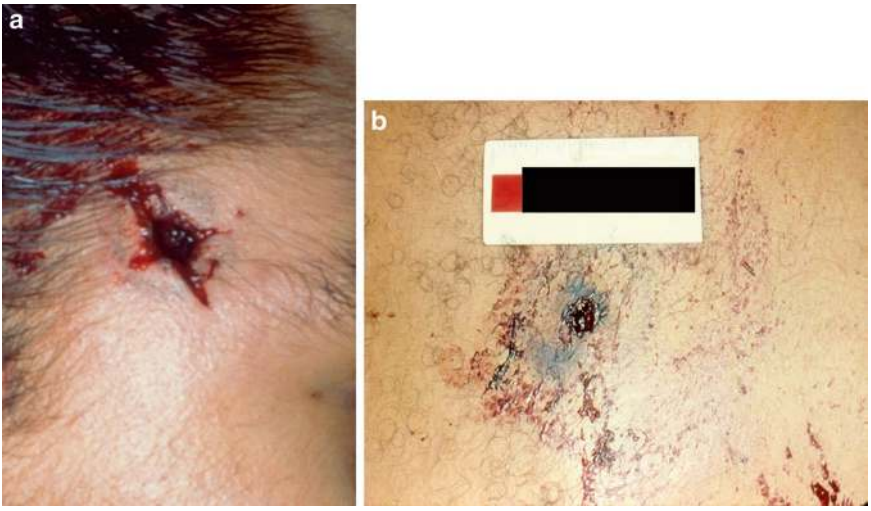


Fig. 11.2 Range of fire showing stellate contact wound gunshot over bone (**a**), and close range with soot deposition (**b**)

(hence the term tattooing) and cannot be washed off (Fig. 11.3a). The diameter in density of powder tattooing patterns around an entrance wound can be used to determine a more exact range of fire by comparing it with the pattern produced by test firing the gun used.

It is important to remember that hair and clothes may interfere with both soot and powder deposition on the skin. Distant gunshot wounds occur at a range where neither soot nor gunpowder reach the target. This range will be greater than the distance for intermediate wounds. An exact range for a distant gunshot wound cannot be determined from examination of the body alone as in (Fig. 11.3b).

During the internal examination portion of the autopsy, the track and trajectory of the bullet through the body is documented. Even though the bullet usually pursues a straight line through soft tissues between entrance and exit or its final resting place, documentation of the internal course is required because the projectile may ricochet off internal bony structures and alter its internal path.

This basic information obtained from the autopsy examination of a gunshot wound fatality, namely entrance and exit wounds, range of fire, and the bullet track in the body, can be correlated with investigative information from the scene and/or witness statements to determine the position of the victim, the position of the assailant and the angle at which the weapon was held when the shot was fired.

11.6.2 Sharp and Blunt Force Injuries

Description of injuries in forensic pathology requires precision and specific terminology. Careful examination and classification of injury types allow the forensic

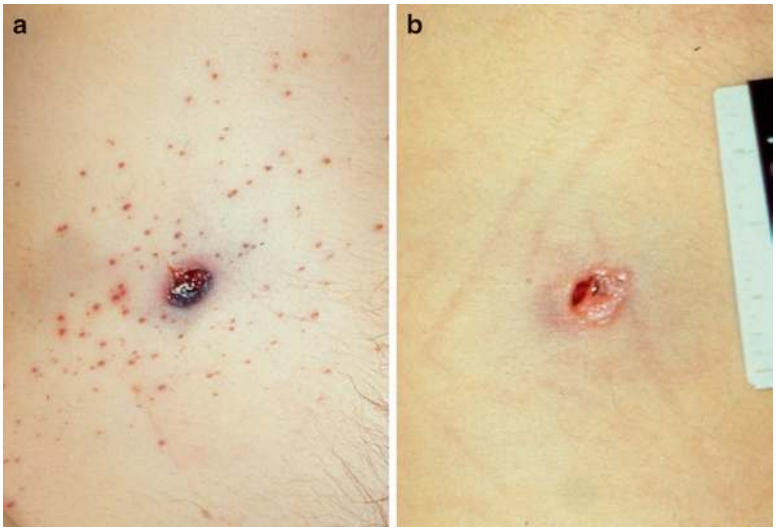


Fig. 11.3 Range of fire showing intermediate range gunshot wound with gunpowder stipple (**a**), distant range (**b**)

pathologist to determine the weapon or weapons likely to have inflicted specific injuries and thus aid in identifying the murder weapon. This precision of wound description is not always understood and used by other health care professionals such as emergency room physicians, surgeons, hospital pathologists, or family practitioners. Thus, the forensic scientist must be cautious when relying on patient-injury descriptions written by other doctors or in hospital records in determining mechanisms of injury.

An understanding of the basic concepts in terminology and blunt and sharp force injuries will allow the forensic practitioner to understand not only simple injury patterns but combinations that are important in understanding more complex types of injuries that occur in motor vehicle accidents or more mutilating injuries such as assaults, falls, or industrial accidents.

In studying the injuries produced by blunt and sharp force instruments, the forensic pathologist tries to reconstruct how the trauma occurred, what sort of object(s) could have produced it, the direction of force, and how much force was required to produce the injury. Forensic pathologists also try to determine whether the trauma occurred before death (and, if so, how long before) or after death.

11.6.2.1 Blunt Force Injuries

Blunt force injuries are produced by impacts with blunt objects (objects with rounded or flat impacting sites) or with flat surfaces. A careful examination of the wound and skin around the wound is essential. The impacting object may leave

trace evidence within the wound or may leave a unique imprint that might be helpful in identifying the particular object (i.e., a patterned injury). A close examination of the skin, sometimes with a hand lens, may provide evidence of the direction of force application. Although the injuries on the skin indicate the site of impact, the severity of internal injuries correlates with the force of impact.

The application of blunt force to the body is generally classified as producing three types of wounds: the abrasion, the contusion, and the laceration. The pattern of bony skeletal fracture, if any, may be considered an additional type of blunt force trauma.

An abrasion is produced by friction or scraping of the skin surface. Surface layers of skin will be piled up on the side opposite that from which the force came. Postmortem drying of the skin surfaces may cause the abrasion to appear yellow-brown or dark brown-black, making it difficult to distinguish between an abrasion that was sustained during life from one made after death. Examples of abrasion are bullet graze wounds, scratches made by edges of objects or fingernails, or brush burns where the skin is rubbed against a broad surface such as a roadway.

A contusion is the application of blunt force that ruptures blood vessels under the skin without breaking the skin surface itself. It is also known as a bruise. The age of the contusion roughly correlates with changes in its color and histologic appearance as it resolves. Color changes, however, provide only very crude indicators of age. Contusions may also appear in the form of patterned injuries, helping the forensic pathologist identify the impacting object. For example, a blow with a cylindrical object results in two parallel hemorrhagic contusions known as a tram track. This pattern is caused by blood displaced to either side of the area of impact by the pressure of the implement. For example, the impact from looped cord or rope may produce a horseshoe shaped double line we know as a tram-track contusion.

A deep bruise may not become apparent on the skin surface until days after injury. Bleeding underlying intact skin may be confined to deep soft tissues, especially if caused by a blow from a wide smooth object. In addition, hemorrhage may gravitate and dissect along tissue planes and reach the skin surface at a site different from the injury impact. For example, a fractured jaw may cause hemorrhage in the neck or a fractured pelvis may cause hemorrhage in the upper thighs. Thus, the actual site of injury must always be ascertained by autopsy. Finally, because of stretching of the skin of the abdomen, it is not uncommon for severe internal injuries to occur when blunt force trauma is applied to the abdomen without marking the abdominal skin.

It is important to differentiate a contusion made by blunt force trauma from an ecchymosis. An ecchymosis is formed when extravasated blood enters the tissues surrounding blood vessels due to nontraumatic mechanisms such as blood diseases, anticoagulant drugs, or minimally traumatic mechanisms to fragile skin of the elderly.

A laceration is the result of tearing tissue due to stretching and crushing of the skin and subcutaneous tissues due to impact of a blunt object. The edges of the wound will be scraped (i.e., abraded) and may produce a pattern that conforms to the striking face of the object. Strands of tissue will bridge the deep wound margins

from side to side, a condition known as tissue bridging. These tissue bridges consist of tissue strands of nerves, elastic and connective tissue fibers, and blood vessels that run between the opposite sides of the wound. These elements are relatively more resistant to tearing and as a result can stretch but do not tear (Fig. 11.4). The presence of the surrounding abrasion and tissue bridges are helpful characteristics to differentiate blunt force from sharp force trauma.

If an individual survives the initial application of blunt force trauma, two clinical complications capable of causing death may occur: fat embolism and rhabdomyolysis. When subcutaneous tissues are crushed and torn, or bones fractured, subcutaneous fat and fat within the bone marrow can be disrupted and enter the circulation as fat droplets causing obstruction of small blood vessels and capillaries. This capillary obstruction presents as pinpoint hemorrhages in the skin, conjunctiva of the eye, and brain. Extensive fat embolism can cause death several days after the initial injury. Severe blunt force damage to the skeletal muscles causes release of myoglobin from the muscle cells into the circulation. When filtered by the kidney, myoglobin can cause acute renal failure, which may result in death.

Blunt force trauma to the head can result in abrasions, contusions, and lacerations to the scalp and fractures of the skull. However, because of the unique biomechanics of the brain suspended in cerebrospinal fluid moving within the skull, two particular types of blunt force injuries to the head can be distinguished: coupe and contra coupe injuries. Coupe and contra coupe injuries are distinguished by

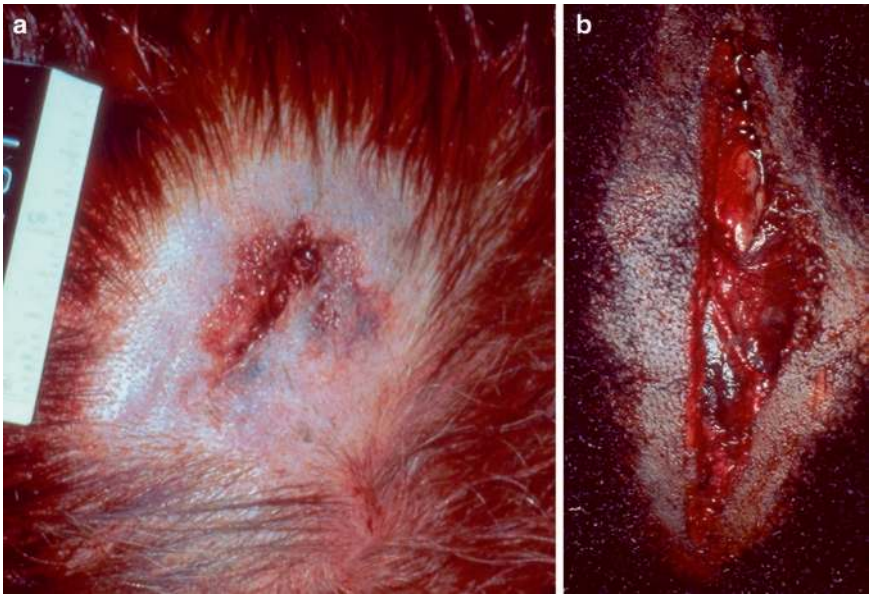


Fig. 11.4 Lacerations showing tissue bridging between the wound margins. Laceration with surrounding impact abrasion (**a**). Laceration showing tissue undermining of scalp on right side of laceration (**b**)

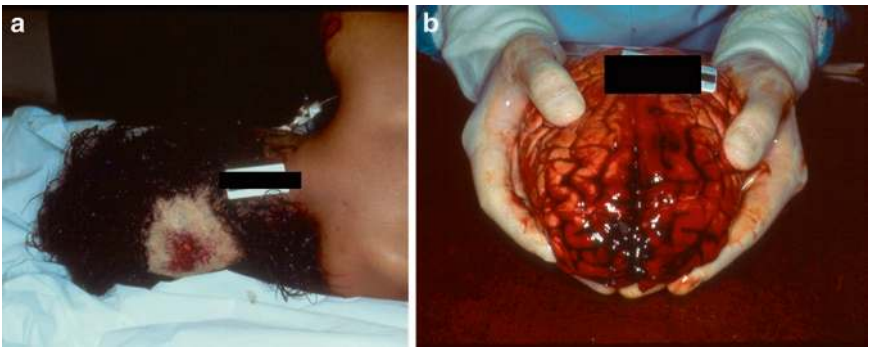


Fig. 11.5 Head injury from fall. Impact (coupe) injury to back of head (**a**), and brain injury to front area of brain (contra coupe) (**b**)

comparing the size and location of injury impacts on the surface of the head (i.e., skin scalp and skull; the coupe injury) to the size and location of the area of injury to the brain (coupe vs. contra coupe injury). The results of this comparison allow the forensic pathologist to understand how the head injury occurred: whether from an assault (a moving object striking a fixed head) or from a fall (moving head striking fixed object). This can differentiate a homicide from an accident. When the largest injury to the brain corresponds to the location of the impacting site on the scalp (coupe injury), the blunt force resulted from a moving object impacting a stationary head. When the largest injury to the brain is 180° away (contra coupe) from the injury of the skull (coupe injury), the blunt force trauma to the head resulted from a fall (moving head hitting fixed object) (Fig. 11.5).

The mechanism usually responsible for death in blunt head trauma is brain swelling (cerebral edema). Because the brain is encased in the bony skull, and when the brain swells as a response to injury, the only opening through which to relieve swelling is through the foramen magnum in the base of the skull. Pushing the brain down through the foramen magnum compresses the brainstem and injures the vital structures that control heart rate and respiration. This is known as brain stem herniation and results in death.

11.6.2.2 Sharp Force Injuries

Sharp force injuries may be clearly differentiated from blunt force injuries by the careful examination of the wound and documentation of particular wound characteristics. Again, the importance of determining the type of weapon that inflicted the injuries cannot be overstated. Sharp force injuries are injuries caused by pointed and sharp-edged instruments. They can be classified into three general types: incised wounds, stab or puncture wounds, and chop wounds.

Incised wounds are represented by cut, slash, or incision-type injuries. Instruments that have a sharp edge, such as a knife, razor, broken glass, or scissors,

produce incised wounds. An incised wound is caused by force that is directed roughly parallel to the skin surface being injured. The incised wound is longer on the skin surface than it is deep. Despite being shallow or superficial, however, incised wounds can be fatal, such as incised wounds of the neck where the major blood vessels are relatively close to the skin surface. Examination of the wound edges of an incised wound will show smooth straight or irregular margins; but any abrasion of the wound margin is usually absent. It is important not to confuse this injury with that caused by a blunt object, i.e., a laceration, where abrasions of the wound margins are usually present. Further, tissue bridging in the depths of incised wounds is not present. All structures including nerves, blood vessels, and elastic tissues are cut (Fig. 11.6).

Incised wounds may have skip-areas where the sharp edge makes irregular contact with the skin as it is drawn over its surface. This is described as a discontinuous or interrupted incised wound. It is important to recognize because it is the result of one application of sharp force causing more than one wound.

Stab wounds are caused by penetration of the body by sharp or pointed instruments that may or may not have a sharp edge. Examples of implements that cause stab or puncture wounds are ice picks, needles, knives, swords, rods, or scissors. A stab or puncture wound is a wound where the depth of the wound is greater than its length on the skin surface (the exact reverse of an incised wound). Examination of the two corners of the stab wound may indicate whether a single- or a double-edge blade was used: a double-edge blade has two sharp corners and a single-edge blade, one sharp corner and one square or rounded corner. Small abrasions or

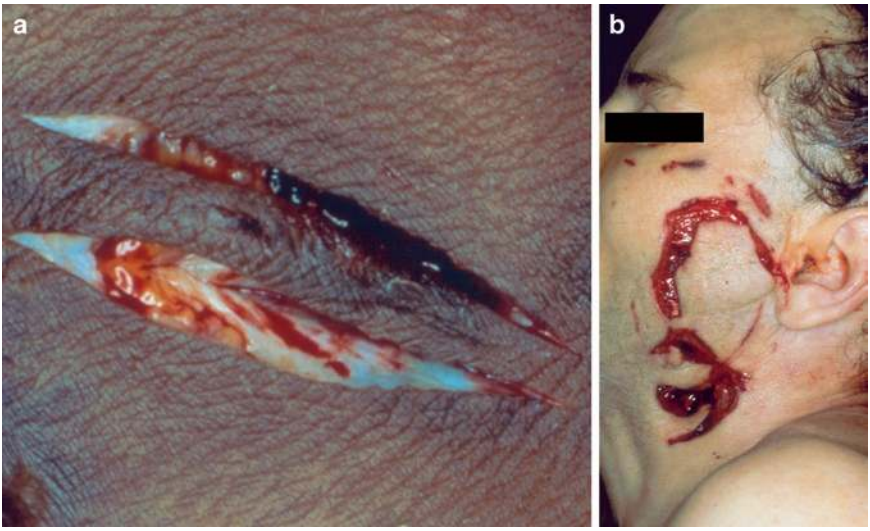


Fig. 11.6 Incised wounds produced by scalpel (**a**). Incised wounds produced by a broken beer bottle (**b**)

contusions around the corners of the wound may represent a hilt mark and indicate that the knife was plunged into the body for its full length (Fig. 11.7a, b).

A knife with a serrated blade may produce a regular pattern of linear parallel abrasions or punctures when the blade edge is scraped across the skin surface or pressed against it (Fig. 11.8a, b).

The absence of such marks, however, does not exclude a serrated knife. Other patterns of sharp force injury include pairing of wounds such as can be produced by a barbecue fork or open scissors. Sharp force injuries located on the palms of the hands or the forearms may be interpreted as so-called defense injuries caused by a victim trying to ward off his or her assailant. Other groupings of sharp force injuries are hesitation wounds or marks. These incised wounds are characteristic of suicidal manners of death and may be quite dramatic. Hesitation marks consists

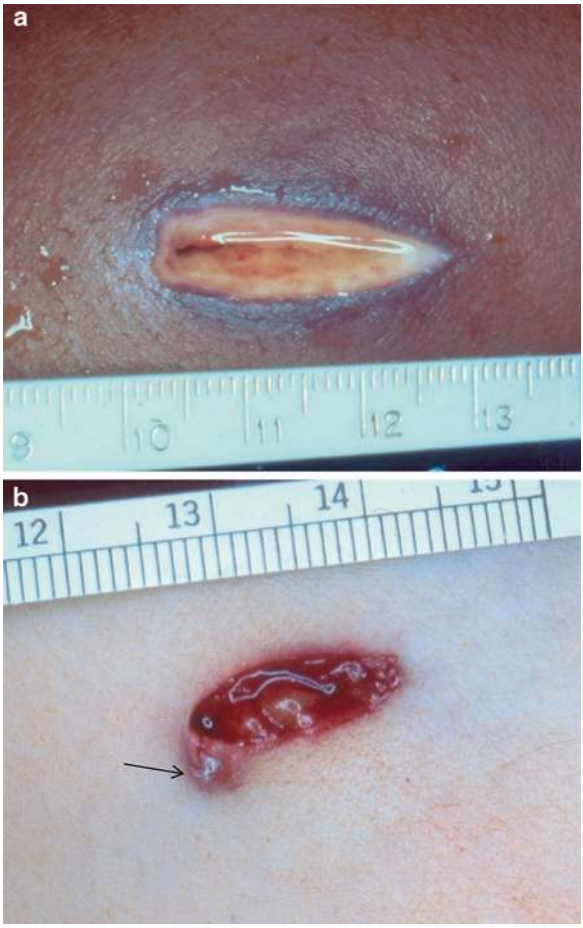


Fig. 11.7 Stab wound produced by single-edge blade (**a**). Stab wound with associated hilt mark (*arrow*) (**b**)

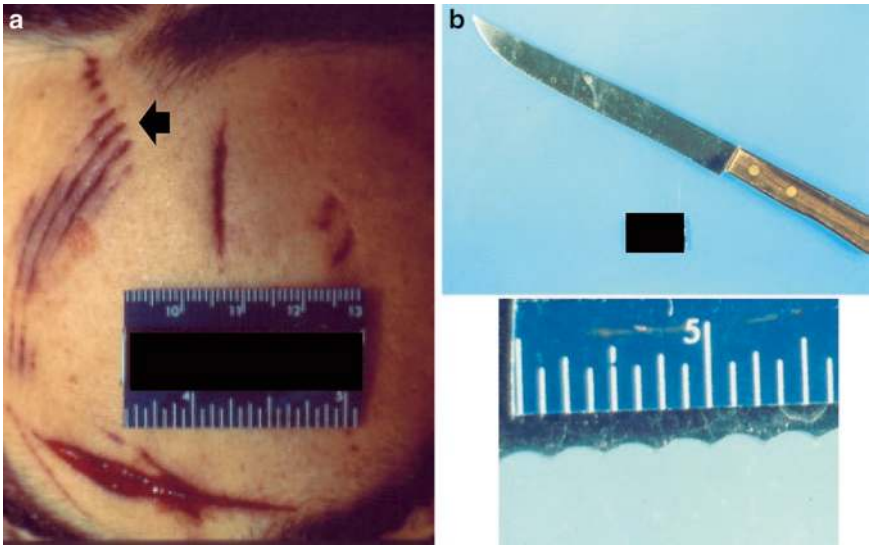


Fig. 11.8 Patterned injury produced by a serrated knife (*arrow*) (**a**). Knife and serrated edge producing injuries in (**a**) (**b**)

of several parallel linear incisions that are superficial and are located next to a deeper fatal wound. They are presumably due to the individual assessing the amount of pain and gathering his or her resolve prior to a more forceful, deep, and fatal incision(s).

Chop wounds are cutting wounds caused by heavy objects with a cutting or sharpened edge such as a machete, an axe, or a boat propeller. These wounds are often deep and gaping and cause wedge-shaped injuries on the underlying bone. The wound may show tissue crushing and may have finely abraded wound margins.

Finally, medical interventions may be the source of incised and stab wounds. For example, "stab wounds" are made for insertion of drainage tubes. Original wounds may also be incorporated into a larger a surgical incision such that the original injury is no longer clearly visible.

The most common mechanism of death in sharp force trauma is blood loss or exsanguination. This fatal bleeding may occur outside into the environment (external bleeding) or, most commonly, occurs into the body cavities (usually the pleural or peritoneal spaces) with little external bleeding (internal exsanguination). Additional mechanisms of death in sharp force injury are asphyxiation due to the inhalation of blood; air embolism, occurring when a major vein is cut and exposed to the outside (usually an incised wound to the neck); or a pneumothorax causing a collapsed lung when air enters the pleural space due to a stab wound of the chest.

In sharp force injuries, there is usually close proximity between the victim and assailant and evidence is likely to be transferred between the two. Thus, the forensic pathologist should be particularly aware of the potential for recovery of important trace evidence on the victim.

11.6.3 Complex Injury Patterns

An understanding of the pathology of the basic types of injuries, namely firearms, blunt force, and sharp force, allows the pathologist to decipher more complex groupings of injury patterns such as those occurring in motor vehicle accidents, pediatric accidental and non-accidental injuries, and asphyxial deaths, as well as complex homicide cases.

11.6.3.1 Motor Vehicle Collisions and Pedestrian Deaths

Several categories of persons can be found dead in motor vehicle incidents. The deceased individual may be the driver, passenger (front seat/back seat), pedestrian, an individual present in the road either sleeping, drunk, incapacitated, or confused, or an individual expelled from a motor vehicle either accidentally or intentionally. Each present characteristic injury patterns that allow the forensic pathologist to determine the position of the decedent at the time the death occurred.

Injury patterns to the occupants of motor vehicle are a combination of the presence or absence of properly worn restraint systems and patterned injuries from internal contours and parts of the vehicle. All occupants, however, may show internal damage from deceleration of the internal organs that continue to move and are pulled away from their attachment on the body wall after the outside of the body has stopped,. The most common and rapidly fatal deceleration injury results from tearing of the thoracic aorta at a ligamentum arteriosum, a fixed attachment point. This results in rapid internal exsanguinations and may occur whether or not the occupant is properly restrained (Fig. 11.9).

Front seat occupants may impact the windshield area. Because the windshield is composed of laminated glass (plastic material sandwiched between two layers of glass) the head will impact and deform the windshield causing a spider web-type fracture, but not proceed through the windshield. This impact results in vertical incisions and abrasions of the forehead, nose, and chin. Breakage of any side window glass, composed of tempered glass, breaks into small glass fragments in the shape of small cubes, rectangles, and triangles. This configuration of broken side window glass causes characteristic small abraded superficial incisions and contusions with sharp angles known as dicing injuries (Fig. 11.10).

Dicing injuries will be present on the driver's left side of the face and left arm. The driver's chest may impact the steering wheel, causing fractures of the sternum and anterior ribs. Impact with the top of the steering wheel may cause horizontal lacerations to the chin. Fractures of the wrist and forearm may be caused when the hands are on the steering wheel at impact. The lower extremities can sustain fractures of the patella and/or femur if the knees impact the dashboard, leaving abraded contusions or superficial lacerations on the skin of the knee. This impact may drive the femur backward and fracture the pelvis. Ankle fractures result when the feet are braced against the floorboard or pressed firmly against the accelerator or brake

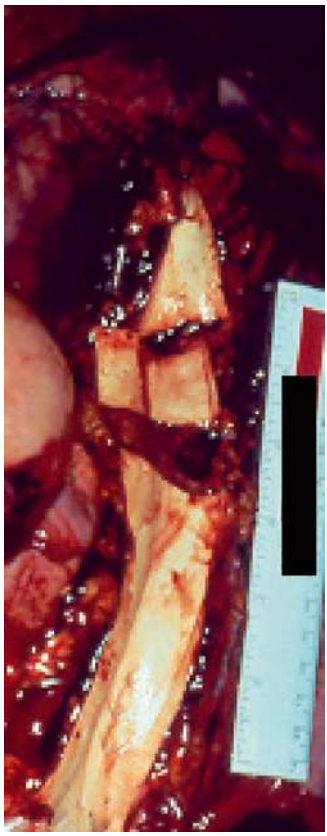


Fig. 11.9 Deceleration injury showing tearing (complete transection) of the aorta in two locations.

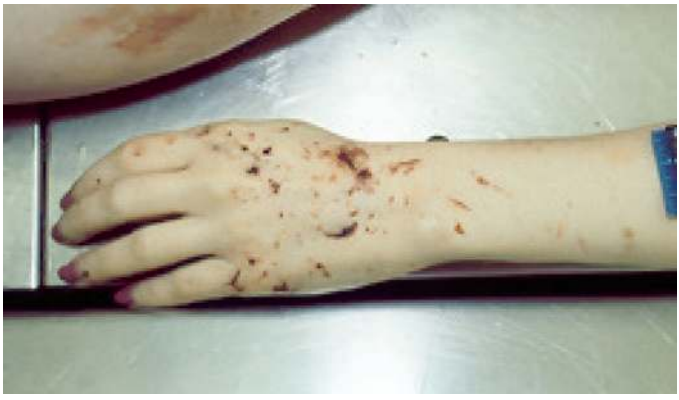


Fig. 11.10 Dicing injury to left arm of driver of a car caused by broken side window (tempered) glass

pedal. Injuries to front seat passengers tend to be the same as those of the driver, except the unrestrained passenger will strike the dashboard and not the steering column, and the dicing injuries should be on the right arm and/or right side of the face. The rear seat passengers, if unrestrained, may be thrown forward and hit the back of the front seat, the front seat passenger, the sun visor area, or even the windshield.

Restraint systems have dramatically reduced the number of injuries and fatalities, especially in low-speed collisions. If worn at the time of collisions, these restraint systems may leave characteristic abrasions and contusions of the body. Depending on the forces of the collision, internal injuries from restraints may be severe. The shoulder and lap-belt injury patterns on the driver consist of a rectangular or linear abraded contusion that angles downward from the left neck and shoulder area toward the anterior midline of the chest. The opposite configuration will be shown by the front seat passenger wearing the three-point restraint system. Wearing a lap belt alone may cause a horizontal linear contusion or abrasion across the lower abdomen. Dashboard air bag systems can be triggered by collision speeds (usually at or above the equivalent of hitting a fixed barrier at 10–15 mph) or bumper deformation. The inflation of the bag is produced by a pyrotechnic device producing gas. The bag itself expands at a velocity of inflation that can range from 100–200 mph. Any individual positioned too close to the air bag, usually occupants not utilizing belt restraint systems, can sustain serious or fatal blunt force trauma to the head, face, and neck.

Occupant injections from the motor vehicles occur most often in vehicle rollovers particularly when no restraints are worn. The occupant may be partially or transiently ejected, with a body part crushed or amputated. Alternatively, an occupant may be fully ejected and sustain fatal injury by impacting objects in the outside environment such as trees, rocks, or pavement. The victim may be crushed under the vehicle or may be pinned under the vehicle such that respiratory motions cannot occur, resulting in compressive asphyxia.

The forensic pathologist, armed with specialized knowledge of injury patterns in motor vehicle accidents, should be able to ascertain the decedent position within the motor vehicle, correlate patterned injuries to objects in the vehicle, or if ejected, reconstruct the ejection and rollover sequence. Autopsy findings should always be correlated with scene investigation, including visiting the scene of the accident and examining the vehicles involved. Only in a complete medicolegal death investigation of the motor vehicle fatality, including not only the autopsy but study of medical records, police reports, and eye witnesses, can the pathologist be an active member of the team trying to determine the cause of the accident. The cause of the accident should include consideration of environmental factors such as poor highway design, wet, slick pavement, broken structures, etc.; mechanical failure of the car; or human factors. Human factors may be the result of the onset of an incapacitating natural disease process (so-called natural death at the wheel), driver impairment by drugs or alcohol, falling asleep at the wheel, or recklessness, speeding, or other distractions (passengers, radios, CD player, cell phones, texting, etc.).

Pedestrian injury patterns can be can be divided into three different categories: primary impact, secondary impact, and tertiary impact. The primary impact represents the site on the pedestrian that first contacts the motor vehicle. This is usually on the legs and is due to the bumper. The secondary impact is the result of the body impacting other parts of the vehicle as it is thrown from the primary impact up onto the hood or windshield of the striking vehicle. The tertiary impact is caused by the pedestrian landing back onto the ground after being thrown off the vehicle. The presence and severity of injuries from these three subdivisions of a pedestrian motor vehicle impact will depend on the speed of the vehicle involved, type of vehicle involved, whether or not breaking occurred, and the size of the pedestrian (i.e., adult vs. child).

At medium speeds, the victim is hit and then picked up and thrown onto the car; at low speeds, the victim may be knocked down and run over. Typically, children, because they are usually impacted above their center of gravity, are knocked down and run over rather than being lifted and thrown onto the vehicle. A pedestrian hit at high speed (greater than 60 mph) may be picked up and thrown entirely over the car, impacting the rear trunk or landing on the road behind the car. Clothing may literally be stripped from the body and the pedestrian knocked out of his or her shoes.

The forensic pathologist at the autopsy of a pedestrian fatality should not only document the injuries, but identify the injury patterns as being due to the primary, secondary, or tertiary impacts, and relate those injuries to the motor vehicle and scene characteristics. The primary impact usually presents as contusions and possibly fracture(s) of the leg(s) due to the impact of the bumper (Fig. 11.11).

The location and characteristics of these bumper injuries may help determine the side of the impact and determine whether the victim was walking or standing still. Vehicle braking will cause the front end to dip lower and change the level of bumper impact on the pedestrian. Thus, measurement of the location of the primary impact site with respect to the heel of the foot is critical to document. Secondary impact of

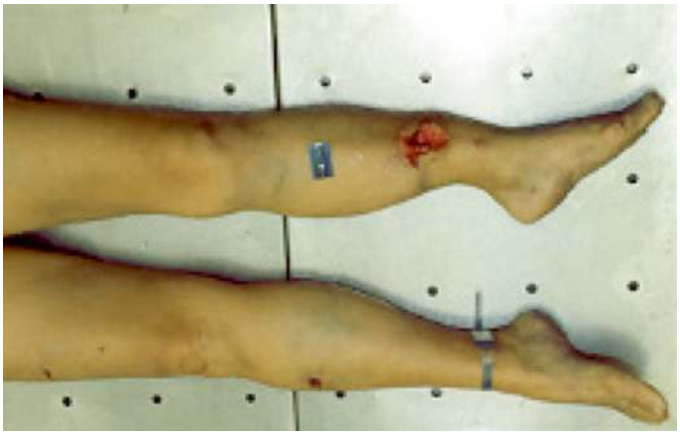


Fig. 11.11 Primary impact injury (bumper fracture of left leg) in pedestrian hit by car

the buttock or thigh area with the front of the vehicle, front grill or hood, produces large subcutaneous filled pockets of hemorrhage as well as possibly characteristic patterned injuries from grill work, the head light, or hood ornamentation. The head, neck, and upper torso may impact the hood and windshield of the vehicle, producing blunt and sharp force trauma patterned injuries from the structures of the car, such as the windshield and wiper trough area. Tertiary impacts, usually on the ground, produce broad, road-rash type abrasions. It should also be remembered that the pedestrian, on the ground after the tertiary impact, may also be run over by a second vehicle, producing patterned contusions and abrasions from the tire tread and deposit grease marks on the body or clothing. Careful study of injury patterns, severity, and associated bleeding may be required to determine whether the first impacting vehicle or the vehicle that subsequently ran over the victim was actually responsible for the death.

Trace evidence may be transferred between the pedestrian and the impacting vehicle. The vehicle may retain hair, skin, or blood of the victim. For example, a broken windshield glass may retain a strand of hair or fabric. Even weave imprints of clothing may be left on the hood. The clothing on the victim may reveal tire marks, as mentioned above, or grease or paint chips. In the case of a hit and run, such evidence can positively associate a suspect vehicle with the decedent.

The manner of death in motor vehicle accidents, as the word accidents implies, is indeed accident, although various levels of negligence may be present. However, suicide, homicides, and natural manners of death may also occur in motor vehicle-related deaths. Suicidal intent should be considered and further investigation pursued particularly in a single-occupant motor vehicle collision with a fixed object or a pedestrian witnessed to run out or walk directly in front of a motor vehicle. By convention, leaving the scene of an accident, a so-called hit and run, is classified as homicide. The deliberate running down of a victim with an automobile is also classified as homicide. A natural disease process may cause unexpected incapacitation that results in a collision. In these cases, traumatic injuries are minimal and inadequate to cause death. When the cause of death is due to the natural disease process, most commonly a heart attack, seizure, or ruptured aneurysm, the manner of death is natural even though the deceased was in a motor vehicle “accident.”

11.6.3.2 Asphyxia

Asphyxia refers to death caused by interference with the exchange of oxygen and carbon dioxide in the body. Interference with this process of oxygen exchange may occur at the environmental level, when the atmosphere contains insufficient oxygen or toxic gases such as carbon monoxide; or it can occur at the cellular level, where ingested poisons such as cyanide can interfere with oxygen utilization for energy production in the mitochondria. Asphyxia due to a toxic environment or ingestion of poison rarely produces diagnostic findings at autopsy. The forensic pathologist must rely on scene investigation and toxicology to correctly diagnose the asphyxial death.

When asphyxia results from the application of force to the body itself, it is classified according to the particular anatomic level or structure that is involved. Here again, this terminology has specific meanings in forensic pathology, and these terms may be used incorrectly by other health care professionals or laymen. The injuries produced on the body that are hallmarks of asphyxia can be small and subtle, often consisting of patterns of small abrasions, contusions, and lacerations. A detailed and careful autopsy with abundant photographic documentation is paramount. Particularly, a careful examination of the lips, mouth (or including all mucosal surfaces and tongue), posterior oropharynx and larynx, and a layer-wise dissection of the neck structures and muscles is an essential part of the postmortem examination.

Obstruction of gas exchange at the level of the mouth or nose is known as suffocation or smothering. This may occur by the application of a hand over the mouth and nose, placing a gag in the mouth, or placing a plastic bag over the head. An obstruction at the level of the larynx or trachea can occur when food or other foreign bodies are inhaled and obstruct the airway. This is known more commonly as choking or medically as aspiration of foreign material. Certain groups of individuals are susceptible to this type of asphyxia. Children who place small objects in their mouths or the elderly with neuromuscular impairment are at risk. It should be remembered that neuromuscular impairment, such as stroke, can also be the result of intoxication by certain drugs or alcohol. A particular type of asphyxia has been termed the "café coronary." Here the individual effected, often eating rapidly or having imbibed several alcoholic beverages, will suddenly clutch at his or her throat or chest, become cyanotic, and collapse. Although having the outward appearance to witnesses of having suffered a heart attack, postmortem examination on these victims usually reveals obstruction of the airway by food. This finding, obtained by forensic pathologists from many postmortem examinations, has made the public aware that such deaths are the result of obstruction of the airway by food and not a cardiac event, and that the application of the Heimlich maneuver may be life saving.

Asphyxia due to compression of the neck is termed strangulation, either ligature, manual, or hanging. A key concept in understanding the death from strangulation is that it results from the restriction of blood flow, and hence oxygen, to the brain and not from actual obstruction or closing off of the airway (i.e., trachea) itself. Pressure to the sides or circumference of the neck, whether by hands or ligature, results in compression of the jugular veins, thereby stopping the blood flow out of the head. This blockage of venous outflow eventually leads to the stoppage of arterial flow into the brain that carries oxygenated blood to the brain. When this arterial flow of oxygenated blood into the brain stops, the brain, being particularly sensitive to oxygen deprivation, is damaged. This results in unconsciousness first and, if the lack of blood flow persists by continuing pressure on the neck, then death. Understanding the physiology of strangulation allows for a clear understanding of how petechiae, a finding classically associated with asphyxia, develop. Petechiae are pinpoint hemorrhages visible in the conjunctiva of the eye and periorbital skin due to the rupture of capillaries caused by the increased blood pressure in the head due to blood outflow obstruction (Fig. 11.12a).

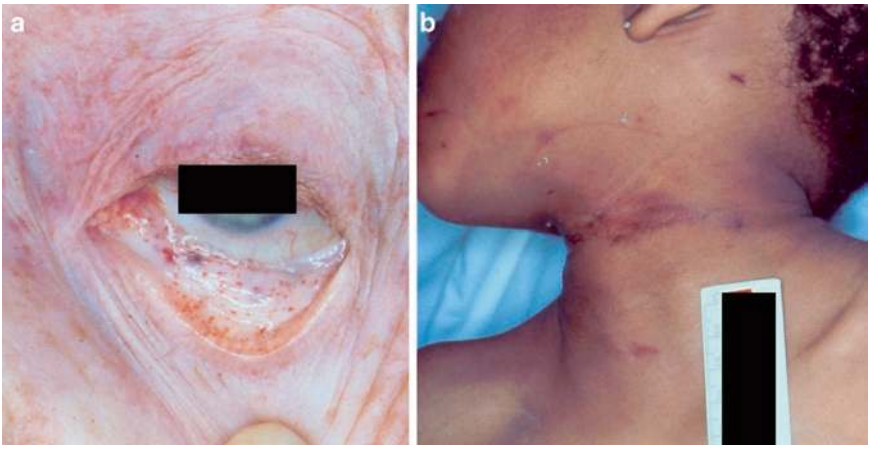


Fig. 11.12 Petechiae in palpebral conjunctivae of eye in manual strangulation (**a**). Contusions and fingernail abrasions on skin of neck of victim of manual strangulation (**b**)

However, petechiae are suggestive but not diagnostic of an asphyxia death. Other autopsy findings in manual or ligature strangulation may be subtle or massive, depending on the length and violence of the struggle between the victim and assailant. Curvilinear abrasions due to fingernails and small circular contusions due to pressure from the pads of the fingers may be seen on the skin of the neck (Fig. 11.12b). Internally, focal hemorrhages in the strap muscles of the neck underlie the points of application of pressure. The ends of the hyoid bone, a U-shaped bone anchoring the muscles of the tongue and positioned at the top of the neck, can be fractured by pressure from the assailant fingertips on either side of the neck. Ligature strangulation will show patterned linear abrasions and contusions on the skin of the neck, usually in a horizontal position. Fingernail abrasions caused by the victim trying to remove the ligature may be present on the skin of the neck as well.

Deaths due to hanging result from external compression of the neck by objects such as a rope, scarf, or belt, where the person's body weight or portions thereof constitute the compressive force. In hanging, the neck compression mark is usually oblique or angled upward if there is some degree of suspension and is absent from the back of the neck. The force required to occlude the blood flow through the jugular veins is surprisingly low, on the order of 4–5 lb. Because the average head weighs approximately 10 lb, it can be seen that fatal hanging can occur with the body in many positions other than being fully suspended. This is in contrast to a judicial hanging, where the force of the drop of the body and position of the ligature knot under the chin causes massive hyperextension of the neck and fracture of the high cervical spinal column with fatal spinal cord transection. A judicial hanging is not an asphyxial death.

Compression or confinement of the movement of the chest wall may also result in asphyxiation. This is called compressive asphyxia. The mechanics of ventilation or breathing require the diaphragm to contract, expanding the volume of the chest cavity inferiorly, and the intercostal muscles to contract, which in turn elevates the

ribs and expands the chest in the anterior to posterior direction. This enlargement of the chest cavity causes air to be drawn into the lungs. If this movement cannot take place, oxygen will not be delivered to the lungs. Situations where compressive asphyxia may be the cause of death occur when heavy machinery or other objects fall onto the chest and/or torso and trap the victim, thereby restricting respiratory movements. Alternatively, an individual may fall into a crevice or tight space and be unable to extricate himself. Common findings at autopsy may include severe vascular congestion and even petechiae of the skin of the body above the level of compression, along with contusion, hemorrhages, and, potentially, rib fractures underlying the areas of compression. The term positional asphyxia is applied to cases were asphyxia is due to the inability to cause chest wall excursions due to the physical position of the body or obstruction of the upper airway by abnormal kinking of the neck or positioning of the face. This is usually the result of unconsciousness or incapacitation due to a natural disease process or to alcohol or drug intoxication with collapse into a position restrictive of respiration.

11.6.3.3 Pediatric Accidental and Non-Accidental Injuries

Investigations of infant and childhood deaths are among some of the most difficult that the forensic pathologist will undertake. Not only is compassion aroused due to the death of a child, but emotions can run high and sometimes out of control on the part of police, prosecuting attorneys, child protective agencies, and the media. It is up to the forensic pathologist to remain neutral, analyzing only objective findings and using sound, scientific reasoning to determine the cause, circumstances, and manner of death in such cases. This may require weeks or even months of work to accumulate and analyze the required testing and investigations.

Accidental deaths are the most common causes of death between the ages of one and eighteen years. The type of accident depends on the age, mobility, coordination, and developmental ability of the child. Common accidental causes include asphyxia due to drowning, choking, or entanglement to objects, blunt force trauma due to falls or motor vehicle accidents, toxic ingestion of prescription medications or household products, electrocution, or thermal and inhalation injury in house fires. Although many childhood accidents may involve a degree of negligence or neglect on the part of a caregiver, such lapses in supervision in these events fall short of recklessness or homicide intent.

The diagnosis of child homicide or child abuse requires that the forensic pathologist demonstrate a discrepancy between the injuries on the child and the presenting story of the parent or caregiver. This may be a discrepancy in the severity or pattern of the injury, a discrepancy in the age of the injury or a discrepancy in the developmental ability of the child with that of the history provided. Often times the death of the child is due to a single acute impulsive act. Usually the child has annoyed the adult, often by crying or lapses in toilet training, to a point where the adult reacts by kicking, punching, shaking, or throwing the child. Less often, this acute injury may be accompanied by evidence of chronic battery, as evidenced by multiple bruises and abrasions of different ages or healing skeletal fractures.

In contrast to the child death by an action or commission such as described above, child abuse may also occur due to omission or neglect. The parent or caretaker has the responsibility to care for the child by providing adequate food, shelter, and medical care. Unfortunately, the caretaker may fail to meet these responsibilities resulting in death from dehydration, starvation, or exposure to an overly hot or cold environment or to a treatable disease where symptoms were ignored. Again, the findings present at autopsy will be at odds with the history presented by the caregiver.

A much less common type of child abuse is Munchausen syndrome by proxy. In this syndrome, the parent, usually the mother, gains sympathy and attention for herself by having a child who requires constant medical attention for symptoms that are, in fact, caused by the parent. For example, the mother may repeatedly partially suffocate her child causing periods of unconsciousness or administer prescription drugs or poisons that cause vomiting, bleeding, or other alarming symptoms. When the child is subsequently brought to medical attention, usually in an emergent fashion, no cause can be found, prompting many series of hospitalizations, unnecessary testing, and even surgeries. If not suspected and stopped, this pattern of abuse will usually continue until death results. A high index of suspicion is required to discover this type of abuse prior to a fatal outcome. Helpful clues include a parent who has a medical background of some sort, one who is particularly friendly with hospital personnel, and one who is eager for her child to have multiple medical procedures. Covert video surveillance is usually required to establish a diagnosis of Munchausen syndrome by proxy.

11.6.4 Sudden Unexpected Death Due to Natural Causes

11.6.4.1 Adults

Sudden unexpected natural death usually accounts for up to 50% of the autopsy case load of a medical examiner's office. It usually occurs in the older population, and is relatively uncommon in individuals younger than thirty years old. These reportable natural deaths may be instantaneous, where the death occurs within seconds of the onset of symptoms; sudden, where the death occurs within minutes of the onset of symptoms; or unexpected, when death occurs in an individual with known significant natural disease but who was not expected to have died at that particular time. The first two types of death often occur at the individual's home or in public places; the third may occur in hospitals, nursing homes, or even a hospice, where known disease is present but the death unexpected at that particular time. Toxicologic analysis is usually necessary in all of these cases to determine whether the individual died due to a particular disease or died of a drug-related cause with a particular disease also present.

The most common organ systems involved in causing sudden unexpected natural death are cardiovascular, respiratory, and the central nervous systems.

Within the cardiovascular system, atherosclerotic coronary artery disease causes the majority of sudden natural deaths investigated by medical examiner offices. Often, no history of previously diagnosed coronary artery disease is present. Symptoms may be minimal or absent. Indeed, in patients with undiagnosed coronary artery disease, sudden death may be their first presenting symptoms up to one-third of the cases. Any chest discomfort may be attributed to indigestion (it is not uncommon to find antacid tablets at the scene or on the deceased) or musculoskeletal strain when symptoms present as back, neck, or shoulder pain.

Atherosclerosis (also known as hardening of the arteries) is a narrowing of the lumen of a blood vessel (stenosis) caused by the build-up of fatty material such as cholesterol in the vessel wall [24]. The most common finding at autopsy in an unexpected death due to atherosclerotic coronary artery disease is at least one coronary artery with 75% stenosis or greater (Fig. 11.13).

There may or may not be associated thrombosis in the lumen of the artery, because thrombosis is found in less than 15% of sudden unexpected death cases due to coronary artery disease. Examination of the myocardial muscle tissue itself may not show evidence of damage. Alternatively, myocardial fibrosis may be present, indicating prior episodes of silent ischemia and tissue damage, or acute myocardial necrosis (myocardial infarction) may be found, depending on how long after the acute ischemic event the death occurs. In order to visualize ischemic tissue damage, the individual must have a period of survival after the ischemic event. The mechanism of death in such cases is usually a sudden cardiac arrhythmia terminating in ventricular fibrillation and then asystole. The ischemic event causes the arrhythmia by interfering with the normal, organized passage of the electrical impulses from cell to cell initiated by the conduction system. Again, toxicology and evaluation of the organ systems must be carried out, because many individuals have atherosclerotic coronary artery disease but die of other causes.

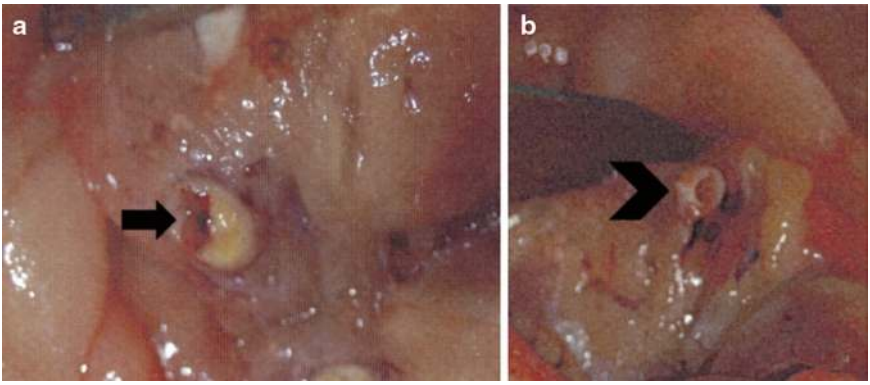


Fig. 11.13 Atherosclerotic coronary artery disease. Coronary artery with stenosis of lumen (approximately 50% narrowed) due to thickening of artery wall by yellow atherosclerotic plaque (**a**). Coronary artery showing less than 25% narrowing of lumen (**b**)

Hypertensive heart disease may also present as sudden unexpected cardiac death, again due to the onset of a sudden unexpected arrhythmia. Individuals who suffer from hypertension over a prolonged period develop increased muscle mass of the heart. Similar to the biceps muscle, which enlarges with exercise, the cardiac muscle also increases in size when forced to pump against higher pressure in the vascular system (i.e., hypertension). This is judged at autopsy by an increase in the normal cardiac weight, a thickened muscular wall of the left ventricle, and microscopically enlarged nuclei of the myocytes. This increase in muscle mass can perturb the conduction of electrical impulses, similar to ischemia. It is not uncommon to find atherosclerotic coronary artery disease coexisting with hypertensive heart disease.

Pulmonary thromboembolism is another common cause of sudden death from pathology in the vascular system. If 60% or greater of the pulmonary vasculature is suddenly blocked, the heart cannot pump blood to the lungs, leading first to acute right heart failure and then to cardiovascular collapse. The source of blockage is usually a clot (thrombosis) that has formed in the deep veins of the lower extremities, has dislodged, and traveled (embolized) up the inferior vena cava, through the right heart, and then lodges tightly in the pulmonary arterial vasculature. The original thrombosis may be due to blood stasis in the lower extremities caused by risk factors of obesity, immobility, or abnormalities in blood clotting mechanisms. If immobility has precipitated the deep vein thrombosis in the legs, it is important to recognize that although the immediate cause of death may be pulmonary emboli, the proximate cause is the condition initiating the immobility. If the immobility is due to injury, the manner of death will be accident or homicide, not natural.

Respiratory causes of sudden unexpected death commonly include infections such as bacterial or viral pneumonia and asthma. Pneumonia is an invasion of lung tissue by organisms, usually viruses or bacteria. These cases, normally felt to be treatable either through drug therapy or medical supportive therapy, can cause a sudden unexpected death when the signs and symptoms have been ignored, attributed to other causes, or ineffectively treated with over-the-counter products. An acute asthma attack, often precipitated by exposure to an allergen, may develop into status asthmaticus or present as a sudden collapse. Sudden death from asthma is caused by obstruction of the airways by muscular constriction and mucus production such that air can get into the lungs but cannot be exhaled out. At autopsy, the lungs are overinflated and billowy with clear mucous plugging the bronchi.

The most common cause of sudden unexpected death involving the central nervous system is a seizure disorder or a ruptured blood vessel. Epilepsy is a group of disorders that have in common an abnormal discharge by groups of neurons in the brain. Similar to a cardiac arrhythmia, it is a disorder of function caused by an uncoordinated and abnormal electrical discharge from neurons. The exact mechanisms that cause sudden unexpected death in epilepsy (often abbreviated SUDEP) and how they differ in seizures that do not cause death is unclear. In most cases of epilepsy, so-called “idiopathic” epilepsy, the brain is both grossly and microscopically normal. Toxicology may reveal sub-therapeutic levels of anticonvulsant medication. A hemorrhagic area within the musculature of the tongue, representing a bite, although not always present, may suggest that uncontrolled muscular

contractions have occurred. All other significant possible causes of death must be excluded. Occasionally, a structural abnormality, such as an undiagnosed congenital brain malformation or brain tumor, may be discovered as the cause of a fatal seizure. In post-traumatic epilepsy, an abnormal neuronal discharge starts in an area of prior brain injury; here, although the immediate cause of death is the seizure, the proximate cause of death is the injury, thus requiring an investigation of the circumstances of the injury to determine the correct manner of death.

A ruptured blood vessel that rapidly releases blood into the meningeal spaces around the brain can result in sudden death. The most common sources of this blood are ruptures of a vascular malformation (such as an arteriovenous malformation – a tangle of small arteries and veins) on the surface of the brain or the rupture of an aneurysm (often called a berry aneurysm because of its round berry-like shape) located on the blood vessels at the base of the brain. Rupture of vascular malformations or aneurysms may be associated with episodes of increased blood pressure that can be caused by intense physical activity, drugs such as amphetamines or cocaine, emotional upheavals, or hypertension. In most cases, however, the rupture appears to be spontaneous, without a precipitating event. In some cases, the presence of blood in the subarachnoid space will cause the onset of a severe headache often described as a "thunderclap" headache, followed by collapse. If a small warning bleed occurs prior to a total rupture, the aneurysm can be corrected neurosurgically using clips or intraluminal coils to stabilize the vessel wall. Unruptured vascular malformations and berry aneurysms are not infrequently found at autopsy in cases where death occurred due to other causes.

11.6.4.2 Infants and Children

Pediatric deaths are often due to natural causes, especially during the first year of life, however, homicides and accidents obviously do also occur in that age group as well. Natural deaths can be due to infections, congenital abnormalities, or inborn errors of metabolism. Sometimes these are not diagnosed prior to their fatal outcomes, despite medical care and parental vigilance. Leukemia, brain tumors, and Wilms tumor are common childhood cancers responsible for death.

Sudden infant death syndrome (SIDS), is one of the most common natural causes of death in infants younger than 3 months and, by definition, is always investigated by the medical examiner's office where the diagnosis is made. SIDS is a diagnosis of exclusion meaning that a thorough medicolegal death investigation must be conducted and, if unrevealing of findings deemed adequate to cause death, by convention the death is called SIDS. The initial definition was formulated in 1969 and required a "negative postmortem examination" [25]. This definition was revised in 1989 by the National Institute of Child Health and Human Development and now requires the death of an infant, usually younger than one year of age, where first, a thorough scene investigation reveals no evidence of a potential unnatural death; second, a review of the infant's and mother's medical records reveal no history of disease sufficient to cause death; and third, a thorough postmor-

tem examination fails to demonstrate an adequate cause of death [26]. Because SIDS is a diagnosis of exclusion, it is essential that medical examiner's conduct a thorough investigation, with the aid of standard protocols and knowledge of recent scientific advances reported in the literature. This is necessary to ensure not only a consistency of diagnosis across jurisdictions but to eliminate accidental and homicidal deaths, as well as rare natural diseases where diagnostic findings may be subtle or involve rigorous laboratory testing.

The scene investigation must take place even if rescue personnel have removed the infant from the scene. The position of the infant when put down to sleep, the temperature of the environment, and the sleeping structure and associated items should be documented and witness interviews conducted. The goal is to recreate the sequence of events (i.e., a timeline), in as much detail as possible, of the hours, or, in some cases, possibly days, prior to the infant being found dead. In some cases, a red flag from the scene investigation alone will eliminate the possibility that the death can be attributed to SIDS. For example, finding plastic bags or sheets near the infant, a bed stuffed with fluffy bedding or stuffed animals (a scenario possibly conducive to asphyxia by rebreathing), ill-fitting mattresses or damaged cribs with areas of possible wedging, and bed sharing are findings that suggest an unsafe sleep environment, raising questions as to whether SIDS can be an appropriate diagnosis.

As mentioned, the above postmortem examination and testing must be rigorous in order to exclude as many other causes of death as possible. The extent of examination, however, may vary depending on available resources, experience, and training of the forensic pathologist, and on customary local practices. Full-body X-rays, full toxicology, microbiology, a complete internal and external examination including neuropathology, full histology, vitreous electrolytes quantitation, and screening for inborn errors of metabolism are usually done. In addition, specialized molecular biology studies, examination of the retina, inner ear, and/or deep soft tissues may also be added.

The typical SIDS case is an infant with a negative past medical history, possibly with mild recent upper respiratory tract symptoms, who was found dead in a safe sleeping environment and apparently died quietly during sleep. Postmortem findings are nonspecific and include pulmonary vascular congestion and edema with the appearance of froth in the nose, mouth, and airways. Petechiae on the epicardial or pleural surfaces or on the thoracic portion of the thymus may be found in up to 80% of cases.

The cause of SIDS is still unknown and, further, whether or not it is indeed a true syndrome is unknown. The manner of death, however, is presumed natural. Research into the field of SIDS is ongoing. Some studies have found subtle brainstem abnormalities or failure in arousal mechanisms that seem to explain why these infants may have stopped breathing. This work, however, has not yet translated to practical diagnostic or prevention strategies. As diagnostic testing becomes more sophisticated, more subtle disease processes are able to be diagnosed, such as the molecular channelopathies, including prolonged QT syndromes, where defects in the membrane ion channels in the heart muscle can cause sudden, unexpected fatal arrhythmias; such cases would otherwise be diagnosed as SIDS.

The initiation of the back-to-sleep program, where parents are urged to place infants on their back to sleep, has coincided with a decline in the number of SIDS cases. Whether this association is causal, or has resulted coincidentally from more rigorous postmortem investigation and testing that excludes a SIDS diagnosis (a diagnostic shift), is not yet clear [27].

11.7 Education and Certification

11.7.1 Education of the Forensic Pathologist

Forensic Pathology is the medical component of the forensic sciences. It is also known as "forensic medicine." Forensic pathologists are medical doctors (MDs or DOs) who, after graduating from four years of medical school, go on to complete three or four years of specialized training in postgraduate internships and residency programs, studying anatomical and clinical pathology. Following residency programs, forensic pathologists complete additional training in one or two year fellowships to obtain a subspecialty in forensic pathology.

The foundation of medicine is the study of pathology, which, at its most basic, is the study of disease. A pathologist must have a complete understanding of normal and abnormal tissue structure, as well as a thorough knowledge of the structure and function of organs, which, taken together, form the basis of all clinical medicine and surgery specialties.

Anatomic pathologists study the body's organ systems to understand disease and organ failure. They also assist the clinician in diagnosing disease in living patients by evaluating tissue biopsies and surgical specimens and by examining cytological (cellular) specimens. In the hospital setting, the anatomic pathologist performs postmortem examinations to develop clinicopathologic correlations relating tissue abnormalities to clinical signs and symptoms. The discipline of clinical pathology focuses on the hospital laboratory in which quantitative and qualitative analysis of biomarkers in blood and other body fluids are used to diagnose and monitor disease processes. Many pathology residency programs today offer combined study in anatomical and clinical pathology.

Accredited forensic pathology residency programs, which today number close to forty, are usually located in medical examiner's offices in large cities. They receive program accreditation from The Accreditation Council on Graduate Medical Education (ACGME) [28]. Residency programs offer postgraduate students a wide range of training in the field. Accredited programs require residents perform between 200 and 300 autopsies per year. Residents must also review medical histories and circumstances of death; conduct external examinations of the body; perform gross dissection; review microscopic and laboratory findings; prepare written reports; and develop sound opinions on the cause and manner of death. Additionally, forensic fellows gain experience in scene investigation and acquire specialized training in toxicology, physical anthropology, and DNA technology. Elements of

the crime laboratory, such as firearms, serology, and trace evidence, are also studied. By the conclusion of the residency program, residents learn how to conduct forensic autopsies, work alongside law enforcement officers, and interact with attorneys and grieving families.

Recently, ACGME, the accrediting organization, adopted broader standards for pathology specialties, requiring forensic fellows to obtain competency in six general areas: (1) Ability to demonstrate a satisfactory level of diagnostic competence and ability to provide effective pathology consultation in patient care, (2) Ability to remain current in medical knowledge of evolving biomedical and clinical sciences and apply this knowledge to pathology, (3) Ability to evaluate pathology practices and assimilate new scientific evidence to improve practice, (4) Ability to communicate effectively with other health care providers and patient families, (5) Develop and demonstrate a commitment to carry out professional responsibilities and adhere to ethical principles, and (6) Understand the value of pathology services in the larger context of systems of health care [29].

11.7.2 Board Certification

Each year, thirty to forty physicians complete pathology training and sit for the American Board of Pathology examination certifying specialty competency in forensic pathology. Only approximately 1,300 physicians have attained board certification in forensic pathology since the exam was first offered in 1959. When compared with about 5,000 medical school graduates entering internal medicine residency programs each year, the number seems particularly low [30].

Currently, only approximately 500 board-certified forensic pathologists are practicing full-time in the United States. The shortage of well-trained forensic pathologists exists, not only in America, but beyond its borders as well. This takes on global significance at a time when deaths from natural disasters, long-running armed conflicts, and emerging infectious diseases appear to be on the rise.

11.8 Court Testimony and Ethics

For a forensic pathologist, expert testimony can be broadly viewed as a social responsibility. By speaking for the dead, the pathologist's testimony aides the jury and judge in understanding the factors causing death from disease- and injury-related issues.

Courtroom testimony is given at the request of the plaintiff or the defendant in a civil lawsuit, or at the request of a prosecutor (state or district attorney or federal attorney) or defense attorney or judge in criminal matters.

11.8.1 Types of Witnesses

In general, a witness is anyone who can provide information to the court. Specifically, there are two different types of witnesses: a witness of fact and an expert witness.

Fact witnesses may testify only to what they themselves experienced with their five senses. Testimony regarding their opinions or interpretations of the facts is not allowed.

The *expert* witness is someone who "through education or experience developed skill or knowledge in a particular subject so that he or she may form an opinion that will assist the fact finder" [31]. The expert witness has scientific, technical, or other specialized knowledge that will help the judge and jury understand evidence. Expert opinion is not intended to supplant the jury's decision-making role. Rather it is intended only to assist the jury in understanding certain facts that are in dispute. They are a crucial part of the justice system [32].

As judicial gatekeepers, judges have a responsibility to prevent unqualified individuals from presenting opinions in court. Judges have to rule that the individual testifying has credentials certifying they are a competent authority in their particular area of expertise. In so doing, judges prevent irrelevant information or unsubstantiated opinions from entering courtrooms [33].

11.8.2 Role of the Forensic Pathologist in Court

In some cases, the forensic pathologist may simply testify to the cause and manner of death. In others, the testimony can be fairly involved, drawing on a broad range of medical and scientific facts. Although the pathologists often give compelling testimony, they are not advocates. As Paul C. H. Brouardel, a leading authority in forensic medicine in France in the nineteenth century, notes: "If the law has made you a witness, remain a man of science; you have no victim to avenge, no guilty person to convict, and no innocent person to save. You must bear testimony within the limits of science" [32]. It is up to the attorney, not the forensic pathologist, to win or lose the case.

Our adversarial form of the legal system allows for vigorous cross-examination of the expert by opposing council to expose any weakness in knowledge, errors of interpretations, or omissions. Thus, the expert should have critically reviewed and studied the case files, their methodologies, reasoning, and current medical literature as it pertains to the facts of the case.

11.8.3 Ethics of Court Testimony

The two key features of sound, ethical medical testimony are scientific validity and personal impartiality. The forensic pathologist's opinion must be based on

reasonable scientific or medical certainty and never be biased for or against the prosecution or defense. The pathologist must testify on facts objectively and accurately recorded and then analyzed in detail to give opinions solidly derived from these facts.

The American Society of Clinical Pathology (ASCP) policy on expert witnesses sets forth the following [34]:

- The expert witness should possess current experience and ongoing knowledge in the area in which he or she is asked to testify.
- The expert witness should be willing to submit the transcripts of depositions and testimony to peer review.
- The expert witness should not accept compensation that is contingent on the outcome of litigation.
- The expert witness should not provide expert medical testimony that is false, misleading, or without medical foundation. The key to this process is a thorough review of available and appropriate medical records and contemporaneous literature concerning the case being examined. After this process is completed, the expert's opinion should reflect the state of medical knowledge at the time of the incident.
- The expert witness should review the medical facts in a thorough, fair, and objective manner and should not exclude any relevant information to create a view favoring the plaintiff or the defendant.
- A pathologist should not engage in advertising or solicit employment as an expert witness where such advertising or solicitation contains representations about the physician's qualifications, experience, or background that are false or deceptive.

As Sir Travers Humphreys, a British jurist, said about Sir Bernard Spilsbury, a noted early twentieth century forensic pathologist: "Spilsbury in the witness box was to my mind the ideal scientific witness. He was unemotional, simple in speech because he was clear in mind, absolutely fair, quite indifferent to the result of a case, paying little or no attention to those parts of the evidence which did not affect the medical or scientific aspects of the matter. He spared no pains in seeking out anything, fact, theory, or latest discovery, which could properly affect his judgment" [35].

11.8.4 Professional Responsibilities of the Medical Examiner

The medical examiner is responsible for performing the autopsy on the deceased, certifying the death, and presenting expert testimony in court. However, beyond these fundamental duties, medical examiners have a broader responsibility to the community. Promoting health and safety is also a key component of medical examiner work. The medical examiner does this by developing ways of sharing death investigation information with appropriate agencies. Sharing critical information aids policy makers in formulating effective strategies that address a broad range of

policy issues, including the environment, occupational safety, product safety, and food and drug safety.

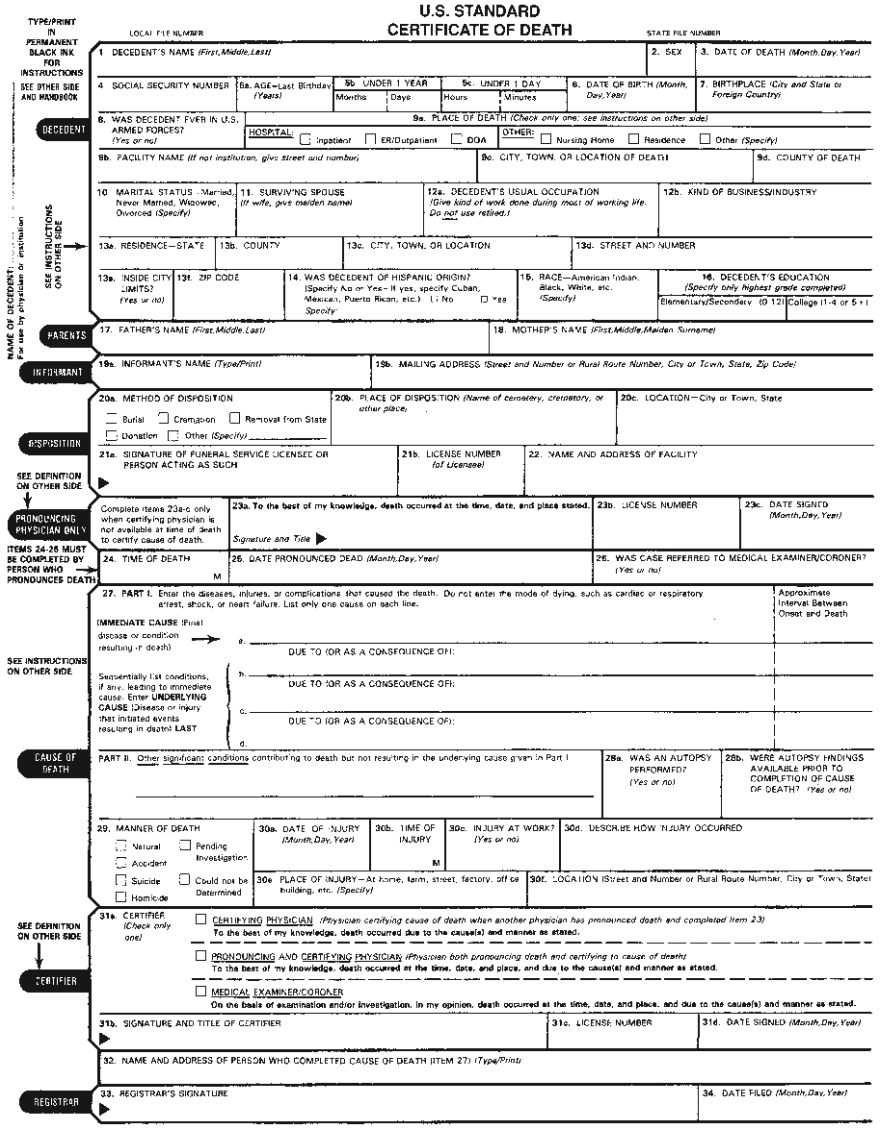
Medical examiners are responsible for educating physicians involved in patient care. Development and/or participation in maternal morality and trauma–death review committees and conferences are examples of the wider roles of medical examiners today. Medical examiners can also provide information to promote safety in the community. Child fatality review committees, for example, can reveal weaknesses in child-protective social services and aid in the detection of child abuse. Beyond the science in medicine, the medical examiner has a responsibility to help grieving families understand what has happened to their loved one. Because of the nature of these deaths, surviving family members often have contact with the medical examiner or coroner to identify the decedent, or to claim remains and personal belongings. Survivors may even assist in the death investigation by being interviewed by scene investigators. In these encounters, surviving family members can be experiencing overwhelming grief. In these critical moments, the medical examiner must have the skills to tactfully deal with the family's sorrow. There is no particular model that guides the medical examiner in these delicate situations. The medical examiner knows the science and medicine behind the death, but only the families themselves know what they are feeling. If they are ready to ask questions about the death, then they are ready to receive answers. However, never assume that loved ones hear and understand every word the first time. One rule to keep in mind is the George Bernard Shaw adage, "The biggest problem in communication is the illusion that it has taken place." Most people want to talk about the death of a loved one and will do so if provided the opportunity. Medical examiners, as the last doctor for the deceased, should be able to meet family at any stage of their grief, from hours to years after the death. In the final analysis, shielding families from unpleasant information is never an option, despite noble intentions. So never lie.

11.9 Final Thoughts: Pathology in the Public Interest

Throughout history, society has sought answers to the mysteries surrounding sudden and unexpected death. As death investigation has evolved from the rudimentary practices of early coroner systems to the discipline of forensic pathology today, medical examiners have gained far-better understanding as to why and how these deaths occur.

Today, medical examiners apply the knowledge of medicine and pathology, not only to better understand the cause and manner of death, but to protect public health and safety and aid in the administration of justice. Their highest goal is to develop strategies to prevent disease, death, and injury. The forensic pathologist has the professional and ethical responsibility to make the study of death benefit the living.

11.10 Appendix



U.S. STANDARD CERTIFICATE OF DEATH

TYPE/PRINT IN PERMANENT BLACK INK FOR INSTRUCTIONS SEE OTHER SIDE AND HANDBOOK

LOCAL FILE NUMBER

STATE FILE NUMBER

DECEDENT

1 DECEDENT'S NAME (First, Middle, Last)

2. SEX

3. DATE OF DEATH (Month, Day, Year)

4 SOCIAL SECURITY NUMBER

5a. AGE—Last Birthday (Years)

5b. UNDER 1 YEAR Months Days

5c. UNDER 1 DAY Hours Minutes

6. DATE OF BIRTH (Month, Day, Year)

7. BIRTHPLACE (City and State or Foreign Country)

8. WAS DECEDENT EVER IN U.S. ARMED FORCES? (Yes or no)

9a. PLACE OF DEATH (Check only one; see instructions on other side)

HOSPITAL: ☐ Inpatient ☐ ER/Outpatient ☐ DOA

OTHER: ☐ Nursing Home ☐ Residence ☐ Other (Specify)

9b. FACILITY NAME (If not institution, give street and number)

9c. CITY, TOWN, OR LOCATION OF DEATH

9d. COUNTY OF DEATH

10 MARITAL STATUS - Married, Never Married, Widowed, Divorced (Specify)

11. SURVIVING SPOUSE (If wife, give maiden name)

12a. DECEDENT'S USUAL OCCUPATION (Give kind of work done during most of working life. Do not use retired.)

12b. KIND OF BUSINESS/INDUSTRY

SEE INSTRUCTIONS ON OTHER SIDE

13a. RESIDENCE—STATE

13b. COUNTY

13c. CITY, TOWN, OR LOCATION

13d. STREET AND NUMBER

13e. INSIDE CITY LIMITS? (Yes or no)

13f. ZIP CODE

14. WAS DECEDENT OF HISPANIC ORIGIN? (Specify No or Yes - If yes, specify Cuban, Mexican, Puerto Rican, etc.) ☐ No ☐ Yes Specify

15. RACE—American Indian, Black, White, etc. (Specify)

16. DECEDENT'S EDUCATION (Specify only highest grade completed)

Elementary/Secondary (0-12) College (1-4 or 5+)

NAME OF DECEDENT — For use by physician or institution

PARENTS

17. FATHER'S NAME (First, Middle, Last)

18. MOTHER'S NAME (First, Middle, Maiden Surname)

INFORMANT

19a. INFORMANT'S NAME (Type/Print)

19b. MAILING ADDRESS (Street and Number or Rural Route Number, City or Town, State, Zip Code)

DISPOSITION

20a. METHOD OF DISPOSITION ☐ Burial ☐ Cremation ☐ Removal from State ☐ Donation ☐ Other (Specify)

20b. PLACE OF DISPOSITION (Name of cemetery, crematory, or other place)

20c. LOCATION—City or Town, State

SEE DEFINITION ON OTHER SIDE

21a. SIGNATURE OF FUNERAL SERVICE LICENSEE OR PERSON ACTING AS SUCH

21b. LICENSE NUMBER (of Licensee)

22. NAME AND ADDRESS OF FACILITY

PRONOUNCING PHYSICIAN ONLY

Complete items 23a-c only when certifying physician is not available at time of death to certify cause of death.

23a. To the best of my knowledge, death occurred at the time, date, and place stated. Signature and Title

23b. LICENSE NUMBER

23c. DATE SIGNED (Month, Day, Year)

ITEMS 24-26 MUST BE COMPLETED BY PERSON WHO PRONOUNCES DEATH

24. TIME OF DEATH M

25. DATE PRONOUNCED DEAD (Month, Day, Year)

26. WAS CASE REFERRED TO MEDICAL EXAMINER/CORONER? (Yes or no)

CAUSE OF DEATH

27. PART I. Enter the diseases, injuries, or complications that caused the death. Do not enter the mode of dying, such as cardiac or respiratory arrest, shock, or heart failure. List only one cause on each line.

Approximate Interval Between Onset and Death

IMMEDIATE CAUSE (Final disease or condition resulting in death)

a. DUE TO (OR AS A CONSEQUENCE OF):

SEE INSTRUCTIONS ON OTHER SIDE

Sequentially list conditions, if any, leading to immediate cause. Enter UNDERLYING CAUSE (Disease or injury that initiated events resulting in death) LAST

b. DUE TO (OR AS A CONSEQUENCE OF):

c. DUE TO (OR AS A CONSEQUENCE OF):

d.

PART II. Other significant conditions contributing to death but not resulting in the underlying cause given in Part I

28a. WAS AN AUTOPSY PERFORMED? (Yes or no)

28b. WERE AUTOPSY FINDINGS AVAILABLE PRIOR TO COMPLETION OF CAUSE OF DEATH? (Yes or no)

29. MANNER OF DEATH ☐ Natural ☐ Accident ☐ Suicide ☐ Homicide ☐ Pending Investigation ☐ Could not be Determined

30a. DATE OF INJURY (Month, Day, Year)

30b. TIME OF INJURY M

30c. INJURY AT WORK? (Yes or no)

30d. DESCRIBE HOW INJURY OCCURRED

30e. PLACE OF INJURY—At home, farm, street, factory, office building, etc. (Specify)

30f. LOCATION (Street and Number or Rural Route Number, City or Town, State)

SEE DEFINITION ON OTHER SIDE

CERTIFIER

31a. CERTIFIER (Check only one)

☐ CERTIFYING PHYSICIAN (Physician certifying cause of death when another physician has pronounced death and completed Item 23) To the best of my knowledge, death occurred due to the cause(s) and manner as stated.

☐ PRONOUNCING AND CERTIFYING PHYSICIAN (Physician both pronouncing death and certifying to cause of death) To the best of my knowledge, death occurred at the time, date, and place, and due to the cause(s) and manner as stated.

☐ MEDICAL EXAMINER/CORONER On the basis of examination and/or investigation, in my opinion, death occurred at the time, date, and place, and due to the cause(s) and manner as stated.

31b. SIGNATURE AND TITLE OF CERTIFIER

31c. LICENSE NUMBER

31d. DATE SIGNED (Month, Day, Year)

32. NAME AND ADDRESS OF PERSON WHO COMPLETED CAUSE OF DEATH (ITEM 27) (Type/Print)

REGISTRAR

33. REGISTRAR'S SIGNATURE

34. DATE FILED (Month, Day, Year)

11.11 Questions

1. Describe the difference between the mechanism of death, the immediate cause of death, and the proximate cause of death. Why are these distinctions important?
2. What are the differences between a coroner and a medical examiner?
3. Describe the different manners of death.
4. What are the parts of a forensic autopsy examination?
5. What are the parts of a medicolegal death investigation?
6. List the types of information that the autopsy of a firearm victim should document.
7. What is the difference between an incision and a laceration? Why is the difference important?
8. Define petechiae. How are they formed in deaths from manual strangulation?
9. How is the diagnosis of child abuse made?
10. How is the diagnosis of sudden infant death syndrome (SIDS) made?

11.12 About the Author

Dr. Elizabeth Laposata, a native of Washington, DC, attended University of Maryland School of Medicine in Baltimore, MD, where she obtained her Doctor of Medicine degree and completed her internship and residency in Anatomic Pathology at Johns Hopkins Hospital in Baltimore and her subspecialty fellowship training in Forensic Pathology at St. Louis University School of Medicine in St. Louis, MO. She is a Diplomat of the American Board of Pathology with certification in anatomic and forensic pathology.

She has held faculty appointments at the University of Pennsylvania School of Medicine in Philadelphia, where, as Associate Director of Medical Pathology, she was responsible for the autopsy service. She currently holds faculty positions as Clinical Associate Professor of Pathology and Laboratory Medicine at Brown University School of Medicine and as Adjunct Professor of Biomedical Forensic Sciences at Boston University School of Medicine, where she teaches forensic pathology and medicolegal death investigation. She operates Forensic Pathology and Legal Medicine, Inc., an independent consulting practice.

She has worked as an Assistant Medical Examiner for the City of St. Louis, the City of Philadelphia, and the State of Delaware. From 1993 to 2005, she served as the Chief Medical Examiner for the State of Rhode Island.

In 2003 the Rhode Island Commission on Women honored her as Woman of the Year and in 2004 she was selected as one of the top 25 public health figures in the country. She has authored papers in forensic pathology, and has lectured widely to the medical, legal, law enforcement, and victim-advocacy communities. She has provided expert witness testimony in numerous criminal and civil court proceedings.

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Chapter 12
Quality in the Forensic Science Laboratory

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Contents

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12.1 Introduction

The value of forensic science's contribution to justice depends on the reliability of the tests conducted in the laboratory and the validity of the interpretations that the scientist places on those results and conveys to investigators and courts. Assuring quality in the crime lab is not only about doing the right thing, but having a system in place to make sure that the right thing is indeed done and having objective information to prove it. Quality assurance and quality control are therefore about understanding the concept of quality and implementing a management system to ensure its delivery.

The Quality Management System (or QMS, and often referred to as the "Management System") is simply the policies, procedures, resources, and organizational structure required to achieve the desired performance of the organization. The key determinant is defining the desired performance or quality of output to be delivered by the laboratory. We all have our own notion of what constitutes quality, but, before examining quality in the laboratory, let us think about a few everyday examples. If asked "Is a million-dollar penthouse on Miami Beach a quality residence?" most of us would answer "Yes." But if we started with the question "Considering your personal circumstances, define your ideal home," few would give the Miami Beach penthouse as the answer. Factors such as income; family circumstances such as proximity to schools, work, and shopping; and personal lifestyle choices such as preference for city, beach, or mountains would all factor into the decision. The same general situation applies to automobile selection, music tastes, and food preferences.

This takes us back to "desired performance" and the fundamental concept that the quality of goods or services depends on the user-defined requirements. For the

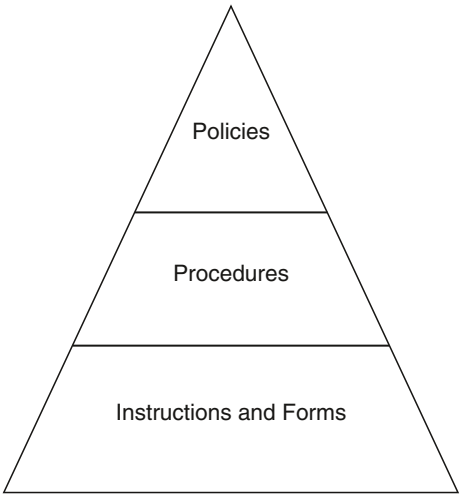

Fig. 12.1 Document hierarchy in a Quality Management System (figure created by author)

purposes of this chapter, we will use the following definition: "Quality (of goods or services) is measured by (their) fitness for the intended purpose."

Quality as defined above assumes that there is a single purchaser of the goods or user of the services – the customer – and that the provider knows the needs of the customer and can develop a specification against which fitness for purpose can be measured. This is not the case with forensic science. Almost all forensic science testing is conducted in government facilities on evidence brought to the laboratory by the police seeking testing that will support their case. However, the results of the testing, and the interpretations placed on the results by the forensic scientist, are also available to the defense, who has an opposing purpose to that of the police. Finally, the trial is conducted under the control of a judge who has absolute authority as to fitness for the intended purpose. It can be very difficult to meet the demands of all three parties (Fig. 12.1).

12.2 The Quality Management System

The QMS consists of the policies, procedures, resources, and organizational structure that control how the forensic science or crime laboratory will test evidence and interpret the results. Policies are the highest-level components and define:

- The physical structure of the organization
- The roles of the personnel in it
  - Permissions (what can be done)
  - Obligations (what must be done)
  - Prohibitions (what must not be done)

Procedures are the next level and describe:

- The work that must be done
- How it is performed
- By whom, and under what circumstances
- The documents and records that must be used

The QMS must be documented in a quality manual. The quality manual *must* contain all of the key organizational policies. It may contain or refer to the source of other policies and all relevant procedures.

12.3 The Quality Manual

The reasons for documenting the QMS in a quality manual are:

- To ensure all members of the staff know what is expected of them
- To provide instructions how the staff perform the tasks and duties expected of them describing the limitations, authorities, and resources
- To provide a tool through which the performance of the QMS can be monitored and improved
- To prevent outdated and "folklore" (that is, unofficial word of mouth) policies and procedures being followed
- Be sure the right thing is done in the right way at the right time and in the right circumstances.

The quality manual can be in written (paper) or electronic form.

Most laboratories are part of a larger organization, such as a Department of Public Safety, Police Department, or Sheriff's Office. The host agency will have policies and procedures governing matters such as purchasing, administrative rules and regulations, and standard job descriptions. It is not required that these be reproduced in the quality manual, but they must be referenced and copies must be available to all personnel.

Likewise, the QMS requires that all procedures are documented, but the quality manual can refer to the source documents rather than reproducing each procedure. However, the quality manual must contain all key policies.

It is an absolute requirement of an effective QMS that the organization has a quality manual. Without the manual, there is nothing to guide the laboratory to deliver a product of the required standard. According to Garfield et al. [1], the quality manual structure should be:

1. Table of contents
2. Quality policy
3. Description of the quality manual
4. Description of the laboratory

5. Staff and human resources
6. Equipment, testing, and measuring
7. Environment
8. Test methods and procedures
9. Updating control of documents
10. Handling of test items
11. Verification of results
12. Test reports
13. Diagnostic and corrective actions and audits
14. Records
15. Subcontracting

12.3.1 Preparing the Quality Manual

A good way to cover the importance of the quality manual and its essential content is to consider how to write one. The key steps are:

- The manual covers the organization's QMS, therefore:
  - It must contain all essential policies and contain or reference all procedures and secondary policies
  - All requirements specified in the manual must be followed
- It is best to begin by capturing what actually happens in the organization, then making sure that it is followed
  - "If you do it, write it"
  - "If you write it, do it"
  - And, referring to records of tests and compliance with policies, "If it ain't written, it didn't happen"
- Remember that the quality manual is a living document that will undergo continual revision and updating, so the first version is the foundation for what will come, not the absolute end of the project
- Organize the manual in a helpful way
  - The chapters could follow the clauses in the laboratory's accreditation program standards, which would cover all of the topics suggested by Garfield et al. [1], but be more up to date and relevant
  - Minimize size by publishing separate volumes for functional areas such as technical methods, administrative procedures, personnel management
- Involve operational (non-management) staff in writing and reviewing the manual so that they understand its function and format and develop a sense of ownership

- Guidance can be obtained from quality management system consultants and through various software programs available, but ultimately no one knows your business better than you do

Careful attention must be paid to language in the quality manual. The writing must be clear and unambiguous. The word "must" is used to describe something that is obligatory and the word "should" is used to describe something that is desirable but not obligatory. Note that the quality manual can contain notes or recommendations for things that should be done but are not obligatory.

12.4 The Quality Manager

One of the requirements of the QMS is that it describes the roles and responsibilities of personnel. There is a personnel position with very special responsibilities with regard to the QMS and the quality manual, namely, the Quality Manager. The main international standard dealing with quality management as it applies to the competency of testing laboratories is ISO/IEC 17025:2005 [2]. The standard will contains considerable detail, but, at this point, we are only concerned with clause 4.1.5 i, which requires that the laboratory has a member of staff appointed as quality manager, and who shall have defined responsibility and authority for ensuring that the management system related to quality is implemented and followed at all times. The clause also requires that the quality manager shall have direct access to the highest level of management at which decisions are made on laboratory policy or resources.

Typical functions of the quality manager to meet the requirement of "ensuring that the management system related to quality is implemented and followed at all times" include:

- Control of the quality manual
  - Revise to reflect new or altered policies and procedures
  - Ensure it is available to all staff
  - Make sure only current versions are used by personnel
- Monitor compliance with requirements of the QMS including
  - Conduct and review of annual QMS audits
  - Manage annual management review
- Manage the laboratory quality assurance program, including
  - Review of instrument calibration and maintenance records
  - Administration of proficiency testing
  - Investigate technical problems, propose remedial actions, and verify their implementation

12.5 Quality Assurance and Quality Control

12.5.1 Quality Assurance

Quality assurance is defined as all the planned and systematic actions necessary to provide adequate confidence that a product or service will satisfy given requirements for quality.

Garfield et al. [1] expand the concept of quality assurance to include those laboratory operations undertaken to achieve the following objectives:

1. Documentation that quality control procedures are indeed being implemented
2. Procedures and documentation to ensure that accountability of data is maintained are in place
3. Procedures and documentation to facilitate the traceability of the analytical results to the analyst and the status of the analytical system at the time the analyses were run are in place, including those for method evaluation
4. Procedures and documentation that ensure the integrity of data against loss, theft, or tampering are in place.

Every aspect of the organization can impact quality and therefore is part of the planned and systematic actions of quality assurance. However, the main aspects are:

- Personnel
- Environment
- Equipment and reagents
- Test procedures
- Sample integrity
- Records and documents
- Procedures to assure the quality of test data
- Quality control operations

Personnel include education and training of staff, and steps to define competency requirements and to ensure that members of the staff are competent to conduct the tasks asked of them. Environment includes physical plant, temperature and humidity control, and laboratory design to facilitate work flow, and prevent loss, degradation, or contamination of samples. Equipment includes reliability, calibration, maintenance, and performance of analytical instrumentation. Test procedures includes using methods that are appropriate to the analysis requested, with a preference for standard methods that have been validated and published through a consensus process such as that used by the American Society for the Testing of Materials (ASTM).

Sample integrity is a major issue for forensic scientists, but it has been an integral part of the basics of quality assurance in all fields of testing for much longer than the relatively recent formalization of the subject in forensic science.

The basic premises of quality assurance are:

- Quality must be the foundation of everything that is done in the forensic science laboratory – it is not an extra to be dealt with in the spare time between testing and testifying
- Everyone must be actively involved with quality, every day on every sample, not just periodically on proficiency test (PT) samples or when an audit is due
- The buck stays with you; you are responsible for what you do, not management or supervisors
- Nothing is perfect but that is not a reason to not do your best within the recognized limits
- Although the quality of the final product can be subjective (does it meet the needs of the end user) the quality assurance system is built on facts and objective data, not opinions or luck
- Records matter – all relevant quality data and checks need to be recorded and retained as confirmation of the effectiveness of the QMS and as data for continuous improvement
- Bad data is worse than no data

12.5.2 Quality Control

Quality control is defined as the operational techniques and activities that are used to fulfill requirements for quality

Analysts working in a laboratory often equate quality control (QC) with the inclusion of reference or check samples in a batch of test samples. Results are only released if the "QC" sample gives an acceptable result. However, the quality control operational techniques and activities extend far beyond the use of check samples. There are several points at which quality control operations access laboratory activities. Each contributes to the compilation and interpretation of statistical data that permit the laboratory to identify actual or potential problems and implement corrective or preventative action. The statistical data also provide the objective measurement of the effectiveness of the organization's quality assurance.

The main points at which quality control operations access laboratory activities are:

- Instrument calibration and maintenance
- Control charting and trend analysis
- PT and reference samples
- Method validations

12.5.2.1 Instrument Calibration and Maintenance

Calibration refers to the procedures used to determine and verify the performance parameters of an instrument. It is the process that ensures the instrument itself is

functioning correctly. As a simple example, an ultraviolet spectrophotometer may be used to measure the amount of DNA in a sample from the absorbance of light at a wavelength of 260 nm. The absorbance reading is converted into amount of DNA by reference to the extinction coefficient of DNA. However, unless the spectrophotometer has been correctly calibrated in regard to wavelength, the conversion will be incorrect.

Instrument maintenance is a planned series of activities to clean and calibrate instruments to ensure that they are operating to specification. This is the opposite of the popular dictum "If it ain't broke, don't fix it." An effective QMS contains quality control procedures that prevent breakdowns.

12.5.2.2 Control Charting and Trend Analysis

Control charting and trend analysis are dealt with later. In summary, compiling and interpreting the results of laboratory control (or "check") samples is one of the most important quality control functions.

12.5.2.3 Proficiency Test and Reference Samples

Proficiency testing (PT) is a powerful quality control operation that is based on sending identical materials to a number of laboratories (either samples from a homogenous bulk, or identically manufactured artifacts, or passing on a single artifact) and comparing the test results. Proficiency testing can demonstrate and validate the ability of a laboratory to achieve acceptable results. The true value in the PT sample of the attribute to be measured need not be known – the power of the procedure is the comparison of results. In contrast, reference materials are manufactured and validated such that there is a defined target value. Reference materials are an excellent way for a laboratory to validate its own testing. Unfortunately, very few reference materials are available and routinely used in forensic science.

12.5.2.4 Method Validations

Method validation is the process used to show the ability to achieve the desired results with the method. Extensive validation is required for new methods. Although standard and official methods will have had adequate validation before being published, the laboratory must be able to show that it has the ability to use the method within the specified performance criteria defined.

Methods may be validated by comparison with other established methods using certified reference materials (where available) or materials of known characteristics.

In validating test methods, the following issues (among others) may need to be determined, as appropriate:

- Matrix effects
- Interferences
- Sample homogeneity
- Concentration ranges
- Specificity
- Stability of measured compounds
- Linearity range
- Population distribution
- Precision
- Measurement uncertainty

Validation studies can be conducted by the scientific community (as in the case of standard or published methods) or by the forensic science laboratory itself (as in the case of methods developed in-house or where significant modifications are made to previously validated methods).

12.6 Audits

12.6.1 Introduction

The QMS is a living system that has to be subject to continual review to make sure that it is up to date. Factors such as:

- Data from quality control procedures
- Feedback from customers
- PT data
- Staff changes
- Physical plant changes

all mean that the QMS will need updating. The quality audit is the formal process to manage the review of the sufficiency of the QMS and provide objective information on the conformance of the laboratory operations with the standards set out in the QMS. The process is an active signal to staff that the organization is serious about its commitment to quality.

12.6.2 Auditing and Management Review

Webster's Dictionary defines an audit as: transitive verb, to examine and verify (as the books of account of a company or a treasurer's accounts).

This has led to the largely negative image of an audit in the public eye, as being a punitive exercise designed to catch wrongdoing. However, in the quality systems management world, the audit is a very positive factor, designed to help the laboratory improve its performance.

The task to "examine and verify" the books of account of a company could be conducted solely from the books themselves, searching for internal consistency. However, in practice, a laboratory audit measures performance against a stated standard. This will be, at a minimum, the laboratory's QMS, but could include external standards such as the National QA Standards for DNA testing, and ISO/IEC 17025:2005 [2].

12.6.2.1 The Audit Plan

The audit process begins with a formal plan. The plan must define the scope, making clear what is and is not being audited, and the particular standards that apply. The scope may be *horizontal*, that is, it looks at all instances of an activity (such as instrument calibration) throughout the laboratory, or it may be *vertical*, that is, it looks at all aspects of the QMS that apply to a discrete unit within the laboratory (such as drug analysis). Team members are identified. They should be independent of the activity being audited whenever possible and be trained in laboratory auditing. The team must be able to deal with the technical subject matter and with the quality systems requirements.

The plan should identify the authority under which it is conducted. This is usually the laboratory Quality Manager, acting with the authority of the Director. This top-down endorsement gives the audit team muscle.

The first step in conducting the audit is to hold a pre-audit conference with the team to:

- Determines dates when members are available
- Identify documents that are to be reviewed
- Identify the parts of the laboratory to be visited (including offsite locations where appropriate, such as Police HQ, long-term evidence storage facilities, and satellite laboratory facilities)
- Identify people to be contacted
- Advise the people being audited
- Develop or confirm the audit checklist

12.6.2.2 The Checklist

An organization with an established quality audit program will have audit checklists as part of its QMS documentation. An organization undergoing its first audit will need to prepare a checklist from the ground up. In either case, the team must make sure that they have a checklist that covers the scope of the audit. It is a good idea to share the checklist with the management and operational personnel in the area being audited so that they can have everything prepared and available for the audit team.

12.6.3 Data Collection

The success of the audit depends on the ability of the audit team to collect valid and objective data. The data will come from:

- Verification of existence of documents and records
- Examination and evaluation of the documents and records
- Interviews
- Examination of physical environment
- Observation of testing

The interviews can be the most challenging of these activities. The personnel being interviewed may be self-conscious and feel somewhat ill at ease by the process. The discomfort may escalate to become lack of cooperation. An understanding of good interviewing is thus important to the conduct of a successful audit.

12.6.3.1 Objectivity in Data Collection

The audit is a fact-finding mission, not a fault-finding safari. Data can be collected by questioning, inspection of documents and records to confirm that they exist, inspection of documents and records for evaluation of their content, and observation of physical environment and of activities.

12.6.3.2 Questioning

When it comes to questioning personnel, the auditor has to deal with something of a paradox: the best communication will flow from an interview that is relaxed and friendly in nature, but it is easy for that to drift away from the objective of gathering objective information.

Objectivity will be built in if the auditor is able to make sure that the interview is constructed around questions that ask:

- Who
- What
- Where
- How
- Why
- When

Important data must be verified, for example, by concluding with a request to illustrate the point made in the interview. Thus, an audit of instrument calibration may include the following dialog.

Auditor: How do you calibrate this balance?
Analyst: We run a check weight every time the balance is used.
Auditor: How do you know the check weight is accurate?
Analyst: We check it against a certified NIST standard mass every 6 months.
Auditor: Do you keep records of the check weights and the calibrations?
Analyst: Yes, we do.
Auditor: That is very good – thank you. You have dealt very well with all the questions and I appreciate your help. Before I go, could we go through the check weight and calibration records please?
Analyst: Of course! We keep the book right here by the balance. At what date range would you like to look?

Some useful hints on questioning

- Keep it simple
- Know what answer you expect before asking the question
- Be ready to seek clarification if an answer is not clear
- Use "I" questions ("I don't quite follow – could you please explain that one to me again?") when seeking clarification, so that you are signaling responsibility for the lack of understanding lies with you
- Paraphrase or restate answers, to make sure that what you heard is what the person interviewed meant

12.6.3.3 Physical Data: Document and Record Review, Environment

The checklist will identify documents and records that need to be reviewed, and why, for example:

- Are there policies and procedures as specified?
- If they exist, do they comply with the standards for Document Control?
- Do records comply with standards?

Remember that documents and records may be cross-referenced and spread over several sources, and that identifying the existence of documents and verifying their adequacy may also involve questioning personnel. For example, some standards require that personnel understand the content of a policy or procedure document and/or that the document is readily available.

12.6.4 Analysis Phase

The analysis phase involves the evaluation of data:

- What does the data tell us about conformity with requirements
- Is it reliable and objective

The data analysis phase is the step that provides the basis for reporting any non-conformances. Apparent non-conformances must be corroborated where appropriate. After being sure of the facts, you must then evaluate them, so that you are sure that you correctly identify the issue as a non-conformance or as an area where, although meeting the requirements of the QMS, improvements could be implemented and perhaps even prevent a quality failure arising in the future.

In regard to identifying a non-conformance, the "*Golden Rule*" of auditing is that: "The auditor *must* be able to describe the non-conformance in the words of the Quality System standard or procedure."

12.6.5 Reporting

The report should identify the following:

- Non-conformances – areas where the organization does not conform with something required in the standard.
- Concerns – areas that are not non-conformances, but which could affect the quality of testing or the effectiveness of operations and that therefore require a response.
- Comments – used mainly to identify good practice.

12.6.6 Corrective Action

The audit is worthless unless the laboratory responds to non-conformances and concerns in the report by implementing an effective corrective action process. Corrective action begins with the audit report, which must:

- Identify each significant non-conformance or concern.
- Identify the standard and clause to which it applies.
- State the corrective action required (that is, describe what it is that has to be addressed, NOT describe the cause of the failure).

The quality manager must respond by initiating a process to identify the root cause of the non-conformance or concern, and presenting management with options for remediation. The process is closed by a further audit that confirms the effectiveness of the corrective action.

12.6.7 Management Review

The audit is the main tool used to review compliance and adequacy of the QMS. However, the focus of the audit is mainly on compliance and the audit is just one

of many sources of information that the laboratory can use to review and improve its QMS. The main improvement tool is the management review.

As with auditing, the frequency of the management review is somewhat open to the laboratory. However, the QMS should have a procedure and schedule, and most accreditation programs will require an annual cycle. The management review is defined as: "Review of quality system and testing activities to ensure continuing suitability and to introduce necessary changes or improvements."
The review shall take into account:

- Suitability of policies and procedures
- Reports from managerial and supervisory personnel
- Outcome of recent internal audits
- Corrective and preventative action reports
- Assessment by external bodies
- PT results
- Changes in volume and type of work
- Client feedback
- Complaints
- Technology changes and other factors identified in scientific literature
- Other relevant factors such as QA data and staff training
- Recommendations for improvement

12.7 Competency

12.7.1 Introduction

Although a systems approach is an essential key to quality assurance, intuitively personal matters such as motivation, self-esteem, and pride in a job well done are also vital. Knowing what is expected of you and having guidance on what to do to meet the expectation is the bridge between the human factors and the systems approach to quality. Someone who is motivated will do what it takes to get the job done right; defining expectations and providing clear instructions keep the less-motivated personnel on track.

The human factors part of quality assurance is encapsulated by the concepts of competence and competency. Webster defines "competence" as "the quality or state of being functionally adequate … as for a particular duty or in a particular respect." However, Webster defines "competency" as a synonym for competence and this is not the meaning generally accepted in quality systems discussions. Here we regard "competency" as the knowledge, skills, and ability to meet complex demands. "Knowledge, skills, and abilities" are sometimes contracted to KSAs.

Knowledge is the body of information applied directly to the performance of a function.

Skill is being able to conduct the tasks involved in the function.
Ability is being able to apply the knowledge and skills in a way that results in the desired observable product.

The two concepts (competence and competency) are brought together thus:

- Competencies are the skills, knowledge, and abilities required by testing, managerial, and support personnel to ensure the competence of the laboratory.

The systems requirements to address competency should be found in the job (or position) description.

12.7.2 The Job Description

A mature laboratory will have developed an organizational structure that identifies all of the key positions and their interactions. Each position will have a well-defined function and associated competencies, which should be captured by defining the required KSAs. This has the following advantages:

- Recruitment. Including KSAs in a posting of a vacancy enables prospective applicants to weigh whether they could be serious candidates. Defined KSAs can be used to structure interviews and assist in selection of the best candidate. Defining the position needs and defining KSAs are closely linked.
- Evaluation. Objective evaluation of job performance is frequently a major and troublesome task for laboratory management. Specific definition of KSAs gives an objective and measurable framework for evaluations.
- Training and development. KSAs allow laboratory management to develop relevant individual training and development plans for staff. As well as making sure that the competency of individual staff members grows as responsibilities grow, the KSA-driven approach to training allows the laboratory to develop staff for new technical and non-technical responsibilities.

For example, consider two laboratories conducting controlled substance testing. Laboratory "A" conducts qualitative examinations only, and has been using microcrystal testing for more than a decade. Laboratory "B" conducts qualitative and quantitative testing using gas chromatography (GC) and GC–mass spectrometry (MS). The competencies required of a drug chemist in the two laboratories are quite different although both have the same objective of reliable identification of controlled substances in evidence such as unknown white powders. If, for example, laboratory "A" is not able to recruit a new analyst with the required competencies, but has an applicant with many years for experience in drug analysis in laboratory "B," they can use the KSA definitions to work out a training program for the individual. Similarly, if laboratory "B" decides to move to new technology such as MS–MS or LC–MS, they should firstly define the KSAs required of an analyst and then use those defined competencies to either develop existing staff or recruit new staff.

12.7.3 Training

Webster's definition of training includes "development of a particular skill or group of skills; instruction in an art, profession, or occupation," and the same source defines education as "a formal course of instruction or training offered by an institution (as a college) primarily designed to provide an education." Although the definition of education is somewhat circular, the essential difference is the implication that training is directed to skill development related to the workplace.
Training is used for the following purposes in the laboratory:

- To provide a new recruit with the knowledge and technical skills required to perform the tasks in the job description
- To prepare someone for future responsibilities
- To address performance deficiencies
- To understand and implement a new technique or instrument

12.7.3.1 Mentoring

Training can be provided as one-on-one mentoring, or "on the job training." Mentoring is an excellent training method, provided the mentor is an accomplished professional who knows the job and can communicate its features to the trainee. However, it has the following drawbacks:

- The mentor may be a poor teacher
- The mentor may pass on his or her bad habits
- It is wasteful of resources, because neither the mentor nor trainee is contributing to the laboratory output during the training
- Professional analysts are not professional instructors and may not understand the principles of adult education and instructional design
- The training may be curtailed in response to workload or budgetary pressures

12.7.3.2 Group Training

Training can be provided by providing courses for groups of students. Group training has the advantages that:

- The programs are usually designed and delivered by professional instructors
- The instruction is more cost effective
- With appropriate guidance, the class will develop into a learning community in which the interaction between students as they respond to the instruction enhances their understanding of the subject material
- The training will be consistent and complete and will not be curtailed in response to laboratory pressures

12.7.3.3 Student Learning

The third training method is that of self-paced learning by the student. In the past this was largely reading, for example, the laboratory quality manual, the laboratory safety manual, or a set of research papers. Today, the use of computers, either stand alone or to access the Internet, coupled with multimedia animations and videos, has made self-paced training much more effective. To get the best from self-paced training, the laboratory must make sure that:

- Each trainee has a firm schedule of what to read/access by computer
- Time goals are set
- The training is monitored and evaluated, for example by using simple tests for the student to demonstrate comprehension and to control progression through the material

12.8 Laboratory Equipment and Quality Assurance

12.8.1 Equipment Selection and Purchase

Advances in the design of electronic analytical equipment – especially in regard to the incorporation of microprocessors – have resulted in equipment with markedly improved performance in regard to specificity, speed of analysis, and interpretation of data. Evaluation of price and performance can be quite demanding when selecting new equipment, and careful consideration of many factors is required.

Selection and purchase should be planned and implemented around objective criteria such as:

- Is the equipment suitable for the purpose intended?
- Can the equipment deal with the likely workload?
- What are the training requirements of operators? Are these consistent with current competencies as included in job descriptions and how will any required training be delivered?
- What is the history of the manufacturer in regard to reliability and maintenance support?
- What is the expected operating environment for the equipment?

12.8.2 Equipment Preventative Maintenance

Preventative maintenance is the antithesis of the everyday expression “If it ain’t broke, don’t fix it.” Preventative maintenance is, like everything else in the systems approach to QA, directed to making sure that it works correctly from the beginning and stays that way – in other words, it does not get broken. This matters because

although QC checks will detect when things go wrong and so will probably prevent incorrect results being reported, time and sample will have been wasted. Indeed, in cases where sample size is limited, this could mean that critical evidence is lost. Preventative maintenance is therefore implemented to make sure that the analyst can depend on the reliability of the equipment before it is used to process case material. Preventative maintenance will also reduce malfunctions and ensure fewer breakdowns. Examples of preventative maintenance include:

- Cleaning – e.g., lenses and mirrors in capillary electrophoresis analyzers
- Lubricating – e.g., moving parts on autosamplers
- Calibration – an on-going verification of functioning
- Performance checks – e.g., off-center load checks on analytical balances

12.8.3 Calibration

Calibration is a process that we can define as "the procedures used to determine and verify the performance parameters of an instrument." The term "instrument" is used broadly and includes anything where an incorrect set-up could affect the accuracy and reliability of testing, such as refrigerators and heating blocks. Examples of calibration include:

- Calibration of analytical balances using reference standard masses
- Calibration of thermometers using fixed points such as ice/water or by reference to a NIST standard thermometer
- Calibration of wavelength of an energy dispersive infrared spectrophotometer using a polystyrene filter

Increasingly today, calibration is dealt with by microprocessors and internal electronics, such as the reference laser in a Fourier transform infrared spectrophotometer (FTIR). In practice, therefore, calibration becomes important in quality assurance when applied to equipment that

- Has some fundamental performance parameter that can vary with time or use, and
- Where that parameter can affect the quality of testing (including challenging the integrity of samples), and
- Where the parameter can be confirmed and adjusted to a specified value

12.9 The Test Environment

12.9.1 The Laboratory and Equipment

The integrity of samples and test results can be affected by factors in the physical testing environment. In forensic science, the most obvious example is access control to ensure that there is no likelihood of accidental or deliberate interference with the

integrity of samples, such as contamination of DNA evidence by sneezing, contamination of physical evidence by touch transfer of a fingerprint or smudging of an existing one, and degradation of biologic evidence by being stored in plastic when moist. Examples of critical environmental factors include:

- Buildings, including access control
- Fixtures, including temperature-regulated storage and biological and chemical hoods
- Heating and air conditioning, including ventilation
- Lighting
- Surface materials (bench tops, flooring)

12.9.2 Building, Including Access Control

Access control to and within the laboratory is required to prevent unauthorized personnel having the potential to accidentally contaminate samples or otherwise interfere with the integrity of materials or records.

The physical environment must be designed and used in a manner that prevents contamination. For example, it is desirable that examination of low levels of materials (samples for drug analysis in toxicology) occurs separately from high levels of the same materials (bulk samples of drugs in controlled substance testing).

12.9.3 Fixtures

We tend to think about biological and chemical hoods as being essential items of safety equipment, but they also are important when working with low levels of materials or where preventing even the smallest degree of contamination is critical, such as in DNA testing by PCR.

Refrigerators and freezers must be controlled (calibrated and maintained) when used to store samples or reagents that could deteriorate if not kept at a critical temperature range. This might not just be a matter of keeping cold – freezing, especially repeated freeze–thaw cycles, can degrade biologic reagents.

12.9.4 Heating and Air Conditioning

Heating and air conditioning are required to prevent instrument malfunction because of operating temperatures outside those specified by the manufacturer. This will usually be achieved by building control, but sometimes local units are required for individual rooms or instruments within a room, for example, capillary electrophoresis units used in PCR analysis. Air conditioning also affects humidity and must be controlled to prevent biological deterioration through mold.

12.9.5 Lighting

Lighting should be non-glare and at a color temperature that matches natural sunlight. As well as providing a less stressful work environment, description of bulk evidence (such as clothing) during initial examination includes a record of its color(s). Good quality lighting is required to make sure that no significant evidence is overlooked at the visual examination stage.

12.9.6 Surface Materials

This material must be chemically inert. Their color is important in evidence examination areas to facilitate screening and cleaning.

Surfaces must be able to withstand physical and chemical decontamination, for example, cleaning of bench tops with hypochlorite in areas where biological evidence is examined.

Flooring should be chemically inert and non-slip.

12.10 Materials and Supplies

12.10.1 Specifications

From a QA perspective, "supplies" means all items the quality of which can influence the quality of test results. These are sometimes referred to as "critical reagents" or supplies. Dealing with supplies in the quality management system therefore starts with preparing a list of critical materials, such as reagents, standards, test kits, glassware, and pipettes. The next step is to define the specifications that items on the list must meet. This permits procurement policies and procedures to be written to ensure that items of the correct specification are ordered and supplied. The National Quality Assurance Standards for DNA Testing require that all critical reagents are validated before release for use, by testing on non-probative materials. The systems approach to QA would be somewhat less demanding and require validation appropriate to the history of the material and supplier. Materials with a solid history of reliable procurement and delivery could be introduced directly into testing.

12.10.2 Inventory

The laboratory should maintain an inventory of all supplies that have been defined as critical and of all its test equipment. The materials inventory should include:

- Specific item identification
- Approved vendors and catalog numbers
- Storage conditions and location for reagents
- QC requirements such as certificates of analysis or internal QC checks to be conducted before the item is released
- Manufacturer name, item description, and serial number for equipment
- Equipment location
- Maintenance requirements and schedule
- Calibration requirements and schedule

12.11 Records

A record is a document that contains objective evidence thatshows how well activities are being performed or what kinds ofresults are being achieved. A record captures something that happened in the past. Records may be dynamic, such as notes on examination and testing of evidence made during the course of the work, or static, such as an inventory.

There are generally accepted standards of good practice in regard to examination records. They should provide an adequate description of what was done, to the extent that they aid the examiner in testifying, and would permit another qualified examiner to evaluate what had been performed and interpret the results.

Records must be created and maintained in a manner that ensures their integrity is unquestionable. Forensic science laboratory records, therefore, should comply with the following requirements:

- Data on instruments used – their settings and calibration
- Physical records of results (or reference to electronic records that can be scrutinized and verified)
- When a test result or observation is rejected, the reason(s) should be recorded.
- Checks on data transfers or result verifications, for example, the verification step in the ACE-V system for latent print comparisons
- Information that identifies the evidence tested and the personnel involved in the testing
- A pagination system that ensures the integrity of the record itself

12.12 Statistics

12.12.1 Statistics and QA

Statistical methods are an integral part of evaluation and decision making in quality assurance because they provide a tool that can be used to determine, separate, and minimize sources of error. Specifically, they allow us to give an objective measure

of the accuracy (the closeness of a result to the true value) and precision (the agreement of a set of replicate results in defined conditions). As the sources of variation are minimized, the results become more reliable.

The statistical measure that addresses accuracy and precision are measures of central tendency and measures of dispersion.

12.12.2 Measures of Central Tendency and Dispersion

Measures of central tendency are single values used to represent a body of data. The usual ones are mean, median, and mode.

The *mean* (also called arithmetic mean, or average) of a data set is calculated by adding all the individual values in the set and dividing by the number of values in the set.
The *median* of a data set is the middle value of the ranked set.
The *mode* is the value that occurs most frequently in the data set.

The most widely used measures of dispersion are range, variance, and standard deviation. *Range* is the simplest measure of dispersion. It is the difference between the maximum and minimum values in the data set.

Variance is the fundamental measure of dispersion in statistics, but the one that we normally encounter is *standard deviation*, which is the square root of the variance.

A property of variance that is important in quality assurance is that of additivity of variances: The total variance of a process is the sum of the variances of the individual contributing parts.

12.12.3 Sample, Population, and Distribution

A *population* is an entire group of persons, things, or events that have at least one trait in common. Most of the time we will never be able to identify and access an entire group and so we must deal with *samples* from the population of interest. Samples are therefore sub-sets of a population, and the most important aspect of a sample is that it must be representative of the population of interest.

An illustration is the description of the population in the everyday sense of inhabitant of a town, county, state, or country. The challenge in defining a sample is to obtain a manageable data set that is sufficiently representative of the population. To be "sufficiently representative" requires either that the sample is carefully constructed to reflect all of the desired attributes in the population or that the sample is entirely random and so will not provide a biased data set.

We can define our population of interest in statistical terms using measures of its central tendency and dispersion that we calculate from a sample. The symbol

μ is used to denote the mean of a population and the symbol σ^2 to denote its variance. The mean and variance of a population are constants that describe that population. Such defining constants are termed *parameters*.

The *distribution* of individual data points within a population is also a defining characteristic. The example we are most familiar with is the *Normal Distribution*, which has these important properties:

- It is symmetrical
  - The mean, mode, and median are the same
- The dispersion of data values about the mean is related to the standard deviation
  - 68% are in the range mean ±1 standard deviation
  - 95% are in the range mean ±2 standard deviations
  - 99.7% are in the range mean ±3 standard deviations

The variance of a large sample is less than that of a smaller sample (the equation has a denominator of *N*-1, where *N* is the sample size). As the size of the sample increases, so will the sample variance approach that of the population; likewise, the mean will approach that of the population. This is in line with the intuitive feeling that data derived from large samples are more reliable than data derived from small samples.

12.12.4 Statistical Control of Quality – Control Charts

Control charts are a tool used to distinguish between a pattern of random variations and a pattern that results from assignable causes. The chart most widely used in QC is often called a Shewhart chart in honor of W.A. Shewhart who, some 70 years ago, was the first person to recognize the value of statistical charting as a process control tool. The chart is a graph of results of analysis of a check or control sample included with every batch of test sample.

The mean and standard deviation calculated from repeated analysis of one of these sample types is used to define the center line (CL) and upper and lower control limit (UCL, LCL). The CL is the mean and the UCL and LCL are set from the standard deviation. It is accepted practice that there are in fact two lines for the boundary control limits, one at the mean ±2 standard deviations and one at the mean ±3 standard deviations. The control limits at two standard deviations are the warning limits, and those at three standard deviations are the action limits (Fig. 12.2).

The usual procedure is one check sample for every twenty to thirty test samples. The check sample results are plotted on the chart and scrutinized to see if the result lies in the acceptable range and if there are any trends apparent. The laboratory can set whatever intervention levels it chooses. Normal practice is that intervention is required when:

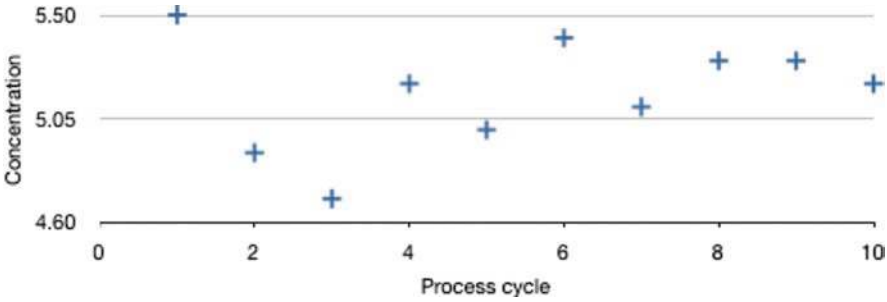

Fig. 12.2 A Shewhart control chart showing the values observed for a check sample in each of ten analytical runs (process cycle). UCL and LCL are the upper and lower control limits CL is the center line or target value. The UCL and LCL are the CL ±2 standard deviations

- There is any point outside of the 3 standard deviation UCL or LCL
- More than two points between the 2 and 3 standard deviation UCL or LCL
- Seven consecutive points on the same side of the mean, even though within the 2 standard deviation UCL or LCL
- Seven consecutive points showing the same trend (i.e., all rising or all falling) even though within the 2 standard deviation UCL or LCL

12.12.5 Uncertainty of Measurement

Uncertainty of measurement (UM) is a parameter associated with the result of a measurement that characterizes the dispersion of the values that could reasonably be attributed to the measurand.

UM is, in essence, a measure that characterizes the dispersion of values, usually standard deviation.

Thus, when we construct a Shewhart chart, we have also obtained a value for the UM of the test. Direct measurement by performing repeated measurements and calculating the variance is a simple and straightforward way to deal with UM. This is defined as a Type A evaluation of uncertainty.

However, it is not always possible to conduct direct measurement, and, in these cases, an indirect approach is used. The most straightforward approach is one that lets us produce a reasonable objective quantitation of UM starting with our professional judgment. This is called as Type B evaluation of uncertainty.

For example, a firearms examiner may be asked to testify to the distance from which a gun was fired. It is not possible to conduct repeat firings and obtain a mean and standard deviation – the type of ammunition used may be not be known, the gun may be unsafe to use, the matrix with the residue impression may not be repeatable, the ability of the method used to identify the discharge is variable. However, firearms examiners know from experience more or less what dispersion of discharge residue to expect from a given gun–ammunition combination. The examiner

might conclude, for example, that "the gun was fired from eighteen inches give or take six inches either way." The range about the estimated mean is defined as the "expanded uncertainty" and denoted by the symbol *U*. Just exactly what the examiner intends to convey by "give or take" is determined by how much "give or take" he or she wants to allow. The degree of latitude to be given around the mean is known as the "coverage factor" and is defined by the symbol "*k*."

This then leaves us with the question of how to obtain a measure that is an acceptable substitute for a formal calculation of variance. If our professional judgment allows us to place an upper and lower limit on the range of possible results (for example, between six and thirty inches in the above illustration) and there are no grounds to believe that the true value is more likely than not to be at any part of the range, then the measurement of dispersion to be used is:

$$\text{Half} - \text{width interval} / \sqrt{3}$$

where half-width interval is [(upper limit of range) – (lower limit of range)]/2.

If, however, we have reason to believe that the true value is more likely to be found in the midrange and less likely to be at the extremes, then the measure of dispersion to be used is:

$$\text{Half} - \text{width interval} / \sqrt{6}$$

UM is used to put an objective number on the fundamental principle that no measurement is absolutely repeatable. If we make 100 measurements, we will obtain 100 different results. However, there will be acceptable tolerances on how wide the range of the 100 estimates can be. We have to be able to show that the UM of any quantitative measurement is appropriate to the purpose to which the measurement is applied.

12.13 Standard Operating Procedures and Standard Methods

12.13.1 Standard Operating Procedures (SOPs)

Standard operating procedures (SOPs) are an integral part of the quality system. They are *documented instructions on how to perform tasks*, but, in particular, they address instructions for carrying out procedures that address specific quality assurance objectives. Most analysts use "SOP" synonymously with "test procedure," but, as the definition implies, they refer to any procedure that can affect quality. Examples include:

- Calibration and maintenance of instruments
- Purchase, receipt, and handling of supplies and equipment

- Receipt and handling of test samples
- Laboratory safety
- Recruitment, training, and authorization of personnel
- Proficiency testing
- Analytical methods

In general, SOPs have the following characteristics:

- They are formal written instructions that are included in the Quality Manual
- They are specific in regard to their field of application
- They include specific step-by-step instructions to perform the task
- They include quality control procedures wherever possible to ensure that the SOP has been applied correctly and is achieving the desired QA objective

There are many ways to write an SOP. Some will be determined by the laboratory's document control procedures. However, a good SOP will contain the following:

- A unique identification of the SOP, including version number
- A descriptive title and description of the field of application
- An introduction, including essential literature references
- A description of reagents and equipment required, including reagent specifications and instrument settings
- A step-by-step set of instructions
- A clear identification of safety issues
- Description of QC steps
- Description of the circumstances if any in which deviations from the method are permitted
- Description of any calculations or data transfer steps and checks
- Guidance on reporting

12.13.2 Standard Methods

A standard method

- Is defined in law or by regulation of a government agency (such as the Environmental Protection Agency or the Food and Drug Administration), or
- Is a consensus method that is accepted in the field, and
- Has been published by an organization such as the ASTM or the Organization of Official Analytical Chemist (AOAC)
- Has been published only after extensive validation involving several participants

The main attribute in the list is the last one – publication coupled with extensive validation. ASTM and AOAC procedures incorporate steps to ensure that rigorous validation has been demonstrated, as do those of the various government regulatory bodies. Factors important in developing a Standard method in forensic science are:

- Matrix effects – How does the medium containing the sample affect its analysis, for example, recovery of bloodstains from different substrates, and different surfaces present different challenges to the development of latent fingerprints.
- Interferences – For example, inhibitors of the polymerase chain reaction present in sample on certain fabrics.
- Sample homogeneity – This may be subtle, for example, in a break in, glass fragments from the broken window may be spread onto the clothing or footwear of the perpetrator; recovered fragments can be compared with samples from the source glass by measuring their refractive index (RI) and or trace element composition, but these physical and chemical properties can vary over a sheet of manufactured glass and will not be identical.
- Concentration ranges – Methods that work well on bulk may not be suitable for trace quantities.
- Specificity – For example, the presence of cross-reacting metabolites in blood being tested for drugs.
- Stability of measured compounds – Which is why environmental control of storage matters so much.
- Population distribution – Racial and geographic differences in blood types.

Unless specified by law or regulation, or by the customer, a laboratory is not required to use a Standard method. If developing a non-standard method for its own use, the laboratory must make sure that the validation is sufficiently rigorous to ensure that the method will give the desired quality of results. Essentially, this means that all the validation factors mentioned above have to be considered. An additional element is that of comparing results from the laboratory-derived method with those from the Standard method if one exists.

12.14 Traceability

There are several definitions of traceability in the QA literature. One of the best, because it focuses on functionality, is that traceability is the degree to which a relationship can be established between two or more products of the development process, especially products having a predecessor–successor or master–subordinate relationship to one another.

In QA in the forensic science laboratory, we are interested in the master–subordinate relationship. We use standard materials such as reference materials for control of analytical procedures and calibration of equipment. The actual materials used in the laboratory are subordinates to a master, which will be of the highest metrological quality possible, such as a NIST (National Institute of Standards and Technology) reference standard.

When we use materials like these, we must be able to prove the traceability, through procedures such as NIST certificates. We must also know the UM associated

with the standard, because each step that the creation of the artifact used in the laboratory is away from the national or international reference artifact adds to the UM of the certified value.

12.15 Proficiency Testing

Proficiency testing is a systematic program of inter-laboratory comparisons designed and operated to assure laboratory performance in specified areas of testing, measurement, or calibration. Laboratories participate in PT programs in order to:

- Obtain an objective assessment of the reliability of their testing
- Monitor and improve the quality of their testing
- Comply with accreditation program requirements

Proficiency testing has become the accepted best practice tool for assessing the reliability and improving the quality of testing because:

- The samples are prepared independently of the testing operations; the correct or target value is not known to the analysts
- The tests are inter-laboratory comparisons. Each laboratory can measure its performance against peers using the same or different test methods
- The PT program manager provides an extensive statistical analysis of results that provides an objective base for determining whether or not a given result is acceptable
- The proficiency testing is usually operated as a continuing program and provides an objective measure of performance with time
- The PT data can be incorporated into control charts and used to trigger preventative actions

The above factors make proficiency testing an integral part of accreditation programs. However, it is important not to lose sight of the preventative nature of the systems approach to QA, and make sure that over-reliance on PT does not convert our approach to quality into one in which quality is "inspected in," that is, there is a reliance on catching errors rather than preventing them.

12.16 Accreditation

12.16.1 Accreditation and QA

Accreditation is the process of formal recognition of competence to perform specific tests, through an audit conducted by an independent and authoritative body. Accreditation contributes to QA by providing assurance that the testing laboratory

is following good laboratory practice in its day-to-day testing. The accreditation assessment consists of an audit. The process therefore starts with selection and definition of the standards to which the accreditation audit will assess conformity. The audit is conducted by a team with a matrix of expertise in the interpretation and application of the standards, and technical expertise in the areas of testing conducted on the laboratory.
The main activities of the assessment team are:

- Review documents to ensure that all policies and procedures required by the standards are present and in an acceptable form
- Review laboratory records to ensure that they comply with the standards
- Observe the physical environment and the conduct of testing
- Interview staff to confirm their awareness of standards and conformance with personnel requirements

The team will pay particular attention to any apparent non-conformities to ensure that there is objective proof that can be documented and provided to the laboratory and accrediting body (AB). The Lead Assessor will pay particular attention to making sure the apparent non-conformity is indeed real and not simply a reflection of the personal preference of a team member – the golden rule of auditing is: "If a non-conformance cannot be expressed in the language of the standard then it is not a non-conformance."

The team will provide a report to the laboratory and AB detailing the non-conformities and any areas of concern or otherwise worthy of comment. The "authoritative body" in the definition is an AB. An AB can earn its "authoritative" status in several ways. The easiest is for it to be accepted by a government or industry test sector and build up experience. The more rigorous way is for the AB to demonstrate conformance with the requirements of ISO/IEC 17011:2004 "Conformity assessment – General requirements for accreditation bodies accrediting conformity assessment bodies." This is done through a peer evaluation process associated with the International Laboratory Accreditation Cooperation (ILAC, see www.ilac.org).

There are two accreditation programs for forensic science in the U.S. One is operated by the American Society of Crime Laboratory Directors/Laboratory Accreditation Board (ASCLD/LAB) and the other by Forensic Quality Services (FQS).

12.17 Questions

1. The Management System for a crime laboratory is:
   (a) The organization chart showing where the laboratory fits into the agency structure
   (b) The Director and Quality Manager of the laboratory
   (c) The policies, procedures, resources, and organizational structure required to achieve the desired performance of the organization
   (d) The computer hardware and software used to control and gather data from analytical equipment and prepare reports for management

2. The Quality Manual is the responsibility of:
   (a) The quality manager
   (b) The laboratory director
   (c) Everyone
   (d) The HR department

3. Calibration is:
   (a) The use of a standard curve to quantify the concentration of an analyte in a sample
   (b) The procedures used to determine and verify the performance parameters of an instrument
   (c) The comparison of test data with results from a traceable standard
   (d) The adjustment of results to compensate for systematic error

4. The process of verification of existence of documents and records, examination and evaluation of the documents and records, interviews, examination of physical environment, and observation of testing is the definition of:
   (a) A management review
   (b) Quality assurance
   (c) An audit
   (d) Quality control

5. The golden rule of auditing is:
   (a) It must be thorough and identify all non-conformities
   (b) A non-conformity must be described in the language of the applicable standard
   (c) It must be conducted annually
   (d) It must be conducted by persons independent of the activity being audited

6. Which of these is not part of the management review
   (a) Changes in volume and type of work
   (b) Client feedback
   (c) Complaints
   (d) HR annual appraisal

7. I AC is:
   (a) Independent Laboratory Assessment Consortium
   (b) International Laboratory Accreditation Cooperation
   (c) Internal Laboratory Audit and Complaint
   (d) Inventory of Laboratory Apparatus and Consumables

8. A standard method is:
   (a) One that is used routinely and is described in the laboratory SOP manual
   (b) A method published by law or by an organization such as ASTM
   (c) A procedure for validating and establishing the traceability of reference materials
   (d) An analysis that uses an internal standard to establish qualitative and quantitative values

9. A type A procedure for determination of UM is:
   (a) Based on uncertainty budgets
   (b) Based on professional judgment
   (c) One that applies to qualitative tests
   (d) One that uses direct measurement from replicate analyses

10. The mean ±3 standard deviations encompasses:
   (a) 99.7% of replicate test results
   (b) 50% of replicate test results
   (c) 66.7% of replicate test results
   (d) 95% of replicate test results

12.18 About the Author

William Tilstone, born in Scotland in 1943, received his BSc (with first class honors in Pharmacology) in 1965 and his PhD in 1968, both from the University of Glasgow. He joined the faculty in the School of Medicine at Glasgow as Lecturer in Pathological Biochemistry, then moved across the city to a post as Lecturer in Forensic Science at Strathclyde University in 1972.

Dr. Tilstone taught forensic biology and toxicology, performed biology case work for the local public prosecutor, and biology and toxicology for the defense, and did research in toxicology as well. He held various academic and professional offices including Editor of the Journal of the Forensic Science Society; subsequently he was appointed to the first Professorship in Forensic Science at Strathclyde in 1979.

Dr. Tilstone moved to South Australia in 1984 to be Director of the State Forensic Science Centre. There, he was President of the International Association of Forensic Sciences (1987–1990), a member of Council of NATA (the longest-established ISO AB in the world), member of NATAs Forensic Science Program development committee, and became an Inspector for the American Society of Crime Laboratory Directors/Laboratory Accreditation Board (ASCLD/LAB).

While in Adelaide, the Center became the first non-US crime laboratory to be accredited by ASCLD/LAB (1990) and the first Australian laboratory to be accredited by NATAs ISO program (1996). Dr. Tilstone conducted several quality systems reviews for the South Australian Government including very non-forensic areas such as the State Abattoir and the Office of Fair Trading. He moved to Florida to set up the National Forensic Science Technology Center in July 1996. He established and managed the US's first ISO accreditation program in 1998, and is a qualified ISO 17025 assessor and lead assessor.

References

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2. ISO/IEC 17025:2005 General requirements for the competence of testing and calibration laboratories. Available in the U.S. from the American National Standards Institute (ANSI) web store http://webstore.ansi.org/

Suggested Reading

IALC Guide 19:2002 Guidelines for Forensic Science Laboratories. Available free of charge from http://ilac.org/guidanceseries.html. NOTE: This document is currently under revision by an ILAC Working Group.

Chapter 13
Forensic Document Examination

William L. Leaver, BS, D-ABFDE

Contents

13.1 Introduction

Examiners of questioned documents are referred to as Forensic Document Examiners, Questioned Document Examiners, Document Analysts, and sometimes simply as Handwriting Experts. The examinations performed by Forensic Document Examiners involve much more than handwriting comparison. The type of examinations required of an examiner include handwriting and hand printing comparisons, deciphering erasures and obliterations, indentations, counterfeit checks, currency and credit cards, determining the authenticity of documents and identification cards, typewriting, computer printing, commercial printing processes, office machine products, stamp impressions and, in some instances, comparison of footwear impressions. Examinations of ink and paper are usually non-destructive. However, some document examiners perform chemical analysis of ink and paper.

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The field of document examination has become diverse, requiring specialization in some of the sub-categories of examination. In the past, the majority of the examinations were handwriting and hand printing, but, with technological advances, some examiners spend much more of their time doing other examinations and comparisons. Some government examiners devote a large portion of examination time to photocopier and computer-generated documents and anonymous threatening notes or letters. Some examiners specialize in identification documents.

Entire chapters can be written on the different categories of forensic document examination. This chapter will provide insight into the various examinations required of the competent document examiners, but will serve as an introduction to the varied types of examinations. The types of examinations and what an examiner can and cannot do with evidence will be presented in this chapter.

13.2 Handwriting and Hand Printing

In school we are taught to write a style or system of writing. Hand printing is first taught and then we graduate to cursive writing. Usually the cursive writing systems taught are the Palmer System or Zaner–Bloser System, and sometimes the more recent D'Nealian System. Handwriting systems are simply a style of writing that shows how the letters of the alphabet are formed. These model letters are practiced individually and then combined to form words and sentences. In the past, these systems were referred to as "Copybook Style" because the student received a book containing the handwriting style and repeatedly practiced the letters and words on each page in the book. Sometimes, rather than a Copybook, mimeographed sheets were used in the schoolroom to practice writing. The practice and perfection of penmanship has become less important in the classroom and a wide assortment of writing styles are taught in schools [1].

As we practice our handwriting, we develop our own individual writing habits, characteristics, and style. The more we write, the more ingrained the individual handwriting habit becomes. Soon we are not conscious of the intricate details we have developed in our writing; the writing has become automatic, it has become our individual handwriting. Some people, due to their own preference, occupation, or to attempt better legibility may stay with a hand printed style. Some may introduce hiatuses or breaks in their cursive writing while others try to maintain a close relationship to the copybook style they were taught. Others may introduce ornate flairs and rubrics into their writing, especially their signatures. Some persons will develop specialized signatures different from their normal handwriting style. Each person's hand–eye coordination and the amount of practice in perfecting their writing will formulate the individual writing habit. Usually a person is not able to write above their developed skill level. One might think that calligraphy may be an exception to being able to write above one's skill level, but calligraphy is artwork and not necessarily handwriting.

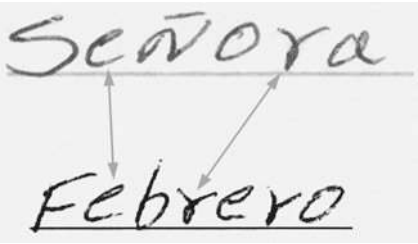

Fig. 13.1 The *arrows* indicate two different people who share common similarities in their writing

Handwriting must look sufficiently similar to be recognized as letters and words to convey written thoughts, but given enough writing, the handwriting of different people can be separated and identified to an individual. There may be general similarities between the writing of some people, but characteristics such as details in construction, height and spacing proportions, baseline habit, beginning strokes, connecting strokes, and ending strokes when comparing entire words and sentences, taken together, can be identified to each individual.

In Fig. 13.1, notice the similarity between the "e" and the "r" indicated by the arrows. These words were written by two different people. The identity of a person's handwriting is not based upon one or two characteristics, but is based on a sufficient combination of significant characteristics in number and kind between the questioned and known writing. An untrained person might determine that both the words in Fig. 13.1 were written by the same person when, in fact, the words were written by two completely different people; thus, there is danger of the insufficiently trained person making mistaken identifications. The basis of identification will be discussed later in this chapter (see subheading 13.4).

Factors that may affect a person's handwriting can be inebriation, medication, substance abuse, injury, advanced age, infirmity, illness, nervousness, stress, and even fatigue. These factors or a combination of any of these factors may affect the appearance of a person's handwriting, making it appear different from their normal writing. However, an examiner cannot necessarily pinpoint a specific feature in handwriting that is a result of a specific factor, but is aware that these different stimuli or problems can affect the appearance of the handwriting. Handwriting that looks uncontrolled and lacks detail in writing movements may be due to inebriation or substance abuse or actually some other factor such as a stroke. It might be inaccurate for an examiner to identify that the trailing off stroke in a signature must have been the result of substance abuse when in fact the errant pen stroke may have been caused by the infirmity of the writer.

Most naturally executed handwriting has a fluent, smooth line quality in the pen stroke. Writing performed at a normal rate will have smooth, non-tremulous line quality having variation in pressure. Line quality can be defined as the condition of the written line left by the stroke of the writing instrument [2]. Some people write at a faster rate than others, leaving a scribbled appearance, whereas some people

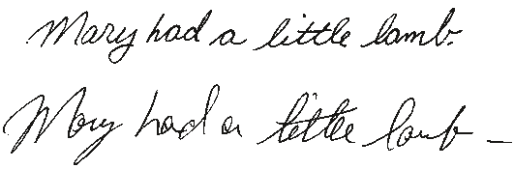

Fig. 13.2 The sentences show the difference speed of writing can introduce to the appearance in the writing of a person. Both sentences were written by the same person

write at a slower pace. The slower pace may give the appearance of labored writing having little variation in pressure but is natural for that writer. The speed of execution and fluency of the stroke of the writing instrument, or lack thereof, are usually evidenced in the writing. Speed of execution alone can make a given person's writing appear as if written by a different person (Fig. 13.2).

Both sentences in Fig. 13.2 were written by the same person using different speeds of execution. Signatures written with careful attention to detail can look different than a signature hastily dashed off even when written by the same person. A determination whether the writing was written at a normal speed for a particular writer should be made if possible.

Writer position and pen position can also affect the appearance of handwriting. Writing a signature while standing, sitting comfortably at a desk, on a clip board, or lying down can introduce variation into a signature. The writing instrument held at an extreme angle or straight up can change the appearance of a signature. Different writing instruments, i.e., pencil or marker or ink pen, can also introduce a slight difference in appearance due to how freely a ball point or roller ball flows or compared with the increased coefficient of drag of a pencil or fiber tip.

13.3 Natural Variation

All have variation in their handwriting. No matter how skilled the writer, handwriting cannot be exactly replicated, meaning that a person cannot write or sign their name exactly the same each time, so there will be some variation. Highly skilled writers will have less variation in their writing than lesser skilled writers will have. Poor writers will usually have a wide range of variation. Writers that have a very rapid speed of execution can also have a wide range of variation. Depending on the range of variation of the writer, a larger volume of writing will be needed for comparison. All comparisons require a sufficient amount of known writing to encompass the range of variation of the writer (Fig. 13.3).

The figure shows variation in a series of signatures all written at the same time by the same person. The beginning loop of the "W" is similar in signatures 1, 3, and 4, but the first underhand bowl/loop of the "W" of 1 is different than any of the other signatures, as is the beginning stroke of 2. The first "i" in all the signatures begins similarly, without an introductory stroke and with a high i-dot. The

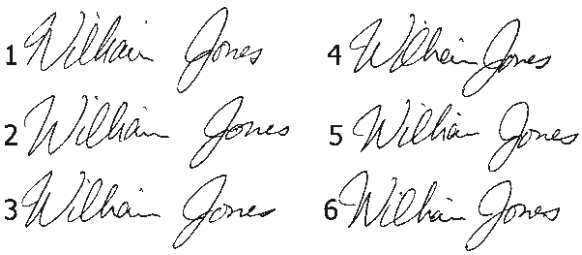

Fig. 13.3 Variation in the signatures of a person

Fig. 13.4 Variation in the construction of the letter "*t*" dependent on the position of the letter in the word, first, middle, or last

second "i" in signatures 1, 2, and 5 finishes at the baseline with a break from the "a", whereas, in 3, 4, and 6, the second "i" connects to the "a". The "on" combination in signatures 3, 4, and 5 are similar, but the "on" combinations of the remaining signatures are variations of this feature. The "on" combination of signature 1 is not like the other signatures. The spacing proportion between the "m" and the "J" is slightly variant from signature to signature. The finishing stroke of the final "s" varies from signature to signature. If any one of these signatures were singly submitted for comparison, a large number of known signatures would be needed to include the range of variation of this writer.

A letter may vary in construction depending on where it is placed in the word—at the first, middle or last position (Fig. 13.4).

Variation is found in the construction of the letter "t" depending on whether the letter is at the start, the middle, or the end of a word is shown. The arrows indicate the locations of the letter "t" at the beginning, the middle, and the end of the word. The first "t" is absent a beginning stroke with the cross bar leading into the start of the next letter, the middle "t" has a beginning stroke with a standard crossing stroke, and the final "t" has an ampersand-style crossing stroke.

Natural variation in writing is important in identifying a writer. When the variations in the characteristics are accounted for in the known writing, it has great significance, it is the proof of authenticity. A forger would not be aware of the existence of the variation much less be able to replicate variations from signature to signature with any normal speed of execution. The tendency would be to attempt to make multiple signatures resemble each other too closely, each being a simulation of a model signature or of each other.

Variation in writing should not be confused with different writing styles. A writer may have more than one style of writing. One style of writing may be formal with attention to detail and form while handwritten notes and memos may

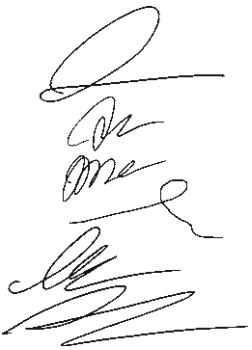

Fig. 13.5 Signatures that are too simple lack sufficient individual characteristics and may be easily imitated

be hastily written without regard for legibility as shown in Fig. 13.2. Some writers may have a formal style of writing their name for legibility but also have a personalized signature, sometimes referred to a stylized signature. These signatures are sometimes complex but all too often are simplified, lacking sufficient identifying characteristics, and are not difficult for someone else to imitate. Examples of simplified personalized signatures are displayed above (Fig. 13.5).

13.4 Basis of Identification

Identification of handwriting is not based upon a few similarities. The identification of handwriting is based upon a sufficient combination of significant characteristics in agreement in number and kind between a questioned and known writing. The questioned and known writings must contain characteristics that are repeated, consistent natural features of the writing. There must be a sufficient quantity of these individualized characteristics in agreement between the questioned writing and exemplar writing and an absence of unexplainable variations to effect the identification of the writer [2, 3].

The science of handwriting identification relies upon the fact that no two individuals share the same combination of handwriting characteristics. The repeated execution of handwriting formulates a person's handwriting habit. The writing habit becomes so ingrained and automatic that the writer is unaware of how uniquely individual the handwriting habit has become.

The identity of a person's handwriting is not based upon one or two characteristics, but is based upon a sufficient combination of significant characteristics in agreement between the compared writings. The compared writings must contain characteristics that are repeated, consistent natural features of the writing. There must be a sufficient quantity of these individualized characteristics in agreement between the compared writings and an absence of unexplainable variations to effect the identification of the writer.

Fig. 13.6 Different styles of writing preclude comparison of the writing; block printing vs. script vs. cursive

The identification of handwriting goes beyond the general appearance. Identification is based on writings having a sufficient number of unique, identifying, individual features or characteristics in the handwriting that are in agreement in number and kind with no unexplainable differences.

However, when there are dissimilarities in the compared writings that are fundamental differences, identity cannot be made and may indicate a different writer.

Draw your attention to Fig. 13.1, where two different writers wrote the words pictured there. Basing the identification of handwriting on a few similarities will lead to errors. Basing the identification on too limited an amount of writing, unnatural writing, and different styles of writing will certainly lead to errors in identification. Cursive handwriting cannot be compared with hand printing. Handwriting must be compared with handwriting and hand printing compared with hand printing (Fig. 13.6).

The same word is written in different styles by the same person. The different styles in letter construction prevent any attempt to compare the words with one another. An opinion that the words were written by the same person could never be rendered because the words can simply not be compared.

13.5 Exemplar Writing

To properly compare any writings, the examiner must have a sufficient amount of known writing to compare with a questioned writing. There must be a sufficient volume of writing. Known writing, also referred to as exemplar writing, can be request writing or non-request writing. Request writing is when a person is instructed to write on exemplar writing forms, the London Letter, or some other extended text of writing [4]. The exemplar forms containing several repeated combinations of words, numerals, sentences, and paragraphs that provide a reasonable cross section of the writing habit of an individual. Non-request writing is writing performed in the normal course of business. The importance of normal course of business writing is that when the non-request writing is performed, there is not an expectation that it will be used for a handwriting comparison and should represent a natural execution of writing. When request writing is taken, the expectation is that it specifically will be used for comparison and the person may try to

introduce unnatural execution or disguise into the writing. The best option is to have both request exemplar writing and non-request (normal course of business) writing. Questioned writing can be competently compared using only request exemplar writing if it is natural writing and contains the range of variation of the writer.

The inclusion of non-request writing for comparison may supply the examiner with much needed forms of natural variation that may not be contained in request writing. Non-request writing may reveal alternate styles of writing not apparent in request writing or a mixture of script style that would not normally be included on a formal exemplar.

13.6 Limitation of Copies

Though document examiners prefer to compare original documents, there are occasions when the only documents available are copies. The examination of copies should be approached with caution.

There are certain features that cannot be perceived on copies that can be obvious on an original document. The line quality of the ink stroke, variation in pressure, subtle trailing strokes, subtle connecting strokes, pen lifts deftly overwritten by a subsequent stroke, variation in density of the ink, color of the ink, direction of strokes, skillful patching/retouching, shading, and construction minutiae that can be found under a microscope on an original cannot be detected on most copies.

In addition, printing methods, skillful manipulations, detection of erasures, specular reflection, infrared and ultraviolet examination, examination for indentations, and deciphering of obliterations cannot be performed on copies, only on original documents. As good as the copy process technology has become over the years, there are many features of the document and writing that cannot be properly evaluated when examining a copy. Certain aspects of manipulation by cut-and-paste, computer transfer, tracing, and simulation may be masked by the copy. Some rubber stamp impressions of signatures may resemble original signatures on a copied document.

Polymer stamps and even some rubber stamps of signatures deftly kissing the paper may be mistaken for original signatures even on an original document. A stamp impression will be sans the furrow caused by the pressure of the writing instrument, but a fluid ink pen signature written with light pressure on certain substrates may leave an undetectable writing instrument impression. Under those conditions, it would be impossible to identify the signature as a stamp impression on a copy. Facsimile copies further exacerbate the problem.

Much more information can be obtained from an original document. Thus, it is important that the document examiner be provided with the original document for examination.

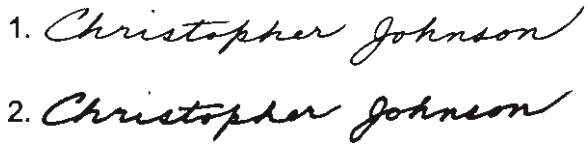

Fig. 13.7 Signature *2* is a copy of a tracing of model signature *1*. The copy may hide elements of tracing

When rendering an opinion on a copy, a definitive conclusion should not be given. It is generally accepted in the forensic document community that an absolute conclusion cannot be reached based upon the examination of a copy. Only a qualified opinion should be reported when the examination involves the comparison of a copy. At times, nothing more than a qualified opinion may sometimes be rendered on an original document depending on the condition of the document, the circumstances, and the exemplars provided or the limitations thereof.

A photocopy of a traced signature may mask many of the characteristics associated with a traced or simulated signature. If the tracing is skillful attempt to combine some speed of execution with natural characteristics of the model signature, it may be difficult to determine the tracing to be a tracing on a photocopy that lacks contrast (Fig. 13.7).

As shown, signature 1 is the original model signature and signature 2 is a photocopy of a tracing of signature 1. Signature 2 and signature 1 superimpose as proof that signature 2 is a tracing of model signature 1. If the model signature is not in possession of the examiner, it might be difficult to determine that the copy of signature 2 is a tracing.

Today's computer software and hardware accessories easily allow the capture of legitimate signatures and transfer of the signatures to spurious documents. The problem this presents is that the true person's signature can be placed on a document that is a non-authentic document but appears to have a legitimate signature. Thus, a true signature can appear on a falsified document through computer manipulation. If the examiner is fortunate enough to have the document from which the model signature was taken, then the falsified document can be shown to contain a manipulated signature. Also, the source of the signature can be identified. If the source document is not discovered, then a copy of a seemingly authentic document can be presented with a plausible excuse why the original document is unavailable. Again, the need for the original document becomes compulsory.

A skillful computer forger can create a signature with variations from several authentic signatures. Even worse, portions of authentic signatures can be combined to create a signature that contains all the elements of authentic signatures without a true single model signature to identify as the source of the manipulation.

Figure 13.8 demonstrates the resultant manipulated signature A created from five other signatures, b through f, while Fig. 13.9 shows which portions of the signatures b through f were used to create signature A, thus constructing a signature that contains portions of each authentic signature but cannot be physically

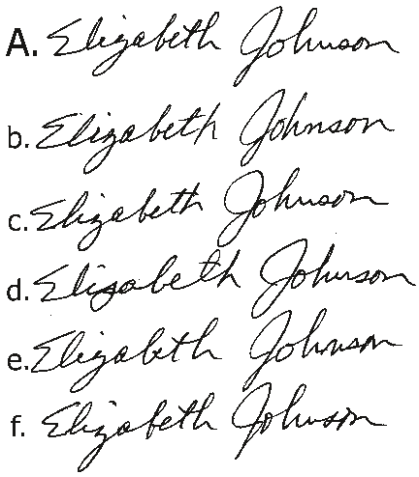

Fig. 13.8 Signature *A* is a computer-manipulated signature constructed from portions of signatures *b* through *f*

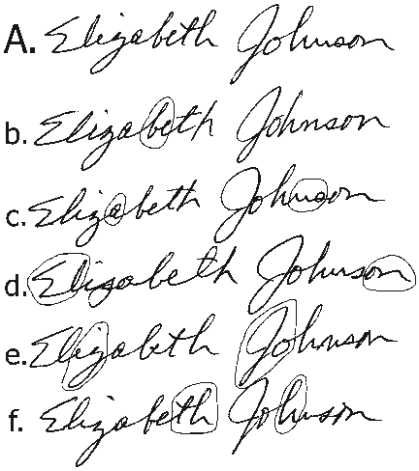

Fig. 13.9 The circled portions of signatures *b* through *f* were used to create signature *A* using computer software

matched to one particular signature. The original signature, of course, does not exist because it is a manipulation. The demand to examine the original document is obligatory.

13.7 Ink and Papers

Most document examiners perform nondestructive examinations on ink. These examinations are commonly ink differentiation rather than chemical analysis on ink. A small population of the document examiner community does chemical ink analysis.

Numerous methods of ink analysis have been developed over the years using thin-layer chromatography, microscopy, x-ray, densitometry, electrophoresis, and spectroscopy methods, some more successful than others. Some of these methods have attempted to determine sequence of line crossings. Examination using simple dichroic filters is a very successful method of non-destructive ink differentiation that may rival the results obtained using sophisticated equipment [5].

The nondestructive methods usually rely on equipment that makes use of infrared absorption and luminescence spectral analysis, and hyperspectral analysis. Several companies produce equipment for this purpose. These range from handheld units that tether into computers to large desktop systems with integral computer systems.

Fiber analysis of paper can be used to compare paper products more accurately than simple ultraviolet examinations. Watermarks in documents can be used to date the production year of some paper. Perhaps in the future, measuring the effective residual ink concentration (ERIC) of recycled papers may prove to help with recycled paper comparison to seek common sources of questioned and known documents [6].

Indentations on paper can reveal important evidence. Examination of documents for indentations use imaging devices such as an electrostatic detection device (EDD) can reveal impressions on a document of handwriting, typewriting, shoeprints, and fingerprints. Research has been successful in determining the sequence of indentations, i.e., which came first, the writing on the document or the indentations from another source [7–9].

13.8 Computer Printers

Inkjet printers use print head systems that propel ink onto the paper through nozzles. Color inkjet printers use cyan, magenta, yellow, and black (CMYK) color mixtures to produce different colors. The eye perceives the color as a solid color when it is actually a mixture of CMYK colored ink dots. Different brand names of ink jet printers usually have distinctive characteristics to the application of ink "dots" that make up the letters printed on the paper. A note of caution: different companies will often use engines/print heads manufactured by a common company. Figure 13.10 shows a photomicrograph of the colored ink dots from a color inkjet printer.

Laser jet printers affix fine toner to the paper by fusing the toner. Color laser jet printers also use CMYK color mixtures to produce different colors. The mixture of different proportions of colored toner produces various colors. The naked eye perceives the mixture of toners as a solid color. The perceived solid colors are actually composed to differing proportions of CMYK fused toner. Figure 13.11 is a photomicrograph of the colored toner from a color laser printer.

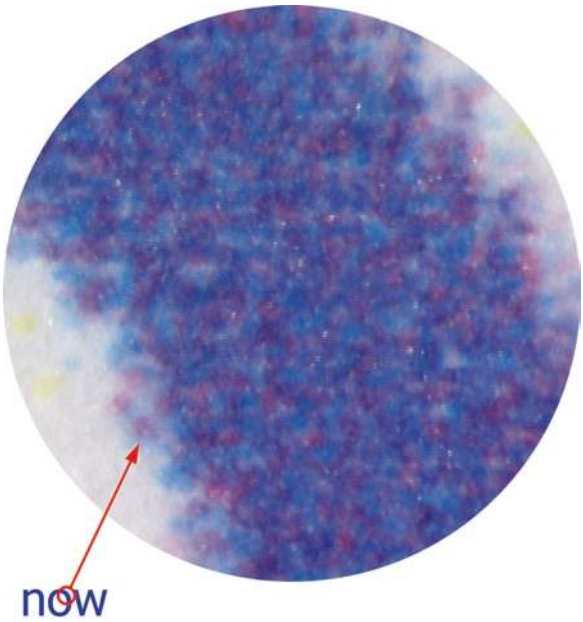

Fig. 13.10 A microscope enlargement of color ink jet that looks *blue* to the naked eye

A few manufacturers have begun using gel ink in their ink jet printers. This provides a more permanent ink on documents, with more vivid colors and lower cost per page.

Memjet Technology has introduced high-quality, high-speed inkjet print heads for application in various formats that significantly increase the production speed of inkjet printers [10].

13.9 Photocopiers

The newest development over the last years in photocopy technology, other than machines that produce better imaging, is the identification code technology many color laser copy machines incorporate in the copy [11]. This technology has been in use for several years, but recently the manufacturers codes have been cracked and can be found on websites.

13.10 Summary

This chapter updates information from the First Edition of the Forensic Handbook. The information in the First Edition is still valid as of this writing, and this edition serves to supplement the information in the previous edition.

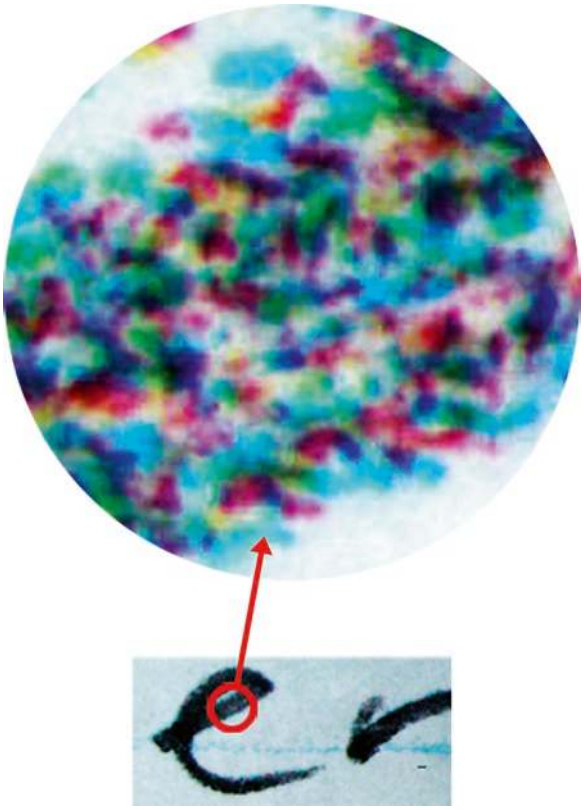

Fig. 13.11 A microscope enlargement of fused color toner (laser jet) that looks *black* to the naked eye

The study of the information on forensic document examination in the First Edition and the Second Edition will not make someone an expert in the field of forensic document examination, questioned document examination, or comparison of handwriting. The application of this information should not be attempted by the untrained or by persons who are not currently involved in a comprehensive training program under the direction of a qualified expert.

The author might add that simply calling oneself an expert does not make it so. There are individuals who do just that and should not be considered experts in this field, even though they think of themselves as such.

13.11 Questions

1. If an examiner observes one or two similarities in a signature, but not more, an identity can still be made based on those few similarities. If true, state why. If false, state why.

2. Handwriting can be identified to an individual, but hand printing cannot. Why or why not?
3. If all of the characteristics in a questioned hand writing are found to be in agreement with the known writing, it still may not be that person's writing. Why or why not?
4. It is easy for a forger to imitate an entire paragraph of handwriting and not leave any evidence of tracing or simulation. Discuss the possibilities of why this statement may or may not be true.
5. The technology in modern color photocopy machines is so perfect that color copies from these machines cannot be traced back to that particular machine. True or false.
6. A document examiner can always ascertain the sequence of writing strokes no matter what type of ink, pen, or computer printing intersects the writing stroke. True or false?
7. What type of equipment would an examiner use to attempt to determine the sequence of writing strokes?
8. An absolutely positive conclusion can be rendered when examining photocopies of handwriting. Discuss the reasons this statement may or may not be true.
9. What methodologies would be used to date a document?
10. What does a color inkjet printed document look like under the microscope?
11. Can anyone testify in court as an expert in handwriting identification by just reading a book? Explain your answer.
12. My handwriting is so perfect, it looks exactly the same every time I sign my name. True or false, explain.
13. What are various methods ink can be examined non-destructively?

13.12 About the Author

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Chapter 14
Toxicology in the Forensic Lab

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Contents

14.1 Introduction

Toxicology is the science of poisons and their effects on the human body. To paraphrase Paracelsus (1493–1541), all substances are poisons. The only difference between a remedy and a poison is the size of the dose. Toxicologists, therefore, deal

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with those substances that may cause bodily harm if taken in sufficient quantity. They deal with substances ranging from illicit street drugs to rat poison to prescription drugs, and everything in between.

Poisons rarely leave unique marks on the body. When searching for a cause of death, the medical examiner (ME) cannot determine from an autopsy whether or not drugs were involved. Samples of body fluids are collected and sent to the toxicology lab for study by the toxicology staff.

Similarly, erratic driving may be caused by any number of medical conditions as well as drugs or alcohol. Although police officers are well trained in evaluating individuals in these situations, only the results of the toxicology exam can tell for sure whether a drug is involved.

Most of the work of toxicologists involves the identification and quantitation of poisons in biological fluids and tissues, e.g., blood, urine, and liver. The toxicologist measures the amount of drug or poison in the blood and assists the ME in determining if that amount was sufficient to cause death. Toxicologists also rely on their knowledge, education, and experience to assist courts in determining if an individual may have been impaired.

The scope of the toxicology aspect of a modern in crime lab depends in large part on the organization of the local criminal investigation apparatus. Traditionally, the crime lab has been a function of the police department, and the investigations undertaken by the crime lab have focused on crime scene investigation, firearms, toolmarks, trace evidence, arson investigation, fingerprints, questioned documents, and similar fields. Most of these traditional crime labs also have a forensic chemistry section, whose function is to identify unknown chemical substances in bulk form, i.e., powders, liquids, pills, and plant material. Toxicology in these labs is generally restricted to blood alcohol determinations and the investigation of "under the influence" situations, including driving under the influence and date rape.

In these traditional organizations, investigations involving death fall under the jurisdiction of the ME's office and any toxicological investigation in these cases is performed by a toxicology lab selected by the coroner or ME. In many large cities, the toxicology lab is located in the ME's facility and is a permanent fixture of that office. In smaller jurisdictions, there is little need for a full-time toxicology lab (or ME for that matter), so any toxicology work is sent to an off-site reference laboratory.

As a result, the toxicology lab in many crime labs is a rather small unit with limited capabilities. Since many deaths involve criminal activity or criminal investigations, the toxicology aspect requires close coordination between the crime scene investigators, the medical investigators from the ME's office, the investigating police officers, and the ME. Since these entities are generally located at different sites, proper coordination can sometimes be difficult.

Several large jurisdictions in the United States (e.g., Bexar County (San Antonio) and Harris County (Houston) in Texas and Sedgwick County (Wichita) in Kansas) have addressed this problem by creating centralized forensic science centers. These centers contain most of the laboratories involved in criminal investigations, thereby allowing consolidation of physical plant requirements as well as the regular close

interaction of the personnel investigating the crime. Thus in a death case involving drugs or poisons, the autopsy, the toxicology, and the trace evidence from the body as well as any other necessary examinations, like firearms or forensic chemistry, can all be performed in a central location, minimizing chain of custody requirements and reducing the chance that evidence will be lost or mishandled.

No matter which type of organizational structure is in place, the toxicological aspect of the crime lab involves two fundamental types of investigation: antemortem and postmortem. Depending on the organization, bulk drug identification may also be performed in the toxicology lab, but this is generally not good practice since the possibility of contamination is always a concern.

In toxicology, as in every other aspect of forensics, a good rule that must always be remembered is that *every time a forensic examination is performed, no matter how simple, someone's life is at stake.*

14.2 Interpretation of Results

The primary purpose of the toxicoglogy lab is to analyze specimens in order to determine which drugs or toxins are present and in what quantities. Even though this process may take many hours or days to complete, the analytical process is only the first step. In order to be useful, those analytical results must be interpreted.

The complete interpretation of the analytical results requires that a number of parameters be considered, including postmortem redistribution, the nature of the tissue used for the analysis of the drug, genetic considerations, the possible effects of the presence of multiple drugs, and drug tolerance.

One mechanism of postmortem redistribution depends on the location of the blood and the time since death. After death, blood tends to pool in the body and minimal mixing occurs. This lack of mixing, coupled with the fact that some organs or tissues, like liver, may contain high concentrations of drugs, means that blood that is pooled next to the liver will contain more drug than blood that is located farther away. The accurate interpretation of analytical results requires that the toxicologist know how specific drugs redistribute and the collection site of the sample.

Most toxicologists prefer to use blood that is collected from *peripheral* reservoirs, like the femoral artery, rather than *central* reservoirs, like the heart. Even though the heart contains more blood, the possibility of postmortem redistribution is greater due to the close proximity of the heart and the liver. Other tissues may also provide valuable information that can assist in interpretation, particularly brain and liver.

Drugs are metabolized by a number of enzymes in the human body, and the particular enzymes present in an individual is a gift from the parents. Each individual will have a unique set of enzymes and will metabolize drugs differently. For instance, many people of Asian ancestry have low levels of aldehyde dehydrogenase, an enzyme that is necessary for the complete metabolism of alcohol. As a result, the ingestion of alcohol by these individuals results in unpleasant

side-effects. Of course, the exact genetic make-up of an individual is not known to the toxicologist, but an awareness of the variations in metabolism due to genetic uniqueness is critical to a proper interpretation.

In the case of the presence of multiple drugs, the interpretation can become more difficult. Not only must the individual effects of all the drugs be considered, but drug interactions are also possible. In a simple case, the effects of the drugs will be additive or perhaps synergistic, where the effect of two drugs is greater than the sum of the effects of the drugs taken individually. In still other cases, one drug may interfere with an enzyme responsible for metabolizing a second drug. This may lead to higher concentrations of the second drug, perhaps even reaching lethal levels.

If an individual has been using a drug for a long period of time, it is likely that a tolerance to the drug has developed. To the toxicologist, this means that a high level of a drug in one individual may not necessarily mean that a lethal level is present. As an example, the level of methadone after a single dose for the relief of pain may be as low as 0.03–0.05 mg/L, while a non-tolerant individual may die at levels of 0.1–0.2 mg/L, and an individual using methadone daily in a methadone treatment program for chronic pain or heroin addiction may function quite normally at levels as high as 0.8 mg/L.

Forensic toxicology is not an exact science. The techniques used to detect and quantitate drugs are quite accurate, but the exact meaning of those findings is subject to the experience and interpretation of the forensic toxicologist. For many drugs, the amount of drug seen in the blood in one person when the substance is taken as prescribed may be the same as the level in another who suffers severe toxicity or even death. For example, in thirteen individuals who were determined to have died from methamphetamine overdose, the blood levels ranged from 90 to 18,000 ng/mL (nanograms per milliliter). However, when methamphetamine is taken for the treatment of obesity, blood levels in 10 volunteers ranged from 62 to 291 ng/mL [1]. An example of the task faced by the toxicologist is to determine whether a level of 200 ng/mL is lethal or not, since it falls in the ranges seen in therapeutic use and in reported fatal overdoses.

Another example of interpretation used commonly with blood alcohol concentration (BAC) results involves a technique called *extrapolation.* Almost a century of research on blood alcohol levels has established several well-founded principles. Alcohol is absorbed from the gut in approximately thirty minutes to two hours. One standard drink will raise the blood alcohol approximately 0.017 g% (grams percent) (the legal limit for driving in most states is 0.080 g%). The average human will eliminate alcohol from the blood at a rate of approximately 0.017 g% every hour. Since these averages are well-established, blood alcohol levels at an earlier time can be estimated from a BAC in a sample taken at a later time.

This technique makes several assumptions and is at best only an estimate of the earlier BAC. Some of the factors affecting the metabolism and elimination of alcohol are the individual's percent of body fat, sex, age, genetic rate of metabolism, the presence of food in the stomach, the time of the last drink, and the efficiency at which the liver functions. A number of these factors have been incorporated into computer programs (e.g., BAC Tracker™ [2]) that produce graphical plots of the BAC as well as numerical estimates and probable margins of error.

The toxicological analysis of body fluids provides a snapshot of what drugs were present in the body at the time the specimen was collected. The results of that analysis *cannot* reveal how the drug was ingested (oral, IV, nasally), how much drug was ingested, what exact effect the drug had on that individual at a particular time, or what form the drug was in when it was ingested (powder, liquid, crack).

14.3 Instrumentation

As any viewer of CSI knows, the modern crime lab is packed with highly complex instruments. In toxicology, the primary function of these instruments is twofold: first, to separate the drugs and poisons from blood or tissue and from each other and second, to identify those drugs and poisons.

14.3.1 Separation Technology

Modern toxicology laboratories rely extensively on the technique of chromatography and most of the analytical instrumentation found in the lab is based, at least in part, on this principal. Chromatography is a separation technique capable of separating minute quantities of chemicals from similar substances. Gas chromatography is performed on a gas chromatograph (GC), employing a tube (column) up to 100 feet or more in length. The tube has a very small diameter and the entire 100 feet can fit into an oven the size of a shoebox. The GC is attached to an injector for the introduction of the sample and a detector for the identification of the components of the sample after separation by the column. The sample is dissolved in an organic solvent like hexane or methanol and injected into the GC injector with a small syringe. The injector is quite hot and the solvent and sample are immediately vaporized. The sample is carried through the column by a stream of gas, usually helium, and by the time the sample reaches the end of the column, the components of the sample are separated from each other. Using identical conditions for each injection, the time required for a compound to move through the GC (called the retention time) should be the same each time. Modern GCs are capable of reproducing retention times to within a few hundredths of a second.

The second most common type of chromatography seen in the toxicology lab is high-performance liquid chromatography (HPLC, or sometimes just LC). The principles are the same as for GC, except in HPLC the column is much shorter, usually approximately 6–12 inches in length; and the separation takes place at much lower temperatures, usually employs at least some water as a solvent, and does not require vaporization of the sample. This low-temperature separation is used for compounds that decompose under the high-temperature injection conditions of GC, compounds that are non-volatile, or compounds that dissolve in water but not in organic solvents (e.g., proteins, peptides).

Some toxicology labs still use thin-layer chromatography (TLC), although it is not seen as frequently today as it once was. TLC is similar to HPLC except that instead of a column, a glass plate coated with silica is used. Separation is less efficient than with GC or HPLC and sensitivities are lower.

14.3.2 Detectors

No matter which chromatographic technique is used, once the separation is complete, the components must be identified. This identification may be accomplished by a number of different techniques, all of which have strengths and weaknesses. In principle, any detector may be attached to any chromatographic device. The pairing is usually identified by combining the acronym for each technique employed. The combination of a GC (separation device) and a mass spectrometer (MS, detector) is referred to as a GC/MS or GC–MS. An HPLC using an MS detector is called HPLC/MS or an LC/MS.

Detectors commonly seen in the toxicology lab include the flame ionization detector (FID), the nitrogen–phosphorus detector (NPD), the UV detector (UV), and the mass spectrometric detector (MS). The FID and NPD are used on the GC to provide GC/FID and GC/NPD techniques, the UV detector is employed on the HPLC to give HPLC/UV and the MS detector is seen on both the GC (GC/MS) and the HPLC (LC/MS) instruments. It is even possible to piggyback detectors to create hybrids like LC/MS/MS or GC/MS/MS.

The FID responds only to substances that burn. The NPD responds only to substances containing either phosphorus or nitrogen. The MS is the most versatile of the three, providing a "mass spectrum" containing a wealth of information about the unknown substance. As practiced in most toxicology laboratories, the mass spectrum is compared (by computer) to a vast library containing the known mass spectra of hundreds of thousands of substances, and identification is made based on that comparison. Another method compares the mass spectrum obtained from an unknown sample to the spectrum of a known standard substance injected the same day.

Most toxicology labs use the GC/FID for the determination of blood alcohol. There are only a few substances that are occasionally present in the human body that are vapors and that burn, so the GC/FID is a good choice for routine samples. Methanol, ethanol, isopropanol, and acetone, the most commonly encountered "volatiles" in the human body, are easily detected and quantified using this technique. It can also be used to detect organic solvents such as toluene and xylene.

The major drawback of the GC/FID is the fact that the only information it imparts is that the detected substance burns. The presence of unusual substances has caused laboratories to erroneously report the presence of ethylene glycol [1, 2]. While this can lead to inappropriate legal action being taken against the individual, a false identification also may cause a delay in medical treatment if the misidentified substance is a toxin or an indicator of a metabolic disorder.

Since the vast majority of drugs and poisons contain either nitrogen or phosphorus, the GC/NPD is a good choice for the general screening of toxicological samples. The NPD has excellent sensitivity down to the nanogram level (billionths of a gram), the range in which most drugs and poisons are found in the body.

The disadvantages of the NPD are (1) that it is restricted to compounds containing nitrogen or phosphorus, so it will not detect substances like aspirin or tetrahydrocannabinol (THC, the active ingredient in marijuana) and (2) that there are many non-drug substances that contain nitrogen that may make correct identification difficult. For this reason, GC/NPD is widely used as a "screening" instrument and any identification made by NPD is confirmed by a more specific method.

Mass spectrometers are the best all-around detector available today. The amount of information available from a mass spectrum is several times greater than with any other detector. In routine operation by a trained operator, an MS is capable of definitively identifying thousands of drugs, poisons, and other substances. A good mass spectroscopist can extend that capability many-fold and can frequently identify a new, unknown substance even though it has never been seen before.

Even though a mass spectrum provides a wealth of information, some drugs (e.g., amitriptyline and cyclobenzaprine) produce mass spectra that are quite similar and thus difficult to distinguish without special treatment of the samples. The techniques of GC/MS/MS or LC/MS/MS provide an additional level of specificity. MS/MS spectra are usually much simpler than MS spectra and special care must be used in their interpretation, with special attention paid to such things as parent ions and daughter ions.

Several other MS techniques are used occasionally for special analyses, including chemical ionization (CI) MS and time-of-flight (TOF) MS.

Chromatographs, both GC and LC, can handle only one sample at a time. A typical run time for a single sample is on the order of 15–30 min, not including sample preparation time, which, coupled with interpretation and data analysis, may add several more hours to the analysis. We are not yet to the Star Trek "tricorder" stage, where answers are instantaneously available. As good as the technology and instrumentation is, it must also be remembered that quality control, interpretation, and common sense all play a critical role in the final outcome of a toxicological analysis.

14.4 Analytical Procedures

One of the fundamental principles of toxicology is that the identification of a drug or poison should be by two techniques that are based on different chemical principles in order to minimize the chance of error. A common means of accomplishing this is to perform a *screening* test and a *confirmatory* test. A screening test is generally designed to allow rapid, inexpensive testing of large numbers of samples for the *probable* presence of drugs or toxins. Confirmatory testing focuses on those samples that the screening test identified as probables (called *presumptive positives*) and uses an analytical procedure based on a different chemical principle and that is more specific than the screening test.

14.4.1 Screening Tests

The majority of modern forensic toxicology labs utilize one of two fundamental types of screening tests. The first is a chromatographic method utilizing GC/NPD (described above under Instrumentation). The GC/NPD is useful as a broad-spectrum screen, detecting substances that contain phosphorus or nitrogen atoms, including most drugs and poisons.

The second widely utilized screening test is based on the principle of *immunoassay* (IA). Immunoassay tests rely on the antibody–antigen reaction. Basically, the kit contains an antibody to the drug(s) in question and an indicator. If the sample contains the drug, the indicator will change. Some manufacturers use an indicator that results in a color change, others a change in the ultraviolet (UV) range, still others use a radioactive tracer. The basic principle is the same in all IAs. IA kits are commercially available for most of the common drugs (amphetamines, opiates, barbiturates, benzodiazepines, cocaine, marijuana, PCP, methadone, methaqualone) and many others that are encountered less frequently (fentanyl, LSD, and many more). In addition, several manufacturers produce assays that utilize different visualization techniques and different physical construction, although still relying on the antigen–antibody reaction. EMIT, ELISA, KIMS, and CEDIA are examples of different IA techniques.

One limitation to IA kits is that they only detect the targeted drugs or drug classes and the sensitivity to specific drugs in a given class varies considerably. For instance, the Syva EMIT® (a brand name) opiate assay detects morphine and codeine quite well, but is some 50 times less sensitive to oxycodone (Oxycontin®) even though all three drugs are opiates.

Another potential problem with IAs is that the antibodies are not 100% specific. The antibody will frequently detect substances that have chemical structures similar to the target compound. The amphetamine assays sometimes detect pseudoephedrine (Sudafed®) and similar drugs. The phencyclidine (PCP) assay sometimes reacts to large amounts of dextromethorphan, a cough suppressant.

Overall, because of the cost effectiveness and the ease of automation, IAs are a mainstay in the toxicology laboratory. Due to the limitations cited above, it is standard practice that all IA results are verified by GC/MS or a similar specific technique.

14.5 Antemortem Toxicology

Antemortem toxicology in the crime lab is focused on three general areas: (1) driving under the influence of alcohol (DUI) or of other substances (driving under the influence of drugs (DUID)), (2) erratic or unusual behavior in non-drivers, and (3) drug-facilitated sexual assault (DFSA). *Human performance testing* is an umbrella term that generally refers to DUI, DUID, and sometimes sports testing, although sports testing is rarely performed in crime labs.

14.5.1 Driving Under the Influence (DUI)

The most frequently performed tests in the modern crime lab toxicology department are breath alcohol (BrAC) or BAC determinations. Most states have a legal BAC limit for driving of 0.080 g%. Years of research have shown that there is a good correlation between the amount of alcohol in breath and the BAC, although there is some variation among individuals. When a Breathalyzer® or similar instrument is used, the instrument automatically converts the breath alcohol level to BAC.

Breathalyzer® examinations must conform to specific standard operating procedures, including a fifteen minutes wait prior to the analysis, removal of dentures or other objects from the mouth, certification of the operators, and regular calibration of the instrument. The Breathalyzer® exams are routinely administered by trained personnel outside of a laboratory with the procedure being fully documented or videotaped.

When blood is used to determine BAC, the toxicology lab performs the analysis. Several techniques are used for this analysis, but the most common one, and one of the most reliable when properly performed, utilizes GC/FID.

The proper determination of a BAC begins at the collection site. The individual responsible for drawing the blood must sterilize the venipuncture site with a non-alcohol-containing antiseptic such as iodine or Betadine®. The blood must be collected in a tube containing fluoride preservative. The commercially available grey-top Vacutainer® tubes used in many hospitals are appropriate for BAC blood collections. The blood should be stored in a refrigerator after collection, with only minimal time at room temperature, because the alcohol concentration can change due to evaporation or bacterial action if the specimen is not properly stored.

After arrival at the lab, storage should again be in a refrigerator until analysis. At that time, a small amount of blood is taken from the tube and placed in a vial, which is then sealed and heated. A small amount of the vapor above the blood is then introduced into the GC. The volatile components are separated from each other automatically by the GC column and the ethanol is detected by the FID. Quantitation is accomplished by comparing the detector response (usually the area under the peak) with standards of known concentration.

Quality control for DUI analyses should include a minimum of the following calibrators and controls.

- A *standard* containing all of the volatile substances that might commonly be found in blood (methanol, ethanol, isopropanol, and acetone) should be run to show that the instrument is capable of distinguishing among them.
- A *standard curve* should be constructed by injecting ethanol standards of known concentration to show that accurate BACs can be determined by the method.
- A *blank* should be run to show that the instrument can distinguish between a specimen containing no alcohol and one containing alcohol and also to show that no alcohol was introduced into the samples during preparation.

14.5.2 Driving Under the Influence of Drugs (DUID)

This analysis is generally performed only when the arresting officer suspects the presence of a substance other than alcohol or when alcohol is suspected but the GC/FID analysis fails to detect any alcohol. The procedures followed are a simplified version of those employed by the ME's office when investigating the cause of death. In short, the specimen may be analyzed by IA. Alternatively, the blood or urine is subjected to an extraction procedure that moves any drugs from the blood into an organic solvent. The resulting solution is then analyzed by GC/NPD, GC/MS, or LC/MS.

If the analysis is by GC/NPD or IA, the sample should be reanalyzed by GC/MS or LC/MS to provide definitive identification of any suspected substances. Once the substance is identified, a known sample of that drug should then be injected to verify that the proper identification was made.

Quality control for DUID analyses is similar to that for DUI cases.

A *standard* containing several common drugs should be injected to show that the instrument is capable of separating the components.

A *standard curve* should be constructed by injecting drug standards of known concentration to show that accurate concentrations can be determined by the method.

A blank should be run to show that no drug was introduced into the samples during preparation.

It is good laboratory practice to run positive samples in duplicate to show that no errors were made during the measurement of the sample.

It must be remembered that many prescription or over-the-counter (OTC) drugs may cause erratic behavior in some situations and any quality analysis will search for and identify those drugs as well as the common drugs of abuse. For instance, the common OTC allergy medication diphenhydramine (Benadryl®) may cause drowsiness in moderate doses and hallucinations in excessive doses.

In some cases it may be necessary to search for the *absence* of a drug. An individual with epilepsy may have permission to drive when taking the proper medication. Erratic driving or accidents may result from seizures due to the absence of the appropriate medication.

14.5.3 Non-driving Situations

A number of situations involving erratic behavior but not involving driving may require toxicological examination. Many jurisdictions have laws against public intoxication or being "under the influence" of drugs. Frequently a crime will involve the use of a drug to incapacitate a victim. The classic example of this is the old "Mickey Finn" used to shanghai sailors in the 1800s and has evolved to "trick

rolls," where wealthy individuals are rendered helpless by the addition of drugs to a drink so that they can be robbed.

All of these situations require the analysis of blood or other body fluids for the presence of drugs. The procedures used are identical to those used in DUID cases.

14.5.4 Drug-Facilitated Sexual Assault

DFSA has become a more common occurrence in recent years. A drug is placed in a woman's drink so that she will become sufficiently incapacitated that she can be sexually assaulted. The two most common substances used in these situations, flunitrazepam (Rohyopnol) and γ-hydroxybutyrate (GHB), also produce anterograde amnesia, rendering the victim incapable of recalling the events surrounding the assault.

DFSA cases are usually analyzed for alcohol and common drugs of abuse, since many of these drugs can also incapacitate a victim. In addition, special tests are performed that are designed specifically to detect flunitrazepam and GHB.

Flunitrazepam is a potent drug, and is administered in extremely small doses. This means that the concentration of the drug in blood or urine is quite low and difficult to detect unless special procedures are used. Because the concentrations in blood are so low, analysis for flunitrazepam is usually performed on urine samples.

GHB is administered in high doses (grams per dose) and is relatively easy to detect. However, the drug is eliminated from the body quite rapidly, and is virtually undetectable in blood four hours after administration, and is undetectable twelve hours after administration in urine. Samples must be collected from potential sexual abuse victims as soon as possible in order to provide the toxicologist with the best chance to detect the drugs.

14.5.5 Other Antemortem Situations

Poisoning by other substances such as household products, rodenticides, or insecticides, intentional poisoning by prescription medications, and similar situations are investigated by law enforcement officials, but the actual analysis is rarely performed by a crime lab. In many cases, the point of first contact of the victim is with the emergency department at a hospital and the initial toxicology is done at the hospital lab. These hospital labs are seldom equipped to perform full forensic toxicology screens, so it is conceivable that many potential poisonings are misdiagnosed. Unfortunately, in many cases, the best samples for full-screen toxicological testing, i.e., those from the initial hospital admission, are either of insufficient quantity, are destroyed, or are never collected by hospital personnel, so follow-up testing is difficult.

Although not used regularly in routine crime laboratory work, the testing of hair and sweat for drugs has been useful in some situations. Hair and sweat testing are

useful for detecting longer-term drug use than urine or blood. Blood is effective for detecting drug use for only a few hours after ingestion. Urine can detect use for about a week, while hair and sweat can be used to monitor drug use for several weeks (sweat) to several months (hair).

14.6 Interpretation of Results

As discussed in Sect. 14.2, interpretation of toxicological lab data is critical, both in postmortem and antemortem cases. The information available from a toxicological analysis of an antemortem sample depends to some extent on the sample. Blood samples provide more information about which drugs might currently be affecting the individual, while urine samples are better at revealing what drugs the individual has been exposed to in the past several days.

14.7 Postmortem Toxicology

As a general rule, the most thorough toxicological analyses are performed by toxicology labs involved in the investigation of death. The *cause* of death may be almost anything, e.g., blunt trauma, gunshot wound, or heart attack. The *manner* of death may only be natural, homicide, suicide, accidental, or undetermined. Since the purpose of a postmortem examination is to determine the cause and manner of death, the possible contribution of foreign agents like drugs and toxins must be evaluated.

Autopsies are performed by forensic pathologists in an effort to unravel the circumstances surrounding a death. During the autopsy, specimens are collected for toxicological analysis. Because of the untidy nature of death, the type of specimens that are available may vary from case to case, so the toxicologist must be able to adapt the analysis to the available specimens. Routinely, the autopsy team will collect vitreous fluid (from inside the eyeball), liver, heart blood, femoral blood (from the femoral artery in the upper leg), gastric (stomach) contents, and urine. In some cases, other tissue specimens are collected, including kidney and brain.

The specimens collected at autopsy are processed in the lab using a variety of extraction procedures designed to separate the drugs and poisons from the body fluids. Once the extractions are complete, any drugs are then located in a relatively clean solution, which can be analyzed by one of the methods outlined above. Rare or unusual poisons (ricin, aconitine, and tetrodotoxin) or new illegal synthetic drugs may be more difficult to detect and may require specialized methods or instrumentation.

The presence or absence of drugs or poisons can never be determined without performing a complete toxicology screen. The purpose of the screen is to determine whether the death was caused by drug overdose or whether a particular drug was present (or absent, in some cases) in sufficient amounts to alter behavior and thereby contribute to the death. A few examples will help to make the possibilities more clear.

14.7.1 Example Cases, Postmortem

The cases outlined in the next few paragraphs are fictionalized accounts of the type of situations encountered by forensic toxicologists.

14.7.1.1 Case 1

A deceased 23-year-old man is found in a tenement with a tourniquet around his left arm and a syringe in his right hand. Toxicological analysis finds that his blood contains a large amount of heroin. Based on these results coupled with the autopsy findings, the ME determines:

Cause of death	Drug overdose
Manner of death	Accidental, suicide or homicide, depending on the results of the investigation by law enforcement and the medical investigators

14.7.1.2 Case 2

A fight between two construction workers results in one of the men being killed by blunt trauma to the head by a piece of lumber. Toxicological analysis reveals a significant amount of phencyclidine in the blood of the deceased man. Further investigation reveals that the victim was behaving in a bizarre, aggressive manner and attacked the other man, who defended himself. Based on these results coupled with the autopsy findings the ME determines:

Cause of death	Blunt trauma of the head
Manner of death	Accidental

14.7.1.3 Case 3

A 43-year-old woman with a history of epilepsy is involved in a fatal single car accident, with the automobile hitting a tree. Toxicological analysis reveals no drugs in the blood even though the victim's physician reports that she is supposed to be taking daily doses of phenytoin and carbamazepine to control her seizures. Based on these results coupled with the autopsy findings, the ME determines:

Cause of death	Blunt trauma
Manner of death	Accidental

Peak BAC	0.131
Female	
Time Elapsed (hr)	Pos.-Moz. BAC (gm%)
0	0.000
0.1	0.028
0.5	0.067
1	0.067
1.5	0.090
2	0.131
2.5	0.128
3	0.119
3.5	0.111
4	0.102
4.5	0.093
5	0.084
5.5	0.076
6	0.067
6.5	0.058
7	0.049
7.5	0.041
8	0.032
8.5	0.023
9	0.014
9.5	0.006
10	

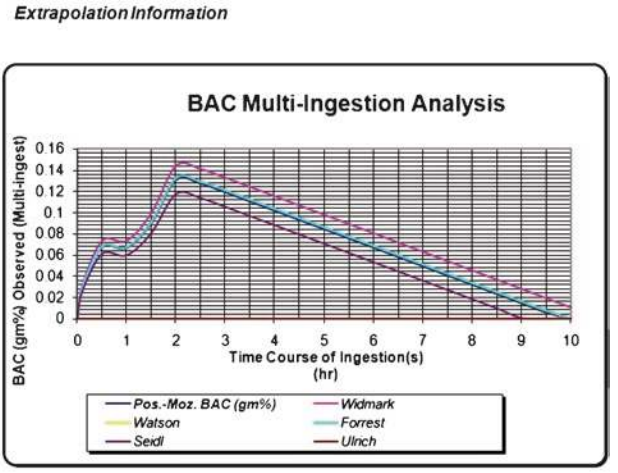

Fig. 14.1 BAC tracker results for Case 5

14.7.1.4 Case 4

An individual is arrested at the scene of an automobile accident 30 miles from the nearest hospital. The officer responding to the scene suspects that the individual is intoxicated, so he requests that blood be drawn at the hospital for a blood alcohol determination. The accident occurred at 1:00 AM, the officer arrived at 1:45 AM, the ambulance arrived at 1:55 AM, the individual arrived at the hospital at 2:45 AM, was stabilized, and blood was drawn for the alcohol determination at 3:00 AM.

Security cameras at a local bar showed that the woman consumed two shots of 90-proof tequila between 9:00 and 9:30 PM, and another two shots between 10:30 and 11:00 PM. The BAC on the 3:00 AM sample was 0.070 g%. The toxicologist is asked to estimate the BAC at 1:00 AM based on established alcohol metabolic parameters.

The forensic toxicologist uses his knowledge of the principles of alcohol metabolism, assisted by the computer program BAC Tracker™ to determine that the BAC was near 0.107 g% and thus the individual was probably driving with a BAC above the legal limit of 0.08 g%. Figure 14.1 shows the BAC of the individual from 9:00 PM (t = 2,100) to 7:00 AM (t = 0700 h) as calculated by BAC Tracker, taking into account the amount and type of food consumed, the elimination rate, the age, sex, height, and weight of the individual, and the type of alcohol consumed.

14.8 Real Examples from the Case Files

The following examples are taken from actual cases and are intended to impress on the reader the complexities of toxicological interpretation.

14.8.1 Case 5

A nurse in a hospital in an eastern state was accused of injecting patients with epinephrine. Epinephrine (adrenaline) is a powerful drug used to start the heart after cardiac arrest. In high doses, it can cause cardiac irregularities leading to death. The reason suggested by the prosecution for her alleged behavior was that she enjoyed the excitement surrounding the "code," i.e., the attempt to resuscitate a heart attack victim. She was suspected of injecting many patients, but the actual trial focused on six patients, four of whom died. Since she was not suspected of foul play until many months after the deaths, the deceased individuals had been interred for several months. In three of the cases, no samples were available from the time of the suspected attacks. In those three cases, the bodies were exhumed and autopsied.

The samples taken during the autopsies were sent to a reference laboratory for analysis. The laboratory focused on detecting metanephrine, a metabolite of epinephrine. The reason for this was that epinephrine exists in the body only minutes before it is converted to metanephrine, which remains in the body for several hours. The analytical procedure employed by the laboratory had never been used by any other laboratory and thus its validity was never verified. Quality control procedures employed by forensic laboratories generally require method validation to ensure that the method is accurate and reproducible.

The results of the analysis revealed the presence of metanephrine in several of the tissues collected at autopsy. The testimonies before a grand jury indicated that the levels of metanephrine found in the exhumed bodies were as much as 10,000 times greater than normal. Based to a large extent on this testimony, the grand jury indicted the nurse for murder.

The original laboratory data was later analyzed by other toxicologists who are considered to be experts in their field. What these experts determined was that parts of the original results were inaccurate in several respects, all stemming from a lack of adequate quality control procedures.

As a result of the investigation by the defense experts, the prosecution announced that they would not use any of the toxicological data from the original laboratory, and no toxicological evidence was presented. The defendant was convicted based on other evidence.

14.8.2 Case 6

A forensic pathologist was suspected of murdering his wife by using some type of drug or poison that was difficult to detect. Tissue collected from the wife at autopsy was sent to a reference laboratory in an attempt to identify the drug or poison. The laboratory initially determined that the cause of death was a potassium overdose, probably by injection of potassium chloride into the arm.

The pathologist was subsequently arrested and charged with murder. The defense felt that the laboratory's claim of potassium overdose was scientifically

invalid and a Frye hearing was convened to determine the validity of the science. A Frye hearing (or a Daubert hearing in some states) is an attempt by the court to determine whether scientific evidence meets certain minimal standards, one of which is that the methods used must be "generally accepted" by practitioners in the field. The generally held opinion in the toxicology community is that postmortem potassium levels are always elevated and are not at all useful in determining antemortem administration of potassium. The Frye judge ruled that the technique used by the laboratory was not generally accepted in the toxicology community and therefore the toxicological "evidence" that potassium overdose was the cause of death would not be allowed in court.

The pathologist was released, but the prosecuting attorneys continued their investigation. Several years later, the autopsy tissues were sent back to the same reference laboratory. The lab had developed a process that they felt could reliably detect and identify a group of toxins known as *quaternary ammonium compounds.* The laboratory analyzed the tissues using this procedure and identified succinyl monocholine, a metabolite of succinylcholine. Succinylcholine is a muscle paralysis agent that paralyzes the diaphragm, causing death by asphyxiation. The pathologist was taken into custody and was again put on trial for murder, this time with the prosecution claiming that he had administered succinylcholine rather than potassium to his wife.

During the second trial, defense experts testified the possibility of several occurrences of inaccuracy in the analytical procedures and interpretations and even possibility endogenous succinyl monocholine in her body. The defendant was convicted of murdering his wife and was sentenced to life in prison. His case was overturned by the state Court of Appeals based primarily on the inadequacy of the scientific data.

14.9 Conclusion

As demonstrated by the cases outlined above, toxicology is a complex science even in the simple cases. Each case must be approached with a trained, experienced eye. The forensic toxicologist must look at all possibilities, examine each piece of evidence with objectivity, "stand on the shoulders of the giants" who have provided the mountains of pertinent research, and to process the bulk of the findings into a logical, coherent explanation. The process is an arduous one, but the search for the truth is never easy and is always fulfilling.

14.10 Questions

1. Name three methods of screening for drugs and discuss the advantages and disadvantages of each.
2. Explain why femoral blood is considered a better sample than heart blood for the determination of antemortem drug levels.

3. What is the difference between a crime scene investigator and a medical investigator?
4. What is a chain of custody and why is it important?
5. Name the five possible manners of death and give an example of each.
6. Define forensic toxicology and its purpose, and describe where it might be used.
7. Can forensic toxicology methods be used on exhumed tissue? Explain.
8. What is the difference between screening tests and confirmatory tests, and why are both necessary?
9. What volatile compounds might appear in blood besides ethanol?
10. Name two drugs used in DFSA and explain why they are effective.

14.11 About the Author

Dr. Mozayani is the Crime Laboratory Director and Chief Toxicologist for Harris County Institute of Forensic Sciences (HCIFS). She is a board-certified forensic toxicologist with Diplomate status in the American Board of Forensic Toxicology (D-ABFT). Dr. Mozayani has more than fifteen years of laboratory management and more than twenty years of experience conducting forensic toxicology, clinical chemistry, and hair drug-testing studies. Prior to her tenure with HCIFS, Dr. Mozayani was the Chief Toxicologist at the Office of Chief Medical Examiner in Washington, DC. She is an active member of several scientific professional organizations, including the Society of Forensic Toxicologists (SOFT), The International Association of Forensic Toxicologists (TIAFT), Southwestern Association of Toxicologists (SAT), and the Canadian Society. She is also a Fellow of the American Academy of Forensic Sciences (AAFS). She serves as a laboratory inspector for the National Laboratory Certification Program (NLCP) and for the American Board of Forensic Toxicology (ABFT). She was previously on the Board of Directors for SOFT, ASCLD, and SAT. She is Past President of SAT.

Dr. Mozayani is holds adjunct academic appointments in the Department of Medicine at the University of Texas; the Department of Pharmacy at Texas Southern University; the Department of Pathology at Baylor College of Medicine, Houston, Texas; the Department of Pharmacological and Pharmaceutical Sciences, University of Houston; and in the Department of Pathology at University of Texas Medical Branch, Galveston. She is also Senior Forensic Advisor in International Criminal Investigate Training Assistance Program.

Dr. Mozayani has published and presented numerous articles related to crime laboratory management, forensic toxicology (cocaine, marijuana, amphetamines, drug testing in hair, inhalants, and opiates, GHB, alcohol, and several prescription drugs). She is the first United States Editor of the Journal of Forensic Science, Medicine and Pathology. She is also editor of three books: Drug-Facilitated Sexual Assault, A Forensic Handbook; Handbook of Drug Interaction-A Clinical and Forensic Guide; The Forensic Laboratory Handbook.

Dr. Mozayani is an Assessor/Inspector/Auditor for: The American Crime Laboratory Directors/Laboratory Accreditation Program; Standards Council of Canada; National Laboratory Certification Program; The American Board of Forensic Toxicologists; The College of American Pathologists (Forensic Urine Drug Testing). Dr. Mozayani also serves as a consultant in toxicology and crime laboratory management to other government and private industries. Dr. Mozayani has been qualified as an expert witness in forensic toxicology and pharmacology in the states of Texas, Virginia, Maryland, Oklahoma, Florida, Kansas, California, Idaho, Montana, the Federal Court in Massachusetts and the numerous Military Courts of the United States. She has presented nationally and internationally at numerous meetings, including Istanbul, Manchester, Bogata, Tashkent, Paris, and Bonn.

References

1. Baselt, R.C, ed., Disposition of Toxic Drugs and Chemicals in Man, 8th Edition and references cited therein. 2008, Biomedical Publication, Foster City, California. 947–950.
2. www.BAC-Tracker.com

Further Reading

Principles of Forensic Toxicology by Barry Leume and Barry Levine
Toxicology: A Case-Oriented Approach by John Fenton and John Joseph Fenton
Criminal Poisoning: Investigational Guide for Law Enforcement, Toxicologists, Forensic Scientists, and Attorneys by John Harris, III Trestrail
The Forensic Pharmacology of Drugs of Abuse by Olaf Drummer, et al
Karch's Pathology of Drug Abuse, Third Edition by Steven B. Karch
Casarett & Doull's Essentials of Toxicology by Curtis D. Klaassen and John B. Watkins
Drug Facilitated Sexual Assault, A Forensic Handbook by Marc A. LeBeau and Ashraf Mozayani
Handbook of Drug Interactions: A Clinical and Forensic Guide by Ashraf Mozayani and Lionel P. Raymon

Chapter 15
Trace Evidence

William M. Davis, PhD

Contents

15.1 General Considerations

Prior to completing this chapter, a much-anticipated report entitled "Strengthening Forensic Science in the United States: A Path Forward" [1] was issued by the Nation Research Council, the investigative arm of the National Academies. The report was the result of a congressional mandate that the National Academies evaluate the state of Forensic Science practices. The panel of experts interviewed practitioners, educators, and representatives from the Criminal Justice Community. This report should be considered mandatory reading for anyone associated with forensic analyses and interpretations.

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A. Mozayani and C. Noziglia (eds.), *The Forensic Laboratory Handbook Procedures and Practice*, DOI 10.1007/978-1-60761-872-0_15,

The report was highly, but necessarily, critical of the scientific bases of such disciplines as impression evidence (e.g., fingerprints) and comparison analysis (hair and fiber comparisons). Many topics in this chapter deal with the latter and the author wants to emphasize at this juncture that an examiner must be absolutely clear in relaying results to truth finders and the limitations of these comparisons. The "necessarily" caveat is added as most of the report holds nuclear DNA analysis and its associated statistical interpretation as the benchmark to which all others are compared.

Essentially the recommendations, while not binding, call for the establishment of an autonomous Federal agency, the National Institute of Forensic Science, that would be responsible for creating standardization of research, education, certification, accreditation, methods, reporting, ethics, and enforcement in forensic disciplines. Additionally the report calls for the removal of organizational and budgetary involvement of law enforcement/prosecutors from forensic laboratories.

Trace evidence is an all-encompassing set of physical samples that range from microscopic to macroscopic. Generally, non-biological, non-controlled/dangerous substances and non-impression evidence are excluded from the category. While this may appear to eliminate most forms of evidence, it does not.

This chapter is a mere overview of some of the types of evidence, issues, and techniques that a trace evidence examiner may utilize in her or his analyses. Additionally, this chapter is not meant to provide detailed information as to all of the techniques that are used or their limitations.

To that end, the trace evidence section of a crime laboratory is one of the most diverse when all sub-disciplinary services are offered. The sub-disciplines of trace evidence as accredited by the American Society of Crime Laboratory Directors/Laboratory Accreditation Board (ASCLD/LAB) are the following:

Fire Debris (Chap. 5)
Explosives (Chap. 5)
Gun Shot Residue (Sect. 15.2)
Hair (Sect. 15.3)
Fibers and Textiles (Sect. 15.4)
Paint (Sect. 15.5)
Physical Comparisons (Sect. 15.6)
Analysis of Unknowns (Sect. 15.7)
Other Materials (not addressed)

While these sub-disciplines are specific in accreditation language, it is not uncommon to find these services offered by other sections of the crime laboratory, e.g., gunshot residue analysis may be performed in a laboratory section where firearms determinations are performed.

The examination of trace evidence has a rich history in forensic sciences. Sir Edmond Locard, considered by many to the founder of forensic science, states in the eponymous Locard's Exchange Principle: when two objects come into contact, material is exchanged. A corollary of this principle is that the quantity of material exchanged is directly proportion to the duration of contact, the intensity of contact, and the physico-chemical properties of the two materials. That is to say that material

is exchanged via contact, unwittingly, by contact of a perpetrator and victim, or perpetrator and weapon, or perpetrator and the crime scene.

An important caveat must be noted, however, i.e., the courts and juries of our criminal justice system are the finders of fact. Facts, using the journalistic "who, where, when, why, how, and what," constitute the basis for the decisions of those who are given that particularly difficult but dutiful task. Trace evidence examinations can generally provide the "what" and sometimes the "where," while the remainder of the facts will be determined by other investigative means and/or interpretation. As an example, let us consider a person who is charged with possession of cocaine. A forensic chemist is equipped with the education, experience, and methodology to identify the evidence in this case as cocaine, but these laboratory methods in no way can demonstrate "possession."

Most practitioners in the trace evidence analysis have earned Bachelor's degrees in a biological or physical science. This is the minimum entrance requirement in most laboratories. A strong chemistry background is encouraged because many of the substances examined require chemical characterization to some extent. Additionally, excellent verbal communication skills will enable an examiner to explain difficult scientific terms to laypersons.

While laboratory accreditation is becoming more and more a mandatory requirement for forensic laboratories, the certification of examiners has been slower in evolving. That is not to say that certification is not available. The American Board of Criminalistics offers certification in Trace Evidence and a specialty certification in Fire Debris. In light of the National Academy's report, professional organizations are using specific language that requires certification prior to offering opinions as an expert witness.

15.2 Gunshot Residue

The analysis of gunshot residue (GSR) is based upon the chemistry and physics of the discharge of ammunition. However, as most laypersons are wont to believe, this residue is not a product of the powder portion of ammunition; rather it is a product of the primer. Most primers, particularly in inexpensive ammunition, are comprised of a percussive explosive (a chemical substance that releases energy when forcibly struck) and other substances. Typically, one will find the chemical substance lead (Pb) styphnate as the percussive explosive. Also common in primer formulations are barium (Ba) nitrate and antimony (Sb) sulfide. While the exact composition of primer is generally proprietary, these three substances will be found in ammunition, with the exception of small-caliber rim fire cartridges.

GSR formation is inherent to the high-energy discharge (i.e., high temperature), which is sufficient to render the primer combustion products liquids. While molten, droplets of these liquids are dispersed randomly in the rapidly expanding gases that result from the subsequent explosion of the gunpowder. These gases then escape through breaches in the weapon, e.g., barrel, cylinder gap, and ejection port, carrying along the dispersed liquids. While in this chaotic aerosol, the droplets can mix,

resulting in new liquids that may contain binary elemental composition (Pb–Ba, Ba–Sb, Pb–Sb) or even the ternary product containing Pb–Ba–Sb. As the aerosol cools extremely rapidly upon exposure to the surrounding air, these droplets are essentially quenched into solid particles that deposit on nearby surfaces, e.g., hands or interiors of vehicles. One difficulty in the collection of this evidence is that the residue is not visible to the naked eye. An investigator must decide which surfaces were likely deposition sites, and select appropriate sample collection points on these surfaces. Samples collected are then submitted to the laboratory, and only then may the presence and composition of any GSR be elucidated.

15.2.1 Bulk Analysis

Examiners of GSR have two options in approaching this evidence. One is a bulk analysis wherein the total chemical composition of the sampled surface is determined. Analytical techniques include atomic absorption spectroscopy (AAS) or inductively coupled plasma/mass spectrometry (ICP/MS). Each of these instrumental methods will give the analyst the concentrations of the targeted elements, and an opinion would be issued as to whether these concentrations are what one would expect for GSR. Typical sampling for these two methods is to apply a cotton swab to the surface of interest thereby transferring residue to the appliqué. A serious drawback to this approach is that the presence of the three elements on a given surface may be benign. Lead has a wide variety of occupational and environmental sources (e.g., plumbing, solder, some men's hair products), while barium is found in medical procedures (e.g., imaging soft tissues via X-rays), and antimony can be found in some cosmetic products. Hence the interpretation of the results of bulk analysis, i.e., whether they are congruent with GSR or not, is not very sound.

15.2.2 Particle Analysis

The other method available to a GSR examiner is a combinatory microscopic/spectroscopic method. The technique utilizes a scanning electron microscope equipped with an energy dispersive X-ray spectrometer serving as the detector. This microscope configuration is referred to as an SEM/EDS and provides a true analysis of the particles that result from the quenched aerosol as described above. The principle behind this technique is based a study performed by scientists at the Aerospace Corporation published in 1977 [2].

If we return to the aerosol that forms in the short time following detonation of the primer and subsequent explosion of the powder, one could visualize that, upon cooling, the liquid droplets form small particles typically of spherical character and

dimensions on the order of microns. These size and shape characteristics, collectively referred to as morphology, infer that the particles have originated from a liquid environment. The second part of the analysis (EDS) allows the analyst to confirm the chemical composition of any particles that satisfy the morphological criteria. The below are a secondary electron micrograph of a GSR particle along with the EDS spectrum (Fig. 15.1a, b).

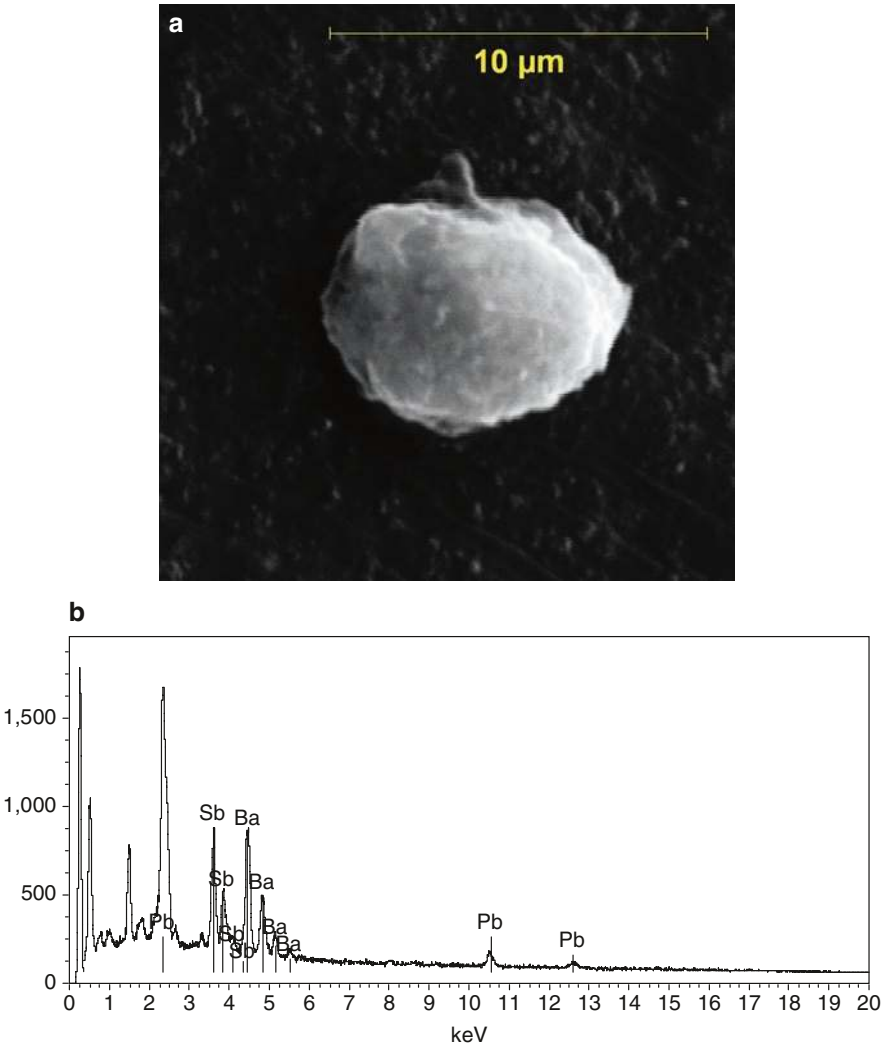

Fig. 15.1 (**a**) A secondary electron scattering image of a GSR particle. (**b**) The energy dispersive X-ray spectrum

15.2.3 Interpretation

Caution should be exercised when interpreting the findings of a GSR examination. A positive finding, i.e., that particles with a composition characteristic of GSR (i.e., Pb–Ba–Sb) have been confirmed on samples from person's hand, does not provide conclusive proof of that individual having fired the weapon. Since the aforementioned aerosol can cover areas well away from the weapon, simply being in the vicinity of the discharge may explain its presence.

Additionally, if a surface contains GSR, the number of particles will decrease with activity. Hence a negative result does not necessarily lead to a valid conclusion of exclusion from the incident. The reasons are all based upon the fact that GSR, if present, is easily transferred or removed. Activities subsequent to the deposition of the particles are important parameters to consider in negative results. For example, suppose that a person has been exposed to GSR. If the surface of interest is that person's hands, then simply washing those hands could eliminate the residue, or at least certainly reduce the amount to be found.

15.2.4 Statistical Evaluation of GSR Data

Statistics can be an important tool in the interpretation of GSR, if used properly. As outlined in the preceding sections, a number of variables may contribute to erroneous interpretations. A study published in 2006 by Cardenetti et al. [3] gave a first approximation of the utility of statistics when interpreting GSR results.

It has been well established that random counting events (e.g., the number of coins in the pockets of a population, nuclear decay phenomena, and GSR) follow a probabilistic distribution function, known as the Poisson distribution:

$$P(n) = \mu^n \left[e^{-\mu} \right] / n$$

where P(n) is the probability of finding n particles in a population with a mean number, μ, which has been determined from a sampling of that population.

Before we address the results of the study, it is necessary to consider some features of a case that involves GSR evidence. The truth finders will be asked to determine which of two hypotheses are more likely beyond a reasonable doubt. The first is the hypothesis put forth by the prosecution that the defendant was in the vicinity of a fired weapon, which usually implies that the accused did fire the weapon. A common defense hypothesis is the opposite of the prosecution's. Let us call these hypotheses H_P and H_D respectively. Then the probabilities associated with these hypotheses follow an appropriate Poisson distribution. In the case of H_P, the value of n would be that found by an examiner on a surface related to the defendant (e.g., hands). The value of μ would be the mean number of particles found in a population of persons that have been in the vicinity of a fired weapon, provided the primer has a sufficient chemical composition. The value of this mean would be time/activity dependent.

Conversely, H_D would be constructed similarly, with n remaining the same, but a new mean would be introduced, representing the results from a sampling of person not involved in a shooting.

Let us now go back to the Cardenetti et al. study, in which three separate samplings were taken from two populations, shooters and non-shooters. Two samplings were taken from the shooter population, police officers who had fired a specific number of rounds at a firing range. These were subsequently divided into groups for a time-dependence study. The third sampling was taken from the non-shooter population, police officers who had been assigned administrative duties and who had not fired a weapon for longer than a month. As the authors point out, given that there is a chance of contamination in law enforcement environments, this population was the most generous to H_D.

To avoid issues such as contamination, sampling locations, and post-shooting-event activities, all of which make evaluation of H_P problematic, let us focus upon H_D. Recall that this is the hypothesis that the defendant had no association with a shooting event. Hence, let us only consider the results of the non-shooter data. In their study, 81 police officers assigned to administrative duties were sampled during their daily routines. The results were that one characteristic GSR particle was found in this group. That represents a mean, μ, of 0.0123 particles per person. One should note that, based upon the sample size, other statistically significant values for this study are the standard deviation and the standard error of the mean, which are 0.0124 and 0.00133, respectively.

Now let us turn our attention to the findings of the examiner. Table 15.1 lists the Poisson probabilities of finding a certain number of characteristic GSR particles on a surface. As we have selected to focus on H_D, the non-shooter mean is employed.

These derived data are based solely on the absolute numbers with no statistical inference. When one takes into consideration a 99.7%, three sigma (3σ) confidence interval, the lower Poisson probability of finding three GSR particles in the non-shooting population is 7.45×10^{-7}, or about one in a million. Thus in a case where the defendant's position is that they were not in the vicinity of a fired weapon and an examiner found three characteristic GSR particles, then the probability that H_D is valid is extremely small.

Biedermann et al. [4] have expanded on the original Cardienetti et al. work by introducing various Bayesian networks into the analyses. The authors attempt to develop a probabilistic assessment of the source of GSR, i.e., primary association with a fired weapon vs. contamination. While this may be useful in the future, no new data are presented upon which to propose statistical inferences.

Table 15.1 Poisson probabilities for finding *n* particles in a "non-shooting" population

Number of particles, *n*	Poisson probability (*P*)	"Odds" (P/1–*P*) x:1
0	9.88E-01	82.3
1	1.23E-02	1.24E-2
2	7.62E-05	7.62E-5
3	3.16E-07	3/16E-7

15.3 Hairs

Because most hair-bearing creatures shed hair on a regular basis, and a human may shed hundreds of hairs daily, it is of little surprise that hair may be left at crime scene unwittingly. This example of Locard's Exchange Principle is the main reason that hair evidence and its examination remains a fixture in most trace evidence laboratories. Critical to the interpretation of the analysis, however, is the availability of appropriate samples for comparison.

An examiner relies upon one of the most indispensable tools available: the optical microscope. An experienced examiner will be called upon to determine whether hair evidence is of human origin and, if so, the location of the hair: head, pubic, or ancillary (e.g., chest, facial). These features are easily discerned upon microscopic examination. Additional information can be gleaned in these examinations, such as whether a hair was removed via struggle vs. natural release, or the hair was cut by scissors vs. a razor or naturally colored or dyed, to name a few.

15.3.1 DNA Screening

The most compelling information that can be obtained from the analysis of hairs arises from the examination of forcibly removed samples. A hair that has been removed by force will inevitably retain follicular, or cellular, material. Microscopic examination of a hair that has this feature can be further processed to obtain a nuclear DNA profile, hence providing a possible answer to "who" or, perhaps more importantly, "not who."

15.4 Fibers and Textiles

A particularly complex type of trace evidence consists of fiber debris left at a crime scene. The complexity arises from the myriad substances available to textile manufacturers. These materials range from natural sources (cotton) to highly engineered polymeric species such as Kevlar®. Where textiles are exclusively man-made, the fibers used to manufacture them can be both natural and man-made.

15.4.1 Physical Properties

Typically, natural fibers will display cross-sectional morphologies that are circular or ovoid. However, owing to the various manufacturing methods that are used to produce synthetic fibers (e.g., spinning or extrusion), the variety of shapes of these cross-sectional morphologies are beyond the scope of this chapter.

What is important is that trace evidence examiners have tools available that can help them in identifying fiber types and comparing them with exemplars for probative information. First, however, is identifying the type of fiber that was recovered from the scene.

The identification is done, ideally, with a combination of microscopic and spectroscopic techniques. In these examinations, the analyst uses cross-sectional information along with infrared and visible spectroscopies to determine type and color. When suitable exemplars are available, comparisons can be made.

A very popular example of the use of fiber evidence is that found in the case of the State of Georgia vs. Wayne Williams. During the late 1970s and early 1980s, a series of suspicious disappearances and deaths of mostly young black men (aged 8–27 years) in Atlanta caught the area's interest and subsequently that of the nation. Fiber and a limited amount of pet hair evidence comprised the bulk of the prosecution's case against Mr. Williams. Statistical analysis of the fiber evidence in the case presented by the State of Georgia suggested that there was an approximate 1 in 8,000 chance of randomly finding this type of fiber anywhere in the Atlanta area. While Mr. Williams was convicted of only two murders, law enforcement closed the cases of 23 others with Mr. Williams being the alleged perpetrator. It should be noted that Mr. Williams maintains his innocence and continues to file appeals seeking to overturn his conviction.

15.5 Paint

Paint is a type of coating that, when applied to a surface, may protect that surface from environmental or other conditions. Additionally, paints serve a highly decorative purpose in their readily available array of colors. When one considers the use of paints, they are typically classified as architectural or automotive.

Typical paints are composed of essentially three components: pigments, constituents that add color and durability; vehicle or binder substances, such urethanes, oil, or acrylics, whose properties facilitate adhesion to a surface; and solvents, whose choice will affect properties such as how easily the paint is applied. It is noteworthy that most pigments are minerals of potentially toxic metals that have a rich history of providing color to any surface. However, as chemistry advances the synthesis of organic pigments (to differentiate the difference between the inorganic and organic colorants, one refers to the latter as dyes), these are being used in increasing quantities.

Forensic paint examinations are most commonly associated with the automotive industry, although interest in architectural paints does exist. The primary analysis of architectural paint occurs in the environmental realm. Application of Locard's Exchange Principle tells us that a painted object will transfer material to another on contact. Examples of contact can be between two vehicles, a vehicle and an inanimate object, or a vehicle and a person.

Automotive surfaces are not simply painted with a given product with subsequent reapplication as a wall in one's home. The process of preparing the vehicle's surface

for delivery to a dealership is complex and may involve more than one paint. Generally, a primer coat is applied to provide extra corrosion resistance and adhesion of the pigment coat (sometimes termed the topcoat). The pigmented topcoat is then applied, providing the vehicle color. Further protection will then come from the application of a clear coat that serves a number of functions to include protecting the topcoat from damage from UV radiation. Each one of these layers may be applied multiple times during the process.

Paint analysis is comprised of:

- Determining the number of layers, typically through the use of optical microscopy or scanning electron microscopy (SEM).
- Classifying components of the pigments and binders using a micro-spectrophotometer. UV-VIS will assist in color determination and IR in chemical components.
- SEM/EDX can be used to determine the inorganic components of pigments.

Atlases and databases of automotive paints exist and may be of use in determining the difference between a red paint used by motor company A vs. B.

Combining physical and chemical properties of paints leads to a set of data that can be used to compare with known exemplars or to develop leads in an investigation. The comparison and interpretation thereof must be reported with sustainable statistical information based upon production numbers, geographic sales information, and state motor vehicle data.

15.6 Comparison Analysis

The three preceding sections commonly offer little probative value in an investigation without a comparison analysis. In these analyses, the questioned hair, fiber, or paint chip will be compared with exemplars of similar evidence that have a known source, i.e., ones that can be demonstrated to be associated with a person or place. Keep in mind that while non-exclusion (or exclusion) of a questioned sample from a known source is the typical reporting language, report conclusions and subsequent testimony of the results must be made with care because these are extremely critical and there are uncertainties involved.

Let us consider a rational approach to comparisons. The most effective way for an examiner to begin is by comparing properties until an exclusion opinion can be rendered. As an example, if two blue fibers are submitted as evidence and are clearly distinguishable by their morphologies or their chemical composition, a common source can be excluded. Conversely, if two blue fibers are submitted as evidence and their morphologies and compositions indicate that they are potentially of a common source, comparison continues via examination of additional characteristics, and the result may be that no properties are different. Hence, exclusion becomes less probable.

The operative word above is probable. There are two implications. First, when two pieces of evidence have been thoroughly examined and found to have no distinguishable differences, one could presume that they share a common source. However, many other

factors must be considered. Again, in the case of fibers, two fibers from a common source (e.g., a carpet made with polyethylene terephthalate and dyed indistinguishably) an obvious question arises; how common is the source? This was addressed in the Williams murder trial and given the relative rarity of that particular evidence, the fact finders were satisfied. To that end, a careful examination of the prevalence of certain class evidence is also warranted. While this may not be part of the examiner's duties, the necessity of the task should be communicated to those that requested the comparison.

A second implication of probable may not be as apparent as the first. That is: How probable is the non-exclusion of a questioned fiber from a known source? To reach this conclusion, the examiner has obviously considered copious amounts of information, both physical and chemical. Some of this information may have involved measurements such as spectroscopic characteristics of the chromophore (dye), and hence there are errors associated with these measurements.

Since the examiner is considering so many variables in reaching an opinion, it would be prudent to make use of a statistical evaluation of all of the data. However, given the complexity, often times going well-beyond the two- or three-dimensional comfort zone (a linear relationship between concentration and the signal response of a detector), standard statistical practices become problematic. A solution to this is to apply a multivariate statistical approach sometimes known as chemometrics. Such approaches are finding their way into forensic analyses [5].

The theories and techniques of multivariate statistical analyses are beyond the scope of this chapter. Generally, these large, multi-dimensional data sets are examined with computer algorithms to find the two or three variables or combinations thereof that provide the most variation within the data. These discriminators can then be used to ascertain the degree of certainty that two substances may share a common source. While some may argue that this is simply quantitation of one's experience in a given field, it should be apparent that statements to the effect that "to a 95% degree of certainty, the source of the questioned item cannot be excluded as that of the known item" relays a more scientific inference than "the questioned item cannot be excluded from having the same source as that of the questioned item." Note here that source simply implies that the items are of the same class, and actual source cannot be individualized until further statistical evaluations have been made as to manufacturing, end use, and distribution of the items that were analyzed.

15.7 General Unknowns

The analysis of unknown substances presents some of the most challenging issues to a forensic examiner. Consider that the unknown substance could be in any of the three standard states of matter or mixtures thereof: solid, liquid, or gas. Compound this with the chances that these unknown materials may not be pure and one can appreciate the complexity not to mention the importance of safety. The vast array of analytical techniques and instrumentation that is required for this sub-discipline precludes commonplace practice.

Consider an unknown liquid that is submitted to a laboratory for identification. Many times the request may be made with the expectation of a specific identity assignment. However, to avoid any contextual bias, the liquid should be treated as a complete unknown. Adhering to specific procedures, to include pre-determined safety practices, an analyst would be able to ascertain whether the liquid is organic or inorganic. Simple miscibility studies would give an indication as well as an ignitability test. Let this liquid then be determined to be inorganic in composition, i.e., water or an aqueous solution. An examiner would then undertake conductivity measurements to determine if an ionic solute is present or use pH measurements to determine the acid/base content. Spectroscopic information, such as UV-VIS, IR, and Raman spectroscopies would provide valuable insight to the nature of some of the chemical species in the solution. The examiner would also perform an extraction of either an acidified or basified sample of the solution with an organic solvent to isolate any neutral drug species that may be present. Finally, utilizing a sufficient portion of the unknown and allowing that to evaporate to dryness provides a residue that can be analyzed by X-ray diffraction. The scenario above may appear to encompass an arduous set of tasks with a large investment in instrumentation; however, this type of thorough investigation into the identity of unknowns has its place in the treatment of trace evidence.

15.8 Common Tools for a Trace Examiner

The most indispensable tool of the trace examiner is the optical microscope. These microscopes are generally equipped with various stages and optics that allow the examiner to measure any number of optical properties of interest. Additionally, the comparison microscope is a valuable tool in assisting the examiner in the initial stages of determining exclusion of certain types of evidence.

Other tools available to the examiner and some of their uses:

- AAS – can provide quantitative information about elemental composition, particularly metals. AAS is most useful in bulk analyses.
- Energy Dispersive X-Ray Spectroscopy (EDS or EDX) – allows for the determination of elemental constituents in an unknown, typically used with scanning electron microscopes. Generally not used in quantitative analysis.
- Fourier Transform Infrared spectroscopy (FTIR) – provides vibrational information of chemical species. It is particularly good for determining the presence of certain functional groups for organic molecules or anionic information of certain salts.
- Gas Chromatography/Mass Spectrometry (GC/MS) – provides separation of mixtures as a function of a user-specified property, generally boiling point, and gives sufficient structural information to allow identification of a certain types of chemical substances.
- ICP/MS – similar to AAS in that elemental information is attained and can be used as a quantitative technique.

- Raman Spectroscopy – a complementary technique to FTIR in that structural information can be gained that is not observable in the regular FTIR measurement.
- The Randox Evidence Investigator is a new IA. It uses a biochip array that is capable of detecting standard drugs of abuse, as well as some compounds that would only be found by the GC/MS library screen. An additional benefit is that it uses a 9-point semi-quantitative curve, which provides valuable information on estimating the concentration of the drug.
- SEM – a versatile instrument for observing small features of substances unattainable with an optical microscope. When coupled with EDS, yields qualitative and, at times, quantitative chemical composition.
- Ultraviolet/Visible spectroscopy (UV/VIS) – provides electronic information of chemical species particularly useful in describing the color of a given substance.

15.9 Questions

1. Why is it important to report the inherent limitations of a particular analysis along with the results?
   Consider two statements:

   (a) Two pieces of evidence come from the same source.
   (b) Two pieces of evidence are analytically indistinguishable.

   Evaluate the following logical conditions:

   (a) If a then b
   (b) If not a then not b
   (c) If b then a
   (d) If b then not a

   Do any of these constitute a possible false positive? Do any of these constitute a possible false negative?
2. The "non-shooter" GSR (15.2.4) study was expanded and an additional 60 persons were sampled. In the expanded study, 1 of the 60 had three characteristic particles confirmed. How would this affect the Poisson probabilities listed in Table 15.1? Does this indicate anything about sample size?
3. What is Locard's Exchange Principle?
4. As an exercise in the uses of the Poisson probability, canvass coworkers regarding the number of US $1.00 bills (currency and denomination left to the reader) they have in their possession. Tabulate the results to obtain averages and other statistically relevant information. Finally, calculate the Poisson probabilities of finding a given number in a population and test it in the field, e.g., find someone who did not participate in the study and ask them how many they have in their possession.
5. Name two analytical instruments that provide structural information.
6. Name two analytical instruments that provide compositional information.

7. What is the National Research Council (NRC)? Has the NRC ever published other controversial reports and recommendations? (Hint: Look at the units on a speedometer from an American-made automobile in the 1960s vs. in the 1980s.)
8. What sub-discipline of trace evidence requires a substantial investment in instrumentation?
9. What is the most indispensable instrument available to a trace evidence examiner?

15.10 About the Author

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Chapter 16
LIMS: Laboratory Information Management Systems

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Contents

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16.1 Introduction

Like most other business environments today, forensic laboratories have come to rely heavily on computer software as a tool to help them meet the increasingly difficult demands placed on their time. As workloads increase, it becomes more important to squeeze efficiency out of every aspect of lab operations in order keep up. Forensic Laboratory Information Management Systems (LIMS) started their evolution in the 1970s with forward-looking laboratories commissioning the creation of custom programs on departmental minicomputers in an attempt to make the production of reports more efficient. A number of other laboratories caused modules to be added to existing policing systems to accommodate their needs. These systems were costly and maintenance intensive and so adoption was limited. In the 1980s, the introduction of the desktop computer meant that forensic staff that understood both the business challenges of the lab and the opportunities presented by this new platform could write business applications that began to deliver some of the efficiencies that computing promised. In the 1990s, several vendors started software ventures that focused exclusively on the forensic lab as a market, and the modern forensic case management system was born. Today, most forensic LIMS vendors have either completed or are in the process of delivering new generations of forensic case management systems based on the latest operating systems and that take advantage of the interconnectivity offered by the internet.

16.2 What is a LIMS?

The term Laboratory Information Management Systems or LIMS has come to mean different things to different types of laboratories. In a clinical or diagnostic setting, for example, LIMS are primarily concerned with the efficient transfer and interpretation of large volumes of instrument data to a report generation system. In the forensic laboratory, LIMS have evolved into line-of-business management systems that are expected to automate all aspects of forensic laboratory operations as they move toward and achieve ASCLD/LAB (American Society of Crime Laboratory Directors/Laboratory Accreditation Board) and ISO 17025 accreditation. For a forensic analyst, a LIMS must act as a filing system, a communications hub, a productivity tool, and a daily planner. The central mission of a forensic LIMS is therefore case management. In most cases, a forensic lab will purchase or build a LIMS around the principle of acquiring and organizing all of the necessary information to manage a case into a single, easy to use structure that meets all of the operational requirements. These can be summarized into several phases: Case submission, evidence management, evidence analysis and report generation, and laboratory management. Each of these areas require one or more sub-systems to effectively deal with the specific requirements.

Like any enterprise software system, LIMS will consist of the following major modules.

16.2.1 Data Storage

In order to effectively store all of the information required for case management, all LIMS should use a database management system. The requirements of any forensic data management system may be summarized into three areas:

Data security – the ability to prevent unauthorized access to information and the prevention of data loss due to system errors.
Efficiency – the ability to quickly store and retrieve information from storage so that users do not experience unacceptably long wait times while using the software.
Interoperability – the use of industry standards for data storage and retrieval such that information may be stored and retrieved without the need for proprietary tools or knowledge.

Typically, forensic information is stored in a desktop database management system such as Microsoft Access®, a Relational Database Management Server such as Microsoft SQL Server® or Oracle®, or text files such as XML. Desktop database management systems offer the advantages of being readily available, inexpensive to acquire and easy for non-programers to use, but have the disadvantage of not being able to efficiently handle the large volumes of data generated by the typical forensic laboratory. Additionally, they are generally not as secure as enterprise products, which is a major drawback considering the type of information in question. Text-based data storage such as XML is very easy to use, allows information to be transferred between almost any type of software application regardless of vendor or operating environment, but is even less secure than desktop database management systems. Relational database management servers are the most widely used LIMS database management system due to their high performance, data security features, and wide acceptance. While they require professional programers experienced in Structured Query Language to implement properly, and professional database administrators to manage, their clear superiority in the areas of data security and power make them the default choice for most modern LIMS systems.

16.2.2 Software Application

The bulk of the functionality of the LIMS is found in the software application. Best practices in software development usually dictate that this functionality is organized into business logic and user interface so that changes to the underlying business logic do not require dramatic changes to the users' experience and vice versa.

16.2.2.1 Business Logic

The goal of any good software application is to make the performance of a user's job function easier by and organizing required information, automating tedious and

repetitive tasks, and preventing mistakes. The processes and procedures developed to accomplish the forensic labs mission while maintaining consistency and quality are called business rules. Business logic is a programing term used to describe a body of code that encapsulates the rules that the software application enforces. Some examples of business logic specific to a forensic LIMS include these requirements:

- Evidence currently is in the possession of a transferring lab staff member before he or she can move it into a storage location
- A report has been reviewed before it can be finalized as a laboratory report
- Supporting documentation must be read before a result may be marked as having been reviewed

16.2.2.2 User Interface

The user interface portion of an application controls how the end-user actually interacts with the software. Any good user interface is ultimately a balancing act between the use of software conventions that are consistent with other applications that the user is likely to encounter in other areas, and the implementation of the functionality specific to the task at hand. Fortunately, mass-market operating systems such as Microsoft Windows®, Apple's Macintosh OS, and others include standard tools that make it easy for software developers to implement commonly used functions such as deletions, cut and paste, menu navigation, etc.

To summarize: the user interface will govern how the user interacts with the software, while the business logic ensures the fewest mistakes possible and the database makes sure that the information is securely stored and retrieved.

16.2.3 Categories of LIMS and How to Choose One

A forensic scientist is likely to encounter a number of different software systems during the course of a career. The "build or buy" decision is usually made early in the process of implementing a LIMS and has an effect on the downstream success of the software. With that in mind, it is important to note that there is no answer to the build or buy question that is universally correct for every forensic laboratory. The decision as to whether to purchase an existing system, develop a system with in-house resources, or hire a company to build the system will be influenced by a number of factors and the ultimate mission of the software.

Depending on requirements, there are three main approaches.

16.2.3.1 Commercial Off-The-Shelf

An application that has already been developed by a reputable vendor is usually referred to as "Commercial Off-The-Shelf" software or COTS. COTS applications

are usually the result of a substantial investment by the vendor based on the input of multiple customers and are licensed rather than sold, meaning that the laboratories investment buys the right to use the software in perpetuity, but specifically precludes the ownership of the intellectual property. COTS software vendors also normally provide a maintenance program that gives the laboratory access to software upgrades and technical support. As with any approach, COTS has advantages and disadvantages

Advantages:

1. COTS software usually encapsulates best practices developed in consultation with a large number of customer labs.
2. There is no lengthy development period and implementation can generally begin immediately.
3. The vendor usually enhances the software frequently in order to remain competitive and the costs of enhancements are shared by many customers.
4. The software is generally built with interoperability in mind allowing for easy access to the information.
5. Technical Support is readily available.

Disadvantages:

1. COTS software rarely conforms exactly to existing laboratory business processes and some changes in laboratory procedures may be required to use it.
2. Little or no control over the source code and subsequently, no absolute control over product features.

16.2.3.2 Custom Development LIMS

Frequently a lab will survey available products and determine that their requirements are not met by any of the existing COTS products. This generally results in the decision to develop a software application tailored to exactly what the laboratory needs. In the custom development scenario, the lab then hires a software development company to collect the laboratory's requirements and write an application that meets as many of them as the budget allows. The process is usually divided into requirements collection, design, development, testing, and commissioning. This process of "work-for-hire" is generally performed by the vendor on an hourly basis. While this is very expensive for the laboratory, it can result in an application tailored specifically to the current processes and procedures. The laboratory generally retains intellectual property rights to the software under this scenario.

Advantages:

1. Custom development usually results in the laboratory getting software that is exactly what they asked for and mirrors current laboratory practice and procedures.

2. The laboratory retains the intellectual property rights and has absolute control over the future direction of the software.

Disadvantages:

1. Custom software is usually very costly as all project risk is borne by the laboratory.
2. Education of the software development company is a substantial part of the development cost and can slow the initial phases of the project.
3. The laboratory must fund 100% of the cost of any future enhancement or defect correction.
4. Future application enhancements are at the mercy of future budgets.
5. The laboratory must provide or purchase application support infrastructure.

16.2.3.3 In-House Development LIMS

A third and surprisingly common option is internal development of the LIMS. Laboratories generally arrive at this option by the process of elimination: there is no product on the market that precisely matches the laboratory's requirements, yet there isn't enough of a budget to realistically consider having it developed outside of the laboratory. If there is a forensic scientist with computer skills, then very often the decision is taken to develop the application internally.
Advantages:

1. The laboratory can often get exactly the application they want without the high cost of custom development.
2. There is no learning curve for the developer as forensic scientists are presumably intimately familiar with the laboratory's requirements.

Disadvantages:

1. Software developed by forensic scientists may not be as architecturally sound as that developed by professional programers.
2. The programer/scientist may leave the staff, resulting in an orphaned product.
3. The laboratory suddenly has one less forensic scientist.

16.2.3.4 Which LIMS is Right for You?

As previously noted, no one of the above approaches is correct for all laboratories. In order to determine the correct approach, ask some of the following questions:

(a) Is the software intended to solve a problem specific to our laboratory?
(b) Does our laboratory have the expertise necessary to develop software and if so, is that expertise likely to remain with the laboratory?

(c) Does the laboratory intend to align processes and procedures with other laboratories or is our laboratories mission specifically different from the mainstream in ways that require specialized procedures?
(d) Is there a specific requirement to interface the LIMS with other commercial software?
(e) Is there budget to be able to complete a software development project once it has begun?
(f) How much LIMS support can the laboratory expect from the Information Technology Group?
(g) Do I trust the software vendor to remain in business and continue to enhance the software?

In most cases, the answers to these questions will quickly make the correct choice for your lab apparent.

16.3 Case Management

The primary mission of any effective software program is to streamline the functions that members of an organization have to perform in order to meet their mission objectives. How a software program meets that mission can be described in the following bullet points:

- Automation – rapid execution of calculations and procedures
- Record keeping – automatic storage and retrieval of information
- Rules Management – enforcement of the business rules governing forensic laboratory operations

Because forensic labs usually organize their workload by case, it is no surprise that most LIMS adopt that as the central organizing metaphor.

If the investigative case is the organizing principle of most LIMS software, then the case number is the primary index for information. The forensic LIMS effectively manages a database of cases and the information they contain. The way information enters the LIMS is invariably through some type of case creation process. The case number is assigned during the case creation process and most systems are flexible enough to be configured to follow the laboratories business rules for case number creation. Automatically assigning case-unique case numbers accurately is a key software function.

16.3.1 A Place for Everything

Once a case has been created within the LIMS, all subsequent forensic lab functions tend to add information to the database. This gradual accumulation of information is

a key feature of line of business (LOB) software applications and is what enables one of their key benefits: the reuse of information. Every piece of information entered into LIMS is available to the next process without reentry. This saves time and reduces errors. Most forensic LIMS software categorizes information as follows.

16.3.2 Case Summary Information

Case Summary Information is information that is applicable to the case as a whole.

16.3.2.1 Offenses

The Offenses category usually contains information about the alleged offenses that generated the forensic investigation. Offense information usually includes offense type, date and time, where the offense allegedly occurred, etc.

16.3.2.2 Individuals

The Individuals category usually contains biographical information about the case principles, such as suspects, victims, decedents, etc.

16.3.2.3 Evidence

The Evidence category usually contains information about the items submitted to the laboratory for forensic examination. This is covered in some detail later in the chapter.

16.3.2.4 Requests for Analysis

The Requests for Analysis category usually contains information about the type of work being requested on the items submitted. This is covered in some detail later in the chapter.

16.3.2.5 Case Documents

The Case Documents category usually contains all supporting documentation necessary to allow the analyst to testify in court.

16.4 Workload Management

16.4.1 The Multi-Disciplinary Forensic Lab

One of the key challenges for any software developer is the inherently multi-disciplinary nature of the forensic laboratory. If the mission of a forensic LIMS is to help analysts perform their work more efficiently and help manage the lab, then the software has to have an effective model for dealing with the differences in each discipline's requirements while measuring productivity consistently. One of the important requirements, then, is an application structure that generalizes the request for analysis lifecycle while providing customized modules to handle specific analyses.

16.4.1.1 The Request for Analysis Lifecycle

The request for forensic analysis lifecycle begins at the point where the laboratory receives a request from the customer to examine evidence in connection with an investigation. The request for analysis is either entered into the LIMS manually, or received electronically via an interface with a records management system. Once the request is entered, it becomes part of the laboratory's workload, and available for assignment. Based on the type of request entered into LIMS, the management can perform an assignment, moving it to an individual analyst's backlog. The analyst retrieves the evidence and starts work based on the procedures specific to that type of analysis. Once the analyst enters the results and drafts a report, that report is made available for review. Forensic labs usually perform both a technical review and an administrative review prior to releasing a report as part of their quality procedures, and then the report is made available to the customer. The following sections identify some of the areas where software can contribute to lab efficiency during this process.

16.4.1.2 Managing the Examination Process Across Disciplines

The generalized request for analysis lifecycle discussed in the previous section provides for the basis for a software application's ability to manage workload across disciplines. The fact that all examinations, regardless of type, basically go through the same steps, allows the software application to abstract the examinations and therefore to track requests as the basic unit of laboratory work. In order to be able to consistently manage the requests of different types, several software vendors use the concept of milestones. As each of the general tasks listed above are completed, the software records the date and time of completion along with the personnel who completed the task. This milestoning process achieves a couple of goals: it allows the system to record productivity information in a way that is consistent across different types of analysis while imposing the minimum overhead on the staff performing the work.

16.4.1.3 Request Entry

The process of recording that the laboratory received a request for analysis is the entry point for the software's workflow. From a software perspective, this represents both a problem and an opportunity. The data entry involved in accurately entering a request for analysis is usually more work than the manual process that it replaces, namely countersigning the laboratory request form during the receipt of evidence. It should be noted however that all of the information, once entered, is available to every subsequent laboratory process and never has to be entered again. In spite of the initial labor involved, this information reuse usually leads to much better accuracy and downstream efficiency. Furthermore, depending on the software, there is also the opportunity to import the data from other systems automatically – an option simply unavailable to a manual process. There are generally three main ways to get request information into any software system

1. Manual data entry – Data entry usually requires a dedicated operator to key in all of the request and evidence information, produce the necessary evidence labels and barcodes, and print a receipt for the submitting member's records. While time consuming and prone to create delays during the evidence submission process, this method does have the advantage of being possible to implement immediately with a minimum of IT involvement.
2. Case pre-logging – Many forensic LIMS provide a small software application that replaces the manual laboratory request form that submitting staff members use to initiate a laboratory request. In addition to providing a way for the laboratory to enforce certain business rules for the case submission process (such as making sure that required information is included), there is the obvious advantage in that the information can be imported to the LIMS, eliminating manual data entry. Pre-logging applications may be implemented either as standalone software or as web pages and may be deployed into customers' offices or operated as kiosks at evidence entry. In either scenario, pre-logging must be managed like any other application and may require some configuration and/or customization before it can be used effectively. In many agencies not affiliated with a law-enforcement agency, pre-logging represents the only viable method of obtaining request information electronically.
3. Application interface – Many laboratories function as units with organizations that already have either a records/investigations management system or a larger evidence management system. These systems represent an opportunity for an application-to-application interface that allows evidence and request information to move seamlessly from the RMS to LIMS and back again.

Regardless of the method used to enter a request, the information recorded should include at least the information listed in Table 16.1 and the software should automatically record the date and time that the request was entered or received for workflow purposes.

Table 16.1 Information entry

Submitting customer representative	Defines where the report should be sent and records workload generated by customer agencies
Analysis type	Records the type of analysis to be performed, determining backlog and workflow to be followed
Due date	Records any time requirements for the analysis and allows the lab to determine order of analysis
Evidence to be examined	Records which of the submitted items are to be examined
Requestor notes	Records any information to be passed from the customer to the lab staff concerning the analysis

16.4.1.4 Request Assignment

Once the request has been received and entered, the laboratory can start to realize some of the benefits of software automation. The LIMS can automatically group requests by examination type and quickly show an analyst or a unit supervisor a list of all currently unassigned work by discipline. The next step in the request workflow is to assign the examinations to an analyst or a group of analysts so that work can begin. Assignment is generally performed in one of two ways:

1. Batch assignment – An analyst or discipline supervisor accesses a screen showing all currently unassigned requests as well as a list of analysts with the qualifications to perform the work. A key advantage is that the software can also show the analysts' existing workloads to help with the assignment decision and provide a way to quickly perform assignments of many requests simultaneously.
2. Individual assignment – Requests are assigned one at a time, usually in response to a rush request or other extenuating circumstances.

This assignment process gives the analysts software tools with which to manage their workload as they now have a list of all work they are responsible for along with the associated information such as due dates and the evidence to be examined. Additionally, the LIMS notifies them of new assignments providing an opportunity to streamline communication and shorten the time required to process casework.

16.4.1.5 Analysis

While the forensic analysis is a single step in the overall request lifecycle, in reality it may represent the bulk of the work performed by the forensic laboratory. This step includes all of the analytical work necessary to generate conclusions as well as the collection of the documentation necessary to support them in court. If the LIMS is to be effective, it must provide the tools necessary to support the examiners while providing the efficiencies that are a hallmark of good software.

16.4.1.6 Workflow and Result Types

LIMS software can handle requests for any of the forensic disciplines the same way…right up until the analysis begins. The number of chapters in this book is a graphic illustration of the amount of variability that LIMS software must manage when attempting to provide a common automation platform for forensic analysis. It is helpful to divide these differences into two main categories:

1. Workflow – The processes and procedures that an analyst must go through in order to perform a forensic examination differ from one discipline to another. Where a firearms examination may consist of the observation and recording of a series of characteristics followed by a database search and a narrative description of findings, a toxicology examination will consist of sample preparation, followed by a screening test, that might in turn generate a confirmation test based on the results. Providing tools that are optimized to help analysts through their workflow with as few compromises as possible, is the challenge.
2. Results – They types of examinations on which analysts base their conclusions yield very different data from one discipline to another. The fields used to capture the optical density observations in a toxicology screen will be of no use to a document examiner. LIMS software must therefore provide data fields that are relevant to the examination type in order to be useful.

16.4.1.7 Supporting Variability in Examination and Result Types

LIMS software generally takes one of two approaches to solving the challenges of supporting the different disciplines: Analytical Modules or Customizable Service Definitions.

Analytical Modules

Analytical modules are series of software subsystems programmed specifically for each type of forensic discipline. When a LIMS administrator defines a type of service to be performed in the laboratory, he or she selects the analytical module to be used. As a software subsystem, the analytical module will follow the workflow specific for a particular discipline and present the analyst with screens that capture only the data relevant to that step in the analysis. The advantage of an analytical module is that it can be tailored specifically to the requirements of a particular discipline, which results in a very efficient process that requires few compromises by the analyst and very little configuration effort by the LIMS administrator. The primary drawbacks with analytical modules are that they dictate discipline-specific workflow to the laboratory and it requires a programer to support new or additional types of forensic analysis.

Customizable Service Definitions

Customizable service definitions require the LIMS software to provide a framework under which the LIMS administrator may define both a workflow specific to a service type as well as the screens necessary to capture the discipline-specific results. Developing the workflow requires that the administrator be able to specify the tasks that make up a forensic examination, the order in which they are to be performed, and the business rules that govern their behavior. The programing effort necessary to generate a tool with this flexibility is substantial and therefore customized service definition sometimes requires compromises on the part of the analyst. The primary advantage of customized service definitions is that they can support variability between examinations within a discipline, and that support for new types of analysis rarely requires programing.

16.4.1.8 Batch Processing vs. Single Analysis

The differences between disciplines can sometimes be so great that they result in a fairly fundamental difference in approach, and the forensic LIMS has to support both analysts that work on a single examination involving one or several items of evidence and batch analysis. Where contamination is a concern, or where the examination is generally not performed in high volume, analysts will typically perform a single request for analysis at a time. Generally the software should include an interface that allows the analyst to proceed through the analysis from beginning to end.

One of the areas where the LIMS can contribute to efficiency is in the area of batch processing. It is often possible for an analyst to perform the same process on a number of items simultaneously and make casework more efficient. In order to process items in batches, contamination concerns must be absent or managed by procedure, and the operation to be performed should be discrete and the same for every item. Batches can be created using the software to retrieve all items eligible for the operation according to the request for analysis ordered and the business rules they dictate, or the user can manually build a worklist by scanning item barcodes. Either method allows the analyst to process their casework more efficiently.

16.4.1.9 Instrument Interfaces

Once the user can create a batch of items to be examined, automatically importing the results from the instrumentation is an obvious next step: if processing case work in batches is more efficient, then importing the results from the instrument is more efficient still. Instrument interfaces can essentially be defined as the ability to eliminate the need for an analyst to enter information generated by one software process into another software process.

Bi-directional interfaces vs. result import – Instrument interfaces may be either unidirectional, where information flows from the instrument to the LIMS, or bi-directional, where sample information from the LIMS is used to set up the instrument run and results information from the instrument is imported into the LIMS for reporting.

Real-time interface vs. file import – Instrument interfaces can be divided into real-time, where the LIMS establishes a protocol driven conversation with the instrument and can control it in real time, and store and forward, where LIMS and instrument information are exported to flat ASCII files and then subsequently imported.

16.4.1.10 Report Drafting

Without automation, the production of the laboratory report or certificate of analysis is a labor-intensive process of drafting, proofreading, redrafting, and review, with each step and correction causing the report or be recreated. The laboratory report is therefore one of the big payoffs when it comes to laboratory automation software. Using standard database merge technology and a reporting tool such as Crystal Reports or Microsoft Word, the process of creating a laboratory report based on information already in the system becomes as simple as the push of a button. Of course, getting the software to the point where a user can instantly produce a laboratory report takes some expertise with the reporting tool and usually a not insignificant amount of configuration to get the report template exactly right, but the downstream time savings pay back the effort many times. The key advantages to using a LIMS in concert with a report generator may be summarized as follows:

1. Information reuse – Information entered during case entry, analysis, or any of the other processes completed prior to reporting is available for reuse with no further data entry effort from the user. This has the additional benefit of eliminating a potential source of data entry errors.
2. Consistency – The use of a report template can ensure that all reports produced by the laboratory, regardless of analyst or department, have a consistent and professional look and feel.
3. Speed – Most modern reporting tools can merge a template with data almost instantly, making it possible to print large batches of reports in a short time.

As powerful as this technology is for creating reports is, at the point that a report has been reviewed and released, it instantly becomes a liability for the laboratory because any further changes to the case information would result in the production of a report that may be subtly (or not so subtly) different from the one that was sent to the customer. In order to prevent changes to a report from accidently being included in a previously released report, most forensic LIMS software converts the report from a dynamically generated report to a static document type such as Adobe Acrobat at the point all of the reviews are completed.

16.4.1.11 Technical and Administrative Reviews

While the Technical and Administrative reviews are two very definitely discreet steps that reports must go through in a laboratory, from a software point of view, there are no significant differences between them, other than the order in which they occur. We will therefore discuss some of the implications of automating these two steps as though they were the same.

The review process is part of the laboratory's quality management and ensures that each report is reviewed at least twice: once for technical content and once again for typographic errors, etc., before they are released. Reviews are typically assigned to a staff member, performed, and result in either the acceptance of rejection of a report. These review tasks may potentially be performed a number of times, depending on how many reviews are necessary to produce an error-free report. Once the review process is automated, it becomes possible to assign, perform, and complete the reviews online. Notification models fall into two categories:

1. "Push Notification" – The software actively notifies interested parties of system events according to business rules established by the LIMS administrator.
2. "Pull notifications" – The user periodically interrogates the software by producing worklists of information that meets certain criteria.

In the case of work assignment notification, a system that sends an e-mail to the analyst is using push notification and a system where the analyst is provided with a dynamically updated to-do list is an example of pull notification. Ideally, a completely developed software system should provide both types of notification in order to support the individual laboratory's procedures.

Notifications are the key benefit that software brings to the review process. LIMS users are notified (using either push or pull) when a review is assigned to them and when a review of their work results in the rejection of a report. The reduction in the time to notification is a key tool in speeding up the workflow cycle.

16.4.1.12 Report Delivery

Report Delivery is the final step in the lifecycle of a request for analysis and the LIMS ability to produce and retain an electronic version of the report makes it possible to deliver reports several of different ways:

- Paper reports – It is of course, still possible to print reports on paper, stuff them in envelopes, and mail them to the recipient. Although this is a well-understood process, it does not leverage the advantages of a computer system very well.
- Electronic reports – All of the established forensic LIMS products are capable of producing and storing laboratory reports as electronic documents in formats such as Microsoft Word and Adobe Acrobat and this makes it easy to deliver them electronically. Delivery of electronic reports is usually via e-mail, on a web site, or delivered by web service.

- Report data transfer – Another opportunity that LIMS software presents is the ability to deliver not only the report document, but the ability to transfer report findings as data elements that can be imported into other law enforcement applications. This approach makes the storage and retrieval of key report data element easier than having to parse it out of a report document.

16.5 Evidence Management

Evidence Management is a key part of forensic laboratory operations, and as such forms a major part of the functionality of any good forensic LIMS system. While evidence handling may seem to be an operation so fundamental to the forensic laboratory that all software would look the same, the truth is that the implementation differs tremendously from product to product. Some LIMS packages are evidence centric, where laboratory results are treated as a property of an evidence item, while others are request centric, where the forensic request is the primary focus. Whichever method a LIMS uses, it has to account for a many-to-many relationship between the forensic request and the items of evidence; the software has to allow an item of evidence to appear on more than one report and a report needs to be able to include more than one item of evidence.

16.5.1 The Evidence Lifecycle

In order to understand the opportunities and issues that software present the for the laboratory's evidence staff, it is useful to review the evidence lifecycle. In most laboratories, evidence is received at the laboratory and the necessary identifying numbers and labels produced. After the receipt process is complete and the chain-of-custody initiated, the evidence will be stored pending analysis. Once the work plan for the evidence is identified, the analyst will transfer the evidence out of storage and into their custody to perform the examination. Once the work involving the item is complete, the analyst will either transfer the evidence back into storage or transfer it to whomever is to perform the next examination. The laboratory's evidence control staff monitors items to make sure that all examinations have been performed and then they dispose of the evidence by destroying it, transferring it for archival storage, or returning it to the customer agency. While evidence control is a process that is important to all justice practitioners, forensic labs have an additional requirement that is often not necessary elsewhere: the requirement that evidence be sampled, and in many cases sub-sampled, during the course of analysis. The movements of samples and sub-samples must be documented like any other item of evidence.

16.5.2 What is Chain of Custody to a Computer?

In its most basic form, the chain of custody for an item of evidence is the documentation that demonstrated that the laboratory was at all times aware of the individuals who handled the evidence and the conditions under which it was handled and stored. This has obvious implications for the forensic laboratory when it comes time to testify to the likelihood of contamination and particularly to the issue of transference. For the vast majority of forensic LIMS found today, the implementation of the chain-of-custody functionality is achieved one of two ways:

(a) Evidence receipt history – The chain of custody consists of a chronologically ordered list of individuals or storage locations that have received the evidence and the date and time of receipt.
(b) Z-order chain – The chain consists of a chronologically ordered list of transfer records that include the source of the evidence, the individuals or storage locations that have received the evidence, and the date and time of receipt. The requirement that each transaction's source be the same as the previous transactions destination give these custody report the characteristic "Z" flow that gives this method it's name.

In either method, the entire history of every movement of every item of evidence can be reconstructed by looking at the list of transactions associated with it.

16.5.3 Recording Evidence Transfers

The accuracy and, therefore, the value of the chain of custody is in the granularity of the transactions that are entered into the system. The easier the software makes it to record evidence movement, the higher the likelihood of an accurate and unimpeachable chain of custody.

Software automation offers several key opportunities to a forensic laboratory when it comes to the chain of custody:

1. Speed – Using barcodes or Radio Frequency Identification (RFID), evidence can be efficiently transferred either singly or in batches.
2. Integrated inventory control – The ability to quickly determine both where an item is currently stored and to produce a list of all items in a particular storage location instantly.
3. Audit trail – The ability to document on all changes to the information that makes up the chain of custody.
4. Error detection and prevention – The ability to automatically compare the source of the evidence in the transaction to the last known location in the database, providing early detection and correction of potential breaks in the chain.
5. Given that electronic data is quite easy to change, forensic LIMS software must provide some way for analysts to authenticate each transaction in the chain of

custody to provide confidence in the integrity of the information that the LIMS contains. Most forensic LIMS solve this in either or both of the following ways:

(a) Electronic signatures – A combination of a physical key (such as a barcode or keycard) and a logical key (such as a PIN) that, together, uniquely identify the user involved in the transaction.
(b) Digital signatures – An encryption algorithm that uses a public key available to the system and a private key available only to the user that, together, generate an encrypted value to uniquely identify the users associated with an individual transaction.

16.5.3.1 Barcodes and Radio Frequency Identification

Barcodes and RFID represent an interface of sorts between the LIMS software and the physical items of evidence. Data or identifying numbers (such as evidence or user IDs) can be physically represented by a series of blocks or lines printed onto a label in a format that can be read by the LIMS software using CCD or laser barcode scanners. The software functionality that ensures that the software chain of custody is easy and therefore accurate relies heavily on the ability to rapidly identify the evidence involved in the transaction; barcodes and RFID tags provide this ability. Most forensic LIMS software take this idea one step further by allowing for the use of barcodes to identify all of the entities involved in a transaction, including storage locations, laboratory staff members, and individuals outside the laboratory that may become involved in the chain. The ability to scan a barcode identifying the source (relinquishing party or location), destination (receiving party or location), and the barcodes of all items to be transferred is a key efficiency that forensic LIMS software provides. There are two categories of barcodes in general use in forensic LIMS:

(a) Linear (1D) – Linear or one-dimensional (1D) barcodes represent information in a series of thick and thin lines printed along a horizontal axis. While the data they contain is highly resistant to physical damage, linear barcodes have the disadvantage that the amount of information they contain can be increased only by increasing the width of the barcode. At a certain point, the barcode becomes too wide to scan; therefore, the amount of data they can contain is limited.
(b) Matrix (2D) – Matrix or two-dimensional (2D) barcodes represent information by a series of thin and thick lines or dots printed along both a horizontal and a vertical axis. Matrix barcodes can contain more information than linear barcodes by an order of magnitude, but are much more susceptible to physical damage.

RFID tags are another identification technology that is seeing increased use in the forensic lab based on their ability to actually transmit data wirelessly to scanners and identify items to the LIMS software. RFID tags fall into two categories:

(a) Active RFID – Tags that contain a power source, data storage, and a radio transmitter that broadcast information continuously or at close intervals to receivers and allow for real-time logging of a tag's location. Active RFID tags have a relatively high per unit cost and therefore are generally used for items of high value.

(b) Passive RFID – Tags that contain data and a radio transmitter that are activated by the scanning process. Passive RFID tags function much like barcodes in that they yield data only when interrogated, but can transmit wirelessly. The increased acceptance of passive RFID is lowering the per unit cost and making them a viable evidence tracking option for the laboratory.

16.5.4 Managing Evidence Inventories

It is no accident that some of the first large-scale commercial applications of computing were primarily developed to deal with the issues surrounding inventory control, because the complexity of the coordinated transactions required (decreasing the count of a widget in one count while simultaneously increasing another) lends itself to the kind of lightning-fast calculations at which computers excel. The forensic LIMS brings the very same advantages to the laboratory when it comes to the management of evidence inventory. For every chain-of-custody transaction, the following operations have to be performed:

- Update the current location of the item of evidence
- Remove the item of evidence from list of items in the custody of the source
- Add the item of evidence to the list of items in the custody of the destination
- Update the item's history to reflect that it was moved and when it was moved and record any observations about the process
- Authenticate each of the users involved in the transfer of the evidence
- Update the audit trail to record all changes to the database

16.5.4.1 The Inventory Process

While chain of custody management is a signature process of the forensic laboratory, the inventory management function does not begin and end there. Most evidence control staff face many of the same challenges that other warehousing operators face when it comes to dealing with large numbers of items. Commercial inventory management is concerned with keeping the necessary items in storage for the minimum amount of time before they are sold to reduce costs. Evidence custodians wish to free up the laboratories storage space as quickly as possible by disposing of evidence as soon as possible. The two inventory processes have the same goals, albeit for different reasons. That being the case, the general process of inventory management is divided into the following activities.

16.5.4.2 Inflow

In a forensic LIMS, the inflow of inventory is represented by the login process. Like any other inventory application, the accuracy of all downstream operations relies on the correct identification of the items being received. It is important therefore that

incoming evidence be correctly identified as being associated with a new case, a case that has been previously entered, or indeed is an item that has been previously logged. However categorized, the receipt process and its associated custody transaction adds the evidence to the list of items that must be managed in inventory. While the process of receiving the evidence, associating it with the correct case, printing the barcode labels, and recording the receipt are all made more efficient by software automation, all of the forgoing could be achieved with a paper-based system. There is however a key opportunity that the forensic LIMS, or, for that matter, any other software-based inventory control system offers that cannot be duplicated by a manual system: the ability to update the inventory management system with large quantities of data instantly using data import. Most forensic LIMS products feature some type of case import utility, either file based or from a web page distributed via the internet.

16.5.4.3 Storage

Once the items have been received into the laboratory, the next phase involves storing them until they are needed. While the nature of the costs associated with storing items for long periods differ between forensic laboratory and commercial inventory applications, the goal of storing them for the shortest time possible is the same. In the laboratory, the amount of time that an item spends on the shelf prior to analysis adds directly to the turnaround time, so most forensic LIMS products will provide tools that inform the users of exactly what evidence remains to be analyzed and where that evidence is located.

16.5.4.4 Location Audits, Evidence Reconciliations

Almost everyone has at one time or another seen the sign "Closed for Inventory" in a store window and wondered just how much that actually costs the business. Like a retail operation, forensic laboratories are also required to periodically audit their evidence storage locations to verify that the current state of their recordkeeping is correct. Similarly, the audit function comes at a cost. A forensic LIMS that provides a way to quickly scan all of the items in a storage location and then use the software to quickly produce a list of missing or mistakenly stored items reduces costs by shortening the time that the evidence is unavailable and reducing the number of staff hours required to perform the audit. Most forensic LIMS products provide this capability by offering an Evidence Reconciliation feature that allows custodians to scan items using a handheld device, upload the information into the LIMS, and produce the reconciliation report.

16.5.4.5 Outflow

The *clearance time* or time it takes to move evidence in, through, and then out of the laboratory is an important metric in managing backlog. The faster evidence

moves through the laboratory, the faster the work gets done and evidence storage space becomes available for new items. Forensic LIMS products contribute to reductions in clearance time in the following areas:

- Intended disposition – Capturing the intended disposition at the time evidence is received means that the software can categorize items without the need for storage while the analyst researches where the evidence is supposed to go.
- Evidence requests – The ability for an analyst to transmit a request for evidence to be examined to the custodians who manage storage through the LIMS allows those custodians to efficiently collect and prepare evidence in advance of the actual transaction. This reduces lengthy wait times at the evidence windows.
- Evidence disposition reports – Perhaps the key piece of LIMS functionality that contributes to lower clearance times is the software's ability to instantly compile lists of evidence where the work has been completed, and organize them by disposition type. This capability means that custodians can return or destroy evidence at the earliest possible opportunity.

The final step in outflow is the disposition and it will usually take one of three general forms

(a) Return to submitter
(b) Destruction
(c) Archival storage

Whatever the final disposition is, LIMS allows for all of the operations necessary to remove the item from the laboratory's inventory, collect the necessary signatures, and update the evidence history simultaneously in the final chain of custody transaction.

16.5.4.6 Evidence Hierarchies

Before we leave the subject of evidence management, it is worth discussing another (in addition to chain of custody) of the major ways in which evidence inventory management differs from a commercial inventory system in the forensic lab. While true of some laboratories in general, forensic laboratories in particular have to deal with the issue of evidence hierarchies. Documentation of relationships between items as they are processed by the laboratory is particularly significant in matters of individualization due to source and contamination concerns.

16.5.4.7 Evidence Packaging and Containers

For practical reasons, evidence being transported to the laboratory, either by hand or via commercial carrier, is usually packaged together. Every law enforcement agency has strict protocols governing the packaging of evidence that are designed

to prevent contamination and, for the most part, they are extremely effective. It usually falls to the forensic analyst however, to testify on the issue of potential contamination, so it is vitally important that the forensic LIMS be able to document not only how an individual item was packaged, but a complete history of how it was packaged while in the proximity of other evidence. Many forensic LIMS products use an evidence hierarchy to demonstrate these container relationships. For example, in a sexual assault case, it is common for several items of the victims clothing to be submitted together in a paper bag. Each of the articles of clothing, when unpacked, will be recorded as a separate item and will proceed separately for analysis. Similarly, the laboratory will frequently also receive a subject's clothing packaged in the same manner. The LIMS has to be able to document through the chain of custody and container relationships that laboratory evidence protocols were followed and there was no possibility of cross contamination.

16.5.5 Evidence Genealogy

Forensic analysts will frequently sample or subdivide evidence during the course of analysis in order to perform multiple tests or to isolate a particular item of interest. To extend the example above, once an article of clothing has been taken from the bag, microscopic examination may reveal a hair, which would be removed from the article and then recorded as a separate item in LIMS. It is important that the LIMS should record this as a separate item, because the hair will probably be passed to a different analyst and will therefore have its own chain of custody. It is important however that the LIMS be able to record that the hair was derived from the victim's clothing for purposes of individualization. Most forensic LIMS use a parent/child metaphor to describe these relationships and display them using some sort of tree view.

The forensic LIMS offers the laboratory several efficiencies when dealing with these hierarchical relationships, namely:

- The ability to record and display complex evidence relationships with the minimum of effort
- Documentation that reinforces the analyst's testimony in a single report
- The ability to easily transfer evidence in batches by scanning the barcode on an outer container

16.6 Document Management

For most forensic laboratories, the laboratory report is its ultimate product. In certain jurisdictions and for certain types of analysis, the report is sufficient, however, most analysts will find themselves testifying in court as to the accuracy of their

conclusions. The documentation necessary to support testimony therefore invariably becomes an integral part of any reasonably complete forensic LIMS product. Supporting documentation is usually divided into case documentation that allows for peer review of the actual findings, and quality management documentation that verifies the validity of the findings.

16.6.1 Case Documentation

In general, the supporting case documentation is concerned with the justification of conclusions drawn during a particular examination. The assumption is that two similarly qualified analysts performing the same examination on an item of evidence will reach the same conclusion. In order to provide the tools to verify this, the LIMS must keep track of every observation, every instrument results, every assumption made, etc. during the course of the analysis. Just as importantly, a reviewer needs to be able to retrieve these for examination quickly and in an organized fashion. The diversity in the nature of the information that must be kept means that the software must be flexible in the way documentation is tracked. Most software developers therefore provide at least the following three methods:

- Data records – Text or numeric data either entered by an analyst or imported from an instrument that can be recorded as fields in a database. The primary advantages of entering this data into the application are the ability to report on the information the data records contain by constructing database reports. Some examples include staff communications logs, numerical instrument results, examination notes, reviewer notes, etc.
- Digital images – Images from digital cameras or scanned photographs that provide additional documentation in support of visual observations. Examples include crime scene photographs, micrographs, and images showing the state of evidence packaging.
- "Digital paper" – Primarily documents that have been printed or scanned into a software format. Although digital paper is also technically a digital image, it tends to be different from images in that the file supports a multi-page format that allows for entire documents to be stored as a single file while preserving the ability to page back and forth through the document. Some examples of digital paper include multi-page scanned documents and instrument output that combines text and graphics. Indeed the ability to print the output from any of the many instrument controllers to a format that can be stored and read in a consistent way is a key enabling technology in LIMS.
- Attached files – Files that require other software to load and read. Many laboratories use spreadsheets or word processors to record observations so the LIMS software needs to be able to store and organize the files in a way that makes sense for the case.

16.6.2 Quality Management Documentation

Quality Management is an integral part life in today's forensic laboratories. With most organizations already accredited under ASCLD/LAB or ISO17025 and the remainder pursuing such accreditations, forensic LIMS products must provide quality management tools. The process of continual improvement relies heavily on documentation to establish baselines, track the results of management decisions, and demonstrate conformance with procedures. The goal of quality management documentation is to increase confidence in the veracity of the laboratory report (the lab's product) by showing conformance with procedure. While there are entire applications devoted just to tracking Quality systems, a forensic LIMS must track at least the following:

1. Standard operating procedures – The procedures developed to ensure consistency and thoroughness in the analysis of an item of evidence. Most forensic LIMS offer a procedure library function that will record the SOP and its associated work instructions, as well as the current and prior versions. As a filing system, the LIMS offers the laboratory the chance to record not only which SOP was used during an analysis, but also which version. Should a problem arise whereby prior work needs to be revisited based on procedural issues, the laboratory can use the LIMS to quickly identify all evidence that was examined using the problematic SOP.
2. Instrument maintenance history – The periodic maintenance and calibration analytical instruments require in order to measure accurately, and documentation that this maintenance was performed, are of fundamental importance to the integrity of the forensic analysis. Integrating the maintenance history with results collection, LIMS makes it easier to pull up the maintenance history associated with a particular report. Additionally, LIMS can enforce business rules by preventing the use of results generated by an instrument overdue for maintenance.
3. Staff qualifications – These records indicate that a staff member has developed the required knowledge and proficiencies to be able to perform an analysis or procedure. Staff members must undergo periodic education and review to remain qualified to perform laboratory analysis. If the LIMS can record that an analyst has received the required training and passed the necessary proficiency tests, then it can also enforce business rules that help with work assignment by scoping assignments only to qualified analysts.
4. Report reviews – Documentation that a report has been reviewed for accuracy both by peers and by laboratory management.

16.7 Queries and Reports

The efficiencies that software gives in the area of speed and the enforcement of business rules are important, but perhaps just as important is software's ability to retrieve selected information in an organized way to support management decisions. Before

software, a simple report giving the number of requests of a certain type required hours of work poring through filing cabinets to produce. With software and some advance configuration effort, such reports can be produced almost instantly and with little or no effort. LIMS provides access to all of the operational information compiled during the course of laboratory operations by providing two types of reporting capability: ad hoc reporting and management reports. Reporting engines vary widely, but one of the most commonly used in forensic LIMS is Crystal Reports® by Business Objects.

16.7.1 Ad Hoc Queries

It is not at all uncommon for lab administrators to receive a request from a superior for information about their operations that is not part of the usual management metrics. Such a request is usually accompanied by the question "how fast can you get me that information?" Ad hoc reporting is the ability to quickly construct a query and return results without the need to work through a full-blown reporting tool like Crystal Reports. As long as the question being asked is clear and the information is recorded in the LIMS database, then ad hoc reports can give good results. Ad hoc reports are generally not good for advanced data analysis or reports with complex formatting rules.

16.7.2 Management Reports

Management reports generally focus on a fixed set of key performance indicators that provide laboratory management with information about productivity and performance trends over a set period. As such, while it is theoretically possible to run ad hoc queries to retrieve this information, a report template usually provides a much higher level of accuracy and periodic consistency. With a little planning, a report template can be constructed in such a way as to accept parameters that allow the scope to change. For example, a report that lists all instrument maintenance records chronologically may be constructed to accept a parameter that allows the user to specify which instruments and what time period the report should include.

16.7.3 Caseload Statistics

As a line-of-business application, the bulk of the forensic LIMS reports will be concerned with caseload statistics. A report that measures the average time taken to complete a forensic analysis is a useful tool, but it becomes even more useful when it can compare that same measurement for different disciplines over different time periods. Management reports can show the current state of operations as well as historical trends that may allow extrapolations for future workloads. Some categories of management reports are shown in Table 16.2.

Table 16.2 Typical reporting categories

Report	Description
Caseload statistics	Shows the average turnaround time or time taken to complete a forensic analysis. These reports may be scoped by time period and grouped by discipline, analyst, and service type
Forensic result statistics	Shows the number of certain types of results, findings, or conclusions. These reports may be scoped by time period and grouped by discipline, analyst, and service type
Evidence reports	Shows the number of items received and provides information to help manage them. Some example reports include evidence count by type, evidence ready for disposition, storage inventory listings, and evidence reconciliation
Staff reports	Shows the staff, their qualifications, and training histories as well as demographic and personnel information

16.8 System Management

System management is an important aspect of the forensic LIMS. Although the processes and procedures governing the actual forensic analysis of evidence are moving closer to standardization, no two laboratories have exactly the same business rules for case management. A forensic LIMS therefore has to provide a great deal of flexibility in a number of different areas.

16.8.1 System Administration

The system administration tools of a forensic LIMS are designed to allow for both the initial and ongoing configuration required to use a complex software application. In an ideal world, successful software would provide administration tools that allow a high-level user to make any necessary adjustments to the way the application works without any additional programing being required. In practice this is never achieved of course and software developers must continually enhance the application to meet changing circumstances and requirements. The degree to which an application can approach this goal however, will determine the success of the implementation. Some of the most important areas that should be addressed in system administration are listed below:

Access control – The ability to create user accounts with associated role-based security permissions that control access to LIMS information and functionality.

System configuration – The ability to populate the application with data representative of the forensic laboratory such as branch laboratory locations, evidence storage locations, types of services provided, etc.

Document template definition – The creation of templates that will be merged with case data during use to create application documents such as forensic reports, management reports, barcode labels, etc.

System maintenance – The ability to maintain the system in order to meet changing circumstances, such as the inactivation of ex-staff members, creating new versions of standard operating procedures, etc.

16.8.2 Database Administration

While not technically part of the forensic LIMS application per se, the database is nevertheless a critical component to its correct function. Entire books have been written on database maintenance designed to allow administrators to squeeze the last increment of efficiency out of the system and as such, it is out of the scope of this chapter. At its most basic, database administration should include making backups or archival copies of the data on a schedule that is consistent with the amount of rework that the laboratory is willing to do in the event of failure. Backups are generally of two types: full backup where the entire database is saved and incremental backups where only the data since the last backup is saved. A good and commonly implemented schedule used in many forensic laboratories today is to perform a full backup daily and an incremental backup hourly. This ensures that, in the event of damage to the active database, no more than an hour's worth of work will ever be lost. It is also important to monitor disk space so that the database will not be forced to shut down for lack of storage.

16.9 Systems Integration

While the nature of the information in a forensic LIMS tends to limit the number of users that have access, there is a growing trend toward systems integration. Most of the information that a forensic LIMS requires to initiate a case has already been entered into software elsewhere in the criminal justice system and the forensic results and laboratory report it produces are often merged into other records management systems. The primary benefit that software integration brings is the reuse of information available in other systems, which in turn reduces data entry and reduces transcription errors. There are several opportunities for systems integration in a forensic LIMS.

1. Case origination – The process of starting a case in LIMS. Most of the evidence submitted to a forensic laboratory for analysis has already been a cataloged in an evidence system along with the supporting case information. Data such as evidence descriptions, services requested, case principles, and investigating officer can all be transferred, either over a network or by importing a file.
2. Instrument integration – The automatic export of sample information and import of results from the instruments used to perform the analysis. The LIMS contains

all of the sample data necessary to set up an instrument run, and, having done that, then match up results imported from the instrument.
3. Forensic database integration – The ability to add forensic results to national databases. There are a number of national databases designed to act as repositories against which forensic data can be searched. DNA profiles generated and stored in LIMS can be exported to the Combined DNA Indexing System (CODIS) and Fingerprint Data can be exported to one of the many Automated Fingerprint Identification Systems (AFIS).
4. Status/results reporting.

The benefits of LIMS software have been well established over the last decade and the efficiencies they have brought have allowed many forensic labs to deal with the elevated caseloads subty. The scope of the forensic LIMS has steadily increased to encompass all areas of forensic laboratory operation.

The forensic LIMS marketplace today is a robust one that has a number of established companies as well as new entrants. In step with their customers, most software vendors have chosen to adhere to the strict quality standards of ISO9001:2000 and continue to add rigor to the software development process. The competitive nature of the marketplace should ensure that forensic laboratories continue to have access to the latest software advances.

16.10 Questions

1. Q: What are the two layers of a software application that, together with data storage, make up an enterprise application like a forensic LIMS?
   A: Business logic and user interface
2. Q: Name two categories of LIMS software.
   A: Any two of commercial off-the-shelf LIMS, custom development LIMS, or in-house development LIMS.
3. Q: How does the multi-disciplinary nature of the forensic laboratory challenge developers of forensic LIMS?
   A: The software must accommodate the different processes used during analysis while measuring request-for-analysis metrics in a consistent way.
4. Q: What are the three major benefits of using the LIMS report generation software to create the laboratory report?
   A: Information reuse, consistency, and speed.
5. Q: What two additional features must the evidence management module in a forensic LIMS have that are not necessary in other inventory control programs?
   A: Support for chain of custody and evidence hierarchies.
6. Q: What are the two major categories of documents that a forensic LIMS must store?
   A: Supporting case documentation and quality management documentation.

7. Q: If an analyst wished to know how many items of evidence contained the words "red shoelace" in their description to cross-reference information in a current case, would it be better to use an ad hoc query or a report template?
   A: An ad hoc query as it is unlikely that this will be information that is needed on a regular basis.

16.11 About the Author

Simon Key is the President of JusticeTrax, Inc. and has spent the last 13 years developing and selling forensic case management systems. During that time, Simon has traveled extensively to more than 200 forensic laboratories in North America, Europe, Asia, and Africa, learning about the issues they face and how software can help solve them.

Chapter 17
Forensic Entomology

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Contents

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17.1 Introduction

Entomology in the strict sense is the study of insects. Insects are invertebrate animals in the Phylum *Arthropoda* and contained in the superclass *Hexapoda.* This superclass is variously divided by different authors but the most common division is into two classes: *Entognatha* and *Insecta*. The vast majority of the species are found in the class *Insecta*. As a group, the *Hexapoda*, commonly all referred to as "insects," are probably the single most successful and numerous animals on earth. To date, there have been approximately 900,000 species described, and it is estimated that this number reflects only a small portion of the actual species in existence. At present, there are over three times as many insect species described as for all other groups of animals combined. By way of example, in the Nearactic region alone, there are an estimated 125,000–150,000 known species of insects. By contrast, there are only approximately 3,200 species of mammals described worldwide.

Insects are found in virtually every habitat imaginable, with the exception of the depths of the oceans, and show a wide variety of adaptations to different habitats and food resources. While the vast majority of species of insects is not directly involved with human activities and are a significant part of the world's ecosystems, a number of species are in direct competition with man for food resources and cause millions of dollars loss to food crops on an annual basis. Still others are vectors of pathogens causing human disease or are themselves the etiologic agents. The diseases transmitted are among the most serious and include epidemic diseases such as Bubonic Plague and Yellow Fever. Additionally, some species of insects may cause harm to humans and animals through their bites and stings.

Insects are also beneficial. They serve as pollinators of plants, including those used by man for food, are parasites and predators of a number of species of organisms considered pests due to their activities, and are the major recyclers of dead plant and animal materials in the ecosystem. Additionally, they produce many products used by humans, including bees' wax, honey, and silk. Insects have been used extensively in scientific studies and have contributed to many advances in human and animal health. In many parts of the world, insects are used as food and are a significant source of protein. Without insects, the world as we know it would cease to exist.

Insects include well-known animals, including the cockroaches, flies, beetle, butterflies, grasshoppers, termites, ants, and bees. As adults, all have a body with an external skeleton (exoskeleton) that is divided into three major sections: head, thorax, and abdomen. The adults have three pairs of jointed legs that are located on the thorax and most species have one or two pairs of wings. The head has a pair of antennae and most species also have a pair of large compound eyes.

The development of an insect involves a series of different, distinct stages, termed metamorphosis. The majority of insects lay eggs, although some species, such as the Flesh Flies, produce live young. In some species, the eggs hatch into immature forms that are quite similar to the adults but lack wings. In these, the wings develop, showing as pads on the external surface of the body. This type of development is often termed an Incomplete Metamorphosis and several different types are recognized. In most insects, the eggs hatch into an

immature form that does not at all resemble the adult. These immatures, called larvae, pass through a series of stages, termed instars, until they have reached a maximum size. At that point, the larvae enter an inactive stage called a pupa, often passed within a protective casing. During the pupal stage, the insect essentially undergoes a second embryology and the winged adult insect emerges. This type of metamorphosis is termed Holometabolous or Complete Metamorphosis. The majority of insects involved in forensic entomology show Holometabolous Metamorphosis.

The earliest recorded case of the use of insects in legal investigations comes to us from thirteenth century China. In a book written by the Chinese death investigator, Sung Ts'u, titled "The Washing Away of Wrongs," a case is detailed of a murder in a village. The victim had been slashed to death and the wounds were reminiscent of sickle wounds. Because questioning of villagers and other investigative methods were not yielding any results, the magistrate had all of the villagers assemble, each bringing his own sickle. In the summer sun, flies congregated on one sickle that still had fragments of tissue and blood present. Confronted with this, the owner confessed to the crime. While this, at first glance, may seem relatively basic, it does indicate that the magistrate had considerable knowledge of the behavior and activity patterns of flies. Following this beginning, use of insects in criminal investigations was spasmodic at best, with records appearing of cases in Europe during the mid-1800s and later in the United States and England. Generally these were accounts of a specific case and, once the case was solved, the entomology faded into the background. It was not until the mid-1980s that forensic entomology began to develop as a distinct discipline in the United States, and a core of researchers began to meet routinely to discuss cases and exchange information. This eventually led to the formation of the American Board of Forensic Entomology and, later, the North American Association of Forensic Entomologists. An account of the recent development of forensic entomology in the United States is given by Goff [9].

In the broadest sense, forensic entomology is concerned with all cases in which insects become evidence in legal proceedings. From a practical standpoint, it is subdivided into three subdisciplines: stored product/urban entomology; structural entomology; and medicolegal or medicocriminal entomology. Of these, stored product/urban and structural entomology are typically involved in civil litigation, while medicolegal entomology involves situations in which a crime has been committed.

An example of a *stored product situation* would be a case of insect contamination of a box of breakfast cereal. The box is purchased at a local market and, when opened, it is found to contain insects along with the cereal, occasionally, more insects than cereal. The consumer, assuming they are not entomologists, does not like this and returns the box to the market for a refund. If enough boxes are returned, the market owner seeks to recoup his losses from his supplier. The entomologist is brought in to determine the type of insect involved, what was not done to prevent the infestation, and possibly assist in assigning blame. The bottom line in this situation is money and often involves significant amounts past simple replacement of the product. Typically, the entomologist is brought into the case relatively late in the investigation.

The situation in *structural entomology* is similar, but the problem involved is insect damage to human dwellings. An excellent example of this can be found in termite damage to houses. Typically, in areas known to have termite problems, preventive measures are taken during the construction of a house. These can take the form of physical or chemical barriers to prevent termites from invading and destroying the structure. Some of these are permanent barriers, while others, such as chemical ground treatments, may have a limited period of effectiveness and must be repeated on a routine basis. If the barriers fail and termites invade the structure, the entomologist is brought in to determine what went wrong and, again, assist in assigning blame. The ultimate solution again is financial.

In *medicolegal* or *medicocriminal entomology*, a crime has been committed and monetary considerations are generally absent. Unlike the previous subdivisions, the entomologist is typically contacted and involved in the investigation during the early stages, frequently working in cooperation with police and/or medical examiners. Insects in this context can be of assistance in several ways, including estimations of the period of time since death, determining postmortem movement of a body, assisting in assessment of wounds present on the body, characterization of the crime scene, as alternate specimens for toxicological analyses, as alternate sources of DNA, and in evaluation of cases of abuse and/or neglect of children and the elderly. Each of these will be discussed in this chapter.

In the vast majority of cases, the insect evidence only becomes of significance after a period of longer than 24 hours following death. In order to understand the applications of insect evidence, it is necessary to have some understanding of decomposition.

17.2 Decomposition

Most of the data used in the study of decomposition have been derived from controlled studies. The majority of these studies have been conducted as ecological studies and using test animals other than humans. The size of the animals involved has ranged from frogs and toads (Cornaby, 1974) to elephants [6]. Significant work using human cadavers has been conducted at the Anthropological Research Facility of the University of Tennessee at Knoxville. Among these are the early work by Rodriguez (1986) specifically looking at insect activity associated with decomposing bodies and later work by Schoenly et al. [23]. As early as 1989, the domestic pig was suggested as being a standard surrogate for humans in decomposition studies and this was reinforced by work by Schoenly et al. [23].

A common theme throughout the majority of these studies has been a division of decomposition into a series of discrete stages. While decomposition is, in reality, a continuous process, there is a value to establishe these, admittedly artificial, stages. Decomposition does not take place as a series of discrete combinations of physical parameters associated with distinct assemblages of arthropods. Use of stages does assist when faced with the problem of explaining a complex process to a jury.

While studies have been conducted in a variety of geographic locations and ecological situations, the major groups of arthropods involved remain similar from one area to the next. While the major groups remain constant, there are localized variations in the species within each group involved with the exception of some taxa having a wide geographic distribution. The number of stages proposed has ranged from two to as many as eleven (Goff, 1993). Regardless of location, a generalized pattern of five stages of decomposition has been established [8] that is applicable for most existing studies. These stages have seen a relatively wide acceptance, although the names of the stages have been modified by some workers [1, 24].

17.2.1 Fresh Stage

The fresh stage begins at the moment of death and is considered to end when the first signs of abdominal bloating are first observed. The first insects to arrive at the corpse following death will be adult flies. These are in the families *Calliphoridae* (Blow Flies and Bottle Flies) and *Sarcophagidae* (Flesh Flies). The female flies will typically go to the natural body openings. These will primarily be those on the head, with openings of the anus and genitals as secondary sites of attraction. If wounds are present on the body, inflicted prior to or at the time of death, these will also be attractive. Postmortem wounds are not as attractive to the flies. The female flies will enter the body openings and either lay eggs or deposit live larvae, depending on the species involved.

17.2.2 Bloated Stage

When the gasses produced by the metabolic activities of the anaerobic bacteria first begin to produce a slight inflation of the abdomen, the bloated stage is considered to begin. The continued actions of these bacteria will eventually result in the body becoming fully inflated and having a balloon-like appearance. During this stage, the internal temperatures of the body begin to rise as a result of the processes of putrefaction and the metabolic activities of maggots feeding inside the body. Species in the family *Calliphoridae* are strongly attracted to the body during this stage. As internal pressures increase as a result of the production of gasses, fluids are forced from the natural body openings and seep into the soil beneath the body. These fluids, in combination with the ammonia produced by maggot activities, result in the soil under the body becoming strongly alkaline and the normal soil fauna departs, to be replaced by a fauna specific to decomposition.

17.2.3 Decay Stage

The decay stage is the only stage of decomposition that has an actual physical event marking the start point. When the feeding activities of the maggots penetrate the outer surface of the body, allowing the gasses produced to escape, and the body deflates, the decay stage is considered to begin. The predominant feature of this stage is the presence of large feeding masses of *Diptera* larvae on the body. While predatory species, such as beetles in the families *Staphylinidae* and *Histeridae*, were present during the fresh and bloated stages, they show a marked increase in number during this stage. These, along with late-arriving necrophages, are observed in large numbers during the later portions of this stage. During the decay stage, *Diptera* larvae begin to complete their development and leave the body to pupariate in the soil adjacent to the body. By the end of this stage, most of these will have completed their development and departed. Most of the flesh will have been removed from the body by the end of this stage, and adults of taxa feeding primarily on dried skin and cartilage will arrive.

17.2.4 Postdecay Stage

As the body is reduced to dried skin and cartilage and *Diptera* larvae cease to be the predominant taxa present, the postdecay stage begins. There is no specific start point to this stage and the onset will be determined by local environmental conditions and judgment of the worker. Various species of *Coleoptera* will be the predominant feature of this stage in xerophytic and mesophytic habitats. This will increase in terms of both total numbers and species diversity as the stage progresses. In wet habitats, as encountered in swamps and tropical habitats, the body does not dry sufficiently for many of the *Coleoptera* species to exploit the body and these are functionally replaced by additional species from other groups, such as the *Diptera*. Associated with this in all habitat types is an increase in the number and diversity of the predators and parasites of the respective groups.

17.2.5 Skeletal Stage

The skeletal stage is reached when only hair and bones remain. There are generally no obvious carrion-frequenting taxa present and, as time passes, there will be a gradual return of the normal soil fauna and departure of the fauna associated with decomposition. During the early portions of this stage, there is a characteristic acarine fauna present in the soil under the body. While this fauna has great potential, effective use is currently hampered by the lack of adequate baseline data concerning many species and the great diversity of populations over even limited geographic areas (Schoenly & Reed, 1987). There is no definite end point to this stage. Localized variations in the fauna, particularly the soil fauna, may be detectable for months or even years following death (Goff, 1989, 1991).

17.3 Basis for Use of Insects

Insect invasion of an exposed body can begin shortly following death, often in as little as ten minutes for an exposed body under summer conditions. In the majority of cases, insect evidence is employed after a period of 24 hours. Prior to this, other techniques are available for assessment of the body. In order to understand the use of insects, it is necessary to understand the relationships of insects to a decomposing body. A dead body is a temporary disruption of the ecosystem and presents a progressively changing food resource to a variety of organisms, including insects, algae, fungi, and a variety of microorganisms. Insects encountered on a decomposing body will consist of elements of the insect fauna unique to the habitat in which the body is found as well as insect species specific to the decomposition process. Both types will have an application in investigations. There are five types of relationships of insects to the decomposing body.

17.3.1 Necrophagous Species

Necrophagous species are insects and other arthropods that feed directly on the decomposing body. These include many of the *Diptera* or true flies, as well as many beetles. Species found in this group are often the most significant taxa used in the estimation of the period of time since death or PMI during the early stages of decomposition, days one to fourteen. It must be kept in mind that entomological estimates of the PMI are actually estimates of the minimum period of insect activity on the body and not the actual interval itself.

17.3.2 Parasites and Predators

This is generally accepted as the second most significant group of carrion-frequenting taxa (Lord & Goff, 2003). As the initial invading insects feed on the body and thus alter the body, they make it attractive to other groups of arthropods. Among these are those insects that are predatory or parasitic on the necrophagous insects. In some instances, as is the case for some *Diptera* species, larvae that are necrophagous during the early stages of development become predators during the later stages. An excellent example of this is found in the Hairy Maggot, *Chrysomya rufifacies*. Taxa included in this category are *Coleoptera* (beetles), *Diptera* (true flies) and *Hymenoptera* (bees and wasps) parasitic on larvae and pupae.

17.3.3 Omnivorous Species

Included in the omnivorous species category are insects that feed both on the body and associated arthropods. These include species of ants, wasps, and some beetles. It should be noted that large populations of these, particularly ants, may

actually exert enough pressure on the necrophagous species to retard the rate of carcass removal [8].

17.3.4 Adventive Species

In the adventive species category, we place those species that use the decomposing body as an extension of their natural habitat. This includes species of *Collembola*, spiders, and centipedes. There is no actual relationship to the body except that it can serve as a concentrating mechanism for those animals or plants that are the normal food source for these species. During the later stages of decomposition, these species tend to concentrate in the substrate under the body. Mites in the families *Acarideae*, *Lardoglyphidae*, and *Winterschmidtiidae*, feeding on molds and fungi growing on the body, are included in this category. There are also a large number of mites in the suborder *Gamasida* associated with a decomposing body, but their relationships to the body are not clearly defined (Goff, 1989). These include species in the families *Macrochelidae*, *Parasitidae*, *Parholaspidae*, *Cheyletidae*, and *Raphignathidae.*

17.3.5 Accidental Species

One group often overlooked or assigned disproportionate significance is the accidental species. These insects do not have any relationship to the body but just happen to be there. It seems strange to some workers but, when an insect stops flying, it has to sit on something. Sometimes that is a body. We must also include in this class those insects normally associated with plants that may be in close proximity to a body. When vegetation is disturbed, many insects respond by dropping to the ground. In this type of situation, as the body is moved, insects may fall onto the body from surrounding vegetation and later be found on the body. Common sense and some knowledge of the insects should allow for resolution of these situations.

17.4 Collection of Entomological Evidence

While the insects and other arthropods associated with a dead body are potentially a valuable tool, their ultimate utility depends on proper collection and preservation for later analyses. The techniques involved are not particularly complicated and can be done with a minimal effort if some preparation is done beforehand. Obviously, the ideal situation is to have a trained entomologist examine the body and make the collections. This is generally not possible, so simple but effective techniques are presented here to assist the non-entomologist.

17.4.1 Equipment Needed

Surgical gloves
Forceps
Glass vials
Trowel
Insect net
Artist's brush
Paper bags
Ice cream cartons or their equivalent
KAA or other insect fixative
Vermiculite or sand
Ethyl alcohol (EtOH) (70–80%) or isopropyl alcohol
Can of cat or dog food

17.4.2 Collection Procedures

The insects collected will be divided into several groups, depending on where they are found on the body: flying, crawling, and soil-dwelling. Before beginning any collections, it is advisable to have people move away from the body for approximately ten to fifteen minutes. When a body is disturbed, as in processing, insects will leave the body. Because the insects of interest are largely dependent on the body as a food resource, typically, they do not move far from the body and will return relatively quickly once the activity ceases. It is important to collect flying insects as soon as possible. These are more mobile and will leave the body permanently if disturbed for a period of time. Collection is best accomplished using the insect net. While the net is relatively easy to use, I suggest that one should practice before attempting to collect at a scene. After all, you have just produced an insect net and you need to preserve some shreds of your dignity. Collections should be made by sweeping the net over the body without hitting the body. Collections should also be made from any bushes or vegetation surrounding the body. Many insects will move to vegetation adjacent to the body when initially disturbed. The insects collected in the net will typically be adults and hard bodies. These should be preserved in the EtOH (70–80%) in the glass vials. If isopropyl alcohol is used, it is generally 70% from the container and should be diluted 1:1 with water. Otherwise the specimens will become hardened and difficult to examine. Samples taken from different areas of the body and different vegetation should be kept separate and labeled as to origin, collector, manner of collection (net, etc.), and the date and time of collection.

Crawling insects are found on, in, and around the body. Collections must be as compete as possible to ensure that a representative sample of everything in the body is obtained. It is also important to remember to keep insects from different parts of the body separate and label as to their origin. In addition to the fact that the distributions of the insects on the body may prove to be significant to the entomologist in

arriving at the estimates, many species will feed on each other and other species of insects on a body. Crawling insects can easily be collected using forceps or by hand. Always wear surgical gloves while collecting. Aside from the obvious need to prevent contamination, some of the insects present may bite or sting. The arthropods collected will be either hard-bodied adults or relatively soft-bodied immature forms. While the hard-bodied insects can be treated in the same manner as the flying insects, the immature forms, or larvae, require special treatment to ensure that they will be in a condition suitable for analysis by the entomologist.

Immature insects are often difficult to identify to the species level and this is necessary in order to arrive at an accurate estimate. Even closely related species may have quite different rates and patterns of development. By contrast, most of the adults are easily identifiable by a trained entomologist. For this reason, it is a good idea to keep a portion of the immatures collected alive to be reared to the adult stage. Generally, the specimens are split into two parts. One is to be killed and preserved; this stops the biological clock. The second part is kept alive and allowed to reach the adult stage for easier confirmation of species.

The outer layer of the insect's body is a wax layer that assists in maintaining water balance. In order for proper preservation, this layer must be broken down to allow the preservative to enter the body. A number of different solutions that will serve this purpose are available. The most common is KAA. A KAA solution consists of 1 part glacial acetic acid, 1 part refined kerosene, and 30 parts 95% ethyl alcohol. Immature insects should be killed and placed into this solution for a period of five to ten minutes and then removed and stored in 70% EtOH or isopropyl alcohol diluted 1:1 with water. If the insect is allowed to remain in the KAA solution, it will eventually expand to the point of bursting and be of no use. If KAA is not available, an easy substitute treatment is to put the insect into hot water (76.7°C or 170°F) for a period of two to three minutes and then transfer the insect into 70% EtOH. Water close to this temperature can be obtained at most fast food restaurants by ordering either tea or decaffeinated coffee.

Rearing of immature insects to the adult stage requires an adequate food source and a set of controlled conditions. For this reason, the specimens collected at the scene should be transported to the entomologist as quickly as possible. The specimens collected should be placed into ventilated containers, most often cardboard ice cream cartons or their equivalent. The best size seems to be a half-pint container filled to approximately one quarter to one half with vermiculite or some other inert substance. It is advisable to add food to this container, and canned dog or cat food serves this purpose well. These containers and/or live specimens should not be placed into plastic bags under any circumstances. If the specimens cannot be shipped immediately to an entomologist, the insects can be reared in the cardboard containers. In this case, the food source should be placed into a watch glass and this placed inside the container. The top of the container should be covered with a fine gauze or organdy material, held in place by a rubber band. The food supply should be checked daily and additional food added as needed. The container should not be unduly disturbed. The larvae will complete their development inside the watch glass and then migrate away from the food source

and burrow into the vermiculite to enter the pupal stage. From this stage, the adults will emerge.

Once they have emerged, the adult insects should be supplied with food and water. The simplest way to accomplish this is to place a cotton ball soaked with water and sugar into the container. Adults should be killed after a period of 24 hours and preserved in 70% EtOH or pinned and dried. During the rearing process, the temperatures should be as close to those encountered at the scene as possible. Records of daily maximum/minimum temperatures should be kept and supplied to the entomologist.

It is essential that each lot of insect specimens be correctly and completely labeled to ensure that the evidence can be properly interpreted by the entomologist. Toward this end, there must be a label for each separate lot of specimens. The label should include the following information:

Date and time collected
Location of the body, as specifically noted as possible, geographic location, and type of terrain
Type of habitat in which the body is found – indoors, outdoors, vegetation type, dump, etc.
Location of the specimens on the body
Name, address, and telephone number of the collector

There should also be information concerning the body, including:

Sex, height, weight
Presence or absence of clothing; description of clothing
Orientation of the body – sitting, lying down, on side, back
Attempts to conceal body – wrapping, burial, in container, etc.
Physical damage to body
Cause of death if known
State of decomposition
Description of insect fauna associated with the body

Anything unusual about the scene should also be noted and a complete photographic record made of the scene. As with all other types of evidence, a proper chain of custody must also be maintained for the insect specimens.

17.5 Applications of Entomological Evidence

As noted earlier, there are a number of different situations in which insect evidence can be employed in criminal investigations. Insect evidence is obviously not present in all crimes and, even when present, may ultimately prove to be of minor significance to the resolution of the case. When the evidence is present, it does have the potential to be a powerful tool in many instances. Each of the known possible applications will be covered here.

17.5.1 Estimation of the Postmortem Interval

In practice, the major use of entomological evidence is in the estimation of the period of time since death or the postmortem interval, often abbreviated as PMI. In consideration of this, two major ideas must be kept in mind. First, this is an estimate not a precise time or date. Any estimate that does not include a range of possible times must be viewed with great suspicion. Second, what the entomologist actually calculates is an estimate of the period of insect activity on the body. This is not a calculation of the actual time of death, although, in the majority of cases, the two may be quite close. Generally speaking, the estimates are presented in terms of a minimum period of activity and the parameters of the estimates are directly proportional to the period of time since death. There are two basic approaches to the estimation of the period of time since death: calculation based on development of individual species and use of succession studies.

For approximately the first fourteen following death, estimates are most frequently based on the development of species of *Diptera*. The adult flies are typically the first insects to arrive at a body, often as soon as ten minutes following death. The female fly is typically attracted to the natural body openings of the head, anus, and genitals. The female fly investigates these areas and, if the substrate is suitable, will deposit either eggs or live larvae. This starts a biological clock that is stopped when the body is discovered. During its development, a *Diptera* species passes through a distinctive series of stages leading to the adult stage (Fig. 17.1).

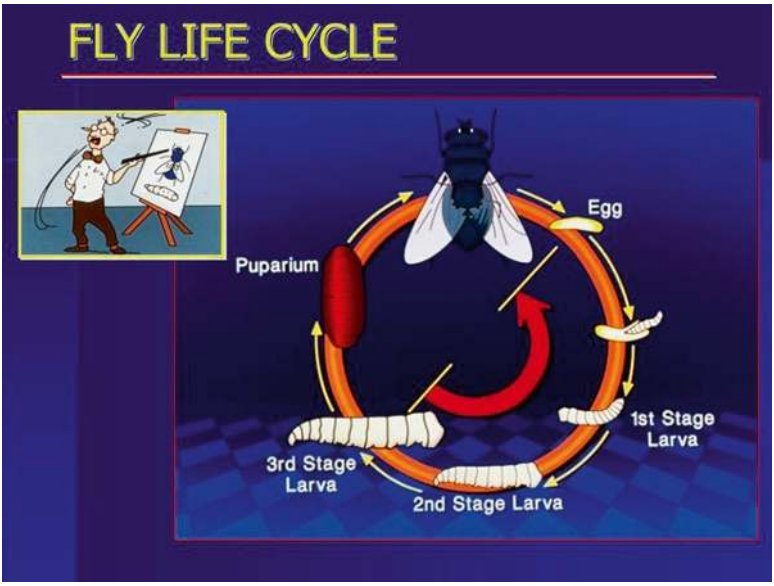

Fig. 17.1 Life cycle of a blowfly, Family *Calliphoridae*

When collecting, fixing, and preserving specimens from the body, the entomologist looks for the most mature specimens present on the body, but also collects a representative sample of all species and stages of development present. By determining the most mature specimens present on the body, the period of time required to reach that stage of development can be estimated by reference to previously conducted laboratory studies. This requires an accurate identification of both the species and stage of development.

One of the major problems facing an entomologist is the accurate identification of the larvae or maggots present. Often the entomologist will not be present at the scene and must rely on dead specimens collected by others. All too often, these arrive in marginal states of preservation and are not useful for identifications. The Appendix gives a protocol for collection of specimens that, if followed, will serve to ensure their arrival in a usable state, and instructions that are more detailed are given in Catts and Haskell [5]. Even when the local fauna is well known, there are significant problems in making accurate identification from only immature specimens, particularly during the early stages of development. Recent publications have provided keys for the identifications of larvae of forensically significant species [15, 22]. While these keys are presented as being somewhat regional in scope, given the relatively wide distribution of many forensically significant species, their applications are wider than indicated. Even with these keys, specimens must often be reared to the adult stage for accurate species-level identifications. Recent investigations of DNA analyses of larvae show considerable promise in identifications of immature specimens [25, 26].

In the calculation of the developmental times, considerable emphasis is placed on the relationships between ambient temperature and the durations of the different stadia. The rate of development and activity of insects, as is the case with other ectotherms, is directly related to temperature. As temperature increases, the rate of development increases and the durations of the individual stages in the life cycle become shorter. For example, the blow fly *Calliphora vicina* requires 11 days to complete the 3rd instar at 12.5°C but only 6.3 days at 22°C [15]. Additionally, there are also lower and upper temperature limits for development and activity of species. These temperature limits vary with the individual species and appear to also be subject to geographic variations within a given species. In the past, many workers have used a lower limit of 10°C as a lower limit for development. Unfortunately, the situation is more complicated, and the easy cutoff points used in the past do not appear to be as relevant as once thought. Fortunately, a number of different controlled studies on developmental rates have been conducted at different temperatures, so baseline data are available for most widely distributed species.

In estimating the PMI, it is necessary to convert time and temperature into units that can be used to compare laboratory data with conditions at a scene. The most common approach is to use the ecological concept of Degree Hours (DH) or Degree Days (DD). This technique was first developed to assist in predicting pest outbreaks in crops, but it has been adapted for use in forensic entomology. In this approach, ambient temperatures from weather stations in the vicinity of the body are used as an indication of the temperatures at which the larvae developed. In reality, this is an oversimplification of a very complicated situation, but, none-the-less, it is functional.

One problem lies in that, as the maggots feed and develop, they form feeding masses. Maggots found infesting a body have typically come from eggs that were laid at about the same time, hatched at about the same time, and then form feeding masses. Maggots are more efficient feeding as a mass, as opposed to feeding alone. These masses generate heat, and temperatures as high as 53°C have been recorded inside these maggot masses. At these temperatures, most species of maggots cannot survive for extended periods and they must rotate through the mass, feeding for a period of time in the center of the mass and then moving to the outside of the mass to cool, then returning to the center to feed. While the ambient temperature does not reflect the actual temperatures at which the maggots are feeding, it does exert an overall influence on the mass and thus allows the DH or DD concept to work for our purposes.

Another common problem lies in the proximity of the weather station used to the actual scene containing the body. Even short distances can result in significant differences in weather conditions. For example, a site near the top of a hill or on a north-facing slope may have significantly different temperatures from a weather station near the base of the hill due to exposure to sunlight and/or differences in elevation. Because relatively few bodies are found close to weather stations, there must be some mechanism to reconcile data from the station to the conditions at the crime scene. The most commonly employed method used is linear regression. In this process, weather data are obtained from a recording device placed at the scene of the discovery of the body for a period of at least five days. Temperature data from that station is compared with corresponding data from the established station and a regression equation developed to allow for adjustment of data. Keep in mind that the resulting temperatures are not actual temperatures, but rather the best approximation of what probably took place at the site.

In arriving at the estimated period of time since death, time in hours or days is converted into thermal units by multiplying time by the temperature in degrees Celsius, expressed as:

$$\text{ADH}\left(\text{accumulated degree hours}\right) = \text{Time}\left(\text{hours}\right) \times \text{Temperature}\left(^{\circ}\text{C}\right).$$

Thus for a period of 24 hours at 15°C, the total number of ADH value would be:

$$24\ \text{hours} \times 15^{\circ}\text{C} = 360\ \text{ADH}$$

This would be the simplest approach; however, there are temperatures below which insect development ceases. As noted above, these temperatures termed “base temperatures” will vary from species to species. To adjust for these, a base temperature is subtracted from the ambient temperature in calculations and the equation is modified as follows, using a cutoff point of 10°C as an example:

$$\text{ADH}_{(\text{base } 10)} = \text{Time}\left(\text{hours}\right) \times \text{Temperature } ^{\circ}\text{C} - 10^{\circ}\text{C}.$$

Thus the same conditions as previously used result in an $\text{ADH}_{(\text{base } 10)}$ value as follows:

$$24 \text{ hours} \times (15°\text{C} - 10°\text{C}) = 120 \text{ ADH}_{(\text{base } 10)}.$$

It has been found that different species of insects have different base temperatures and these may also vary throughout the geographic range. As a general practice, it is preferable to use laboratory studies conducted on populations collected in close geographic proximity to the crime scene. For example, there may be some variations between populations of *C. vicina* in the Northwestern United States and populations from Europe.

In calculating the estimated period of insect activity on the body, ADH values are summed, beginning with the point at which the collections were made and working backward until the required ADH value for the most mature specimens collected is reached. This will estimate the minimum period of insect activity on the body and frequently the PMI. For example, in a case, the most mature specimens collected from a body were determined to be 3rd instar larvae of the Hairy Blowfly, *C. rufifacies*, measuring 13–15 mm total length, mean = 13.7 mm. Based on laboratory rearing data at 26°C, it would require approximately 136 h to reach that stage of development or 3,588 ADH.

Table 17.1 gives the ADH values calculated from hourly temperature data obtained from a National Oceanic and Atmospheric Administration (NOAA) weather station at an airport approximately 0.5 miles from the scene. Because the values are summed for each day, the required value of 3,588 ADH is attained at 2200 on 9 April, giving an estimated minimum period of time for insect activity. Because in this case the body was lying exposed on the ground, this estimate would most probably closely approximate the period of time since death.

Table 17.1 Accumulated degree hours (ADH) values from weather data collected from National Oceanic and Atmospheric Administration (NOAA) weather station for period 15 to 9 April

Date		DH	ADH
April 15		494.6[a]	494.6
April 14		604.2	1,098.8
April 13		597.1	1,695.9
April 12		613.0	2,308.9
April 11		613.3	2,922.2
April 10		607.9	3,530.1
April 09			
Hour	Temp (°C)	DH	ADH
2,400	23.9	23.9	3,554.0
2,300	24.4	24.4	3,578.4
2,200	24.4	24.4	3,602.8[b]
2,100	25.0	25.0	3,627.8

[a] Specimens were collected and preserved at 2000 on April 15
[b] Value of 3,588 ADH required for development of *Chrysomya rufufacies* attained

After the first fourteen days following death, most of the initial colonizing *Diptera* species will have completed their development and departed the body to complete their development through the puparial stage into an adult fly. At this point, the estimation of the period of insect activity becomes more difficult. As previously discussed, exploitation of a body by insects and other arthropods follows a pattern of succession. As one group of insects uses the body as a food resource, their activities change the character of the body, making it attractive to another group of species. As this group feeds, they, in turn, alter the body, attracting another group of insects. These species are not all feeding directly on the body, and the various relationships between arthropods and a decomposing body were discussed earlier. At this point, it becomes necessary to make a complete collection and identification of all of the species present on the body. By comparing the results of these collections with data from controlled decomposition studies conducted in similar geographic and ecologically similar habitats, it becomes possible to arrive at periods of time during which insect colonization most probably occurred.

This case gives an example of how this technique can be applied. The largely skeletal remains of a white woman were discovered in a sugar cane field on the island of Kauai. The cause of death was determined to be homicide due to multiple stab wounds that had resulted in cut marks to the ribs. Time since death was an obvious issue. Although there was little flesh remaining on the body, there were a number of insects present. There were empty puparial cases of the *Calliphoridae C. rufifacies* on and near the body. This species is an early colonizer of human remains in Hawaii, often arriving within ten minutes following death. Given prevailing temperatures in the area, development from egg to emergent adult requires approximately eleven days. Oviposition takes place for the first 5 days following death. Because only empty puparia were present, this indicated a minimum period of sixteen days. Also present on the body were larvae of the *Piophilidae Piophila casei* (Fig. 17.2).

This species, also known as a Cheese Skipper, arrives at remains in Hawaii on day fifteen and completes its development to the puparial stage by day 36. The specimens collected were beginning to depart the body for puparialtion, thus

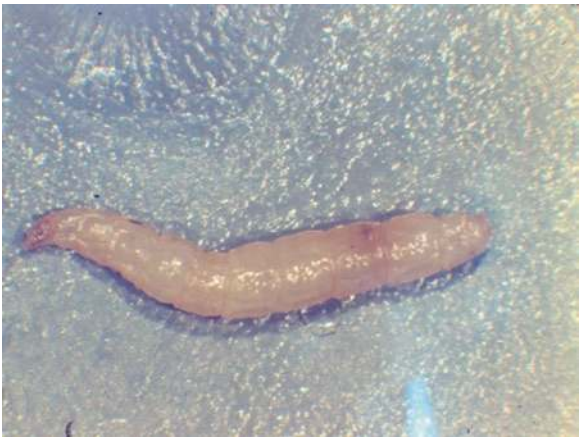

Fig. 17.2 Larva of the Cheese Skipper, *Piophila casei* (Family *Piophilidae*)

Fig. 17.3 Adult of the staphylinid beetle, *Philonthus longicornis* (Family *Staphylinidae*)

Fig. 17.4 Larva of the Black Soldier Fly, *Hermetia illucens* (Family *Stratiomyidae*)

indicating a time period of approximately 36 days. There were also *Staphylinid* beetles, *Philonthus longicornis*, adults present (Fig. 17.3).

These beetles in Hawaii arrive at the body approximately 25 days after death and leave by day 53. The last species identified was the Black Soldier Fly *Hermetia illucens* (Fig. 17.4).

This species is typically a late arrival, twenty days following death, and has a relatively long developmental period. The oldest specimens recovered were determined to be approximately fourteen days old, thus indicating a period of 34 days following death (20 + 14 days of development). Examining data for the species involved, an estimated period of 34–36 days following death was estimated. Although not a precise time, it was sufficient to allow for identification of a suspect who was eventually convicted of murder. While none of the species individually allowed for an accurate estimate, the combination of life cycles and behaviors of all collected proved significant.

As decomposition progresses and the analysis of the insect fauna moves from life cycles of a single species to patterns of succession, the parameters of the estimate become wider. For the first periods, the estimate is presented in terms of a range of hours, later changing to days, then months, seasons, and years. Finally, the only statement possible from an entomological standpoint is "the body has been there a long time." Regardless of the parameters, the estimate remains only that – an estimate – and an estimate of the period of insect activity on the remains, not the actual time since death. In many instances, this period is quite similar to the actual time since death. Regardless of the inherent limitations of the technique, it remains a powerful tool in the investigation.

17.5.2 Postmortem Movement of the Body

As noted previously, insects are among the most widely distributed organisms on earth and are the most numerous animals in the world. However, while insects are found virtually everywhere, individual groups and species of insects frequently have quite distinct patterns of distribution with respect to geography and ecology. In various decomposition studies conducted in a variety of different habitats and regions [1] (Carvalho et al., 2004; Goff, 1993), it has been observed that the general groups occur on a body in a similar pattern regardless of geography, the species composition will vary with the region. While many of the forensically significant species tend to have wider distributions, for example *C. vicina*, many species have narrow geographic ranges. Thus on any body, there will be species having wide distributions combined with species restricted to the particular habitat in which the body is found. Thus, if a body is discovered with insects restricted to a habitat or geographic region different from that in which it is discovered, this is an indication that the body may have been moved following death.

In addition to geographic differences, there may be habitat differences over a relatively short geographic distance. In one case in Hawaii [11], a body was discovered in a cane field in the middle of the island of Oahu. On the body there were three species of *Diptera* larvae. Two of these were in the family *Calliphoridae* and typical early colonizers of remains, *C. megacephala* and *C. rufifacies*. These were determined to be approximately 3.5 days into their larval development. The third species was in the family *Muscidae*, *Synthesiomyia nudiseta*, and showed a 5.5-day period of development. In Hawaii, both of the *Calliphoridae* species prefer an outdoor habitat, whereas the *Muscidae* is typically associated with indoor situations and is only rarely encountered outside of an urban situation. This two-day difference in development was an indication that the individual had been killed in an urban situation, probably indoors, the body was allowed to remain there for a period of approximately two days, and was then transported to the rural sugar cane habitat in which it was discovered. Subsequent investigation confirmed this scenario to be correct.

It is also possible to have insects not actually associated with the decomposition processes provide significant information. Many plant-feeding species have very

narrow food preferences and well as limited geographic ranges. If a body is outdoors near or under vegetation, it is possible for insects associated with that vegetation to move onto the body, although typically not to feed or lay eggs. For many foliage-feeding species, their defense relation to being disturbed is to release their hold on the plant and drop to the ground. If the body is between the insect and the ground, it may be moved with the body to the next location. Obviously this is not the normal occurrence, but it has been observed.

17.5.3 Assessment of Wounds

Insects colonize a decomposing body in a predictable manner [19]. The initial invasion is centered around the natural body openings. The primary site will be the openings of the head (nose, mouth, eyes, and ears), followed by the anus and genitalia, if exposed. This pattern is associated with the feeding behavior of the initial colonizing taxa, primarily *Diptera*. The mouthparts of their larvae or maggots are not constructed in such a manner as to be effective in penetration of intact skin, but are well suited to the mucus membranes associated with the natural body openings. Typically the third choice for colonization will be wounds inflicted antemortem or perimortem, while blood is still flowing. Wounds inflicted postmortem are not attractive to the *Diptera* for oviposition. As the maggots feed on the tissues associated with these antemortem or perimortem wounds, they change the surrounding tissues and a pattern of succession begins, similar to that observed with normal invasion of natural body openings. By contrast, activity associated with postmortem wounds is minimal by comparison. Because feeding activity by the insects often changes the appearance of the wounds, they may not be obvious as decomposition continues. By observing abnormal patterns of inset activity on the body, clues may be detected leading to discovery of otherwise obliterated wounds. For example, in one case, the body of a woman was discovered in the early portions of the decay stage of decomposition. Maggot activity was apparent in the area of her head. Additionally, there were centers of maggot activity observed in the chest and also the palms of both hands. As the skin, particularly in the palms of the hands, was normally not suitable for colonization, the pathologist investigated more closely and found evidence of stab wounds in the chest that had cut into the ribs. Wounds detected in the palms of the hand represented defense wounds. Thus, any deviation from the normal pattern of decomposition should be investigated, because significant information may be otherwise overlooked.

17.5.4 Crime Scene/Habitat Characterization

As noted previously in the discussion of postmortem movement, insects are often restricted in their geographic and seasonal distribution. These patterns can be of assistance in tying a suspect to a victim and/or crime scene. Webb et al. [21]

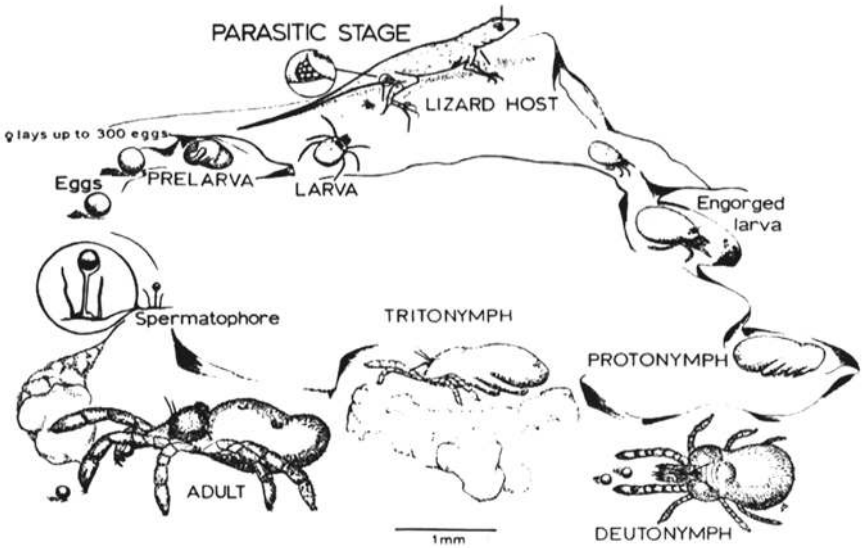

Fig. 17.5 Life cycle of a chigger mite (Family *Trombiculdiae*). Reproduced by permission of Entomological Society of America, Lanham, MD, © 1982

detailed a case from California in which a suspect was tied to a crime scene and victim based on the bites of a larval *trombiculid* mite or chigger. In this case the body was discovered in a scrub vegetation area in California. During the recovery process, most of the involved personnel were bitten by a pest species, *Eutrombicula belkini*. There were several suspects in the case, one with bites similar in shape and distribution on the body that would be anticipated from an attack by chiggers. The life cycle of a *trombiculid* mite is somewhat complex, with a combination of active and inactive stages, a parasitic habit, and a predatory habit (Fig. 17.5).

The larval stage is a parasite on vertebrates and is actually the only stage in the cycle properly termed a "chigger." Other stages are either predatory or inactive. The species tend to be quite habitat specific although exhibiting a wide host range, particularly the pest species biting man. In California, the distribution of chigger that will bite man is quite limited and the presence of the species at the recovery scene and bites on the individual served to tie him to the crime scene and thus the victim.

Another somewhat similar case was detailed by Greenberg (1993). In this case, an individual was tied to a rape by cockleburs found adhering to a ski mask. Access to the victim's bedroom was accomplished by the rapist climbing a tree and entering though a window. The suspect claimed that the ski mask had not been taken out of the drawer since the previous winter. The cockleburs on the mask were consistent with those found in the victim's yard, but the season remained in question. Closer examination of the seeds revealed the presence of beetle larvae that would be inconsistent with the mask having been worn only during winter months when the larvae would not be present. They were, however, consistent with the time of year of the rape.

17.5.5 Alternate Specimens for Toxicology

Often a body is discovered in an advanced stage of decomposition where tissues and fluids that would normally be sampled for toxicology are no longer suitable. In these situations, insects may still be present that can serve as adequate alternate samples for analyses. This subdiscipline of forensic entomology has been termed Entomotoxicology and is itself subdivided. One aspect deals with the simple detection of substances through analyses of insects associated with the body. The second area is more complicated and concerns itself with the effects of the substances in the decomposing tissues on the developmental patterns and rates of development of the insects using those tissues as a food source.

Among the first studies with this topic was that by Nuorteva and Nuorteva [17] dealing with environmental contamination by mercury as a means of determining geographic origin of a woman whose body was discovered in Finland. Subsequently, he demonstrated bioaccumulation of mercury in beetles feeding on maggots fed on tissues with a high concentration of mercury and developmental abnormalities associated with this bioaccumulation. Subsequent to this, beginning with Beyer et al. [2] a large number of toxins, pharmaceuticals, and illegal substances have been detected through analyses of maggots in both cases and experimental studies. Goff and Lord [14] summarized the work to date and subsequently Goff et al. [12],and Bourel et al. [3, 4] have added additional substances to the list. It must be noted that, although the various drugs, toxins and their metabolites have been successfully detected in larvae, there is no reliable technique allowing for determination of the actually dosage of the substance administered to the deceased. There are a number of different factors involved in this, including postmortem relocation of the drugs in the tissues, breakdown over time of the drugs and their metabolites, and depredation on the body by organisms other than insects. Although there have been some attempts at a correlation between concentration in tissues and concentrations in maggots, the results have not proven useful [16].

Maggot activity consists primarily of feeding and growing as rapidly as possible, with reproduction and dispersal left to the adult stage. This leads to the obvious question of "Is there an effect on the growth rate and/or pattern when the maggot ingests the drug or toxin along with the decomposing tissues?" In 1989, a body was recovered on the island of Oahu. Examination of the scene revealed evidence that the individual had been sitting on the limb of a tree overhanging a ravine and appeared to have died as the result of a fall. An estimated minimum period of insect activity was calculated. As the investigation continued, an individual came forward and stated she had seen and had a conversation with the deceased several days after the calculated minimum period. Because the deceased was a known cocaine abuser, the question arose as to the effect of cocaine in his tissues on the rate of development of maggots feeding on the body. As a result of this question, a controlled study was conducted and it was determined that maggots feeding on tissues from an experimental animal given a lethal dosage by

weight of cocaine did exhibit a significant acceleration in rate of growth [13]. Lower dosages did not have this effect. In the case in question, the dosage was not at a lethal dosage. The question of the conversation was resolved when it was discovered that the individual claiming to have had contact with the deceased had a history of similar claims and was not reliable. The original estimate of a minimum period was accepted.

17.5.6 DNA Applications

At present, applications of various techniques involving DNA analyses to forensic entomology are limited but the potential for significant uses in the future exist. The potential applications fall into two main areas: identification of species during early instars, and linking suspects to victims based on DNA present in gut contents.

It is a simple fact that, with relatively few exceptions, there is a marked similarity between maggots during the 1st instar, even to a trained entomologist. As noted earlier, there are also significant differences in the durations of the different stages of the life cycle even among closely related species. For this reason, accurate identification of the species becomes essential for an accurate estimation of the period of activity on the body. At present, the most commonly employed technique is to rear a portion of the specimens collected to the adult stage and make the species-level identification from the adults. This is a time-consuming process and often is not successful for a variety of reasons. Recent work has centered on the use of DNA for identifications of maggots [25, 26]. Although considerable work is yet to be done in characterizing the different species, improved techniques have significantly reduced both the time involved and the costs of such testing. In the relatively near future, this will become a widely employed technique for identification of early instars.

The other use of DNA material lies in the linking of suspects to victims based on DNA present in gut contents of parasitic insects. Repogle et al. [18] have demonstrated the potential for identification of DNA from gut contents and fecal material of the cab louse, *Pthirus pubis*. Additional studies have demonstrated the potential to determine hosts from gut contents of other insects such as mosquitoes. DiZinno et al. [7] have demonstrated the potential for recovery of mitochondrial DNA from beetle larvae recovered from human bone. Although the applications of these techniques are limited, in those cases where the application exists, this can be a valuable tool.

17.5.7 Abuse/Neglect of Children and the Elderly

Abuse/neglect of children and the elderly is one of the few instances in which techniques of medicolegal forensic entomology are applied to cases involving living

individuals. In the vast majority of instances, this involves a phenomenon known as myiasis. Myiasis is the feeding by maggots on living tissue or dead tissues associated with a wound. There are several subdivisions of myiasis and several routes for its evolutionary development have been hypothesized. In some instances, the species have evolved to the point where the larvae must feed on living tissues in order to complete their development to the adult stage, termed Obligatory Myiasis. This is encountered in a number of specie in the families *Calliphoridae*, *Sarcophagidae*, *Gasterophilidae*, *Oestridae*, and *Cuterebridae*. In some species, considerable damage is done to the host and death may result as a result of the infestation, as in the Screw worm fly *Cochliomyia hominivorax*. Others, such as the Human Bot fly, *Dermatobia hominins*, cause only localized discomfort and only limited damage to the host. Other species are found that feed on dead bodies or, occasionally, dead tissues associated with a wound on a live host. This is termed Facultative Myiasis and is what is most frequently encountered in legal situations. Because the larvae feed only on dead tissues, they cause little if any discomfort to the host and depart the wound when they have either completed development or there are no dead tissues remaining.

Prior to the introduction of antibiotics, "maggot therapy" was an accepted medical technique. It was first observed by Napolean's battlefield surgeon, who noted that individuals left on the field until maggots infested their wounds had a better chance of survival than those brought immediately into field hospitals. During the United States Civil War, the Confederate surgeon Zacharias was known to deliberately introduce maggots into wounds to clean the wound and prevent infections. The process became more refined and generally accepted until the introduction of antibiotics. As there have developed drug-resistant strains of bacteria, the technique has seen a resurgence [20].

In the forensic context, myiasis is most frequently associated with the facultative parasites in the families *Calliphoridae*, *Sarcophagidae*, and *Muscidae*. However, some use may be made of species demonstrating the obligatory state, such as *Dermatobia hominis (Cutrebridae*). If not fully appreciated, myiasis can be a significant point of confusion for the forensic entomologist, appearing to give an estimate of the PMI far longer than the actual period of time since death. In other instances, particularly in cases involving the living, an understanding of myiasis may prove to be a significant factor in resolving the case. In this chapter, several different situations involving myiasis will be demonstrated using case studies. Although myiasis is involved in both human and veterinary aspects of forensic investigations, in this treatment, only human involvement is presented.

In one case, specimens were submitted from the remains of a woman, 58 years of age, who had been in home care on the island of Oahu, Hawaii, in an extended family situation (two daughters, a son-in-law, and five grandchildren). The decedent had a history of stroke with right-side paralysis and only minimal contact with healthcare professionals. She was described as "difficult" and often remained in a wheelchair for extended periods of time, refusing to speak to family members for periods of several days. Specimens were collected at 09.30 on 10 July and submitted to the laboratory for analysis. Submitted specimens consisted of 3rd instar

larvae of *Phaenicia sericata* and egg masses of *C. megacephala*. The 3rd instar larvae of *P. sericata* indicated a mode developmental time of fifty hours, based on conditions inside the house. Based on the idea that the species showing the greatest period of residence on the body is indicative of the minimum period of time since death, this indicated an onset of insect activity at approximately 0800 on 8 July. By contrast, the eggs of *C. megacephala* hatched at 1400 on 10 July, indicating they had been deposited at approximately 0600 on 10 July. The family members stated that the decedent had last been seen alive at 0100 on 10 July.

Examination of the body during autopsy revealed the presence of a large necrotic area on the lower back, penetrating into the abdominal cavity. Maggots of *P. sericata* were restricted to this area, while the egg masses of *C. megacephala* were recovered only from the nasal cavities. The prosecutor in this case felt that this supported the account of the family as to the possible time of death. Although the presence of the 3rd instar larvae of *P. sericata* indicated an instance of neglect and a general lack of care for the decedent, charges were not filed by the prosecutor. Lacking the data concerning distribution of the maggots with respect to the wound and the involvement of *P. sericata* in myiasis in Hawaii, the estimated PMI would have been considerably longer than was actually the case. Too often, specimens are submitted by law enforcement agencies as a single collection from the remains, with no indication of location on the remains of infestations. If pre-existing infested wounds are not noted by those individuals making collections from the remains, the estimated period of time since death could be significantly in error.

Another case involving a still-living victim was described by Goff et al. [10]. In this instance, a 16-month-old child was discovered on the edge of Lake Wilson on the island of Oahu, Hawaii. The child was in a clear area surrounded by heavy vegetation. When found, she was suffering from dehydration and bruising and she had numerous insect bites. Initially, the period of exposure was estimated as being two days. Given the state of dehydration, a pediatrician suggested that the period was longer and that the child would most probably have died within the next 24 hours. The child was clothed in a sweatshirt, t-shirt, a pair of pants, and disposable diapers. On the front of the pants, from the waistband to a point below the knees, there were egg masses of a *Calliphoridae*. When the clothing was removed, numerous 1st instar larvae (measuring 3–4 mm total length) and fewer 2nd instar larvae (measuring 5 mm total length) of *C. megacephala* were discovered in the diapers and pants. Additional 1st and 2nd instar larvae of this same species were recovered from the vagina and rectum of the child and appeared to be feeding on tissues at those sites. Rearing data for this species from controlled studies conducted by Goff (unpublished data) at 26 and 28°C indicated the most mature larvae would have required 39 and 36 h, respectively, to reach the stage of development represented. Using ADH calculations without a base temperature to adjust for normal body temperature, it was estimated that it would have required 23.5 h to reach the most mature stage of development for the specimens collected from inside the diapers.

17.6 Educational Requirements and Certification

Obviously, forensic entomology is a highly specialized area of investigation, requiring a detailed knowledge of insect biology and taxonomy. With this in mind, those working in the field require specialized training. At present, there are no curricula available at universities in the United States offering degrees in forensic entomology. Rather, those interested in pursuing the field will be majoring in Entomology, Biology, or related fields, such as Forensic Sciences or Ecology. Although some workers in the past have begun working in forensic entomology with only a baccalaureate degree in one of these majors, the present trend is to view the Master of Science degree as the minimum level of education to adequately function in forensic entomology. The vast majority of workers in the United States currently hold an earned Doctorate in Entomology or Biology. During their graduate programs, the candidates will take extensive course work in taxonomy, ecology, and biology of insects. The thesis or dissertation topics, while filling all of the requirements of the granting institution, will have an emphasis on forensic aspects of the study, along with the more basis concerns.

Unlike many other areas of the forensic sciences, accreditation has only recently become available in Medicocriminal Forensic Entomology. The areas of Stored Product and Structural/Urban Forensic entomology fall under the purview of the Entomological Society of America through their Board Certified Entomologist Program, and accreditation has been available for many years. In 1996, the American Board of Forensic Entomology was created as an independent board. Certification is offered at two levels by this Board: Member and Diplomate. Member and Diplomate statuses are currently available to individuals filling the requirements from the United States and Canada. Individuals from other areas may become Associate Members, but no certification is associated with this level of membership.

Requirements for Member status include an earned M.S. degree in the field in Entomology, Biology, Ecology, or Zoology. The individuals must have a minimum of 5 years of professional experience following completion of their degree, with the last 3 years of the experience involving a substantial amount of work in medicocriminal forensic entomology. Evidence must be presented at the time of application of publication of relevant work in peer-reviewed journals, presentations at meetings, and submission of case studies. Requirements for Diplomate status are the same as for member, but the applicant must possess an earned Doctorate in one of the listed disciplines. Applicants for both Member and Diplomate status are required to complete a written and practical examination, passing with a minimum score of 80%.

There is no accreditation available for laboratories in the area of Forensic Entomology. Currently, forensic entomologists are either housed in academic institutions where a significant portion of their research is involved with Forensic Entomology or employed in crime laboratories with other duties in addition to forensic entomology.

17.7 Appendix: Protocols for Collection of Entomological Specimens

The insects and other arthropods associated with a decomposing body are a potentially powerful tool in a homicide investigation. Their ultimate utility, however, depends on their being properly collected and preserved for analysis by an entomologist. The ideal situation would entail the collection and shipment of a single specimen. This would be collecting and shipping an entomologist to the scene. The entomologist would then examine the body and make all of the necessary collections. Whenever possible, local law enforcement should consider establishing a working relationship with an entomologist from a local college or university. This individual may not be familiar with the techniques of forensic entomology, but will be familiar with the local arthropod fauna and correct collection and preservation techniques. This will assure that the specimens are properly handled. Because I realize this may not always be possible, this protocol is designed to assist the non-entomologist in proper collection, preservation, and shipment of these specimens.

17.8 Equipment Needed

1. Surgical gloves
2. Forceps
3. Glass vials
4. Trowel
5. Insect net
6. Small artist's brush
7. Paper bags
8. Plastic bags and paper bags
9. Ice cream cartons
10. KAA or other insect fixative
11. Vermiculite or sand
12. Ethyl alcohol (70–80%) or isopropyl alcohol
13. Can of cat food

17.9 Collection Procedures

1. Flying insects

Prior to collecting insects and other arthropods, it is advisable to have personnel move away from the body for a period of ten to fifteen minutes. While many of the flies and beetles that may be present on the body are quite determined and will

remain during scene processing, there are other significant species that will leave the body when it is disturbed. If the body is left alone, these insects may return. It is important to make collections of flying insects as soon as possible to assure that a representative sample is collected. These insects can be collected using the insect net. An insect net is relatively easy to use, but I would suggest some practice before using a net at the scene. This will help to preserve some of your dignity. Remember, you have just produced an insect net and announced that you are going to collect flies. Reactions to this are varied under the best of circumstances. Samples should be taken from the body and also any adjacent bushes that may serve as refuges for insects driven from the body. Insects collected in this manner will usually be adults and hard bodied. These should be preserved in glass vials using the 70–80% ethyl alcohol or the isopropyl alcohol. If the isopropyl alcohol is used, it should be cut 1:1 with water. Otherwise the insects will become hardened and difficult for the entomologist to identify. Formalin should not be used to preserve insects unless there is no alternative available. If preserved in formalin, insects should be transferred to ethyl alcohol as soon as possible. Samples from different areas (over the body, in bushes, etc.) should be kept separate and labeled as to origin, collector, how collected (net, picked up by hand, etc.), and time of collection. This information will be very important to the entomologist.

2. Crawling insects

Insects will be crawling on or in a number of different places on the body. Collections made from each part of the body should be kept separate and labeled as to their origin. These insects can be collected using the forceps or by hand. You should wear the surgical gloves at all times while sampling from the body. The arthropods you collect in this manner will be of two general kinds: (1) hard-bodied adults, such as beetles, and (2) immature and soft-bodied insects. The hard-bodied insects can be treated in the same manner as the insects collected using the insect net. The soft-bodied insects and immature insects require some special treatment to ensure that they will be suitable for analysis by the entomologist.

Immature insects are frequently difficult to identify, whereas the adults can be easily identified by an entomologist. Even closely related species may have different patterns and rates of development. Correct identification of the species is essential to the entomological investigation. For this reason, it is desirable to keep some of the immatures alive to be reared to the adult stage. I generally suggest splitting the collections into two parts. The first will be killed to stop the biological clock that will be analyzed by the entomologist and the other kept alive to confirm the species identifications.

The immature insects, most frequently maggots, to be preserved for later analysis should be killed and preserved in vials of a KAA solution for a period of five to ten minutes, depending on the size of the maggots, and then transferred to 70% ethyl alcohol or isopropyl alcohol cut 1:1 with water for storage. The KAA solution is designed to breakdown the waterproofing on the insect's cuticle or outer body surface. If this is not done, the alcohol will not penetrate the body and the insect will become blackened and rot. The KAA solution consists of 1 part glacial acetic

acid, 1 part refined kerosene, and 30 parts 95% ethyl alcohol. There are other insect preservative solutions available, but this is the easiest to use. If KAA is not available, the insect can be fixed using hot water. In this case, the maggots are placed into hot water of approximately 76.7°C (170°F) for a period of 2–3 min and then transferred to 70% ethyl alcohol for storage. Water near this temperature can be obtained from most fast food restaurants by ordering tea or decaffeinated coffee.

The rearing of immature insects to the adult stage requires a set of controlled conditions and an adequate food source. Rearings are frequently essential for accurate determinations of the species involved in the decomposition process, because the immatures of many species are virtually indistinguishable.

Immatures collected from the scene to be reared to the adult stage should be placed into the ice cream containers. I generally suggest a 1/2 pint container (0.95 L). This container should be filled 1/4 to 1/2 with the vermiculite or other inert material. In selecting your material, be careful not to use anything that has an insecticide added. Moist soil can be used for this purpose if other materials are not available. A food source is advisable and a small amount of the canned cat food or beef liver will serve this purpose. Do not place specimens to be reared or containers with these specimens into plastic bags or tightly sealed vials. They will not survive these conditions, particularly in warmer weather. These specimens should be transported to the entomologist as quickly as possible.

An entomologist will normally have facilities available for rearing of immatures and those specimens collected from a crime scene should be transported to the entomologist as quickly as possible. Generally, normal mail should not be used for transport of live specimens from a crime scene. Package all containers in well-padded shipping containers to avoid breakage. Vials should be individually wrapped and placed in a box with at least two inches of Styrofoam chips surrounding all sides, top, and bottom. Package soil samples and other living specimens in such a manner as to ensure they will remain as cool as possible and in well-ventilated containers. DO NOT ship living materials in plastic bags under any circumstances. Soil samples can be shipped and stored in paper bags that are folded over at the top and stapled shut.

If the specimens cannot be shipped to an entomologist immediately, the larvae can be reared to the adult stage in the ice cream containers if provided with a sufficient quantity of food. For this purpose, I suggest placing the larvae and food material into a small watch glass placed inside the container. The top of the container should be covered with a fine gauze or organdy material held in place with a rubber band around the outside of the container to allow for air and easy observation of the larvae. The larvae should be checked daily and additional food added as needed. There should be as little disturbance of the container as possible. The larvae will complete their development on the food source and then migrate away from the food source, downward into the vermiculite to pupate. Adults will emerge from the puparia and crawl to the surface. The conditions under which the larvae are reared should be as close as possible to those of the actual crime scene to allow for accurate determination of the times required for development. Temperatures (daily maximum/minimum) should be recorded for the area in which the larvae are reared. Emerging adults sold be provided with food in the form of a cotton ball soaked with water and sugar. They should be

allowed to feed for a 24 hour period, then killed and either preserved in 70% ethyl alcohol or dried and pinned. This allows for the exoskeleton to dry and accurate determinations can then be made by the entomologist.

17.10 Labeling

Each lot of specimens collected should be well labeled to ensure proper interpretations of the evidence by the entomologist. Each container should be labeled separately and include the following data:

1. Date collected
2. Time collected
3. Location of body – be as specific as possible
4. Type of habitat – inside house, in bushes, on side of hill, etc.
5. Location on body of specimens collected – DO NOT combine collections from different parts of body
6. Name, address, and telephone number of collector

17.11 Additional Information

A description of the locality is essential to the proper interpretation of the insect evidence. Insects are frequently quite specific as to the type of habitats in which they will be found and their activities may vary from one habitat type to the next. General photographs of the scene are invaluable to the entomologist. While videotapes are of some use, the 35-mm still photograph is currently of the greatest use to an entomologist in analyses. Your written description of the locality should include the following:

1. The geographic location – city, county, street address if applicable, etc.
2. General type of habitat – desert, forest, pasture, inside apartment, dump, etc.
3. Terrain – rocky area, hill side, flat area, etc.
4. Type of vegetation present – samples, if feasible, should be sent to a botanist
5. Soil type – sand, gravel, mud, artificial (cement, blacktop, etc.)

A description of the corpse along with a detailed photographic record. The description of the corpse must include the following:

1. Sex, height, and weight
2. Presence or absence of clothing and description of clothing
3. Orientation of corpse – sitting, lying face down, lying on back, etc.
4. Any attempt to conceal the corpse – wrapping, covered by vegetation, etc.
5. Physical damage – lacerations, scrapes – and location of damage
6. Cause of death
7. State of decomposition
8. Insect fauna observed. Include close-up photographs if possible

Complete climatic data from the NOAA weather station closest to the crime scene and data from any other weather stations (small airports, agricultural experiment stations, etc.) in the vicinity that may be closer to the scene. These should include rainfall and temperature as a minimum. Hourly temperature data are desirable. Insect development is affected by many different factors, but weather factors, particularly temperature, are among the most significant. These govern adult activity, including egg laying, and immature development.

Finally, anything unusual about the scene of general area should be noted. If possible, make a photographic record of any unusual aspects of the scene. A complete photographic record of the crime scene is invaluable to the entomologist, often showing factors that may be of significance, but not obvious to the non-entomologist processing the scene.

As I stated at the beginning, entomological evidence has the potential to be a powerful tool in a criminal investigation. It may well not be present in all cases. When it is present, it will be reliable only if the evidence is properly collected and documented prior to being turned over to the entomologist for analysis. As with all other types of physical evidence, a proper chain of custody must be maintained during the processing.

17.12 Questions

1. What attributes of insects allow for their use in the estimation of a period of time since death and what is actually estimated?
2. What are the subdivisions of what is commonly termed "Forensic Entomology?"
3. When collecting immature insect specimens from a body, the collections are split into two lots. Why is this done and what is done with each lot?
4. What are the two aspects of Entomotoxicology that must be considered in a death investigation dealing with remains during the later stages of decomposition?
5. How can insects assist in the evaluation and/or detection of wounds on a body during early stages of decomposition?
6. What is the Accumulated Degree Day concept and how is this used in forensic entomology?
7. How is DNA currently employed in medicocriminal forensic entomology?
8. How can insect activity assist in cases of abuse and neglect of children and the elderly?
9. What body provides accreditation for medicocriminal forensic entomology in the United States and Canada?
10. What would be the minimum level of education required for a forensic entomologist?
11. In what way can insects assist in determining if a body has been moved following death?

17.13 About the Author

M. Lee Goff received his B.S. degree in Zoology from the University of Hawaii at Manoa in 1966, his M.S. in Biology from California State University, Long Beach in 197, and his PhD in Entomology from University of Hawaii at Manoa in 1977. The early part of Dr. Goff's professional career was spent working at the B.P. Bishop Museum on the biology and taxonomy of the larval Trombiculidae and Leeuwenhoekiidae as well as the role of avian malaria in the decline of endemic Hawaiian land birds. He began working in Forensic Entomology in 1983, while still at the B.P. Bishop Museum in Honolulu. He left that position and moved to the Department of Entomology in the University of Hawaii at Manoa in late 1983. While there, he was a professor of Entomology and Chair of the Entomology Graduate Program. He left the University of Hawaii in August 2001 for Chaminade University of Honolulu, where he is currently Director of the Forensic Sciences Program. He has published more than 225 papers in scientific journals dealing with Acarology, Medical Entomology, and Forensic Entomology and authored the popular book "A Fly for the Prosecution." He has conducted numerous workshops dealing with applications of entomology to forensic problems in different venues around the world, including presentations for the FBI Academy in Quantico, Virginia. He has participated in numerous death investigations and provided expert testimony. Dr. Goff is a Fellow of the American Academy of Forensic Sciences, Affiliate Member of the National Association of Medical Examiners, American Association of Clinical Laboratory Directors, and a Diplomate of the American Board of Forensic Entomology. In addition, Dr. Goff has served as a consultant for numerous television shows, including the popular CSI Las Vegas, CSI Miami, and Bones.

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Chapter 18
Forensic Facility Plan and Design Guidelines

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Contents

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18.1 Introduction

As a lab director, one needs to learn how to develop specific planning strategies and methodologies for assessing the current facility, building support, obtaining financial resources, planning for the future, staying "Green," and achieving facility accreditation. This chapter will begin to address most of these issues and try to enlighten all that read it to what the issues are and the potential ways of handling them. So, other than reading this chapter, one should be out there networking with everyone; not only to enlighten them but to identify those who will listen and who care.

18.2 Can't Sleep

- Not enough staff to do all that is required, must accommodate more staff
- Staff is becoming burned out, need to address quality of life issues
- Staff is working in potentially unsafe conditions, need to improve indoor air quality
- Provide a safe and secure environment for evidence
- How to resolve a functionality ineffective building organization
- The non-assigned spaces seem inefficient and wasteful

Adding staff is not as easy as it seems, getting past budget cutbacks or hiring freezes are just a couple of the road blocks. Posting an opening for a new CSI or an examiner may result in a flood of resumes today. Due to the media's glamorous portrayal of forensic science in recent times, one may receive several resumes from PhDs for one CSI position; a difficult problem to have.

Improving safety and reducing burnout without hiring staff can be a challenge. Most forensic facilities are cramped, lacking equipment and physical space. However, there are ways to improve the use of existing space. For example, stack equipment vertically and bring services to the bench from overhead service carriers to free up bench space. When it becomes necessary to expand services, remember to begin planning from where you should be with existing staff; right sizing the operations. Then one can grow the facility effectively into the future.

To ensure proper health, safety, and security conditions within the lab, begin with checking ergonomics at the bench. Do criminalists have a proper chair or lab stool? Next, check for proper ventilated enclosures; a snorkel, fume hood, or biological safety cabinet might be the right device? Is a hand sink available to ensure proper hygiene? Can evidence be secured properly; provide evidence storing via drawers, cabinets, or rooms for proper storage when the anaylst is away from the workbench?

Involving the users in the planning and design process of building a new laboratory or renovating an existing facility is critical to the project's success. Designate a user representative who can stand in when the lab director is not

available. This individual has the responsibility to communicate the needs of all the staff to the design team. Planning the facility that utilizes lab modules is yet another way to ensure flexibility for the life of the building. This planning method inherently improves the effectiveness of the lab space and the flow of the forensic process.

The design process must begin with the people. As soon as everyone realizes that a new or renovated facility is needed, make a preliminary assessment of your existing surroundings. Document and analyze your needs opposed to the wants, and develop some planning concepts maybe around some new business concepts too. The outcome should establish a projected year of facility usefulness/capacity; often referred to as the "planning horizon." This horizon reflects the number of future staff needed, the size of the facility to accommodate the staff, and the projected construction cost as well as the operational cost.

18.3 To Renovate or Not

Most any structure can be renovated and converted into a crime lab if enough money is thrown at it. The problem is that most have limited funds and what little funds we have must be spent wisely. Beginning the renovation process with a simple evaluation of the existing building into a state-of-the-art forensic facility should only take a few hours. During a tour of the existing building, pay close attention to the following four areas and score each item identified within these areas as "0" for bad, "1" for good, and "2" for great. Remember to be objective and have others, with differing backgrounds, score the building too.

18.3.1 Exterior Envelope

Examine the doors and windows, foundation, and walls, and then check out the roof. Look for straight horizontal and vertical lines of the building's skin. If these lines are no longer straight, then the building may have settling problems, leading to leaks, entry of vermin, and costly maintenance throughout the life of the building. If the building facade (the front face of a building) includes brick, check to see if it is stained or discolored in any way, this could be signs of water damage behind the brick. On the roof, one should not see holes or punctures in the membrane, flashing (pieces of metal, built into the joints of a wall, so as to lap over the edge of the gutters or to cover the edge of the roofing) should appear intact, and there should be few visible signs of patching or repair. Also check inside the building for water damage or stains on ceiling tiles, walls, and floors. Pay particular attention to constructed openings in the roof for roof drains and skylights.

18.3.2 Interior Quality of Life

As one enters the building, ask yourself "How does it feel?" Look for a place that feels open and not confined, includes natural light or the possibility for it, that it is welcoming and shows great potential of meeting the needs of your staff and interfacing with the public. A facility that is inviting stimulates a positive morale and directly effects work habits and productivity. Flexibility. Pace off the distance between columns, do this in both directions (east/west and north/south). If the column bays that run in one direction of the building are a multiple of anything between 10′–0″ and 12′–0″, i.e., 20, 24, 30, 36, one should be in good shape. If the bay in the other direction of the building also follows that planning, terrific! If they are identical in both directions; then that might just outweigh every other problem with the building. Equally spaced column bays in both directions will allow one to rotate individual rooms 90°, changing the circulation paths and adding to a higher degree of flexibility.

18.3.3 Infrastructure

Inspect the building's mechanical, electrical, plumbing, and fire protection systems and rooms. No, one does not need a professional at this point; but rather than trying to determine the condition of these systems, look for the following: space around the systems and in the mechanical room to adequately maintain or replace an air handling unit, water boiler, or electrical switch gear; lots of electrical panels that feed the electrical distribution system throughout the facility; running water with decent pressure; a fire suppression sprinkler system that appears to be primed and ready to go, or are leaks visible or the fire suppression system does not exist. If these items exist and have scored favorably, then the building probably follows basic life safety and building codes.

18.3.4 Non-Assigned Space or Building Core

Finally, inspect the building's core elements: elevators, stairs, toilets, and janitor closets. Determine if they exist and could meet your potential needs. Check the equipment and the condition of these spaces. One should look for working toilets and sinks, floor drains that do not appear to be mucked up, elevators that are working properly, stairs that are in good condition and that stair landings appear wide enough to handle people traffic while accommodating a disabled person for fire rescue, and also to what level the existing core elements meet ADA (Americans with Disabilities Act of 1990) or could be modified to adhere to the Act.

Now, total your score. Of course, your score will be different than my score or another building's score, so use good judgment. These are just estimates, but if the

score is seven or less, run away as fast as you can. If it is eleven to eighteen, further investigation may be needed. If the facility scored higher than 25, do not let it go, retrofitting may be a viable option for this facility. Another way to look at this scoring system is to have three to four "great" scores to every "bad" score.

18.4 Developing a Case for a New Facility

The case one develops is a statement of where the lab is today, where the lab needs to be in the future, and most importantly, "why." Use the following steps as an outline.

- Identify the mission and objectives of the lab's current operation with an emphasis on what is needed and why.
- Identify the lab's new missions and objectives for future operations.
- Tell the story: include the good, the bad, and the ugly.
- Understand current staff and future growth needs and what is driving these factors.

In the justification letter or during conversations with superiors, use every opportunity to highlight the condition of the existing space. Begin this by telling the story of the current facility. While developing the agency's story, keep in mind this main goal of answering the question "Why does the crime lab need a new facility?"

Harold Messler, Manager-Criminalistics of the St. Louis Police Forensic Laboratory, was approached by his superiors to define why their agency needed a new facility. He responded by concentrating on the existing space first. Messler said, "ASCLD/LAB requirements dictate certain policies that must be met to insure the integrity of our work. Adequate space, segregation of activities, and sufficient infrastructure are addressed within these policies. We risk losing our ASCLD/LAB accreditation by not having a facility that would stand up to inspection."

Draw attention to staff changes within your agency. Collect historical data to benchmark where the lab has been, indicate where the lab is today, and where the agency plans to be in the future. Within most forensic laboratories today, the historic view will not reflect the actual need for today or tomorrow. The only reason to address it is to show how little things have changed over several years despite the desperate need. For example, the typical Criminalist is no longer a retired police officer or officer hurt in the line of duty looking for that cushy desk job. Now it is a four to six year college graduate with a degree in chemistry, biology, or forensic science, or perhaps an advanced degree. What will keep the educated, trained, and experienced staff around for another ten years? In projecting for the future, it is important to talk about recruitment and retention. Also discuss increase in caseload with more evidence items in the cases.

As you gather thoughts and prepare the justification letter for a new facility, remember to answer the question "Why?" This first step will open the door and lay

the foundation for a "Needs Assessment." When a needs assessment is performed by experienced forensic laboratory design professionals, the comprehensive tool helps move to step two: building support and obtaining financial resources.

18.4.1 Process Mapping to Help Build Your Case

Another step that one could take is to undergo a process mapping exercise to help understand the current condition, build justification for change, and plan for the future. The Process Map describes a series of connected steps or actions that achieve an outcome enhancing the ability to develop a deliberate course of action to improve the timeliness and quality of forensic services offered.

As forensic planners, we also use process mapping to translate scientific needs into improvements in facility design, incorporating results into the pre-design phase of a facility, adding a greater level of understanding of the forensic scientific methodologies. Additionally, it informs solutions for developing facility space that address equipment needs, variable analytical demands, contamination issues, staff health, safety, and security.

A version of process mapping is software based, it establishes a clear and comprehensive picture of how the forensic laboratory currently works or plans to work. It visually displays starting and ending points for functional activities, standards, and quality of input sequences throughout the process. The process could belong to a scientific group, a department, a single scientist, public interaction with a forensic facility, and even the evidence receipt activity, to name a few.

Many different layers of activities and resources can be reviewed in addition to the analytical process, such as: personnel, performance improvement opportunities, technology, training, case management enhancements, and accreditation. Process mapping can also aid the agency in other ways tied to facilities management, such as: analyzing existing or programmed spaces, validating staff numbers and equipment needs, confirming adjacencies between departments, setting up databases for new protocols, verifying square footage amounts, and enhancing space efficiencies.

A process map uses symbols, lines, and text to depict operations in graphical form. There are three basic types of maps: relationship, cross-function, and flowchart. Relationship and cross-function maps focus on either the big picture of products and services or the organization of personnel and responsibilities. Flowcharts illustrate actual work processes, breaking down tasks into small components.

18.4.2 Level of Detail

18.4.2.1 Time Analysis

A list of activities together with the analyst's estimates of time spent on each activity forms the basis for mapping. Our objective for time analysis is to estimate the average

Table 18.1 Kit analysis time

Sexual assault cases (hours)	
Minimum	20.4
Maximum	45.5
Average	33.0

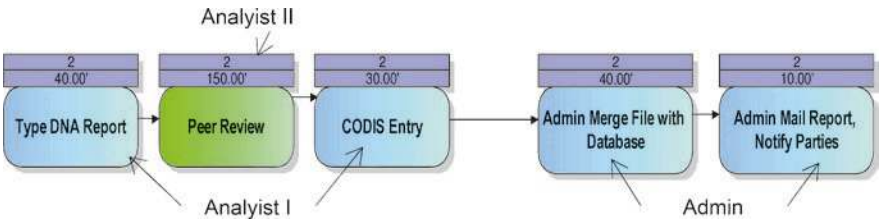

Fig. 18.1 Serology/DNA map

time required to solve a case. By collecting this data and comparing it against other agencies and national averages, we provide a benchmark for goals and expectations.

Table 18.1 illustrates the time spent to analyze four sexual assault kits. On average, 50% of sexual assault cases proceed to DNA analysis, adding 25 of lab analysis, for a total of 45.5 h. The average for two cases is 33 hours of analyst time.

18.4.2.2 Resource Analysis

In process mapping, "resources" are people. A map assigns a resource for each activity. If salary is available, the map can also calculate the total cost of a resource's time. One result of breaking down each task by resource is discovering activities that could be automated, simplified, or reassigned to other resources both within and outside the agency (Fig. 18.1).

For example, the Serology/DNA map above illustrates the use of three resources for a sexual assault case – Analyst I, Analyst II, and Administrative. Analyst I activities include search file folders to pull cases, retrieve evidence, bring evidence to the lab, write chain of custody form, perform analysis, type findings, store evidence, and forward the file to Analyst II or Administrative. If validation is required, Analyst II performs a peer review before moving the case from the lab. Once delivered, Administrative merges the typed report with the lab's database; another analyst reviews it; Administrative mails to the appropriate parties; and follows up by verbal agency notification.

Translating the map (Fig. 18.2) leads to an architectural design solution. The solution locates these resources in close proximity to each other while providing adequate space for each to complete their activities. A closer look at administrative activities reveals that work is currently completed on a word processor. Introducing a Laboratory Information Management System (LIMS) would reduce paperwork

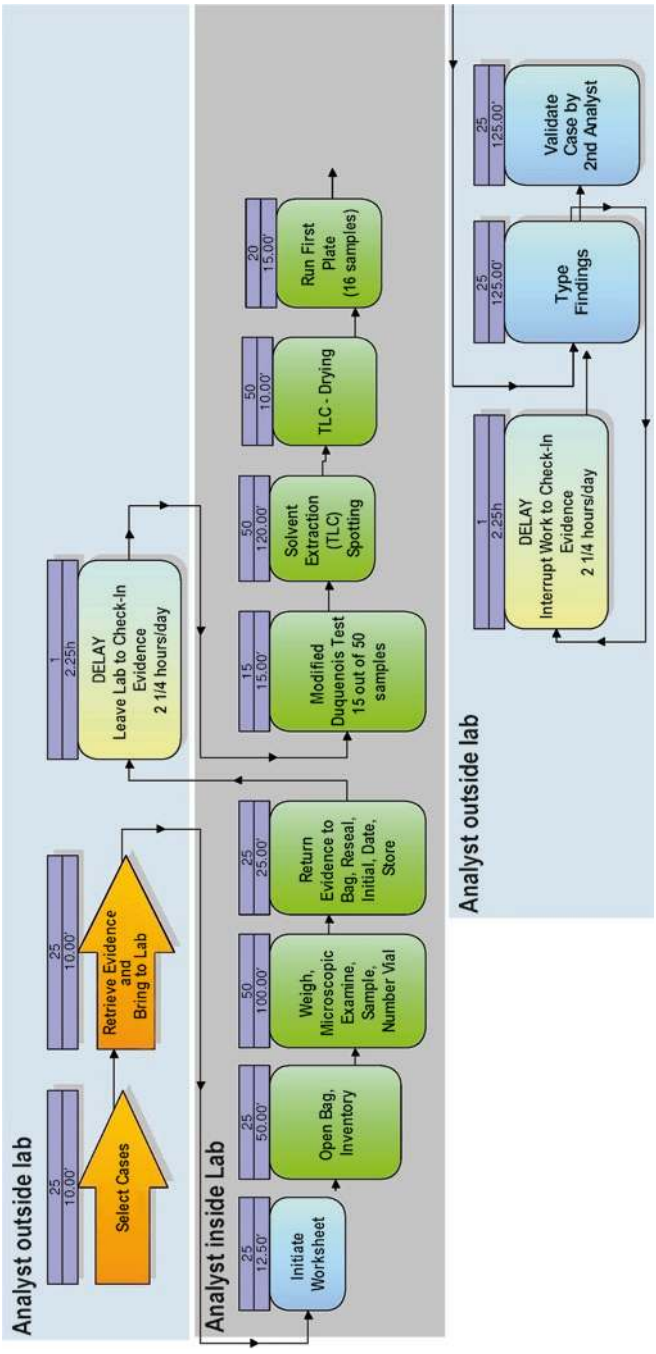

Fig. 18.2 Translating a process map into a lab design or layout

time for all resources. A LIMS does, however, require additional space and services – from location and security concerns of the server to provision of the right amount of surface for remote units and the activity surrounding it.

18.4.2.3 Swim Lanes

Swim lanes are another way to indicate where a resource performs an activity. Figure 18.2 demonstrates a group's activities broken into three lanes either inside or outside the laboratory environment. Identifying the appropriate amount of time spent in a particular environment allows the design team to size the mechanical, electrical, and plumbing systems to match up with the activities – from the amount of fresh air and number of air changes per hour for each space to the number of watts per square foot, and from how clean power must be to deciding if central piped nitrogen is required over a local cylinder or if a generator will meet the need.

18.4.2.4 Occurrence Rate

Above each activity box are activity values including activity frequency. Some activities occur parallel (together), and some occur serially (one after the other).

The two DNA extraction activities are performed in different sequences resulting in different time totals. For crime scene sample extraction, evidence integrity is maintained by working cases separately – thus, for a 180 minutes activity, the total for two cases is 360 minutes. The extraction of known samples (standards) can be worked in parallel, requiring 180 minutes total for two cases.

The analyst establishes occurrence rates based on experience, and the design team validates them through interviews, time collection techniques, and physical observation of the tasks and environment.

18.4.2.5 Activity Type

Each resource activity is "typed" to understand how resources spend time. This benefits process mapping by breaking down time into different types of categories. For example, "report typing" and "report processing" are two different types of activities performed by two different resources: analysts and administrative staff. Usually the analyst types a report document on a computer using software such as Microsoft Word. The administrative staff takes the Word document and pastes it into the final report, still using Word. If analysts used a LIMS with standard report formatting available, the administrative staff's time processing reports would be greatly reduced and thus could be directed to other activities. Refer to Figs. 18.2 and 18.3.

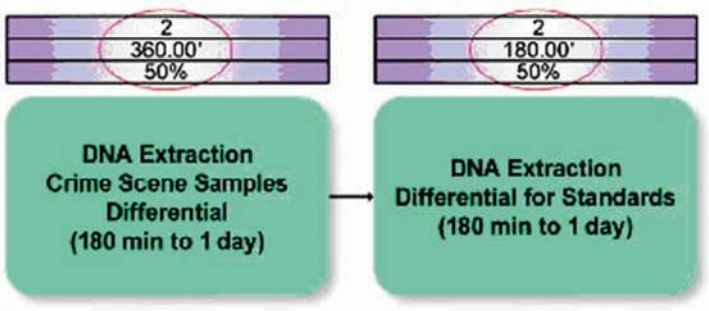

Fig. 18.3 Example of an activity box

18.4.3 Approach to Generating a Process Map

There are several ways to collect the information needed to create a map of existing processes. The design team may submit a time collection tool to the key individual who represents the functional process. The design team analyzes the data and then generates a process map. Another approach is physically observing the activities. Here the design team spends time in the lab with users and documents their activities every step of the way. Documentation includes using the time collection tool, interviews, and photographs.

The design team will also conduct one-on-one interviews with key individuals involved in the function to transfer their knowledge and performance of activities into data for the process map. This information is used to develop a prototype model. Those involved in the process then review the information for completeness and accuracy. Yet another option to this method is to conduct a group interview. This option provides maximum direct interaction among everyone involved, building consensus while forming the process map. With this method, oftentimes the group establishes a sense of ownership for the map and work processes.

Process mapping can help crime labs improve their current forensic processes and operational management. Taking new understandings and translating them into architecture will improve facility design. A well-orchestrated process mapping exercise can benefit the whole forensic facility in several ways: a very specific understanding of forensic scientific methodologies that will influence space, from understanding the delays in the process to adding more staff, more analytical equipment, and more space to improve case turn-around time.

18.5 Forensic Laboratory Planning

In recent years, the planning of forensic laboratories has evolved. Historically, they were planned by healthcare or criminal justice architects, where now they are programmed, planned, and designed by specialized forensic laboratory consultants.

These new forensic laboratory consultants combine the lessons learned from a variety of laboratory facility types to create tomorrow's state-of-the-art forensic lab. Today's forensic facility occupants wish to be a part of the design process that will provide the best possible space for today and for tomorrow. One tool forensic planners use to achieve this is called modular planning or modular design. While modular design organizes the laboratory building, it also organizes the utility systems "infrastructure" and their distribution throughout the facility. The combination of building organization "architecture" and infrastructure "engineering" creates a facility that is intrinsically more flexible and adaptable, easier to renovate and modify, and extending the useful life of the laboratory.

Modular planning uses blocks of space of proportional sizes to give the designer and the user multiple options for achieving a flexible facility. These blocks of space, or modules, respond to the functional dimensions necessary for forensic science activities. Modular planning takes into consideration acceptable lengths and depths of laboratory casework, structural systems and column bay spacing, fixed and movable laboratory equipment, ergonomics and the user's health and safety, along with code requirements. Once a module size is developed for a specific user or facility, the modules can be laid out together as a floor plan and the laboratory begins to take shape. Modular planning does not mean that each module has four walls and a door, rather it is a space assigned to a specific function, activity, or occupant.

Let's look at an example for a typical firearms section with six examiners. Through interviews, benchmarking, and industry standards, we have determined that each examiner requires 120 NSF (net square feet) for an examiner's workstation, 120 NSF for an office, and another 720 NSF of support space for reference weapons, ammunition, and temporary evidence storage within the section. The programmed NSF is equivalent to 960 NSF, or four modules of 240 NSF for each examiner. The firearms section, therefore, is made up of 5,760 NSF or a total of 24 modules of 240 NSF for six examiners.

An industry standard in firearms is the combination of office space with the examiner's workstation area. This is possible because there are no chemical hazards present at the examiner's workstation. If we apply this practice in a planning concept, an open laboratory environment of 1,440 NSF (six modules) for office and examination activities is created, giving the examiners a larger flexible space, rather than their individual space, in which to work.

The open laboratory concept is an efficient floor plan. With fewer walls and doors, fewer dedicated corridors are needed for circulation through the space. Older forensic facilities were designed for each occupant and each instrument to have its own room. This design strategy lacks the internal flexibility of the space; the rooms are "landlocked" and unable to change when additional personnel are added, or there is a change in scientific methods, or new equipment is added. We have seen a 20–22% improvement in today's open laboratory environment net more usable square footage. The net to gross ratios for most new forensic facilities falls between 62 and 66% efficient. An entire building with lots of labs would net 50–58% efficient and a building with lots of offices would net 65–72% efficient. Concepts that can alter the building's efficiency include the use of dedicated corridors for

transporting evidence, incorporating a public tour route with the laboratories, and the open laboratory environments.

It's proven that the better the quality of life, the better the productivity of the occupants in the facility. Forensic scientists have been some of the most resourceful people when it comes to laboratory space. They can take a recently vacated jail cell and convert it into evidence holding or even into laboratory support space without removing a single cubic foot of concrete or even the cell door. However, it is not desirable to set up scientific equipment in such spaces; not only is it bad for morale, it doesn't add credibility to the scientific process of evidence examination. That's why it's important to have appropriate space.

The open laboratory environment can improve morale among the staff and reinforces the credibility of the forensic system. The larger volume of space is better equipped to handle rejected heat from laboratory instrumentation, which translates into better ventilation for the users. Locating the laboratory along an exterior wall allows natural day light into the open lab and travel through it into the corridors and offices beyond. Day lighting also provides a means of visual relief for the laboratory occupants, improves visual acuity, and reduces eye strain; not to mention being able to tell if it's going to rain or see the morning sun. Also, all of these improvements benefit the user and improve the level of safety in the lab.

18.6 Engineering Basis of Design

The basis of design (BoD) is a narrative for the systems found in a forensic facility. One might refer to this as an "Outline Specification." The following is the MEP engineering portion of the BoD.

18.6.1 Heating, Ventilating, and Air Conditioning

18.6.1.1 Introduction

Heating, Ventilating, and Air Conditioning (HVAC) systems that support modern forensic laboratories provide comfort for lab occupants and an environment that supports scientific investigation. They are also critical in maintaining a safe and healthy indoor environment. The control of temperature, humidity, directional air flow, and air quality are necessary performance duties of the forensic facility HVAC system. A number of factors must be considered when selecting and designing the: air supply and exhaust systems; building and safety controls; and the central heating and cooling equipment so that the total system functions correctly.

18.6.1.2 A Key Challenge

Forensic laboratories have a wider range of laboratory spaces than any other type of science facility. Designing HVAC systems that support these laboratory types is one of the key challenges. The ventilation system for a drug chemistry lab is significantly different than that required for a ballistics area.

18.6.1.3 Starting Precept

A number of forensic laboratory operations involve some physical or health hazard. Materials are used or analyzed that are toxic, infectious, flammable, or explosive. Understanding the hazards presented in the different laboratory areas is the first step in the design and selection of the HVAC systems and determining the required contaminant devices.

18.6.1.4 The Basis of Design

A number of decisions go into the design of the laboratory HVAC systems. The design engineer needs input from the scientific staff, the building operations personnel, the lab directors, and the individuals responsible for financial control. All of these individuals bring a different perspective to the decision-making process and managing this process is important. A successful communication tool is the BoD narrative. This narrative prepared by the design engineer in plain English needs to define critical performance factors including:

- Indoor and outdoor temperature and humidity design conditions
- Air filtration and special treatment
- Expected scientific equipment and the amount of cooling being provided for it
- Ventilation rates and pressure relationships for individual spaces
- Exhaust and air intake location criteria
- Types of chemical fume hoods, biological safety cabinets, and other containment devices
- The need for standby or redundant equipment and emergency power
- Monitoring and alarm requirements for critical scientific equipment
- Provisions for expansion or addition of equipment in the laboratory
- Strategies for energy conservation, the savings resulting from them, and their associated first cost

18.6.1.5 Integrating the HVAC System and the Architectural Planning

Successful designs of modern forensic laboratories utilize a modular approach to architectural space planning. Reinforcing the architectural modular planning in the

layout of the HVAC system creates buildings that are inherently more flexible and deliver higher long-term value. Laboratory planning modules are frequently 10–12 ft wide and 20–30 ft deep. HVAC distribution systems need to reflect this architectural planning module.

18.6.1.6 Anticipating Change

Law enforcement objectives combined with scientific equipment that is continually evolving require HVAC systems that are designed to accommodate change without modifications. For example, the cooling capacity for an analytical area may need to be designed to accommodate a shift to high-throughput robotic analytical equipment.

18.6.1.7 Containing Hazards

A number of devices are commonly used in a forensic laboratory to contain potentially hazardous materials and to protect the lab staff. These devices include chemical fume hoods, biological safety cabinets, snorkels, flammable storage cabinets, fingerprint dust workstations, evidence drying cabinets, superglue enclosures, and downdraft tables.

In general terms, fume hoods are utilized to contain odors, vapors, and fumes to protect the scientist that is using these materials. In addition to protecting the scientist, biological safety cabinets also provide protection to the sample being analyzed because the air flowing over the work surface has been high-efficiency particulate air (HEPA) filtered. Containment of hazards in a fume hood or biological safety cabinet is based on the principle that an inward flow of air entering at the face of the fume hood or biological safety cabinet prevents the escape of airborne contaminants into the room. Location of fume hoods and biological safety cabinets out of traffic patterns, and away from doors and supply air diffusers is important to ensure their proper performance.

Other exhaust devices used in forensic laboratories:

- Snorkels to remove heat or nontoxic fumes that may be generated from benchtop research equipment.
- Canopy hoods are used to remove heat or moisture generated by an autoclave.
- Fingerprint dust stations typically re-circulate air back to the laboratory after filtering.
- Compressed gases that present a physical or health hazard are often placed in exhausted gas cylinder cabinets.
- Acid storage cabinets are exhausted to prevent the build-up of hazardous vapors.

18.6.1.8 Maintaining a Good Indoor Environment

The total airflow rate for a laboratory is dictated by either the amount of exhaust from containment and exhaust devices, the amount of cooling required to offset internal heat gains, or the minimum ventilation rate requirements.

Laboratories in which chemicals and compressed gases are used require non recirculating air supply systems. The selection of 100% Exhaust Air systems vs. return air systems should be made understanding the hazards presented in the specific laboratory. Some forensic laboratories like Computer Forensics can be provided with a recirculating air system that is less expensive to install and operate.

Minimum airflow rates are generally in the range of 6–10 air changes per hour when the space is occupied; however, some spaces may have minimum airflow rates established by specific standards or by internal facility policies. A guideline often followed is the National Institutes of Health recommended minimum ventilation rate of six air changes per hour for occupied laboratories.

Where the amount of ventilation is determined by either equipment cooling requirements or exhaust device exhaust rates, it is common to recognize that all exhaust devices or equipment are seldom used at the same time, creating a "usage factor." Applying a "usage factor" in the design of a forensic facility must be analyzed carefully to avoid an undersized ventilation system.

The filtration for the air supply depends on the requirements of the laboratory. Filtration in the 85–95% dust spot efficient filtration is acceptable for most areas in a forensic laboratory. Only limited and very special areas require HEPA filtration.

The exhaust system must be controlled and coordinated with the supply air system to maintain the labs with negative air pressure compared with the surrounding spaces. Laboratory exhaust systems can be constant volume or variable volume flow. Each fume hood may have its own exhaust fan, or fume hoods may be manifold and connected to one or more common central exhaust fans. In general, variable volume, pressure-independent manifold exhaust systems are more flexible, offering the ability to easily add exhaust devices, require less ductwork, involve fewer pieces of equipment, simplify roof penetrations, involve fewer exhaust stacks, and create an opportunity for energy recovery.

There are a number of different options for the control of air exhausted through fume hoods. Hoods can be configured to vary the amount of exhaust volume in relation to the sash opening. They can also be equipped with sensors to reduce airflows when no one is present in front of the hood. Some hood designs incorporate smaller opening sizes and then maintain a reduced constant volume. The decision of hood style and control needs to balance operation, energy consumption, and maintenance complexity.

Care needs to be taken when choosing exhaust and air intake locations to avoid drawing exhaust effluent in the fresh air supply to the building. The height of the exhaust stack, the discharge velocity, and the location of the exhaust stacks and the fresh air intakes are all variables that need consideration during design.

18.6.1.9 Keeping it Working

Forensic laboratories by their very nature are complex buildings, incorporating systems and equipment not found in other types of buildings. The designer should work with operation and maintenance personnel early in the design of systems to gain their input and agreement. The degree of sophistication of building systems

need to match with capabilities of staff responsible for maintaining the building. A number of features can be incorporated to make forensic laboratories more easily maintained, including:

- Centralized monitoring of critical freezers, face velocity of fume hoods, supply flows, and exhaust flows is useful for predictive maintenance of equipment and for ensuring safe conditions.
- High-maintenance items should be placed outside the actual laboratory to reduce disruption of laboratory operations and exposure of the maintenance staff to laboratory hazards.
- Preventive maintenance of equipment and periodic checks of air balance should be scheduled.

18.6.1.10 Saving Energy

Forensic laboratories consume large amounts of energy. Efforts to reduce energy use must not compromise safety. Energy reduction strategies must be both appropriate and economically justifiable. A number of potentially viable energy reduction measures should be considered, including:

- Energy-efficient lighting (reduces both electricity used for lighting and air conditioning).
- Variable-volume control of exhaust air through the fume hoods to reduce exhaust airflow when the fume hood sash is not fully open.
- Night setback controls to reduce the exhaust volume when the lab is unoccupied.
- Fume sash configurations that limit the opening height and width.
- Rotary air-to-air energy exchangers or heat wheels.
- Coil energy recovery loops (runaround cycle).
- Hydronic systems associated with HVAC that capture rejected heat from centrifugal chillers can be used to produce low-temperature reheat water.

18.6.1.11 Making Sure It's Right

Laboratory utility systems not only provide comfort for building occupants, but are also critical in providing a safe and healthy work environment. It is important that before the laboratory is turned over for use by the scientific staff, proper system operation is verified and those technicians, scientists, and maintenance personnel are trained and understand the systems and their operation. The process of validation and training is called commissioning and starts with the intended use of the laboratory and should include development of a commissioning plan, validation of individual components, and evaluation of the entire system. This requires verification that the design meets applicable codes and standards and has been constructed in accordance with the design intent.

18.6.2 Fire Prevention and Protection for Forensic Labs

18.6.2.1 The Challenge

The services provided and the spaces that support the operations of a forensic facility present a wide range of fire protection challenges. The use of flammable chemicals in laboratories, the storage of evidence and reference material, the protection of expensive scientific equipment and providing safe egress for the building occupants are among the issues that forensic facilities must address today.

The goal is to provide a comprehensive fire prevention and protection program. This prevention plan is designed to protect the building occupants and assist emergency response personnel when necessary. In addition to the fire suppression system, providing appropriate fire safety involves good laboratory practices (GLPs), appropriately designed storage facilities, adequate first response devices, smart ventilation control strategies, and proper emergency response plans. All of these pieces need to be in place for an effective prevention and protection program.

Let's look at some of the unique forensic disciplines, their spaces, and their requirements for the operations of a forensic facility.

18.6.2.2 Spaces

Controlled Substances

Controlled substances probably represents the largest user of flammable chemicals. Good practices include an adequate number of chemical fume hoods for staff and their functions, including flammable storage cabinets located in close proximity to or at fume hoods where chemicals are being used. If the analysis of clandestine lab materials (such as methamphetamine) are within the scope of the lab protocols, this should be located directly connected to the exterior of the facility so that large quantities of chemicals are not brought deep into the building.

Latent Prints

Most latent print processing and collection presents limited unique challenges. One that requires special attention is the use of Ninhydrin, a skin, eye, and respiratory irritant. The use of DFO and petroleum ether must be in a fume hood because this form of ether has a very low flash point and is considered highly flammable if not in an effectively ventilated device. Another common chemical used to develop latent prints is silver nitrate, which is an oxidizing agent that should not be stored in the same cabinet as flammable agents.

Instrument Rooms

A large instrument room may be home to millions of dollars worth of scientific equipment. The challenge is twofold, first, preventing accidental discharge of water from the suppression system and, second, the suppression of a fire if indeed one did occur.

Evidence and Property Storage Areas

Evidence and property storage areas vary from small closets to large warehousing facilities and present different fire prevention and protection challenges. A fundamental decision is what amount of investment is prudent to invest to preserve evidence from water damage. Property storage areas often are large warehousing operations that involve the storage of a wide variety of material on rack and shelving systems. These spaces present different suppression challenges and may require higher-density sprinklers and possibly in-rack sprinkler systems. Because the volume of these spaces is so great, the use of chemical or gaseous suppression systems is generally not feasible.

Vehicle Exam Bays

In themselves, vehicle exam bays do not present unique fire protection challenges (unless a pit is utilized for under-vehicle access). Protocols for fire prevention probably have the greatest impact. Defueling vehicles and inspecting them for explosive or other flammable cargo is clearly an important part of the investigatory process.

Firearms

Inherent in firearms examination and testing is the presence of limited amounts of explosive materials. The location of sprinklers in the firing range needs to be detailed to avoid damage from a stray bullet.

18.6.2.3 Systems

Wet Sprinkler System

This system involves overhead sprinkler piping, usually concealed above the ceiling. The system is filled with pressurized water, sometimes containing an agent that prevents the water from freezing. The piping is connected to sprinkler heads that poke through the ceiling; each sprinkler head utilizes fusible links that melts away due to excessive heat allowing water to flow. This system meets basic code

requirements and, in the event of a fire, will activate only in the involved area and is the lowest first-cost solution.

Interlocked Dry Pipe System

This system still uses water as the extinguishing agent, but requires two events to occur before water is discharged. These events can include a temperature rise in the space that melts the fusible link on the sprinkler head and the electronic detection of fire or smoke in the space, which in turn opens a valve upstream of the sprinkler head, letting water flow into the system. The use of an interlocked dry pipe system greatly reduces the opportunity for accidental discharge of water, because events like physical damage to a sprinkler head causing water discharge are now eliminated. An interlocked system has a moderate first-cost premium over a wet pipe system.

Chemical or Gaseous Systems

Both carbon dioxide (CO_2) and FM200 are examples of these system types, which utilize an electronic method of fire or smoke detection to release the extinguishing agent. These systems have the advantage of being fast acting and can catch a developing fire early in its existence. There is either limited or acceptable clean-up required from their discharge and scientific equipment is usually preserved. There are hazards associated with CO_2 systems because the displacement of oxygen from the room presents a suffocation hazard to personnel. Because these systems commonly use extinguishing materials of limited quantity, consideration needs to be given to providing a "double shot." In some cases, code officials have also insisted on providing a wet system as back-up, defeating the main purpose of installation of a chemical or gaseous suppression system. Gaseous and chemical fire suppression systems are the most expensive fire suppression option.

Flammable Storage Cabinets

These cabinets are constructed of 18-gauge steel. Sides, top, bottom, and doors are double-walled, with a 1.5″ air space between walls. Both vents, with 2″ threaded fittings, have a fire baffle and cap. Flammable Cabinets must be clearly labeled with a sign that reads: "Flammable – Keep Fire Away," grounding attachment, 3-point key lock, and 2″ raised, leak-proof door sill, adjustable shelf, supported by four brackets, and can support 350 lb per each flammable storage cabinet.

Venting of flammable storage cabinets is not recommended because it could reduce the fire protection effectiveness of the cabinet and void the Factory Mutual, Underwriter's Laboratory, or other qualified testing agency labels. Also never locate the flammable storage cabinet by an exit door.

Ventilation Systems

Ventilation systems should be designed to stay in operation in the event of a fire to properly remove toxic products of combustion.

Fire Extinguishers

Today the most widely used fire extinguisher is a multipurpose dry chemical type designed to effectively handle Class A, B, or C fire. The extinguisher should be located near the potential source and located to assist the user to egress the space. Fire definitions are: Class A – paper, trash, plastic; Class B – flammable liquid and gases; and Class C – energized electrical equipment. A good rule of thumb when experiencing a fire is to first activate the buildings alarm system, then assist occupants in the safe exit of the facility, and finally (you have been properly trained to do so) attempt to extinguish the fire.

Choosing the right fire protection system for your forensic facility requires serious consideration of all the options. It is important to remember that one system type may not meet all of your facilities needs correctly. It is also important to combine all of the fire protection issues to create the right solution.

18.6.3 Laboratory Plumbing and Piped Utilities

18.6.3.1 The Challenge

Forensic science has a significant reliance on analytical instruments and these instruments require stable and pure piped utilities to support their operation. The piped utilities required in forensic laboratories include hot and cold water, sanitary and laboratory waste drains, instrument-grade compressed air, vacuum, high-purity water, and compressed gasses.

18.6.3.2 Water Supply

Municipal water supplies are the common source of water and generally the quality of the water is suitable for most uses in the building. You should, however, understand the water quality that is available and consider if any treatment, such as filtering or water softening, is merited. In most cases, the water supply for potable water use is also the supply for fire protection, which will present the greatest flow requirements. If you find yourself in an area with unreliable water sources, consider carefully onsite storage requirements for potable, air conditioning, and fire protection needs.

18.6.3.3 Drainage

Historically laboratories have been provided with two separate drain systems. Sanitary drain systems, which connected to water closets and lavatories, and specialized laboratory drainage systems, which connected to sinks and floor drains in the laboratory spaces. These systems were kept separate within the building but ultimately connected outside and into the municipal collection and treatment system. With today's restrictions on materials that can be disposed of through the municipal treatment system, the merits of separate piping systems in the building should be weighed against the first cost of these systems. Often the use of localized treatment at certain systems can eliminate the need for separate systems.

18.6.3.4 Compressed Air

Compressed air is used for a number of different processes within forensic laboratories. Generally a centralized compressed air system that utilizes oil-free compressors combined with a desiccant dryer provides a suitable source. In sizing the compressed air system, consideration of normal laboratory use of bench outlets needs to be considered along with the demands of compressed gas generators.

18.6.3.5 Vacuum

Vacuum needs can be met either by a centralized system or by distributed localized vacuum pumps. If localized vacuum pumps are utilized, planning should include location of these pumps in sound-proof ventilated under-counter storage cabinets.

18.6.3.6 Natural Gas

The use of natural gas in forensic science is very limited and generally the installation of piped natural gas to the laboratory spaces is not merited.

18.6.3.7 Compressed Gasses

Nitrogen, hydrogen, argon, helium, and zero air, among others, are gasses commonly required in forensic laboratories. These gasses can be provided from bottled sources, or, in some cases, from compressed gas generators. Compressed gas generators offer the benefit of reducing the need to change gas cylinders and also reduce potential risks and hazards by limiting the flammable material in the building. Make sure to match compressed gas quality and the cleanliness of piping systems with instrument needs.

18.6.4 Lighting

A well-designed lighting system can have a big impact on the quality of the work environment and on the amount of energy consumed in a forensic laboratory building. Consider carefully an overall strategy for lighting that employs natural day lighting in combination with efficient lighting systems. The orientation of the building on the site and the location of laboratories and offices in the building have a big impact on how effective are the day lighting strategies that can be employed. Generally the north and south exposures of a building are the easiest to design for effective use of day lighting, and locating laboratories and offices in these areas should be part of the strategy. For day lighting strategies to provide energy reduction, they need to be combined with perimeter lighting control systems that automatically reduce electrical lighting levels based on available daylight. Interior spaces can also be equipped with occupancy sensors to reduce lighting in unoccupied areas.

The type of light fixtures and the lamps are important. The use of direct/indirect high-efficiency pendant mounted light fixtures both creates an open feel to the work environment, and also provides for a low energy usage. Utilizing full-spectrum lamps in these fixtures improves color perception, which is important in certain forensic sciences.

18.6.5 Electrical Power

A stable, reliable, and clean source of electrical power is required to support the scientific equipment and functions. The quality of scientific analysis can be adversely effected by electrical power problems and in some cases crucial evidence can be lost if power failures occur at critical times. Understand the quality of the municipal power supply and include power conditioning, uninterruptible power supplies, and an emergency generator.

The emergency power system can be designed to support only critical loads, or sized to allow scientific functions to continue in the building. This should receive discussion early in the design process. At a minimum, items related to life safety, along with critical freezers and refrigerators, need emergency power. Medical examiners facilities that need to function in a disaster may need to have the full facility supported by emergency power.

Understanding the quality of the utility power is the first step in the design process. If the incoming utility power is poor, power conditioning equipment can be provided in the incoming electrical devices. Care also needs to be taken with the design of the internal power distribution system to separate reactive loads like motors and fluorescent lighting from power delivered to the laboratories.

18.6.6 Information Systems and Communications

Information systems are probably the systems in the building with the shortest expected useful life. Improvements in technology and hardware will necessitate

constant change. Designing the infrastructure to support change and be easily adaptable is important. A number of information systems and dedicated networks are commonly required in forensic facilities. An overall building network, sometimes combined with a LIMS, requires a system of cable trays and raceways connecting to readily available outlets to support the networking requirements. Specialty and secure systems support dedicated functions such as CODIS and AFIS.

18.6.7 Security and Access Control

The following are potential loss events that should be considered: internal theft (theft by staff), external theft, robbery (theft involving violence or the threat of violence), assault (includes rape and murder), fire (not arson), arson, workplace violence, bomb threat, hazardous materials (includes chemicals and biochemical), mail bomb, drug use, kidnapping, invasion of privacy, acts of terrorism, vandalism, and civil disturbance.

In terms of physical security, the primary concern should be the safety and security of staff and visitors within the development as well as physical assets of the development. The impact of the threats discussed above can be reduced or eliminated with the implementation of appropriate operational procedures and the installation of appropriate physical security installations. Creating the perception that a facility is secure, well designed, and operated to a commensurate level is of paramount importance in the deterrence of these undesirable activities. The installation of video surveillance system (VSS) cameras controls at vehicular entrances to restricted areas, passive architectural elements, and access control should minimize the incidence of detrimental activities and provide the means to analyze events after the fact, should this be necessary.

The Access Control and Monitoring System (ACMS) will be the primary system responsible for integrating security devices, and processing and consolidating information from the VSS, security intercom system, and any other security systems.

18.7 Building Management Systems

Laboratory facilities by their very nature are complex buildings and one of the keys to making sure that they are manageable and not overly complex is the Building Management System (BMS). A well-designed BMS brings together a number of different systems and centralizes the ability to understand real-time temperatures, flows, and conditions throughout the forensic laboratory. Having this networked control allows overview of conditions, and enables the use of control strategies to maintain safety and reduce energy consumption.

18.8 ISO-17025 and the Effect on Forensic Facility Design

In the forensic industry, if a new standard could reduce doubt in the courtroom and enhance scientific analysis, every director would want to implement it into their laboratory. Additionally, in the future, this may be more than "want," it may be required. ISO-17025 accreditation does just that. Gaining ISO-17025 accreditation is an internationally recognized achievement that enhances the reputation of the laboratory and testifies to the value of continuously reaching excellence. However, as all laboratory directors know, receiving accreditation is not a single milestone, but an ongoing process.

The new standard for laboratory accreditation is ISO-17025. It provides a framework for the specific needs of organizations that want to control their laboratory processes. The requirements of ISO-17025 encompass all aspects of laboratory management, including calibration procedures, analytical testing proficiency, report generation and record keeping, and to ensure calibrations are performed by properly trained personnel using controlled test methods and procedures. The bottom line is that, to be ISO accredited, the laboratory must not only be consistent in their procedures, but have a properly designed facility.

Good laboratory practices (GLPs), when implemented, will assist in the process of gaining accreditation. GLP is the opportunity to incorporate design specifications required for ISO before even applying for accreditation. Having the right laboratory environment for every staff member is a vital part of ISO-17025 requirements and clearly represents GLP. The following spaces may or may not exist in your current or proposed facility, but the Quality Manager (QM) and their staff will benefit greatly if the following spaces are implemented. It is my opinion that as the forensic industry evolves and more state-of-the-art facilities are designed, these spaces will become industry standard for all laboratories seeking ISO-17025 accreditation.

The general requirements of ISO-17025 states in Sect. 4.1.5i that, "The laboratory shall appoint a member of the staff as QM." The QMs office should be a private location with at least 121 NSF. 121 NSF will be used as the typical building block module. This office should be designed with four walls and a lay-in ceiling. Standard office furniture must be provided, including a locking door and two guest chairs. The door can be solid or have a vision panel of safety glass. When implementing a locking mechanism for the office, I recommended using the staff member's ID badge that activates a proximity card reader. Adding a smart board to the office will assist in group discussions and offer the option of scanning data into electronic media. It is also crucial that the office have direct access into a workroom.

The workroom needs to be at least 121 NSF with four walls and a hard, drywalled ceiling for extra security. Other features that are needed include a $3' \times 4'$ table, two chairs, a temporary file cabinet, and a locking door. The purpose of this space is to provide the QM with a room that can be secured for days if necessary and provide enough space to bring files in while working on a large project. Both the QMs office and workroom are intended to be located near the laboratories described below.

Having a Health and Emergency Lab Panel (HELP) station in every laboratory is an asset when seeking ISO accreditation. A fire extinguisher, fire system annunciator, fire blanket, spill kit, first aid kit, and emergency phone are all items found in a HELP station. This is also a suitable place for documents including, but not limited to, the MSDS Sheets and the Emergency Operations Manual. Section 4.3.2.2 of ISO-17025 requires that "Appropriate documents are available at all locations where operations essential to the effective functioning of the laboratory are performed." If an emergency shower and eyewash equipment are required for your specific lab, these can also be located near or in the HELP station.

Having two laboratories dedicated for the QM and staff to use at any time is recommended. This space is required for verifying the quality of reagents and consumable supplies, setting up double-blind tests, and validating new science methodologies and new instrumentations. Both labs should be located near the central receiving and storage space so that materials can be easily accessible for testing.

The layout of these two labs should be similar. The preparation space in the front section needs to be 121 NSF with a fixed perimeter bench, sink, and a chemical fume hood. The next 121 NSF section is for workstations. It consists of a mix of fixed and movable casework to mimic the workstations in the forensic lab. The last 121 NSF space is designed for instrumentation with movable instrument carts. A 121 NSF Exam/Alternate Light Source (ALS) room should be accessible from both laboratories and have a small amount of fixed bench and a forensic exam table in the center of the room. The main difference between these two labs is that one is intended for chemistry activities and the other for biological activities.

Some states have already mandated ISO-17025 accreditation when testifying in court. It is only a matter of time before a national standard is implemented. If you are still in the design phase of your future facility or even looking to renovate your current space, incorporating an office for the QM, workroom, HELP stations, and two laboratories for chemistry and biological activities is strongly suggested.

18.9 Sustainable "Green" Forensic Laboratory Design

Every day the U.S. population is faced with the vast issue of energy reliability and availability. Those who were affected by the "Blackout of 2003," know firsthand the value of our natural resources. The absence of electricity and water dramatically impacts every aspect of our lives. For that reason, protecting and conserving our natural resources should be taken seriously. Laboratories are one of society's major energy users and consumers of natural resources, but that can be moderated by incorporating several different design strategies. Within the forensic industry, we refer to sustainable, or "green," design to create laboratories that will endure the test of time and save energy.

Sustainable design provides facility users with a comfortable, safe, healthy, and productive environment while supporting a building infrastructure that enables the forensic laboratory functions to be energy efficient. These energy efficient laboratories

meet the needs of today, without sacrificing future needs. Forensic laboratories consume considerable resources during various criminal investigations, making sustainable design a challenge in these facilities. To overcome the obstacles that diminish our natural resources, new forensic laboratory projects incorporate several sustainable design strategies. Many facilities also seek U.S. Green Building Council Leadership in Energy and Environmental Design (LEED™) Certification. Fortunately, there are two excellent resources available to help designers and owners achieve their goals.

The first is LEED™, The Leadership in Energy and Environmental Design initiative, sponsored by the U.S. Green Building Council. This is a voluntary, consensus-based national standard for developing high-performance sustainable buildings. The members of the U.S. Green Building Council that developed LEED™ represent all facets of the building industry and are continuously updating the standard. LEED™ standards are available not only for new construction and major renovations, but for existing building and commercial interior projects. Additional information on LEED™ is available at www.usgbc.org.

The second resource is the Environmental Performance Criteria for Laboratories (EPC), jointly sponsored by the U.S. Environmental Protection Agency (EPA) and Department of Energy (DOE). EPC is an extension of the LEED™ rating system, but focused on laboratory projects. EPC requirements are over and above LEED™ because the environmental impact of laboratories is much greater than that of an average building. Currently there is not a formal accreditation process for the EPC. Additional information is available at www.labs21century.gov/toolkit/epc.htm.

After reviewing various LEED™ and EPC resources, many design approaches and strategies will be apparent. When evaluating your laboratory's specific sustainable design strategies, we recommend only seeking those that will help conserve natural resources without compromising performance, safety, and reliability. This chapter focuses on strategies that can be incorporated without a significant negative impact to the project's schedule, budget, and design intent.

The Philadelphia Forensic Science Laboratory (Fig.18.4), takes advantage of the inherent high ratio of glass at the exterior wall combined with ceiling geometries, solar control, and high-reflectance interior finishes to achieve dramatic, diffused deep day lighting. Lighting fixtures are installed parallel to the exterior wall to allow lighting controls to automatically de-energize perimeter zone fixtures when required lighting levels are achieved naturally.

Encourage facility users to use alternative transportation. Locate the forensic laboratory in close proximity to public transportation. Offer bicycle storage and locker room facilities with showers. Provide preferred parking for those that carpool and refueling stations for alternative fuel vehicles. Refueling stations can be shared among neighboring facilities to help offset the initial cost. If the facility uses an on-site fleet, consider using alternative fuel vehicles, in lieu of gasoline-fueled vehicles.

A big part of water conservation deals with reducing potable water use. The first step to reducing potable water in landscape irrigation is to choose landscape materials and plantings that inherently require less water. Consider using captured rainwater, recycled gray water, or eliminating a permanent site irrigation system. Use low-flow plumbing fixtures or waterless urinals within the building sewage system.

Fig. 18.4 Human-centered design and full energy and day lighting simulation are strategies that can help create a superior quality work environment and, at the same time, significantly reduce the total energy cost. Photo courtesy of Barry Halkin Architectural Photography

Potable water use can also be limited within the laboratory areas. First, avoid open-loop cooling systems. This is where water is used then directly discharged to the drain. Instead use closed-loop systems where water is conditioned and recirculated to minimize wastewater. Second, only provide hot water at the sinks, benches, and fume hoods when needed.

First and foremost, design the forensic laboratory to comply with the American Society of Heating, Refrigerating, and Air Conditioning (ASHRAE) 90.1 energy standard. A number of states have already adopted this as their state energy code. Energy recovery is another strategy that is often viable for forensic laboratories. For example, capture heat from the lab exhaust and use it to preheat fresh (outside) air or capture waste heat from a condenser water system and use it for domestic hot water heating.

Pay particular attention to part-load system efficiency. Since not all forensic laboratory systems function simultaneously, the building systems operate in a part-load condition most of the time. We select equipment with maximum efficiency at this part-load condition so that we can better capitalize on the benefits of higher operating efficiencies. When possible, use EPA Energy Star compliant forensic laboratory equipment. Further, we "right size" mechanical and electrical equipment by avoiding oversized systems and excessive safety factors.

One of the keys to superior forensic laboratory performance is commissioning. Include a commissioning agent as part of the design and construction team to verify that the building is designed, constructed, and functions in accordance with the owner's requirements. Many times energy reductions are not achieved because of the lack of a comprehensive commissioning program. For example, a control valve

that is not calibrated properly may still function well enough for the system to operate without a "fault" alarm. However, the system will never achieve the level of operating efficiency expected and will unnecessarily waste energy.

Consider variable volume supply and exhaust air systems, which allow you to reduce air volumes during unoccupied hours. Keep in mind that variable volume systems are not appropriate for all forensic laboratories. When airflow is driven by minimum air change rates (rather than cooling load or fume hood makeup air requirements), it may not be possible to reduce airflow. In these cases, constant volume systems should be considered.

It is also important to evaluate forensic laboratory fume hood requirements and reduce the quantity and size when possible. Snorkels and recirculated air cabinets are excellent ways to provide local exhaust (with lower airflow rates) and often result in a more effective exhaust system because of the proximity to the source of contamination.

Design the laboratory to comply with the ASHRAE 62 standard for ventilation and indoor air quality. This standard primarily pertains to non-laboratory spaces. Remember that the forensic laboratory operation and maintenance staff will spend a considerable amount of time in these areas.

Also, consider demand-based ventilation control via CO_2 monitoring. This enables the optimization of outside air intake based on actual building occupancy rather than speculative values. In the right circumstances, CO_2 can be an excellent indicator of occupancy.

Specify low-volatile organic compound (VOC) construction materials, to reduce irritating or harmful effects of residual VOC emissions. This would include materials such as sealants, adhesives, paint, and carpet. A post construction (pre-occupancy) 2-week flush prepares the building for occupancy by removing any unavoidable VOCs from new building materials and/or construction debris.

Minimize critical environment areas such as hazardous storage, spaces requiring specific environmental control, and areas with unique noise and vibration requirements. These types of areas require dedicated support systems and are square-foot dependent. Thus, as these spaces become larger, the supporting building systems also become larger, using more energy.

Forensic laboratories are always changing. Design for flexibility. Changes may even come up before the original design is completed. Infrastructure systems should be readily expandable. Central energy stations and regional energy plants work well for laboratories seeking flexibility and adaptability. Provide utility service distribution from perimeter locations to enable easier laboratory enhancements and equipment relocations.

18.10 Conclusion

Most, if not all, forensic laboratories are extensions of city, county, state, or federal governments and require these facilities to meet building codes, obtain accreditation, provide law enforcement with forensic support and follow sustainable

practice. In addition with their focus to protect and enhance our society, they also have the responsibility to provide safe and effective space for the occupants. As planners, designers, constructors, directors, and users, we must recognize the possibilities available to achieve these important objectives. Whatever your goals are, we must seek out partners with the same vision as ourselves. This is the best way to meet not only today's needs, but the future changes that lay ahead for the forensic industry. Today, many criminalists and examiners have expressed the need for flexible laboratory space that can respond to the rapid changes in laboratory instrumentation and forensic science methodologies, as well as increased case loads. Now, one can see the multiple benefits of a proper forensic laboratory environment and how to achieve it, and still provide a secure and safe environment for both the evidence and the staff. Today's forensic planning consultants have the knowledge and skills to deliver a safe, responsive, and appropriate laboratory environment for the forensic community.

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18.11 Questions

1. Define "modular planning"
2. Identify the advantages of modular planning with building design.
3. Identify the key building elements that will affect the decision to renovate or build new.
4. Define "Process Mapping."
5. What are the benefits gained from using Process Mapping?
6. Within "Process Mapping," how can time and activity effect space design?
7. Define "ISO-17025."
8. How could ISO-17025 affect building design?

18.12 About the Authors

Kenneth C. Mohr, Jr., a Senior Programer/Planner with CRIME LAB DESIGN, has spent the last 22 years planning and designing laboratories and for the last ten years has specialized in forensic laboratories. Mr. Mohr has worked extensively with forensic agencies around the globe to help them determine their needs and to plan and design laboratories that can achieve or retain ASCLD/LAB, Legacy, International, NAME, or ISO-17025 accreditations by addressing the issues related to those guidelines. He has delivered numerous medical examiner and crime laboratories that not only meet today's criteria but are designed to continue serve their communities for many years to come. Mr. Mohr is also an author of special guideline publications, and articles on programming, planning, and design for forensic science. He speaks on a variety of facility planning topics at conferences and workshops.

Mr. Mohr has done graduate work at the Paris American Academy in Paris, France, and holds a Bachelor of Science degree and an Associate of Architecture degree from Southern Illinois University at Carbondale.

Louis Hartmen, PE, LEED, AP, a Senior Mechanical Engineer with CRIME LAB DESIGN, has spent the last 31 years developing engineering systems for laboratories and for the last 10 years has specialized in forensic laboratories. Mr. Hartman has worked extensively with forensic agencies around the globe to help them determine their mechanical, electrical, plumbing, security, fire protection, and communication needs and to design forensic laboratories that can achieve or retain ASCLD/LAB, Legacy, International, NAME, or ISO-17025 accreditation or addressing the issues related to those guidelines. He has delivered numerous medical examiner and crime laboratories that not only meet today's criteria but are designed to continue serve their communities for many years to come. Mr. Hartman servers on the ASHRE board, is an author of special guideline publications, and has written articles on MEP solutions for forensic science facilities. He speaks on a variety of system design topics at conferences and workshops. Mr. Hartman has a Bachelor of Science degree from Western Michigan University.

Chapter 19
Introduction to Forensic Anthropology

Jennifer C. Love, PhD, D-ABFA and Michelle D. Hamilton, PhD

Contents

19.1 History of Forensic Anthropology

Forensic anthropology is the branch of physical anthropology that involves the scientific analysis of skeletonized, burned, decomposed, or otherwise modified human remains via construction of a biological profile for medicolegal purposes.

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The estimation of the biological profile includes evaluation of the decedent's sex, age, ancestry, and stature, and is used in conjunction with interpretation of trauma, time since death, and other factors that may result in a positive identification or assist in the establishment of cause or manner of death.

The field of forensic anthropology is a relatively young discipline, gaining traction as a formal field of study only within the last few decades. However, its origins trace back to the late 1800s with incipient forensic skeletal research conducted by anatomists and physical anthropologists in the arenas of sex and age estimation from bone [1]. Among the earliest uses of forensic skeletal and dental evidence in the United States is the 1849 Webster–Parkman murder case, which involved the sensational dismemberment and burning of Harvard Professor Dr. George Parkman by his colleague Dr. John Webster, over an outstanding $470.00 loan [2]. Anatomists working with the burned remains examined fragments of recovered bone and were able to determine that they belonged to an older male, and matched dentures to the original molds made for Dr. Parkman. By the early 1900s, anthropologists were increasingly requested by medicolegal authorities to render assistance in skeletonized cases. In 1939, physical anthropologist Krogman published his seminal "Guide to the Identification of Human Skeletal Material" for the Federal Bureau of Investigation (FBI), which represented the first publication on forensic anthropological techniques in legal investigations.

By the end of World War II, there was a pressing need for anthropological identification services for American war dead in the Pacific theater. In 1947, the US Army established the first forensic anthropological laboratory, the Central Identification Laboratory, Hawaii (CILHI), to address the war dead issue. Now known as the Joint POW/MIA Accounting Command (JPAC) [3], this laboratory is still in existence and employs more forensic anthropologists than any other laboratory in the United States. The laboratory's expanded mission is to provide search, recovery, and identification services for all missing Americans from Korea, Vietnam, Iraq, and other global conflicts (http://www.jpac.pacom.mil).

In 1972, the modern period in forensic anthropology was ushered in with the founding of the Physical Anthropology Section of the American Academy of Forensic Sciences. Five years later, the American Board of Forensic Anthropology was created with the purpose of testing and ensuring competence of forensic anthropologists. Today, forensic anthropology is a popular course offered within many college and university departments, and attracts large numbers of competitive students. Job prospects for those with advanced forensic anthropological training include positions within academia, law enforcement, morgue settings, human rights organizations, and military installations.

19.2 Scene Processing

Often the role of the forensic anthropologist begins at the death scene at the request of a medical examiner, coroner, or law enforcement agency. The anthropologist brings a special skill set based in archaeological principles that assist in the

organization and execution of a methodic search and documentation of the crime scene. The anthropologist often makes initial interpretations in the field as to whether a bone is human or non-human and the minimum number of individuals represented. These analyses help direct the search and discontinue it when all remains are recovered or determined to be non-human. It is often the anthropologist's responsibility to organize and lead the search team. Additional personnel that may contribute to the search include law enforcement, death investigators, divers, and cadaver dogs. Each adds valuable training and experience that contributes to the complete processing of a crime scene.

Anthropologists are typically requested to assist in cases of scattered skeletal remains, severely burned individuals, buried individuals, and mass fatality incidents that involve dismemberment and/or commingling of victims. Although each scene presents unique circumstances and difficulties, standard forensic anthropological techniques are flexible and adaptable, and, when applied correctly, result in complete documentation of the scene and the remains. Despite the variability, one constant is the need to adequately document the scene. The scene is photographed as the anthropologist enters it and each element is photographed in situ, prior to manipulation. The scene is also mapped. A datum (a permanent reference point), is identified and all elements are mapped in reference to it. The ultimate goal of documentation is to adequately collect the information for future reconstruction, because it can never be regained once the scene is altered.

19.2.1 Scattered Remains

Comprehensive scene processing of scattered remains is dependent on a thorough, methodic search using a preconceived search pattern. A common search pattern used with a multi-individual search team is the line search. Individuals are lined along one edge of the site and are spaced so that the area between searchers can be visually scanned without moving off line. Then, the line sweeps across the site in one direction. Next, the party realigns and sweeps the site perpendicularly to the first sweep. When only one individual is available to search, a spiral approach, walking from the boundaries to the center of the site, is typically used. As each skeletal element and possible evidentiary material is found, it is flagged in situ. Once the site is completely searched, the flagged elements are mapped in reference to a datum and photographed in place [4].

The condition of the skeletal remains is documented while still in the field. Key details to record are the presence of leaves or soil covering the remains, evidentiary items, and any intentional covering of the remains (Fig. 19.1).

The primary site of decomposition, the area where the body first decomposed, is typically darkly stained with greasy decomposition fluids [5]. Often the vegetation is dead or yellowed at the site. This area is a point of interest and requires troweling through the topsoil in search of small bones, teeth, bullets, and jewelry (Fig. 19.2).

Fig. 19.1 Scene of scattered skeletal remains. Note that the skeleton is partially covered with soil and surrounded with trash. A food label with an expiration date 3 years prior to the date of discovery was found under the remains. Based on the expiration date, the maximum postmortem interval was 3 years

Fig. 19.2 Primary site of decomposition. Note the dark staining of the soil

19.2.2 Buried Remains

Buried scenes are often the most labor-intensive recovery scenes, especially when remains are buried a significant depth or have been disturbed by carnivores, creating a combined burial and scattered scene. The first step in processing a burial scene is to identify the grave. A body can be buried intentionally by an individual or animal,

or unintentionally through natural processes such as movement of silt and debris or formation of ground litter and new plant growth. Correspondingly, a body can subsequently be uncovered by individuals and animals, or natural processes such as soil erosion. Regardless of the type of burial, a grave consists of four levels: the subsoil beneath the body, the body, the fill above the body, and the surface.

Graves are typically recognized by grave markers – intentional and unintentional changes to the surface of the grave. Intentional changes are materials placed by perpetrators in an attempt to conceal the grave. Unintentional markers include backfill soil piles, the grave depression outline, and variation in vegetation [4]. Once soil is removed, it cannot be replaced without accumulating excess soil, especially if a body is place in the hole [6]. Therefore, burying a body results in a mound of soil either over the grave, adjacent to the grave or possibly taken to another site. With time the soil of the grave becomes compressed, and a primary and secondary depression may form. Typically, the primary depression will involve the entire border of the grave, and the secondary depression the area of the abdomen (Fig. 19.3).

The secondary depression forms as the abdomen collapses due to decomposition. Secondary depressions are more common in shallow graves (i.e., 2 feet or less). The extent of the soil settling is dependent on the type of soil, depth of grave, and water penetration [4]. Digging a grave also disturbs the vegetation. Areas of dead vegetation, undergrowth, and overgrowth may be present at a grave. The dead vegetation indicates a recently dug grave. Undergrowth indicates either a relatively recent grave or circumstances that retard plant growth. Overgrowth indicates an older grave with loosened soil allowing for root penetration or a decomposing body acting as a fertilizer [4].

In addition to grave markers, clandestine burials are discovered through probing or ground-penetrating radar (GPR). Probing is an intrusive method that involves inserting a rod into the soil. A probe is either a thin solid rod used to survey the soil compactness or a hollow medium caliber rod used to survey the soil stratigraphy.

Fig. 19.3 Grave site. Note the depression in the soil

Disturbed soil is less compacted than undisturbed soil and a probe penetrates the ground more easily over a grave. The probe is inserted only deep enough to verify the compactness of the soil and not deep enough to damage the remains. A coring probe removes a plug of soil. Undisturbed soil consists of topsoil and uniform subsoil. Disturbed soil consists of topsoil and mottled subsoil. To adequately search a site, a methodic probing pattern over the search area is conducted, keeping in mind that soil disturbances caused by burrowing animals and rotting roots can also create pockets of loose and mottled soil [4].

GPR is a non-invasive subsoil surveying tool. A radar pulse is transmitted through the soil that reflects off objects in its path. The instrument is systematically moved over the site. Buried items create a disruption in the soil profile that is visible on a strip chart. Differentiating between human remains and other objects in the soil such as stones requires specialized training. GPR is best used in uniform soil, free of stones and other objects [4, 7, 8].

Once a possible grave is located, the topsoil is removed to confirm the grave. Under ideal circumstances, the outline of the mottled, disturbed, soil appears in stark contrast to the uniform, undisturbed, soil. Once the grave is identified, it is photographed, measured, and diagrammed. A north arrow is included in all photographs and on the diagrams to enable easy reconstruction of the grave for others, including the jury. Then, the soil is removed using trowels and brushes in a controlled archaeological excavation manner maintaining the original outline of the grave and a flat floor. All of the soil removed is passed through a screen of variable mesh size (usually 1/4 in.). All evidence recovered in the grave is photographed and diagrammed in situ before it is removed. The distance from each grave wall to the recovered items and the depth from the surface are recorded. The remains are pedestaled, photographed, and diagrammed before removal [9, 10]. Ultimately, the remains are removed and inventoried and the soil immediately under the body is removed to ensure the subsoil has been reached. The empty grave is then photographed (Fig. 19.4).

Fig. 19.4 Decedent pedestaled in the grave

Fig. 19.5 The scene of a house fire

19.2.3 Burned Remains

Burn scenes are modified burials, where the decedent is buried in fire debris as opposed to soil [11]. The greatest difficulty the forensic anthropologist is presented with at a fire scene is uniformity of the fire debris. Fire debris resembles burned bone in color and texture, and great care must be taken while excavating the remains (Fig. 19.5).

A second difficulty is that the firefighting process can significantly alter a scene and the remains. A water stream directed at a charred remains can move fragments a significant distance from the decedent and bury them within the debris. Therefore, the area within the water stream line is also searched in addition to the immediate vicinity of the body.

Once the scene is well documented, the debris is systematically removed until the remains are uncovered. Once uncovered, the position of the remains is mapped in reference to the burnt remnants of the structure or vehicle. When the bones are highly fragmented, a grid is placed over the remains. The size of the grid squares is dependent on the complexity of the scene. Fragments within each grid square are collected into a single paper bag labeled with the case and grid numbers. The controlled collection of the fragments eases the reconstruction process in the laboratory [11]. Because friable remains are fragile and can be significantly damaged during transportation, photographs of the remains and fracture patterns are taken prior to collection and transportation activities (Fig. 19.6).

19.3 Postmortem Interval

Evaluation of the postmortem interval also contributes to the scene analysis. Decomposition is the result of autolysis and putrefaction. Autolysis is the process of cell death. Putrefaction is the consumption of the body by intrinsic bacteria.

Fig. 19.6 Thermal trauma of the skull. The trauma is photographed and documented prior to moving the decedent. This bone is friable and delamination (separation of the inner and outer tables of bones of the skull) is likely to occur during transport

These natural processes can completely breakdown a body in the absence of extrinsic factors such as carnivore and insect activity and environmental bacteria [12], whereby extrinsic factors simply accelerate the process.

The rate of decomposition is dependent on the environmental conditions, depositional context, and condition of the body at the time of death. A body in a warm environment with high humidity decomposes faster than a body in a cool dry environment because autolysis and putrefaction are accelerated by higher temperatures [13]. A body buried four feet or greater decomposes significantly more slowly than a body deposited on the surface or in a shallow grave. A deep grave is cooler with more stable temperatures, acts as a barrier to carnivore and insect activity, and protects against solar radiation, all extrinsic factors that increase the decomposition rate. Likewise, a body placed in a cool freshwater stream decomposes more slowly than a body placed on the surface.

The presence of perimortem trauma and infection increases the rate of decomposition. The injury attracts insects and carnivores and is a portal for environmental bacteria. Often, a body with perimortem trauma differentially decomposes; an area of the body is significantly more decomposing; resulting in areas of the body that are significantly more decomposed than other areas [14]. Increased bacteria associated with an infection at the time of death also speeds the putrefaction process and the rate of decomposition.

Decomposition of a body can be broken down into three stages: early, middle, and late. The early stage is the product of autolysis and putrefaction and is observed as *algor mortis, rigor mortis, livor mortis*, bloating, and marbling. Algor mortis is the gradual cooling of a body. The body cools at a regular rate but is influenced by the body temperature at death and the ambient temperature, wind current, and clothing on the body. Rigor mortis is the stiffening of the muscles. Rigor mortis

waxes and wanes through the body in a regular pattern at a predictable rate; however, it is also influenced by activity at the time of death and environmental conditions. Livor mortis is the pooling of blood in areas of the body that are under gravitational pull. Initially, the pooled blood can be forced out of the area with applied external pressure, called blanching. With time, livor mortis becomes fixed and areas will not blanch when pressure is applied. Bloating is the expansion of the body due to the formation putrefaction gases, which collect in the body. Marbling is the darkening of superficial vessels as a result of putrefaction gases reacting with the iron in the blood, forming a black precipitant. These early changes enable the early postmortem interval to be estimated within 12–24 hours [15] (Fig. 19.7).

During the middle stage of decomposition, the body begins to skeletonize. The rate of skeletonization is directly dependent on carnivore and insect activity as well as humidity. In an arid environment, a body mummifies and the breakdown of mummified tissue is a very slow and elongated process. Typically, the face skeletonizes first and the reason is twofold: carrion insects lay eggs in the mouth, nose, and ears, leading to concentrated insect activity in these areas; and there is less soft tissue in this region than other areas of the body. At this stage of decomposition, postmortem interval estimates can range from weeks to months [16].

During the late stage of decomposition, the skeleton itself begins to break down. This stage is completely dependent on depositional context. Skeletal remains exposed to the elements disintegrate much faster than those in a protected environment. With exposure, the cortical bone dries, cracks, and exfoliates. Trabecular bone is also exposed and erodes. At this stage of decomposition, postmortem interval estimates can span several years [15].

Estimates of the postmortem interval can be refined with the inclusion of entomological, soil, and botanical analysis. Forensic entomology is the study of insects and arthropods as they apply to legal matters. Eggs, larvae, and pupal maturity are temperature influenced and are an excellent measuring tool for time since colonization estimates. For example, the blowfly (Calliphoridae) is typically the first carrion

Fig. 19.7 Marbling of the superficial vessels

insect interested in a corpse, and often finds a body within four hours of deposition. If death occurred near the time of deposition, the age of the blowfly larvae is one of the most sensitive indicators of time since death [17]. Vass et al. [18] developed a method to correlate the concentration of volatile fatty acids (VFA) and pH (acidity/alkalinity) found in the soil under a decomposing body to accumulated temperature, the sum of average daily temperatures. VFA are the byproduct of putrefactive breakdown of fat and muscle. The method is complicated by the fact that the concentration of VFA is proportional to the mass of the individual and an estimate of the individual's size is necessary for an accurate assessment. Botanical agents may also be useful in correlating time since death. Roots, like trees, form growth rings. The rate at which rings form is plant specific, and roots entwined with skeletal remains are used to estimate the minimum time since deposition, since the remains had to be in place at least as long as the age of the root.

19.4 Biological Profile

When confronted with decomposed or skeletonized human remains, often the first question the forensic anthropologist faces is, who is the decedent? To determine the answer, the anthropologist builds a biological profile. The biological profile includes age, ancestry, sex and stature estimates, healed trauma, occupational markers, pathologies, and individualizing characteristics. Many of these components, especially age, ancestry, sex, and stature, are estimates, never absolutes. The methods used to estimate the biological profile were developed through comparative studies of known skeletal populations. Once the biological profile is complete, it is used by law enforcement to narrow the list of possible matches.

19.4.1 Sex

Techniques of sex estimation are based on the fact that males and females show a variety of differences in their skeletal framework. This is a matter of human biology; we are a sexually dimorphic species (i.e., males and females differ in size and muscle robusticity), and the female skeletal structure is specially adapted for the demands of childbirth. These factors allow the anthropologist to examine any number of individual bones of the skeleton to arrive at a sex estimation.

However, While sex is evident on adult remains, children's skeletons do not manifest sexual characteristics, owing to the lack of hormonal influence and the corresponding development of secondary sexual characteristics that develop as we age. Therefore, this brief discussion pertains only to adult skeletal structures.

Professional forensic anthropologists have usually examined thousands of human remains, and they are therefore experientially equipped to make estimations based on observations of minute details. This is especially true when discussing general sexual characteristics such as differences in size and muscle attachment

sites, regardless of whether the anthropologist is examining long bones (the humerus or femur, for example) or the skull [19].

The skull is one region of the skeleton that shows the contrast between the sexes. In essence, male skulls are more robust (they have more developed muscle markings) and larger, while female skulls are more gracile (they have less developed muscle attachment markings) and tend to be smaller.

Figure 19.8 shows various indicators of sex on the cranium and mandible. While forensic anthropologists are adept at assessing male and female size differences on the cranium and mandible based on their professional experience, laymen are often unable to make reliable sex estimations because they do not have a large frame of reference upon which to draw and render an opinion.

In addition to size and muscularity differences, there are metric techniques that are used to provide an accurate estimation of sex. Measuring long bones, such as the head of the femur or humerus, for example, yields reliable estimations of sex based on established formulae [20].

The pelvis is another element of the skeleton that exhibits sexual dimorphism. As a result of the physical requirements of childbirth, the female pelvis is broader and angled differently than that of the male, and this difference allows for differentiating between the two sexes [21].

Figure 19.9 shows various indicators on the pelvis used to distinguish between males and females.

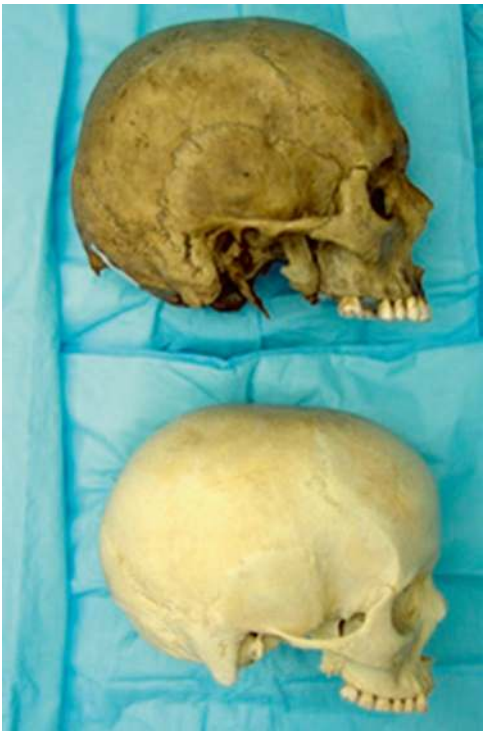

Fig. 19.8 A male (*top*) and female (*bottom*) skull. Notice the smaller mastoid process (bony projection behind the ear opening) and nuchal muscle attachment sites (ridges along the back of the skull) of the female skull

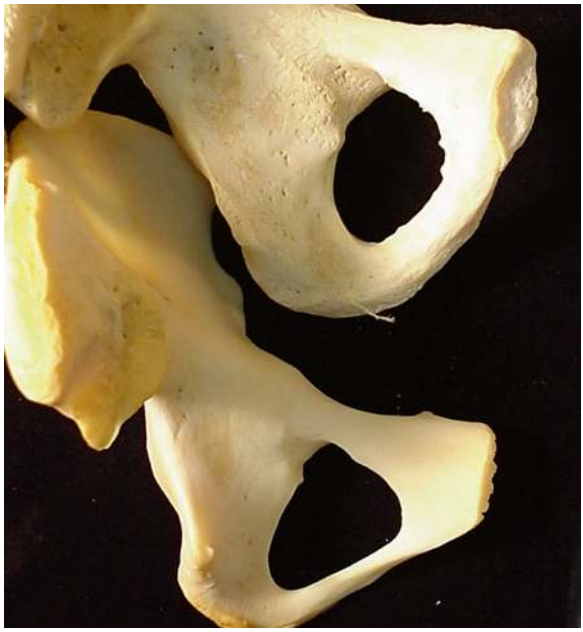

Fig. 19.9 A male (*top*) and female (*bottom*) pubic symphysis of the innominate. Notice the elongation of the bone structure in the female causing the lower strut to be concave as opposed to convex

19.4.2 Age

The skeleton develops and ages in a regular pattern, which allows the anthropologist to estimate age at the time of death. As the skeletal system matures from uterine development and onward, specific bone and dental milestones are reached at known time intervals along expected developmental pathways. With progression of childhood into adulthood, the skeletal developmental changes stop, and the skeleton reaches full skeletal maturity (roughly at approximately 25 years of age). During the period of skeletal development encompassing the fetal, childhood, and adolescent stages, the compounding effects of environment and lifestyle on age markers are minimal, allowing for relatively narrow estimations. The skeletal elements used to estimate age in a developing skeleton are long bone length and cranial development during the fetal stage, appearance of ossification (bone) centers and dental development during childhood, and fusion of growth centers during adolescence [22] (Figs. 19.10–19.12).

Once the skeleton reaches maturity, the developmental markers are no longer applicable and the anthropologist relies on recognition of degenerative changes in the skeleton, which occur with the normal aging process and are simply a reflection of bone and cartilaginous breakdown throughout adulthood. However, the rate of degenerative change is dependent on the individual's nutritional status, lifestyle, and life history as well as their chronological age. As a result, age estimation in adults is often not as specific (or accurate) as that for younger individuals.To account for this

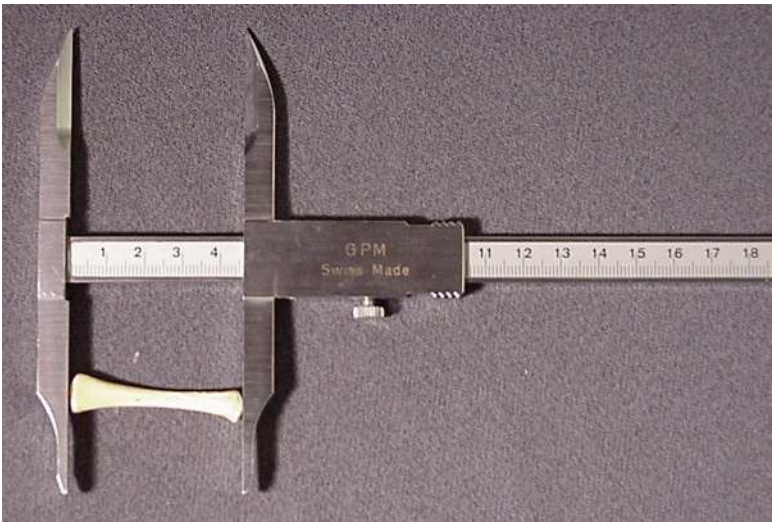

Fig. 19.10 A fetal femur measured using sliding calipers

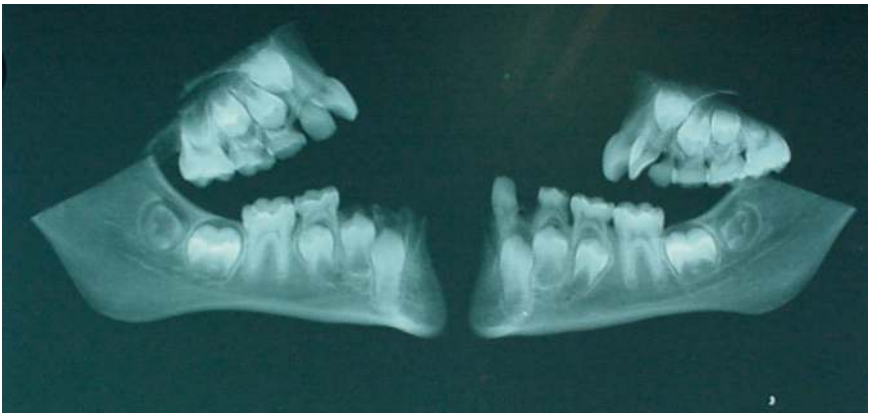

Fig. 19.11 A radiograph of dental development of a young child (age four)

fact of biology, forensic anthropologists will often adjust their adult age estimations to reflect ranges instead of specific ages. While a child's skeleton might be estimated at twelve years of age ± 1 year, an adult's skeleton would be estimated to fall between the ages of 35–50 years of age, for example. Regular degenerative age changes can be observed in the auricular surface and pubic symphysis of the pelvis, in bone cells called osteons, in the sternal end of the fourth rib, and in evidence of osteoarthritic changes, degree of osteoporosis, cranial suture closure, and degree of tooth wear (Fig. 19.13).

Fig. 19.12 A partial open epiphysis of a proximal humerus

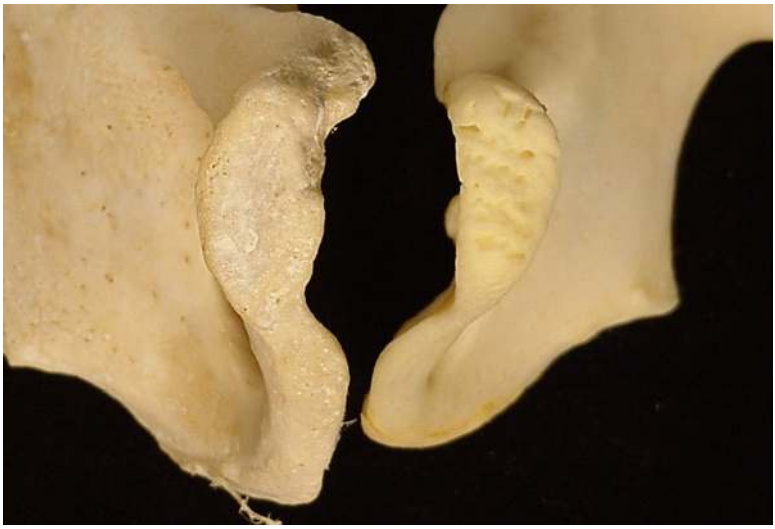

Fig. 19.13 Pubic symphyses. Note the regular and pronounced beveling of the bone of the younger individual (*right*) compared with the flat, more irregular surface of the bone of the older individual (*left*)

19.4.3 Ancestry

Ancestry estimation is a significant component of a skeletal profile; however, it is the most difficult to estimate due to human migration, geographic admixture, and environmental influences. In general, skulls of European, African, and Asian populations are different in the size and shape of the nasal aperture, shape of the teeth, shape and arrangement of the dental arch, shape of the zygomatic (cheek) bones, and shape of the cranial vault [23] (Figs. 19.14 and 19.15).

Fig. 19.14 Skulls of an African American, European American, and Hispanic individual (*left* to *right*)

Fig. 19.15 Skulls of an African American, European American, and Hispanic individuals (*top* to *bottom*)

However, due to the migration patterns of the human species and the continuum of features, ancestry is often very difficult to estimate. Furthermore, race is a social category, not a biological one, and the inherent difficulties with this fact are seen in the example of use of the term "Hispanic," which is assigned to all Spanish-speaking populations, although the migration history is vastly different from country to country.

Ancestry estimates are based on two features: the shape or morphology, as discussed above, and the metric analysis various elements of the skeleton.[24] The most recent advancement in metric analysis is FORDISC. Fordisc, currently in its third version, is a forensic discriminant function computer program used to classify adults by ancestry and sex using any combination of standard measurements. The program compares the measurements of the unknown individual to the known populations included in the Forensic Anthropology Data Bank (FDB). FDB consists of skeletal measurements collected from forensic casework and modern documented skeletal collections. Forensic anthropologists routinely submit measurements from their forensic casework, and several university anthropology departments have skeletal donation programs from which skeletal measurements are taken and submitted. The FDB currently has over 2,100 cases (http://web.utk.edu/~anthrop/FACdatabank.html) [25], 1,200 of which are positively identified. A statistical report is generated with the ancestry and sex classification for the unknown skeleton, enabling the anthropologist to evaluate the degree of certainty of the estimates.

When the statistical results of Fordisc and the morphologic features are equivocal, the ancestry of the decedent is listed as indeterminate, because erroneous race classification may exclude a potential match. As a rule of thumb, anthropologists err on the side of caution and will not assign ancestry if there is a chance that the assignment will fall in the wrong category. Ultimately, failure to assign a race leads to significantly more potential matches to process, but eliminates the possibility of excluding the match based on a descriptor that is difficult to accurately assess.

19.4.4 Stature

Stature is estimated through one of two methods, anatomical and regression. The anatomical method is used when the complete or very near complete skeleton is available for analysis. The method requires the anthropologist to collect and add height measurements of skeletal elements from the calcaneus (heel bone) to the skull. A correction factor is then added for the soft tissue [26]. The decedent stature estimates are highly correlated with living stature, and ancestry and sex have been shown to have no effect on the stature estimate [27].

The regression method is used when analyzing an incomplete skeleton, a process in which the lengths of target bones are regressed upon stature (Fig. 19.16).

Regression models have been developed for various populations using various long bones. Rollet [28] published the earliest stature tables using the humerus,

Fig. 19.16 The maximum length of the femur measured with an osteometic board. Below the osteometric board are spreading calipers (left) and two types of sliding calipers

radius, ulna, femur, tibia, and fibula. Regression formulae have also been constructed for immature and fragmented skeletal remains. Unlike the anatomical method, the regression method is population specific, both for ancestry and sex. Therefore, a formula developed for European females cannot be applied to African females with the same accuracy. Furthermore, the regression method does not correct for age-related changes. With advancing age, most stature is lost in the vertebral column and an age-correction factor must be included for older individuals [29].

19.4.5 Anomalies and Pathologies

In addition to the four biological categories discussed above, there are supplemental characteristics that may yield further evidence toward personal identification. Forensic anthropologists are skilled at discerning unusual or uncommon features that are present on skeletal remains, and these factors include skeletal anomalies or pathologies that point toward a person's life history, including their occupation, skeletal development, or health status.

Skeletal indicators of habitual occupational activity involve subtle changes to the skeleton that reflect specific and recurring movements incurred during life [30]. Migrant agricultural workers, for example, will sometimes demonstrate accelerated (non-age related) degenerative changes to numerous skeletal elements, including osteoarthritic lipping of the vertebrae and fusion of the pelvis at the sacroiliac joint, all incurred as a result of repetitive bending and biomechanical stress loads on the

body specific to that lifestyle. People who regularly ride horses as a condition of their daily activity may show a characteristic bowing of the femora, while professional boxers and martial artists can display healed ulnar and metacarpal fractures in the forearms and hands, and fractures of the craniofacial skeleton.

In addition to occupational markers of activity, skeletal anomalies indicative of periods of stress during skeletal development are recognized on the skeleton. Enamel hypoplasias are a type of developmental tooth defect characterized by deficiencies in enamel thickness [31] that have been traced to systemic stressors such as malnutrition and infectious disease [32]. Linear enamel hypoplasias manifest as horizontal lines across the labial surface of the tooth (Fig. 19.17). They are indicators of compromised health during early development, and can sometimes be traced to single childhood fever episodes. Harris lines are nonspecific markers of stress that appear on x-rays as horizontal lines in the growth ends of long bone shafts. These lines have been correlated with arrested growth due to nutritional stresses, malnutrition, and vitamins A and D deficiencies [33].

Acute and chronic diseases are recorded on skeletal element as well. Neoplasms, tuberculosis, and syphilis are a few examples of diseases that often alter bone [34] (Fig. 19.18).

Chronic behaviors create signature focal defects, such as damaged internal nasal structures from chronic nasal drug usage, and erosional lesions on the lingual side of the teeth from chronic vomiting associated with bulimia. These types of markings and many others left on the skeleton are utilized by the forensic anthropologist to build a comprehensive unidentified decedent description and ultimately assist in the positive identification of unknown skeletal remains.

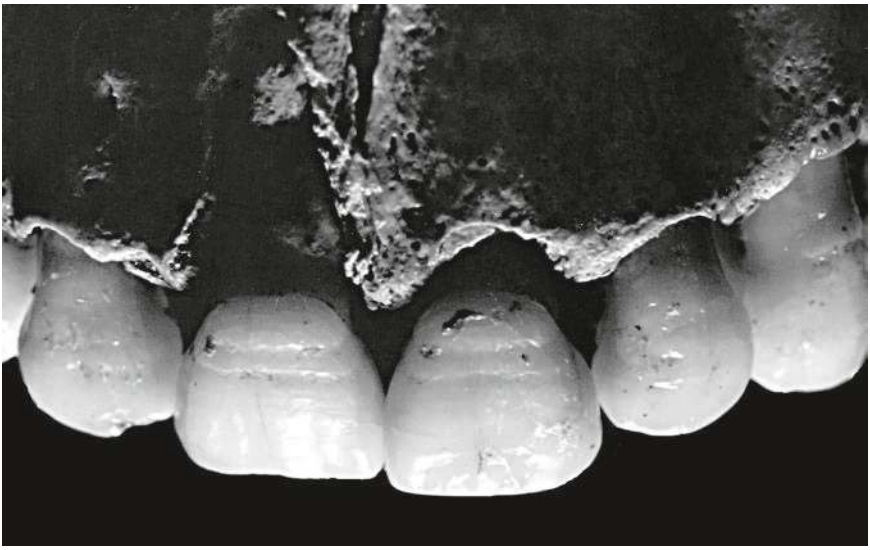

Fig. 19.17 Enamel hypoplasias on the maxillary dentition, especially well defined on the central incisors

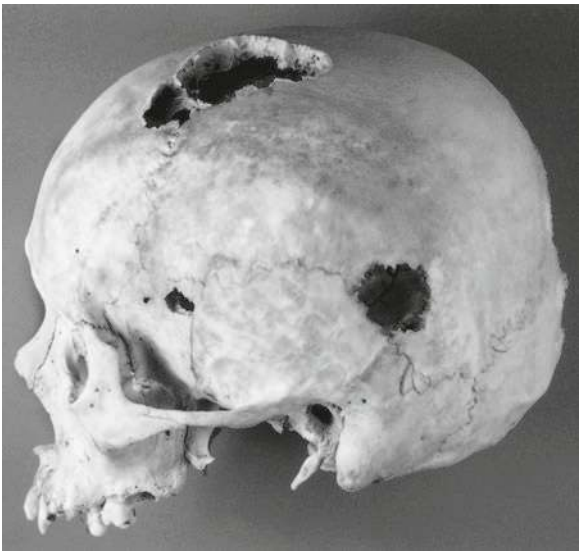

Fig. 19.18 Lytic lesions of the cranium

19.5 Trauma Analysis

Documenting and interpreting bone trauma contributes to the case analysis through recognition of features that may lead to the identification of the decedent, assist the medical examiner/coroner in the classification of the cause and manner of death, and reconstruct the events that occurred during the postmortem interval – the period between death and discovery. Antemortem trauma (trauma occurring before death) is recognized by evidence of healing. Perimortem trauma (trauma occurring around the time of death) is recognized by sharp fracture margins. Postmortem trauma (trauma occurring after death) is recognized by frayed or roughened fracture margins and color variations [35] (Figs. 19.19–19.21).

19.5.1 Antemortem Trauma

Fractured bone first begins to heal when a hematoma forms at the fracture site, and osteoclasts (bone resorbing cells). Resorb the damaged bone at the fracture site, creating rounded fracture margins. Next, osteoblasts (bone-building cells) rapidly lay down primary, unorganized bone to unite the fracture margins. With time, the primary bone is replaced with organized lamellar (mature) bone [36]. In adults, a fracture callus or scar marks the fracture site throughout the individual's life. In children, the bone remodels completely, leaving no evidence of the trauma. The rate

Fig. 19.19 A healing callus of a rib. The regular bone surrounding the fracture site is new bone formation

Fig. 19.20 A perimortem fracture of a rib

of bone healing is dependent on the age and health status of the individual and severity of injury [37]. The age of injury cannot be determined, but can be estimated in reference to the time of death. A healing fracture indicates the traumatic episode occurred relatively near the time of death, while a healed fracture callus indicates the traumatic episode occurred a significant time before death. The traumatic history is part of the skeletal profile and is valuable component of the individual's life history.

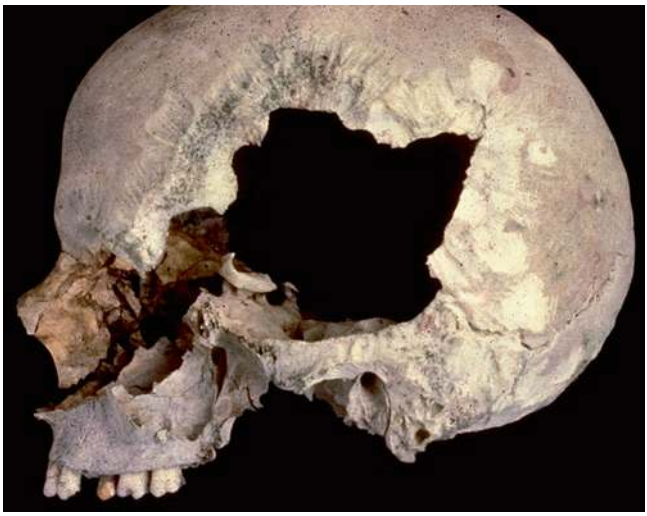

Fig. 19.21 A skull with rodent gnawing; note the double-groove pattern

19.5.2 Postmortem Trauma

Postmortem trauma results from animal and human activity, as well as environmental factors. With time and exposure to the elements, the bone becomes light and friable. The cortical bone exfoliates [38] and the bone dries and loses its elastic property, becoming brittle. Once in a brittle state, bone fractures generate ragged margins. Often the postmortem fracture margins are marked by a differential staining [35, 39], allowing differentiation between perimortem and postmortem fracturing. If the specimen is uniformly soil stained, a postmortem fracture will have light-colored fracture margins in comparison. Carnivore destruction has a frayed appearance at the fracture site, and often gouges and puncture marks at the ends of the bones. Rodent gnawing results in small parallel groves along the margin of bone and is most often seen along prominent ridges, such as the orbital margins [40].

19.5.3 Perimortem Trauma

Bone trauma with a corresponding absence of healing and with sharp fracture margins present is classified as perimortem injury. The responsibility of classifying cause and manner of death lies with the medical examiner/coroner, but the anthropologist can assist in the classifications through accurate perimortem trauma interpretation. Perimortem trauma is conventionally divided into three categories: blunt, sharp, and ballistic. Blunt force trauma is slow-loading trauma that causes plastic deformation or warping of the bone prior to fracturing. Blunt force fractures are described as linear, transverse, oblique, spiral, or butterfly [41]. The type and distribution of

fractures are indicative of the object impacting the body and the direction of force. For example, a linear fracture in the skull is consistent with a broad surface impact and is common in falls, whereas a small depressed fracture is consistent with an implement of small surface area, such as a hammer head [42] (Fig. 19.22). Likewise, a pattern of serial, transverse rib fractures observed on several adjacent ribs is typical of a single impact with a broad surface, common in falls. Several focal, irregularly located fractures in the ribs are consistent with multiple strikes from an object of small surface area.

Recognizing and documenting blunt force trauma associated with child abuse is a significant contribution the anthropologist makes toward the classification of manner and cause of death. Skeletal fractures regarded as highly specific to non-accidental injury in infants include posterior rib, scapular, metaphyseal, and spinous process fractures (Kleinman 1998) (Fig. 19.23).

These fractures are often occult, especially when acute, to standard radiograph and autopsy techniques. Examining the bones directly during autopsy increases the opportunity to recognize and document these injuries.

Ballistic trauma is a very fast-loading force, typically with perforation of the bone by a projectile. The force loads the bone so quickly that the bone fails prior to plastic deformation. As the projectile passes through the bone, it creates a cone of outward beveling. The same beveling pattern is seen in glass when struck by BBs fired from a BB gun. The cone opens to the direction the projectile is traveling. Radiating fractures extend from the defect, and concentric fractures encircle the impact site [43]. Reconstructing fragmented bones followed by fracture interpretation often enables the anthropologist to sequence wounds, with sequentially newer fractures terminating at preexisting fractures, sometimes allowing for the determination of timing and order of projectile impact in multiple gunshot wound scenarios.

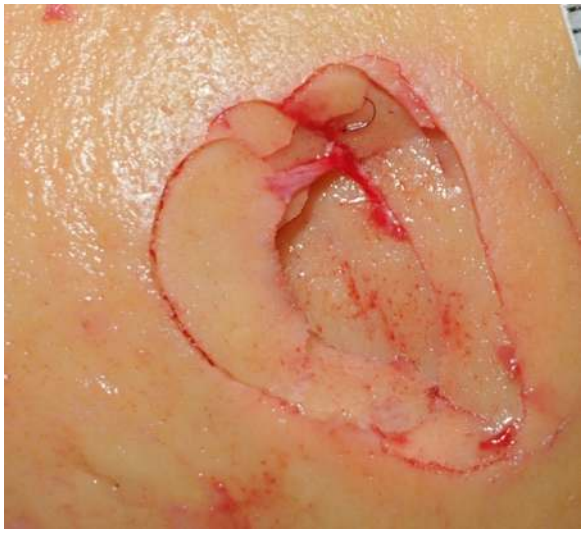

Fig. 19.22 Fracture pattern consistent with an object of small surface area striking the skull

Fig. 19.23 An incomplete classic metaphyseal lesion of the distal ulna of an infant. This fracture was missing until the end of the long bone was exposed during autopsy

Fig. 19.24 Knife stab marks in a rib. The triangular shape indicates the weapon was a single beveled-edge weapon

Sharp force trauma cuts the bone and is described as a single action or multi-action wound. Single-action injures are typically the result of a knife, but include any object with a beveled edge. Single-action wounds are V-shaped when located at the margin of the bone and outline the shape of the object when located within the bone [44] (Fig. 19.24).

Sawing the bone creates a multi-action wound as the blade is pulled and pushed through the bone. A multi-action wound is large and records significant information about the tool, such as the placement of cutting teeth, and the teeth per inch in the blade [45] (Fig. 19.25).

Fig. 19.25 Saw mark. Note the irregular, stepped striations in the cut surface

Fig. 19.26 Cast of cut mark through costal cartilage made with a serrated cutting edge. Note the very regular, pronounced pattern of striations

Costal cartilage (cartilage articulating the ribs to the sternum) is more elastic than bone, less elastic than skin, and an excellent medium for recording details of the weapon's cutting edge. Serrated blades create regular, well-defined striations in the cut surface (Fig. 19.26).

Fig. 19.27 Cast of a cut mark through costal cartilage made by a smooth-edged weapon. No striations are observed on the cut surface. The wound was a notch and both surfaces of the triangular cast mirror the cut surfaces

Smooth-edged blades create a smooth cut surface, occasionally with irregular, typically subtle, striations. The irregular striations result from defects in the cutting edge [46] (Fig. 19.27).

To analyze the cartilaginous cut surface, a negative is created with casting material. Cartilage is a wet, reflective material that is difficult to examine; casting material is uniform in color and less reflective. The negative is examined using a stereomicroscope and indirect light. The indirect light highlights the ridges and valleys on the cut surface. This method enables the analyst to describe class characteristics such as serrated and non-serrated edges.

When a suspect weapon is recovered, test cuts are made and compared with the cut mark. A test cut is made by slicing a relatively malleable material such as sealing wax with the suspect weapon. The test cut surfaces are cast with the casting material and the cut mark and test mark casts are compared. This enables the analyst to determine if the test cut is consistent or inconsistent with the cut mark [47]. Currently, the identification of a specific weapon using tool mark analysis has not been accepted by the courts [48].

19.6 Identification

Once the skeletal profile is constructed and possible missing person matches are submitted, the next step is identify the decedent through comparison of antemortem and postmortem records. IAFIS [49], Integrated Automated Fingerprint Identification System, and CODIS, Combined DNA Index System for missing people, are two

databases that are utilized to identify unknown individuals blindly, that is, without a possible name. IAFIS is a national fingerprint and criminal history system maintained by the FBI, Criminal Justice Information Services (CJIS) Division (www.fbi.gov/hq/cjisd/iafis.htm). Fingerprints of the unknown decedent are entered into the system and compared with over 55 million prints. No prior information is needed about the decedent. CODIS is a database of DNA profiles. Biological family members of missing individuals submit DNA samples for analysis. The profiles are uploaded in the database. Medical examiners and coroners submit DNA samples from the unknown decedent for analysis and the profile is uploaded in the database. The missing and the unidentified profiles are cross-matched and profiles with high kinship indices, likely to be biological relatives, are identified [49]. This system also requires very little information about the decedent; however, the antemortem record typically is the DNA sample from a family member and not the decedent.

All other methods of identification require the name of a potential match to conduct a comparison. Second to fingerprints, most individuals are identified by dental records. An individual's dentition is unique in inventory, restorations, and anatomy. Typically, dental identification is based on a comparison of radiographs. Dental radiographs capture the morphology of the teeth and size, nature, and location of restorations.

In the absence of dental records, antemortem skeletal radiographs are used for comparison. The morphology of skeletal elements is individualistic. The most studied skeletal feature for identification is the frontal sinus pattern (as with fingerprints, most researchers believe every frontal sinus pattern is unique), but any portion of the skeleton can be used [50, 51]. Age-related changes of the vertebral column are also a commonly used feature for comparison. With age, individuals develop osteophytes along the vertebral column. The location, morphology, and severity of the osteophytes are useful as individualizing characteristics.

Unlike fingerprints and DNA, an individual's dentition and skeleton change over time: osteophytic development continues, additional trauma may occur, and teeth are lost and additional restorations are received. Therefore, there are two significant limiting factors to the use of radiographs for identification: (1) the name of the potential match must be known; and (2) the radiographs must be taken relatively near the time of death.

Circumstantial identification is based on circumstantial evidence such as biological profile, clothing, location last seen, date last seen, etc. [52]. Circumstantial identification is used only in the complete absence of antemortem records. A completely unknown decedent description that includes an accurate skeletal profile, record of antemortem trauma, markers of occupational stress, and pathologies can be used to generate a compelling circumstantial identification leading to a presumptive identification.

19.7 Conclusion

The role of the forensic anthropologist begins in the field with organized and methodic scene documentation and recovery of the remains. Once in the laboratory, the anthropologist builds a skeletal profile, interprets trauma, and assesses the

postmortem interval. A comprehensive skeletal profile includes the basic description of the decedent (age, ancestry, sex, and stature) and the more subtle evidence of the decedent's life history, and assists law enforcement in the search for potential matches of missing individuals. The interpretation of trauma and the assessment of the postmortem interval help reconstruct the events surrounding death and ultimately the classification of cause and manner of death. The role of the anthropologist ends with testifying as an expert witness. As an expert witness, the anthropologist gives his/her opinion regarding the scientific findings. Regardless of whether the testimony is requested by the prosecution or defense, the anthropologist must be objective and ethical. The forensic anthropologist must testify only to his or her specialty and refrain from extrapolating beyond the certainty of the methods used.

19.8 Questions

1. Explain the difference between antemortem, perimortem, and postmortem trauma.
2. Discuss the Parkman–Webster murder trial and why it is important to the history of forensic anthropology.
3. Outline the general history of forensic anthropology.
4. What is JPAC? What is its history and mission?
5. Why are postmortem and perimortem traumata not considered important elements of the biological profile?
6. Why are age estimates more accurate for children than adults?
7. Explain the difference between the anatomical and regression methods for estimating stature. Which method is population specific and what does this mean?
8. What are occupational markers and how do they contribute to the skeletal profile?
9. What difficulties does an anthropologist face when estimating ancestry?
10. Why is the pelvis considered a good skeletal element for estimating sex?
11. Describe an organized search method. When is it used?
12. Postmortem interval estimates are more narrow for the early stage of decomposition than the middle and late stage of decomposition. Why?

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Chapter 20
Introduction to Forensic Engineering and Accident Reconstruction

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20.1 Introduction

Forensic Engineering may be defined as the application of engineering principles toward the purposes of the law. Qualified forensic engineers are individuals rigorously educated in traditional engineering disciplines and the physical sciences with expertise in applying that knowledge in forensic settings. A complete description of all areas encompassed by forensic engineering is well beyond the scope of this chapter, which will focus primarily on vehicular accident reconstruction with some discussion on the application to injury biomechanics. At the end of the chapter, there will also be a brief discussion on some other forensic engineering topics, including product liability. This chapter does not cover electrical accidents, chemical accidents, or fire cause and origin. There are numerous detailed treatments of these topics in the literature, and their omission is in no way meant to diminish their significance or importance. We note at the outset that this chapter is meant to provide the investigator with a brief overview of forensic engineering and forensic engineering methodology and is no way meant as a replacement for expert consultation in situations requiring forensic engineering expertise.

In all areas of scientific endeavor, the quality and reliability of an analysis and solution to a problem is directly related to the quality and detail of the input data. This is also true in accident reconstruction. Therefore, we begin with a discussion of the initial documentation of the vehicles and accident scene, typically performed by the police or investigating law enforcement agency. A proper initial investigation is critical to a meaningful scientific accident reconstruction. We begin with a discussion of relevant evidence gathering.

20.2 Documentation of an Accident Scene

20.2.1 Scene Examination

A scientifically proper and valid accident reconstruction is based upon a rigorous application of the appropriate physical laws. However, in order to apply the appropriate laws of physics in a meaningful fashion, certain accident scene evidence must be gathered, and quantitative measurements must be made at the accident scene before key evidence disappears. For example, as will be discussed below, in order to calculate vehicle impact speeds in a two-vehicle collision, the final rest positions of the vehicles must be known in relation to the location of the point of impact (POI) on the roadway. The locations of the vehicle tires should be marked with roadway paint so that the final vehicle rest positions can be easily identified after the vehicles have been removed from the scene. During a severe (or violent) collision, vehicle undercarriages and components are often forced into direct contact with the roadway surface, causing scratching and/or gouging of the pavement. The initial scratching/gouging of the pavement surface often occurs during

maximum engagement at impact, thereby, locating the POI on the roadway surface. This roadway evidence should also be marked with roadway paint, since it also fades with time and may be difficult to identify at a later date. It is noted parenthetically that in situations when it becomes important to identify which vehicle made a specific gouge mark, i.e., in situations where it may be necessary to determine if one vehicle crossed the centerline of the roadway or was in the wrong lane at the moment of impact, the undersides of the vehicles need to be examined for traces of underside damage, asphalt, and/or other evidence of damage caused by forceful roadway contact. Other indicators of the location of the POI include, but are not necessarily limited to collision scrubs, which are typically short tire scuff marks on the pavement made by a rapid lateral motion of the effected tire at the moment of impact. Also, a sudden change (or jog) in the direction of tire marks indicating a sudden directional change in the motion of a vehicle, or the presence of fluid spatter on the roadway surface, such as would occur with the sudden explosion, or bursting, of a radiator or other pressurized fluid-containing vehicle component, are often good indicators of the location of the POI. Generally, solid debris is a poor indicator of the location of the POI on the roadway surface because it is easily moved and scattered both during the impact event and subsequent to the crash. Figure 20.1 is an example of roadway evidence denoting a POI.

The first step in locating (or mapping) the important, or relevant, features of an accident scene is the establishment of a reference point and coordinate system. Typically, it is easiest and most practical to establish a two-dimensional (2D) rectangular Cartesian coordinate system, with a fixed scene feature, such as a sewer grate, manhole cover, utility pole (or adjacent point on a painted fog line), etc. chosen as a reference point. Recall that a 2D rectangular Cartesian coordinate system

Fig. 20.1 Clearly visible point of impact (POI) on the roadway surface. Note the locked-wheel skid mark, the gouge markings, and the presence of fluid debris evidence

is one in which the location of a point is defined in terms of two perpendicular distances, typically denoted as (x, y) and measured from coordinate axes intersecting at the origin. For a discussion of rectangular (orthogonal) Cartesian coordinate systems, the reader is referred to a basic algebra text.

In addition to locating the POI and final rest positions of the vehicles, other physical evidence, such as tire marks, also need to be identified, documented, and recorded. It is important when documenting an accident scene to photograph, measure, and record the locations and extent of all tire marks observed at the accident scene. In addition to identifying the path(s) of the vehicle(s), a proper identification and characterization of tire marks is necessary to properly define the motions and accelerations/decelerations of the vehicles for use in a reconstruction analysis.

Two commonly observed types of tire marks often observed at accident scenes are locked-wheel skid marks and yaw marks. A locked-wheel skid mark is a skid mark made by a non-rotating, sliding tire. For a tire sliding in the longitudinal vehicle direction, the striated markings within the skid mark are oriented in the longitudinal direction. A relatively short locked (non-rotating) wheel skid mark is shown in Fig. 20.1 to the left of the gouge mark, damaged tire scuff/friction mark, and fluid debris evidence. Often times, the physical characteristics of the skid mark can be used to distinguish front wheel skid marks from rear wheel skid marks. It can be demonstrated that for a forward-traveling vehicle, a sudden brake application will cause a forward weight shift. If the weight shift is sufficient to cause an over-deflection of the front tires, then the outside edges of a front tire skid mark will appear darker than the interior regions of the tire mark.

Note that the absence of skid marks does not necessarily imply an absence of braking. Brakes may be applied without wheel lockup and, even in the presence of full wheel lockup, skid marks may, or may not, be left on the roadway surface depending upon roadway conditions. For example, it is not uncommon for no skid (or tire) mark evidence to be left on wet roadway surfaces, even when there is full wheel lockup, uncontrolled vehicle sliding, or side slipping. Sometimes, skidding tires on wet roadway surfaces can leave visible “squeegee” marks, but these marks are often short lived, and may even be gone prior to the arrival of police and first responders on the scene. Also, with the proliferation of Anti-lock Braking Systems (ABS), which prevent full wheel lockup, even on dry pavements it is not uncommon for there to be no discernible physical evidence of braking, even in the presence of a full brake application. ABS systems work by keeping the subject wheels on the verge of full lockup by rapidly applying and releasing the brakes (multiple times per second). This helps the driver to maintain directional control of the vehicle while at the same time providing a high drag factor to aid in slowing the vehicle. We note, however, that even though ABS systems do prevent full, sustained wheel lockup, faint (gap, shadow, etc.) markings may sometimes be left on the roadway surface that can be observed by the trained investigator.

Another type of tire mark commonly observed at accident scenes is referred to as a yaw mark. A yaw mark is made by a rotating tire as it side slips while attempting to follow a curved path. Yaw marks typically display a very distinctive striation pattern as shown in Fig. 20.2.

Fig. 20.2 Yaw mark left by a vehicle on the roadway surface as it was side slipping just prior to rolling over. Note the angled striations in the tire mark and the gouge mark left by the wheel rim on the outside of the yaw mark as the vehicle was leaning heavily just prior to the rollover. The tractor-trailer shown in the photograph was not involved in the accident, but was simply driving through the scene at the time the photograph was taken

The radius of the yaw marks is important to forensic engineers, and is necessary for the calculation of the *critical speed*, or *maximum* potential speed of the vehicle in yaw (as it was traversing a curved path and side slipping). We caution the reader that the *critical speed formula*, commonly used to estimate vehicle speed during yaw, is often misunderstood and misused by investigators who mistakenly think that critical speed calculations yield the minimum speed of a vehicle in yaw. It can be rigorously shown that the critical speed formula is derived for a vehicle traveling at a constant speed, in the absence of braking, acceleration, and/or a yaw angle. It can also be rigorously shown that in the presence of a yaw angle and/or vehicle acceleration or deceleration (braking) in yaw, the critical speed formula overestimates the actual vehicle speed [14, 15]. See the appendix for a discussion on how to determine the radius of a yaw mark. However, the reader is cautioned against attempting to make speed calculations using yaw mark evidence without consulting with a forensic engineering expert.

Although it has not been discussed in any detail, we also note that, in the event that sight lines may be relevant to an accident reconstruction, all potential vision or sight line obstructions should be documented, measured, and photographed to the extent possible when processing an accident scene. For more complex accident scene investigations requiring detailed measurements and documentation or topographic features and potential vision obstructions, it may be beneficial to obtain an engineering survey of the accident scene.

20.2.2 Vehicle Examination

Numerous issues can arise during the course of an accident investigation and reconstruction analysis that necessitate evidence obtained from a thorough and proper inspection of the involved accident vehicle(s). Therefore, in addition to documenting, photographing, and measuring the accident scene itself, it is also very important to properly document the accident vehicles.

20.2.3 Crush Damage

If sufficient scene evidence exists, such as the locations of the final rest positions of the vehicles in relation to the location of the POI on the roadway, the vehicle impact speeds and changes in velocity ($\overline{\Delta V}$ s) can be computed utilizing the scene data. Algorithms that enable the computation of the vehicle $\overline{\Delta V}$ s from the resulting crush damage to the vehicles have also been developed, and are available in numerous computer programs and software packages. It is important to note that, in a two-vehicle crash, the crush damage to *both* vehicles must be known in order to calculate the $\overline{\Delta V}$ of *each* vehicle. The reader is referred to the user's manuals for the various software packages for details and instructions on making crush profile measurements compatible for use with the specific programs.

Although it is well known that vehicle $\overline{\Delta V}$ calculations based upon scene data and measurements, and the appropriate physical laws, are generally more reliable than crush based $\overline{\Delta V}$ calculations, the necessary scene data is not always available. In situations where there is a lack of accident scene data, documentation of the crush damage becomes even more important in approximating the vehicle $\overline{\Delta V}$ s, which are often necessary for a biomechanical analysis.

Several techniques are utilized by investigators and accident reconstructionists to obtain vehicle damage (crush) profiles. Most of the commonly utilized, commercially available accident reconstruction software packages require the crush profile to be input by dividing the crush width into equally spaced intervals defined by two, four, or six equally spaced points (Fig. 20.3).

Crush measurements are typically made utilizing common measuring devices (e.g., tape measures) made from an established reference line, utilizing known vehicle dimensions. Consider, e.g., a vehicle sustaining a frontal impact. With the undeformed length of the vehicle known (i.e., obtained from a database), and utilizing the rear bumper of the vehicle as a reference line, the length of the deformed vehicle measured at predetermined intervals across the width of the vehicle can then be utilized to determine the crush depth at a particular location by subtracting the measured crushed vehicle length from the undeformed vehicle length. Note that the same principle applies to the determination of side impact crush profiles with the undeformed width of the vehicle known, and the non-impacted side of the vehicle utilized to define the reference line, provided the vehicle is not bent in a beam bending mode. We also note for completeness that the reference line need not be located on the vehicle so long as the relevant measurements are made to enable

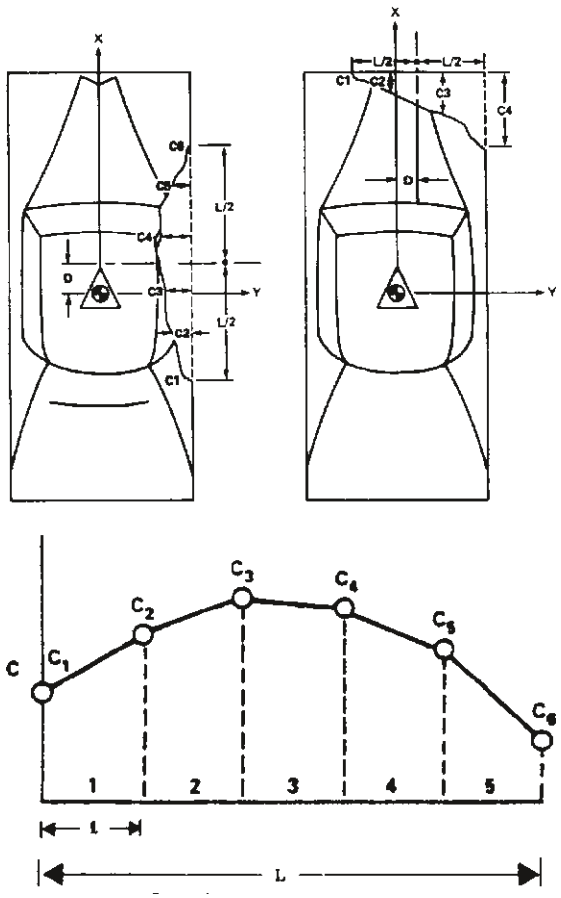

Fig. 20.3 Typical (idealized) vehicle crush profiles. Note that on the laterally impacted vehicle the damage width is divided into five equally spaced intervals defined by six crush points. For the frontally impacted vehicle, the damage width is divided into three equal intervals defined by four crush points. Also shown are the locally defined coordinate systems for each vehicle, with the origins located at the centers of mass of each vehicle. The figure on the bottom is an example of a six-point crush profile of width, *L*, divided into five equally spaced intervals of width, *l* (taken from [8]). Reproduced by permission of NHTSA, Washington, DC © 1986

calculation/determination of the crush profile. We further note that crush profiles can also be determined photogrammetrically if sufficient photographic information and data exist and the proper techniques are employed in photographing the vehicle.

20.2.4 Light Bulb Examination

In some instances, such as in nighttime accidents and in cases involving turn signals, light bulb illumination can be an issue. The discussion to follow applies

to incandescent light bulbs containing filaments, and does not apply to the examination of light bulbs, such as those employing the High-Intensity Discharge (HID), xenon, technology currently utilized in some modern headlights. In severe enough impacts, particularly for incandescent light bulbs located in close proximity to the impact/damage region on the vehicle, illuminated (hot and pliable) filaments are often stretched and deformed by an impact to the vehicle in a phenomenon commonly referred to as *hot shock*. A broken filament with melted ends at the site of the break is also an indication that the filament failure occurred while the bulb was illuminated. However, before it can be concluded that a broken filament with evidence of melting was illuminated at the moment of impact, it must first be determined if the bulb burned out at some time prior to the subject accident. Similarly, before a hot-shocked bulb can be attributed to a particular accident, it must be determined if the subject bulb/vehicle had been involved in any prior accidents. Also, in older bulbs, filaments can exhibit normal age sag, which should not be confused with hot shock.

Often times, the bulb(s) of interest is (are) broken during the impact with the filament(s) being exposed to the atmosphere. In such instances, the remains of the filament of interest should be examined for evidence of fused glass particles to the filament and/or the presence of white/yellow oxide residue, which forms and deposits on a hot (illuminated) filament suddenly exposed to the atmosphere when the bulb glass breaks. However, exposed filament evidence is delicate and, when not carefully preserved, may be easily lost. Therefore, when light bulb evidence is important, special care must be taken to ensure that the vehicle/light bulbs are carefully preserved and protected from the elements. *Cold shock* is the term often associated with an unstretched, but detached filament, often found loose within the confines of the unbroken bulb glass. A cold-shocked filament typically indicates that the filament was not illuminated at the time of the impact, or event, that caused the detachment from the posts within the bulb. It is also noted and emphasized that, while hot shock provides evidence of light bulb illumination at the time of a crash, assuming that the subject filament had not been involved in any prior incident, the absence of hot shock cannot be used as evidence that lights were not illuminated at the time of the crash event. The presence of visible hot shock depends upon the severity of the crash and the location of the subject bulb in relation to the area of impact on the vehicle. As a result, not all (or any) illuminated (and unbroken) light bulbs on a vehicle will necessarily display evidence of hot shock after a crash or collision event, even if the bulb was illuminated at the time of the crash. As part of the vehicle investigation at the accident scene, light switch settings should also be observed, documented, and photographed in cases where light bulb illumination is an issue. See Fig. 20.4 for examples of evidence of light bulb illumination at the time of impact/failure.

20.2.5 Seat Belt Examinations

Evidence of occupant seat belt usage is often an important issue in both civil and criminal litigation. In many states, in civil matters, the seat belt defense may be

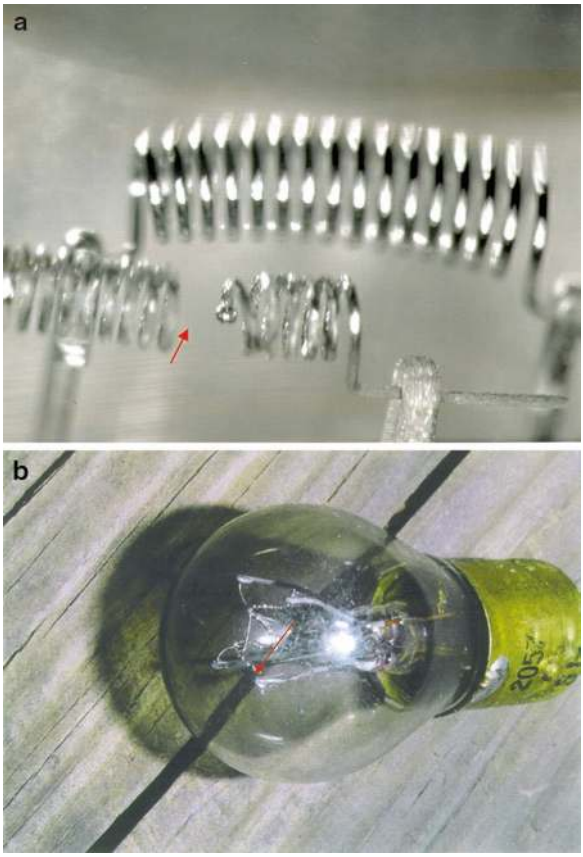

Fig. 20.4 (**a**) Magnified image of the filaments from a headlight of a vehicle that sustained a frontal impact. Note the break (discontinuity) in the lower filament and the globule of melted filament material (see *arrow*) at the end of the break on the right, indicating that the filament was hot (illuminated) at the time of the failure. (**b**) Light bulb filament exhibiting *hot shock* (see *arrow*), indicating that it was in use (illuminated) at the time of impact

raised and used to reduce the damages awarded to a plaintiff not wearing a seat belt, if it can be shown to be more likely than not that use of a seat belt would have mitigated or prevented injuries. In criminal matters, seating position and seat belt usage may also become an issue. In severe crashes causing significant occupant interaction with the restraint system, a seat-belted occupant will often times significantly load (exert high forces on) the seat belt components, leaving evidence of use in the form of loading marks on the soft plastic components, such as the D-ring and/or latch plate. An example of witness markings left on a heavily loaded D-ring by a seat belt in use during a crash is shown (Fig. 20.5).

When examining a seat belt for signs of usage, the webbing should also be examined for evidence of stretching and fabric transfer from the occupants clothing, etc. Broken and damaged fibers in the seat belt webbing may also be present and

Fig. 20.5 Seat belt and D-ring removed from a vehicle following a serious crash. Note the clearly visible (striated) loading marks from the seat belt webbing on the D-ring. Loading marks are not always quite so well defined and readily apparent. Careful examination of the seat belt components, under magnification, should always be performed, if necessary

provide evidence of seat belt usage. The resulting rapid loading, high stresses, and frictional heating in the individual webbing fibers of a seat belt in use during a severe crash can cause failures of individual fibers and melting of the broken fiber ends. Therefore, it may be necessary to have a seat belt/restraint system removed from a vehicle for a careful examination so that the webbing (and other components) can be carefully examined under laboratory conditions, and often times under magnification, for evidence of usage at the time of a crash.

A seat belt inspection should also include examination for the presence and locations of body fluids on the belt fabric. The locations of all such evidence should be noted, photographed, and documented. Blood and/or tissue on a portion of a seat belt that would normally be stowed if the seat belt had not been in use may also provide evidence of seat belt usage at the time of an accident.

In addition to the physical evidence often left on seat belt components during a crash, occupant injury patterns can also provide evidence of seat belt use, or non-use, during a crash. Classic seat belt injuries include, but are not necessarily limited to, upper torso, chest, and abdominal contusing. In cases where seat belt usage and the biomechanics of injuries are issues, biomechanical engineering experts should be consulted.

When examining an air bag-equipped vehicle for evidence of restraint system usage, the locations of all air bags within the vehicle, both deployed and non-deployed, should be noted and documented. Deployed air bags should be examined for evidence of body fluids (e.g., blood), fabric transfer, hair, etc., and other evidence of occupant interaction that may be used to associate occupants with seating positions

within the vehicle. The medical records should also be examined for injuries/injury pattern evidence consistent with air bag deployment, or non-deployment.

20.2.6 Occupant Kinematics

Generally speaking, engineers (and physicists) refer to *kinematics* as the study of the motions of objects, which relate the displacements, velocities, and accelerations to one another without reference to the forces that caused the motion(s), i.e., the geometry of motion. The technical term for the study of the motion relating the displacements, velocities, and accelerations of an object to the forces that caused the motion(s) is scientifically referred to as *kinetics*. The study of the motions of occupants relative to their vehicles during a crash is commonly referred to as *occupant kinematics*.

Occupant kinematic analysis is often important in both civil and criminal investigations. In civil matters, where injury causation and injury mechanisms are often of concern, quantifying the occupant motions and biomechanical loadings experienced by the occupant are of critical importance. In criminal matters, where understanding the injury causation mechanisms may not be as much of an issue, it is often important to determine seating positions and/or to identify who was operating a particular vehicle at the time of an accident and to identify the seating positions of other occupants.

A proper occupant kinematic analysis can only be performed *subsequent* to the completion of an accident reconstruction consistent with the available data and evidence. When examining a vehicle for which a biomechanical and/or occupant kinematic analysis is to be performed, it is important to make sure that key evidence is not overlooked during the investigation and/or analysis. Often times this involves the location and documentation of trace evidence. For example, in criminal investigations where initial seating positions are at issue witness markings, evidence of occupant contact with interior vehicle structure, fabric transfer, blood, hair, and tissue evidence should be documented as to where it was found within the vehicle and who it came from, to the extent that such identification is possible. Seat belt systems should be examined for evidence of use, and occupant injuries and injury patterns should be obtained from the medical records. Once the motion of the vehicle of interest is determined from the accident reconstruction, this information can then be used to study the expected motions of occupants (occupant kinematics) allegedly in specified seating positions at the commencement of the accident sequence. The expected motions of the various occupants used in conjunction with the governing laws of physics, identifiable and documented occupant contact points with interior vehicle structure as determined by the aforementioned trace evidence, and injury patterns may often be used to place the occupants within the vehicle prior to, or at the commencement of, the accident sequence.

It is noted for completeness that, in cases where mechanical failure is suspected as a contributing cause of an accident, the subject vehicle should be properly preserved and secured in a safe location where it is protected from the elements until a detailed mechanical inspection can be performed.

20.3 Accident Reconstruction

In performing a scientific accident reconstruction, the available physical evidence is utilized in conjunction with the governing physical laws to work backwards from the aftermath of a collision (or any accident or disaster) to determine the cause of, or conditions of interest at the commencement of, or immediately prior to, the subject event. In motor vehicle accident reconstruction, this typically involves the determination of impact speeds and/or changes in vehicle velocities ($\overline{\Delta V}$s). We begin our discussion with some fundamental definitions and concepts in basic physics.

20.3.1 Definitions

Classical mechanics may be defined as the science that treats the response of material bodies to the forces, motions, and displacements imposed upon them at nonrelativistic speeds. Basic concepts are *space*, *time*, *mass*, and *force*. A few other necessary definitions:

Vector – A quantity that needs to be specified with both a magnitude and a direction.

Scalar – A quantity that is completely specified by magnitude alone, with no reference to position or direction.

Displacement – Change in position (vector quantity). Specified in units of length.

Velocity ($\overline{V}$) – Time rate of change of displacement (vector quantity). Units are length/time.

Speed (V) – Magnitude of the velocity vector (scalar quantity). Units are length/time.

Acceleration ($\overline{a}$) – Time rate of change of velocity (vector quantity). Units are length/time/time (length/time^2).

g – (approximately 32.2 ft/s^2). Acceleration due to gravity at the surface of the earth. May be specified as either a vector, $\overline{g}$, or scalar, g, depending upon the context of usage.

Force – Action of one body on another, i.e., a directed push or pull. Forces can be due to direct contact or remote action. Force is a vector quantity.

Mass (M) – Amount of matter in a body. Mass (M), a scalar quantity, is *not* the same as weight ($\overline{W}$, a vector quantity). Mathematically, $\overline{W} = M\overline{g}$. However, the magnitude of the weight vector, W, is typically referred to as the weight of an object.

Linear Momentum – Product of mass times velocity (vector quantity).

Kinetic Energy – Energy of motion ($\frac{1}{2}MV^2$).

Note that throughout this chapter a line segment above a quantity denotes a vector. In addition, all velocities are defined at the centers of mass of the vehicles.

20.3.2 Laws of Motion

In 1687 Isaac Newton published his, now famous, three laws of motion for a particle of mass, M. These laws, summarized below, form the basis of the science of classical mechanics.

1. Every body continues in a state of rest, or of uniform motion (zero acceleration) in a straight line, unless acted upon by a resultant external force.
2. $\overline{F} = M\overline{a}$ where the force, $\overline{F}$, and the acceleration, $\overline{a}$, are vector quantities that define the scalar quantity, M, which is the mass.
3. To every action there is an equal and opposite reaction.

20.3.3 Reconstruction Analysis

Newton's Laws can be used to formulate three principles, which are often convenient for solving dynamics problems. These are the *principle of work and energy*, the *principle of linear impulse and linear momentum*, and the *principle of angular impulse and angular momentum*. The reader is referred to a text or reference in physics or engineering mechanics [7, 13] for the derivation and a detailed discussion of these fundamental principles. It is noted that the well-known principles of conservation of energy, conservation of linear momentum and conservation of angular momentum follow from these general principles under specific circumstances (see below for the conservation of linear momentum and the work-energy principle).

Accident reconstruction is a process wherein the available physical evidence and data are used in conjunction with the appropriate natural laws of science to determine the probable circumstances and conditions at the time of, or immediately prior to, the commencement of the accident sequence. In a motor vehicle accident reconstruction where sufficient scene data exists to determine the impact speeds of the vehicles, this often involves a direct application of the *principle of conservation of linear momentum*, which can be readily derived from Newton's second law [3, 7, 13]. The *principle of conservation of linear momentum* states that, in the absence of external forces acting on the system, the linear momentum of the system at the moment of impact (first contact) is equal to the linear momentum of the system immediately following the impact (separation). Mathematically stated, for a two-vehicle collision:

$$M_1\overline{V}_1^i + M_2\overline{V}_2^i = M_1\overline{U}_1 + M_2\overline{U}_2 \tag{20.1}$$

where M_j denotes the mass of vehicle j,

$\overline{V_j^i}$ denotes the velocity of vehicle j at impact (vector),

$\overline{U}_j$ denotes the post-impact velocity of vehicle j at vehicle separation (vector).

Note that (20.1) is a vector equation. Therefore, a separate algebraic equation must be written in each independent (orthogonal Cartesian) coordinate direction. It is assumed that the reader has a working knowledge of vector mechanics, basic linear algebra, and trigonometry. See, e.g., the references at the end of the chapter if a

review of basic concepts is necessary. As an illustration of basic accident reconstruction methodology, consider a right angle intersection collision where both vehicles skidded into the intersection prior to impact. See Fig. 20.6.

As indicated in the figure, an orthogonal Cartesian coordinate system is established, and the final rest positions of the vehicles relative to the location of the POI on the roadway and the vehicle post-impact departure angles are as shown. The goal of the analysis is to compute the impact speeds of the vehicles as well as the speed of each vehicle at the commencement of its respective pre-impact skid. As indicated above, we must work backwards from the final rest positions of the vehicles to obtain the separation velocities (post-impact vehicle velocities immediately following the impact). The principle of conservation of linear momentum is then used to write an algebraic equation in each of the two orthogonal component directions to compute the impact speed of each vehicle. Once the impact speed of each vehicle is known, the pre-impact skid distance for each vehicle is then used to determine the speed of each vehicle at the commencement of the accident sequence. This information can then be used to determine, e.g., if either vehicle was speeding, or if vehicle 2 failed to stop at the STOP sign (shown in the figure) prior to proceeding into the intersection, as may have been alleged by the driver of vehicle 1.

20.3.3.1 Calculation Procedure

As mentioned earlier herein, although accident reconstruction programs and software packages exist, for purpose of illustration we show the accident reconstruction in a step-by-step procedure.

Step 1: Compute the post-impact speed of each vehicle. See Fig. 20.6 for an illustration of the accident scenario and a definition of the variables. Note that the equations utilized follow from a straightforward application of the *work–energy principle* and the derivation is not presented here. For a complete derivation of this equation, see for example [7, 13]

$$U_1 = \sqrt{2\mu g s_1}$$
$$U_2 = \sqrt{2\mu g s_2} \tag{20.2}$$

where μ is the relevant drag factor (coefficient of friction).

Step 2: Use the *principle of conservation of linear momentum* to write equations in each of the two component directions and solve for the impact speeds.

X direction:

$$W_1 V_1^i = W_1 U_1 \cos(\theta_1) + W_2 U_2 \cos(\theta_2),$$

Y direction:

$$W_2 V_2^i = W_1 U_1 \sin(\theta_1) + W_2 U_2 \sin(\theta_2). \tag{20.3}$$

The observant reader will note that (20.3) are written in terms of the vehicle weights instead of the masses. However, since the magnitude of the weight, W, is equal to the product of the mass (M) and the acceleration due to gravity (g), i.e., $W = Mg$,

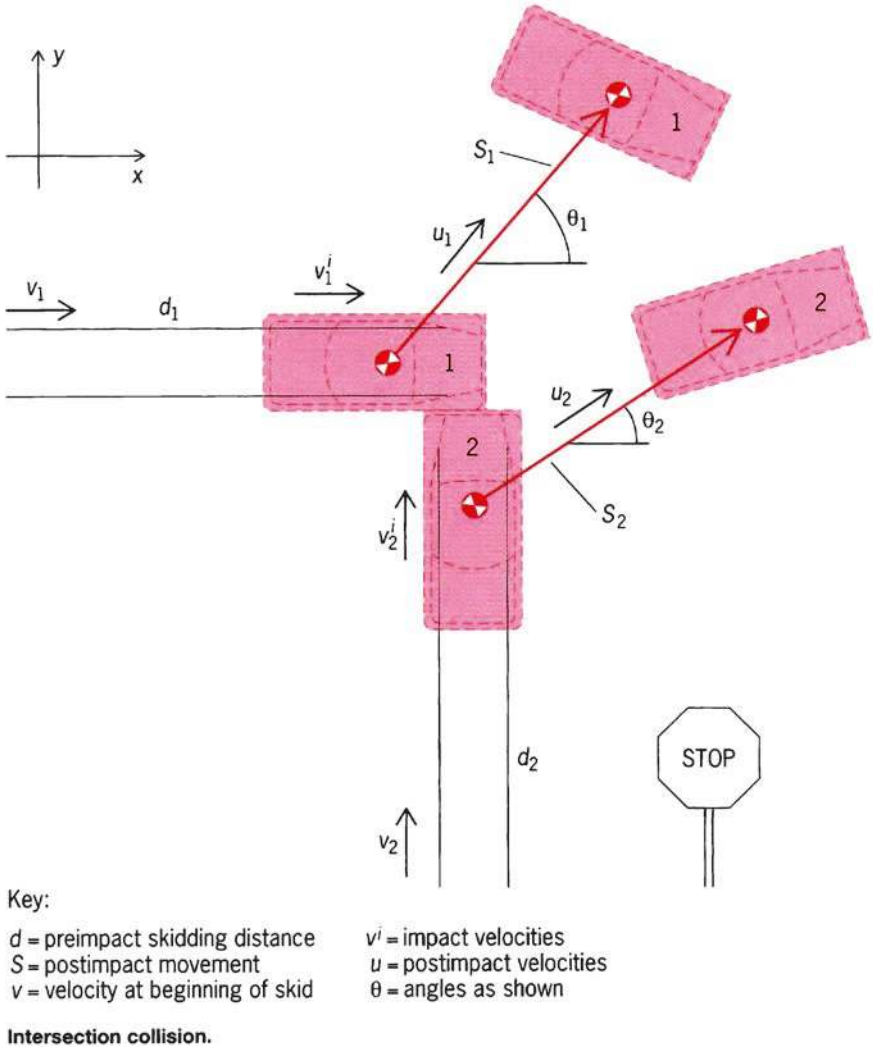

Fig. 20.6 From [5], reproduced by permission of McGraw Hill, NY, NY © 2002

there is no loss of generality in multiplying both sides of each equation by g, and then writing the equations in terms of the vehicle weights.

It should also be noted that, due to the orthogonal (right angle) orientation of the vehicles at impact, there is one (decoupled) algebraic equation for the impact speed of each vehicle. However, for a general oblique angle collision, the impact speed of each vehicle will explicitly appear in each of the two momentum equations. In this more general case, standard solution techniques for simultaneous linear equations would need to be employed to calculate the impact speed of each vehicle.

Step 3: The speed of each vehicle at the commencement of the accident sequence is computed utilizing the impact speeds of the vehicles and the appropriate kinematic

relation derived utilizing the *work–energy principle*. As noted in Step 1, the derivation is not presented here, but can be found in standard references in mechanics [7, 13].

$$V_1 = \sqrt{[(V_1^i)^2 + 2\mu g d_1]}$$
$$V_2 = \sqrt{[(V_2^i)^2 + 2\mu g d_2]}. \tag{20.4}$$

20.3.4 Change in Velocity

The probability of occupant injury in a motor vehicle accident is often correlated with the change in velocity ($\overline{\Delta V}$) of the center of mass of the subject vehicle. Therefore, when a biomechanical analysis, or an analysis of injury mechanisms, is an issue, it often becomes necessary to compute the changes in velocity ($\overline{\Delta V}$s) of the accident vehicles. The change in velocity vector ($\overline{\Delta V}$) for each vehicle, j, is defined to be the post-impact velocity minus the impact velocity, i.e.,

$$\overline{\Delta V_j} = \overline{U}_j - \overline{V}_j, \tag{20.5}$$

where (20.5) is a vector equation and the subtraction must be performed in terms of the vector components and properly combined to calculate the magnitude of $\overline{\Delta V}$ as shown below for vehicle j. For a typical two-dimensional (2D) accident reconstruction:

$$\left(\overline{\Delta V}\right)_{xj} = \overline{U}_{xj} - \overline{V}_{xj}$$
$$\left(\overline{\Delta V}\right)_{yj} = \overline{U}_{yj} - \overline{V}_{yj}$$
$$\left|\overline{\Delta V}\right|_j = \sqrt{\left|\overline{\Delta V}_{xj}\right|^2 + \left|\overline{\Delta V}_{yj}\right|^2}, \tag{20.6}$$

where the x and y subscripts denote the defined orthogonal coordinate directions. Note that the $\overline{\Delta V}$ vector and its components can be defined either in terms of the global scene coordinate system or in terms of a locally defined coordinate system for each vehicle. Typically, in a biomechanical, or occupant kinematic analysis, the motion of the occupant is defined relative to the vehicle and the $\overline{\Delta V}$ is expressed in terms of the local vehicle coordinate system.

As briefly discussed above, the vehicle $\overline{\Delta V}$s can be also computed from the crush damage to the vehicles if the vehicle masses, stiffness coefficients, and damage profiles are known. Also, as previously discussed, in a two-vehicle accident, in general, the crush damage to both vehicles must be known in order to calculate the $\overline{\Delta V}$ of either vehicle. References [8, 9] contain detailed derivations and discussions of the algorithms and equations used to perform damage based $\overline{\Delta V}$ calculations. A crush damage analysis is often performed in situations when there is insufficient scene evidence available to compute the vehicle $\overline{\Delta V}$s utilizing (20.1)–(20.6). In general, due to local variations in actual vehicle crush stiffness, deviations in actual

crush damage patterns from the idealized crush damage patterns required for most damage algorithms, and the overall simplicity of most crush models, scene-based $\overline{\Delta V}$ calculations are preferred and should be performed when sufficient scene evidence is available, even if damage-based $\overline{\Delta V}$ calculations are also made.

The probability of occupant injury is often correlated with both the magnitude and direction of the delta-v vector ($\overline{\Delta V}$) for the vehicle in which he/she was an occupant at the time of the impact. Injuries are often classified according to the Abbreviated Injury Scale (AIS) developed by the Association for the Advancement of Automotive Medicine (AAAM). This classification system is based upon a six-point scale, with injuries ranging from AIS 1 (*Minor*) to AIS 6 (*Maximum*), typically fatal. Injuries are ranked as 1 through 6 based upon a detailed description of the injury classified by type and body part as defined and published by the AAAM. For further information, the interested reader is referred to [1]. Note, however, that a more recent edition may now be available. Therefore, for a proper and complete biomechanical injury analysis, the engineer needs to be provided with detailed medical records and/or a full autopsy report in the event of a fatality. As was also already discussed, injuries and injury patterns sustained by a vehicle occupant can also provide useful information to the engineer/analyst with regard to seat belt usage.

20.3.5 Vehicle: Pedestrian Accidents

Another accident type frequently encountered by investigators is that of the vehicle–pedestrian impact. When documenting the scene of a vehicle–pedestrian accident, it is important for the investigator to record as much information as possible, including, but not necessarily limited to,

1. The POI on the roadway (when possible).
2. The final rest position of the victim (and all body parts).
3. The location of all points of roadway/ground contact by the victim (often denoted by blood and tissue smears, etc.).
4. The locations of all personal effects and items of clothing, i.e., shoes, glasses, bags being carried, etc., knocked loose or dislodged by the impact.
5. The final rest position of the striking vehicle.
6. Any and all pre- and post-impact tire mark evidence left by the striking vehicle.
7. Documentation of damage, blood and tissue evidence on the striking vehicle.

When documenting an accident scene and making measurements, the same type of Cartesian coordinate system discussed above for a multi-vehicle accident should be used. When possible, the POI should be located consistent with the physical evidence, independent of witness statements. The locations of all crosswalks and pedestrian crossing areas should also be documented as part of the investigation. Evidence such as scuff marks from the victim's shoes, or in the case of an impacted bicyclist, scuff marks from the bicycle tires or roadway scratch/gouge marks from the bicycle frame are often good indicators of the location of the POI and/or the post-impact trajectory of the bicycle. It is noted for completeness that, in the case

of motor vehicle–bicycle impacts, the cyclist is typically separated from the bicycle and the final rest positions of both the cyclist and the bicycle (and all components) should be recorded. In cases where the pedestrian is not perceived by the vehicle operator until the POI and skid mark or other evidence indicates post-impact emergency braking, the distance between the POI and final rest position of the vehicle, as well as the location and extent of all tire and roadway markings should be documented, and can be used to determine the impact speed range of the vehicle. In the case where there is evidence of both pre- and post-impact emergency braking, i.e., the vehicle skids through the impact to a stop, the combined skidding distance may be utilized to obtain speed estimates for the vehicle both at the time of the pedestrian impact and at the commencement of the accident sequence. For the governing kinematic relationships see, e.g., [7, 11, 13]. However, the reader is cautioned that care must be taken to properly account for the perception–reaction time of the vehicle operator in a speed calculation utilizing the motion of the vehicle, particularly in situations where the vehicle operator does not perceive the pedestrian until impact. In order to perform a meaningful speed analysis utilizing the post-impact motion of the vehicle, it also needs to be determined that the vehicle was not moved after coming to final rest immediately following the accident and prior to the arrival of police/investigators.

Methods of computing/estimating vehicle impact speed have also been developed utilizing the kinematic relations derived for the study of projectile motion in combination with those used to study sliding/rolling along the ground. In the literature on pedestrian impact analysis, the term pedestrian throw distance is often used to denote the combined airborne, sliding, and rolling motion of the pedestrian from impact to final rest. For further discussion on vehicle–pedestrian accidents, see [10, 16].

20.4 Product Liability

In cases involving allegations of defective products, forensic engineers need to determine, first, if the product was defective, and, second, whether the product defect, if one was found, was causally related to the happening of the subject accident and the resulting injuries. The three types of product defects recognized by the law are (1) design defects (the product lacks those elements necessary for its safe and foreseeable uses), (2) manufacturing defects (the product was not made according to the manufacturer's specifications), and (3) failure to warn or instruct (the product was not accompanied by adequate warnings for its proper and safe use). While product liability litigation is usually a matter for the civil courts, the reader is reminded of the Ford Pinto litigation of the 1970s that resulted in vehicle fires, caused by a design defect, during relatively low-to-moderate speed rear end impacts that Ford was aware of and failed to correct, resulting in criminal charges against Ford Motor Company. Although Ford was eventually acquitted in a jury trial, production of the Ford Pinto was discontinued shortly thereafter.

20.5 Concluding Remarks

The purpose of this chapter is to provide a brief introduction and overview of forensic engineering methodology and motor vehicle accident reconstruction. Other areas of forensic engineering investigation and analysis not covered in this chapter include, but are not necessarily limited to, ballistics (e.g., bullet trajectory analysis), structural collapses, aircraft crashes, fire (and explosion) cause and origin, industrial, electrical, and chemical accidents, as well as slips, trips, and falls, to name a few. In all areas of forensic engineering and accident/incident reconstruction, the methodology is the same. That is, given the final conditions or aftermath of an accident, or catastrophic or injury-producing event, the available physical evidence must be used in combination with the governing natural laws to determine the cause of the incident and/or the initial conditions, or the state of the system at the commencement of the accident/incident sequence.

Forensic engineers also play critical roles in the investigation and analysis of large-scale disasters and purposeful malicious acts, such as massive accidental failures and terrorist attacks that result in the large-scale destruction of property and the catastrophic loss of life. The Hyatt Regency Skywalk collapse on 17 July 1981 that resulted in a substantial loss of life was found to be the result of a simple design error. A reconstruction analysis of the crash of TWA flight 800 that occurred on 17 July 1996 shortly after takeoff from Kennedy Airport in NY determined that crash to be the result of a design defect in the center fuel tank of the subject Boeing 747, despite the continued objections of conspiracy theorists. The reconstruction of this accident was complicated by the fact that the aircraft exploded over, and crashed into, Long Island Sound, necessitating an underwater recovery of the wreckage from a very harsh marine environment. Examples of criminal acts requiring forensic engineering expertise include the 1988 terrorist bombing of PAN-AM flight 103 over Lockerbie, Scotland, the analysis of the 19 July 1995 terrorist bombing and resulting collapse of the Murrah Federal Building in Oklahoma City and the 11 Sep 2001 terrorist attack and collapse of the World Trade Center Towers in Manhattan, NY.

The intent of this chapter is to provide crime lab personnel with an awareness of how engineers can be effectively utilized in many of their investigations and analyses, and to provide the reader with a brief introduction to forensic engineering and accident reconstruction methodology. It is hoped that the information contained herein will be helpful to crime lab personnel in recognizing situations where forensic engineering expertise may be helpful and/or necessary for a proper investigation and analysis of an accident or criminal act.

20.6 Appendix

In order for forensic engineers to utilize yaw mark evidence in making meaningful speed calculations, the radius (R) of the yaw marks must be known. For completeness and in the event that it is becomes necessary for the overall analysis, the

lengths of all yaw marks should be measured. However, unlike skid mark evidence, which typically requires only a length measurement to be useful for calculations, when investigating an accident scene, yaw mark evidence requires additional measurements. Since yaw marks are curved, the chord length (L) and middle ordinate (h) must be measured in order to calculate the radius of the mark. To measure the chord length (L), stretch a measuring tape between the end points of the yaw mark. At the midpoint of the chord $\left(\frac{L}{2}\right)$, measure the perpendicular distance from the yaw mark to the chord created by the measuring tape (Fig. 20.7).

It can then be shown, using the Pythagorean Theorem for the triangle in the figure, that:

$$R = \frac{L^2}{8h} + \frac{h}{2}. \tag{20.7}$$

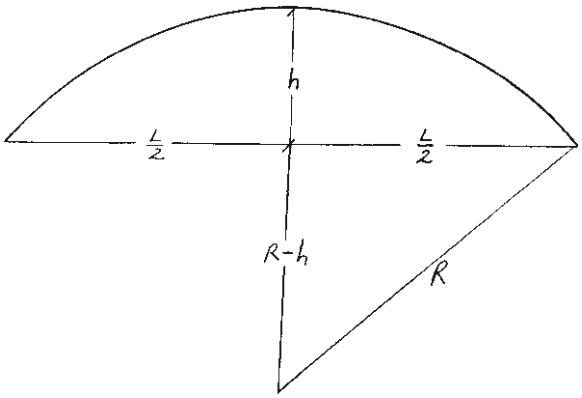

Fig. 20.7 To measure the chord length (L), stretch a measuring tape between the end points of the yaw mark. At the midpoint of the chord ($\frac{L}{2}$), measure the perpendicular distance from the yaw mark to the chord created by the measuring tape

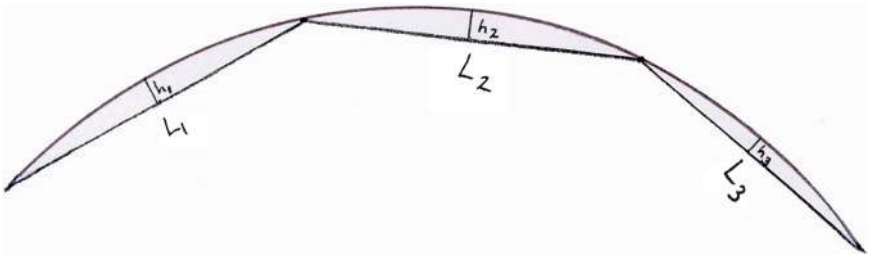

Fig. 20.8 The curve (yaw mark) divided into three segments

It is noted that, in most situations, the radius (R) of the yaw mark is not constant. Therefore, the yaw mark should be divided into segments and the chord length (L) and middle ordinate (h) should be measured for each segment.

Figure 20.8 shows the curve (yaw mark) divided into three segments. A corresponding radius (R) can then be calculated for each segment of the yaw mark. For yaw marks with large variations in radius, several segments may be necessary to adequately approximate the curved path of the vehicle.

20.7 Abbreviations

ABS Anti-lock braking systems
AIS Abbreviated injury scale
HID High-intensity discharge
POI Point of impact

20.8 Questions

1. What is the definition of forensic engineering?
2. Describe the general methodology employed by engineers when reconstructing a motor vehicle accident. What data must be known? What scientific principles are applied? What is typically calculated?
3. What are Newton's three laws of motion? How do these laws relate to accident reconstruction?
4. Mathematically state the *Principle of Conservation of Linear Momentum.* Describe the meaning of this principle and state how it is used in motor vehicle accident reconstruction.
5. Why is the quantitative documentation of an accident scene critical to an accident reconstruction?
6. What are some indications of the location of the Point of Impact (POI) on the roadway surface at the scene of a motor vehicle accident?
7. What is "hot shock?"
8. What are some other indicators of incandescent light bulb illumination at the time of a crash?
9. How is the vehicle delta-v defined? Why is it of interest to forensic and biomechanical engineers when analyzing an accident?
10. What is the definition of occupant kinematics?
11. Give some examples of how occupant injuries and injury patterns are used in a forensic engineering analysis of an accident.
12. Describe some of the evidence that forensic engineers look for in determining occupant seat belt usage at the time of a crash.

20.9 About the Authors

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Dr. Scott D. Batterman is a nationally recognized forensic engineering consultant and Fellow of the AAFS. He received his Ph.D. in Mechanical Engineering and Applied Mechanics from the University of Pennsylvania in 1989. Dr. Batterman is a past Chair of the Engineering Sciences Section of the AAFS, and has served on the AAFS Board of Directors. He has lectured extensively on the subject of accident reconstruction and related concepts, and has numerous publications in the fields covered by the chapter appearing in this book. Dr. Batterman is a registered professional engineer (P.E.) and provides engineering consulting services through Batterman Engineering, LLC, in Cherry Hill, NJ.

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Chapter 21
Wildlife Forensic Science

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Contents

21.1 Introduction

Simply stated, wildlife forensic science involves the application of basic forensic principles and techniques (as well as a wide array of simple-to-highly complex instruments and protocols) to investigative cases in which a violation of federal or state wildlife laws may have taken place, and the victim is a non-human animal.

Prior to July 1, 1975, the resources of a crime laboratory were rarely applied to wildlife – or animal-related evidence. When such applications did occur, it

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was mostly in an effort to determine the family, genus, or (ideally) species sources of blood stains and loose hairs collected at human crime scenes. These identifications were generally based upon immunodiffusion tests using relatively nonspecific antisera, and microscopic comparisons utilizing small collections of known hairs obtained from local museums or zoos. The results were often more useful in eliminating a suspect (e.g., the blood on the suspect's shirt is not of human origin) than in trying to link suspect and victim to a specific crime scene.

During this early phase of wildlife forensics, a few scientists did devote their careers to the examination of evidence seized by wildlife law enforcement officers; but their resources (lab space, sophisticated instruments, comprehensive databases, and "standards" collections) ranged from extremely limited to non-existent. Accordingly, their examinations were mostly limited to the identification of blood, meat, and hair from locally hunted species, utilizing the same immunodiffusion and microscopic comparison techniques of their police crime lab peers. The ultimate goal of making their identifications to a specific species, and to the exclusion of any other species existing on the planet, was mostly a fanciful dream.

July 1, 1975 was a momentous date for wildlife forensics in that 80 nations formally agreed to enforce each other's endangered species laws via the establishment of CITES (The Convention on International Trade in Endangered Species Fauna and Flora) (see www.cites.org). As such, the member countries were expected to enforce uniform import and export laws related to previously agreed-upon lists of endangered, threatened, and protected species. All of this multi-national effort quickly revealed an underlying forensic issue: the fact that illegal trafficking of regulated species would occur mostly in the form of parts and products, rather than whole animals; and that species-specific identifications of questioned items would be needed to enforce the CITES regulations in courts of law. Thus the need for wildlife forensics – functioning on an international scale, and taking into account the huge diversity of the Animal Kingdom – was born.

In 1986, in response to this new forensic requirement, and in an effort to support CITES, the United States established the National Fish and Wildlife Forensics Laboratory (NFWFL) in Ashland, Oregon (www.lab.fws.gov). The primary mission of this new laboratory was – and still is – to develop reliable wildlife forensic procedures, and to provide forensic support to state, federal, and international wildlife law enforcement officers. But the task of providing forensic and expert-witness services to more than 170 countries far exceeds the resources of any one laboratory. At some point, similar labs will have to be established on other continents in order for the science of wildlife forensics to meet its international demands.

In 1993, at a meeting of the Environmental Crimes Group of Interpol in Lyon, France, the role of the NFWFL in assisting CITES and Interpol was documented in the form of signed letters of agreement. As a result of those treaties, the NFWFL now works with scientists and law enforcement officers from the CITES and the Wildlife Working Group of Interpol to continually develop and refine reliable methods of identifying wildlife parts and products, as well as to link suspects and their animal victims to specific crime scenes.

21.2 The Inherent Problems of Wildlife Forensic Science

At a typical homicide scene, the task of linking the suspect to the victim and the crime scene is often complicated by the difficulty of determining what the scene was like before the suspect and victim came into lethal contact. In a like manner, the difficulty of linking the suspect and victim in an illegal hunting situation is frequently complicated by the (1) lack of species-specific definitions for wildlife parts and products and (2) circumstances under which an animal can be legally killed.

21.2.1 The Lack of Species-Specific Definitions for Wildlife Parts and Products

In a police crime lab, the task of identifying and quantifying individual items of evidence tends to be relatively simple. For example, 452 g of white powder is determined to contain 87% cocaine hydrochloride and 13% nonrestricted materials. A venous blood sample is determined to contain 0.18% ethyl alcohol. A lethal projectile is determined to be a 0.45-caliber copper-jacketed hollow-point bullet bearing six lands and groves with a left-handed twist. In the above-listed examples, the task of identifying and quantifying truly is simple and straightforward because precise and commonly accepted definitions for each of these items are available within the international law enforcement and forensic communities.

In a like manner, if the evidence seized by a wildlife investigator consists of a whole animal carcass, the species identification of that carcass is usually a simple and straight-forward process, generally based on internationally agreed-upon sets of *taxa* in which a species is defined by a number of specific physical characteristics, as well as by the country of origin.

However, wildlife investigators rarely seize whole animals as evidence. Instead, they tend to seize parts and products of animals from boats, planes, and warehouses. As such, they rarely know the country of origin of these items, and cannot depend on those who do know (usually, the suspects) to provide a dependable answer. Worse, from a forensic viewpoint: these parts and products rarely possess all of the carefully researched and established morphological characteristics that currently define a "whole animal" species (Fig. 21.1).

Given this inability to use standard taxonomic keys to determine species of origin, wildlife forensic scientists are forced to conduct extensive research to come up with new species-defining characteristics that will enable them to stand up in a court of law and testify that a part or product in question came from a certain species, and no other species in the world. Understandably, it is the "no other species in the world" part of the problem that makes the species-source identification of a wildlife part or product a formidable task indeed.

Fig. 21.1 Elephant foot stool seized as evidence and submitted for species-source identification

21.2.2 Legal vs. Illegal Kills

In a sense, human forensic scientists have it easy because it is almost always illegal to kill a human being (except in self defense, or in an act of war). However, the circumstances under which an animal can be legally hunted, killed, and possessed are often quite complex. Examples of this complexity can be found in the following questions frequently posed to a crime lab by wildlife investigators, all of which have to be answered by wildlife variations of standard CSI (crime scene investigation) techniques (Fig. 21.2).

How was this animal hunted and killed?

Legal hunting may be restricted to the use specific types of weapons (e.g., archery, black-powder firearms, etc.) to kill certain animals during a defined hunting season, or within a defined hunting area.

When did this animal die?

It is usually illegal to kill migratory birds before sunrise or after sunset during a defined hunting season; and illegal to kill most animals the day before a defined hunting season.

Where was this animal killed?

It may be legal to hunt in a federally protected wildlife refuge during a certain hunting season, but illegal to do so in adjoining private property.

How many animals were killed by this hunter during this hunting season?

It may be legal to kill – or possess – a specific number of a specific species during a defined hunting day or season, but no more than that number.

Fig. 21.2 Young deer shot with an arrow at a wildlife crime scene

What are the genders of the animals killed?

It may be legal to kill a male whitetail deer during a defined hunting day or season, but not a female.

Which hunters were involved in the illegal hunting?

In a typical waterfowl hunting blind situation, where several hunters may be shooting in the same area and "dropped" ducks tend to be co-mingled, it may be difficult to tell which hunters killed "over their limit" and which hunters hit nothing at all. The issue can be further complicated if not-to-be-exceeded point values are assigned to certain species of ducks during a hunting day.

Was the animal killed in self-defense?

It may be legal for a hunter to kill an otherwise completely protected endangered species in self-defense if, for example, the bullet trajectories, impact points, and powder burns indicate the animal was charging the hunter instead of running away at the time of the shooting.

21.3 Wildlife Forensic Protocols

Thanks to a great deal of effort by scientists working within and outside the field of wildlife forensics, there are now a wide range of established protocols available for the identification and comparison of wildlife-related evidence. These protocols are typically divided into the following categories.

21.3.1 Morphology

Morphology is the study of structure and shape. In wildlife forensic science, morphological examinations of submitted evidence items are normally conducted by eye, and with the use of simple, compound, or scanning electron microscopes, along with a comprehensive set of "known" standards. These are often the simplest examinations performed in a wildlife crime lab; but, at the same time, they address some of the most complex and difficult identification problems.

> As an example, the vast majority of parents in this world are perfectly capable of identifying their sons or daughters from thousands of similar young men or women. But, could these parents create a written protocol that would enable another individual (i.e., a forensic scientist) to make that same positive identification with the same degree of certainty? The answer is almost certainly "no."

The reasons why such a protocol would be difficult to write lie in the heart of the morphological problem: the lack of standard definitions for individuals, and the fact that no two individuals (even genetic twins) are exactly alike. Two animals (e.g., two whitetail deer that are genetic twins) may start out looking very much alike, if not "identical"; but the normal wear and tear that a young whitetail deer experiences literally from the moment of birth create a series of individual characteristics (a healed cut, a chipped hoof, or broken antler) that quickly separate those twins into distinct individuals.

Thus, the immediate problem for a wildlife forensic scientist is to come up with *class characteristics* that distinguish and identify the family, genus, and species of animals that are separate and distinct from population and individual characteristics. This is not a problem with whole animals; but it is very much a problem in the case of wildlife parts and products wherein the commonly occurring species-defining characteristics of the animal source may not be present (Fig. 21.3).

These identification characteristics typically fall within one of the following morphological subcategories:

Hair and fur	Hooves, horns, and antlers
Leather and hides	Teeth, claws, and beaks
Bones and skulls	Feathers and down
Other miscellaneous parts	

Forensic scientists who perform morphological identifications on wildlife-related evidence typically have bachelor's or master's degrees in biology, or a related science, such as zoology or zoo-archeology.

21.3.2 Molecular Biology (Genetics)

Molecular biology involves the study of genetic information encoded in the DNA molecule, and the expression of that coding into proteins and related biological structures. Given the incredible diversity of biological structures present in the

Fig. 21.3 A collection of primate skulls used as comparison standards

known plant and animal kingdoms, molecular biology offers the wildlife forensic scientist an extremely powerful tool to:

Determine family, genus, and species
Determine gender
Individualize blood and tissue samples

21.3.2.1 Family/Genus/Species ID

Prior to 1996, the forensic process of determining the species origin of an unknown tissue normally began with a series of screening (immunological) tests designed to narrow the possibilities down to the species comprising a single family (e.g., bears – family Ursidae, or deer – family Cervidae). Once the family source of the specimen was determined, the examiners would go forward with either protein or DNA/PCR analysis (along with the necessary and comprehensive databases) to determine the actual genus and species involved (Fig. 21.4).

21.3.2.2 Gender Identification

A number of nuclear DNA-based gender-determining tests are available for blood and tissue samples from mammalian species. The tests typically use PCR

Fig. 21.4 DNA extraction from frozen meat seized from a suspect's freezer

amplification to detect specific sequences of the ZFY and/or SRY genes, both of which are located on the mammalian Y chromosome.

21.3.2.3 Individualization of Blood and Tissue

Early work on individualizing animal blood and tissue samples involved multilocus DNA probe hybridization techniques. However, new PCR methods for detecting single-locus STR markers have been developed and applied in human forensic casework, demonstrating the technical feasibility of similar applications to animal species. Pending the arrival of new technologies, wildlife research and forensic laboratories will focus a considerable amount of effort on the development of STR markers for determining the individual origins of wildlife evidence tissues.

21.3.3 Criminalistics

Wildlife forensic scientists frequently process evidence from an illegal hunt much in the same way that a police forensic scientist works evidence from a homicide scene. In fact, the events associated with a typical illegal hunt often involve the following categories of "criminalistics" (or police forensic science) evidence.

21.3.3.1 Trace Evidence

Trace evidence in an animal case can involve a wide range of materials. A classic example is a case in which a mountain lion was held captive for a period of time and then killed in an illegal "canned" hunt. As it turned out, the mountain lion tried to chew his way loose from the synthetic fiber ropes (two types were used by the suspects to secure the lion), and a forensic scientist was able to link the fibers from the lion's stomach back to chewed ropes found at the crime scene.

21.3.3.2 Firearms

The typical circumstances in which an animal is killed with a firearm vary greatly from those of a homicide case. The most significant differences include:

The distance from suspect to victim
The choice of firearm
The ability of the suspect to "clean up" the scene
The tendency of the suspect to take the victim from the scene
The tendency of the suspect to frequently reuse the same firearm

Unlike human crime situations in which the victim is most commonly killed with a pistol at short – "contact" to 25-yard – distances, the typical animal kill involves a high-powered (and large caliber) rifle or a shotgun at relatively long distances (50–300 yards).

Given the nature of the typical hunting area (brush, trees, and ground cover), it is often difficult for an illicit hunter to retrieve his expended casings; however, the long shooting distances and the fact that the shot could have come from any 360° vector point makes it extremely difficult for a wildlife crime scene investigator to locate the shooting point, much less the expended casings. However, all of these advantages (to the illicit hunter) tend to be negated by two simple facts:

The point of the illicit hunting is for the suspect to take the victim (as a trophy or meat) back to his residence. Thus, the bullet is likely to either be in the carcass of the animal, or in the "gut pile" left at the scene (which can be potentially matched to the trophy head or meat with DNA techniques).

The typical illicit hunter spends a lot of money on his rifle or shotgun, and is rarely willing to discard their weapon after a single illegal kill. Thus, it is very likely that a succession of illegal kills can be linked to a single poacher by matching the spent bullets or casings to their rifle or shotgun.

21.3.3.3 Other Weapons

Other hunting weapons typically associated with an illegal animal kill include:

Long bows and arrows	Spring traps
Crossbows and "bolts"	Poison discharge devices
Spear	Nets

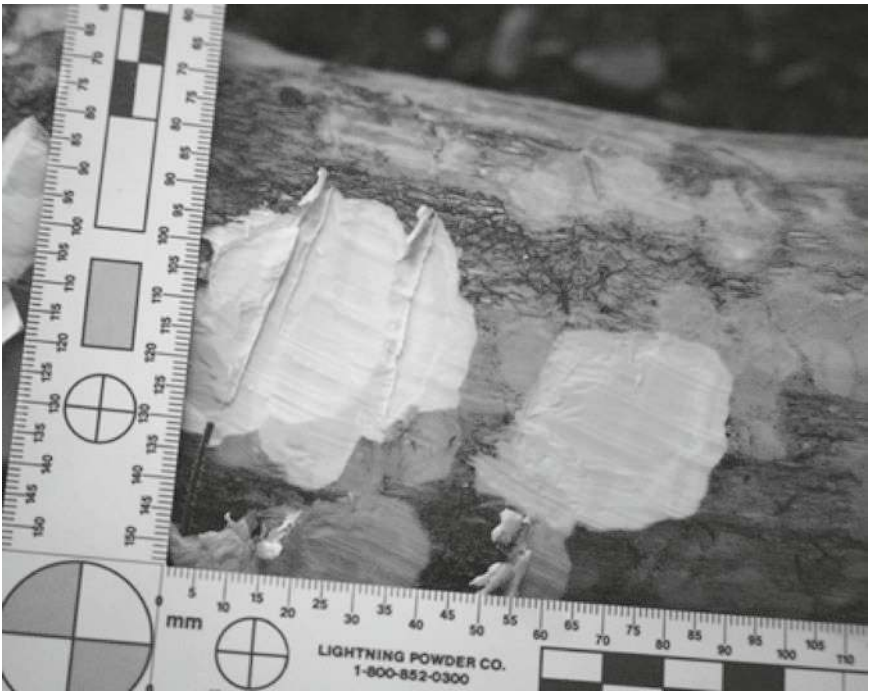

Fig. 21.5 Distinct machete tool marks found on a seized elephant tusk

21.3.3.4 Impression Marks

The fact that most illicit hunting situations occur in remote areas or "off road" situations makes it extremely likely that the suspect will leave tire tracks and boot impressions in soil, mud, or snow. Additionally, the fact that these tires and boots are typically used in off-road situations makes it all the more likely that the tire or boot treads will possess individualistic wear marks. Knives and axes are also excellent sources of tool marks found on disarticulated wildlife parts (Fig. 21.5).

21.3.3.5 Latent Prints

Latent fingerprints are the classic means of linking suspect, victim, and crime scene through physical evidence. The following types of latent-bearing evidence are frequently submitted to a crime lab in wildlife cases:

Firearms
Expended casings (shotgun and rifle)
Knives
"No Trespassing" and "No Hunting" signs
Game tags
Import/export (CITES) permit (Fig. 21.6)

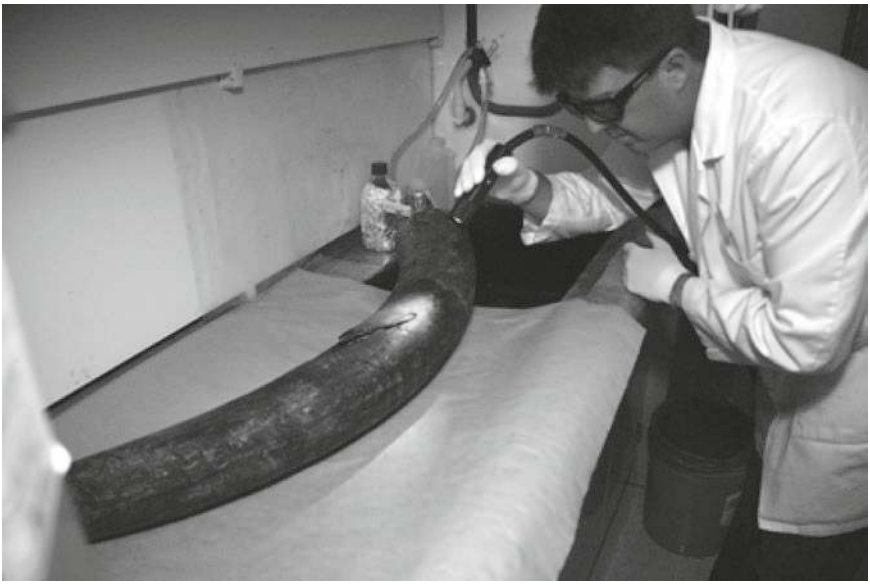

Fig. 21.6 Processing an intercepted shipment of elephant ivory tusks for latent prints using dyes and a monochromatic light source

21.3.3.6 Questioned Documents

Questioned documents are frequently encountered in wildlife investigations involving the import and/or export of wildlife parts and products. The question most frequently by the investigator is whether or not the seized documents (typically import/export permits) are valid. This can be an extremely difficult question to answer when the authorizing seals vary between countries, the names of individuals authorized to approve import/export documents change on a frequent basis, and the shipments must be "cleared" (the documents examined and approved) at the local port of entry.

Questioned documents typically associated with a wildlife case include:

Forged or altered hunting licenses
Forged or altered game tags
Forged or altered import/export permits

21.4 Analytical Chemistry

Chemical analysis techniques are used in a wildlife crime lab to provide different data.

21.4.1 Toxicology Data

In order to accurately determine the cause of death of an animal, a veterinary pathologist conducting a necropsy typically needs a toxicological analysis of blood, urine, stomach contents, and liver and kidney tissues to determine the presence or absence of pesticides and poisons. This work is usually conducted by scientists possessing a bachelor's or master's degree in analytical chemistry or toxicology, and utilizing a wide range of mass spectrograph-based instruments. Similar procedures are routinely employed by these scientists to identify chemical baits and poisons used to trap and kill wildlife.

21.4.2 Biomarker Data

Analytical chemistry procedures (that utilize chemical biomarkers) are also used by chemists in a wildlife crime lab to identify the species source of animal products, such as bear bile and deer musk that are used in the preparation of Traditional Asian Medicines (Fig. 21.7).

Fig. 21.7 Mounted rhino head with samples of seized rhino horn products

21.4.3 Hemoglobin Structural Data

In 1996, forensic scientists at the NFWFL in Ashland, OR, utilized a MALDI mass spectrometer to conduct research on a procedure whereby the species of a blood or meat sample is determined by the analysis of the isolated hemoglobin structure. The development and verification of this protocol made it possible to determine the species source of a blood or meat sample in a few minutes as opposed to hours or days. Additionally, the ability of the MALDI instrument to work with extremely small samples, along with the habit of hunters and poachers not to wash their hunting clothes during an entire hunting season (in the belief that the animals will smell – and be scared off by – the scent of soap), now enables a wildlife forensic scientist to sample perhaps a hundred blood spots at random from a set of hunting clothes, and shortly thereafter provide the game warden with a list of all of the species the hunter "engaged with" during that hunting season; a very powerful investigative tool, indeed.

21.4.4 Stable Isotope Data

It is expected that research on stable isotopes, utilizing instruments such as a Fourier transform mass spectrometer and world-wide databases of stable isotope ratios found in soils, will eventually allow scientists to determine the specific location where a specific animal was born and raised (Fig. 21.8).

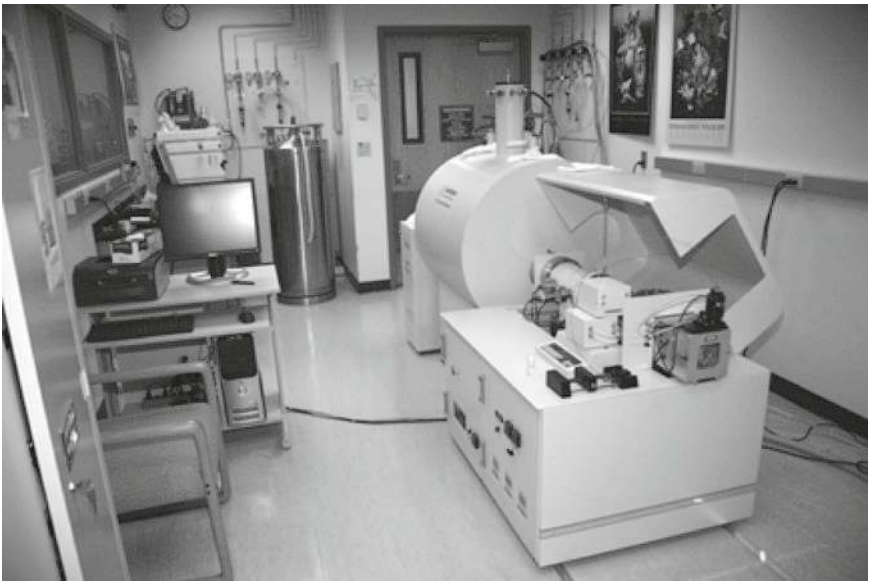

Fig. 21.8 A Fourier transform mass spectrometer (FTIR) used to analyze stable isotope ratios in soils. US Fish and Wildlife Forensic Laboratory Photograph

21.5 Pathology

Veterinary pathologists are responsible for determining cause of death of an animal carcass submitted as evidence. This is accomplished thorough necropsy (autopsy) protocols involving a search for lethal wounds cause by bullets, arrows, spears, and traps; a comprehensive toxicological workup of blood, urine, tissue, and stomach/crop contents to eliminate or confirm a poison or contaminate cause of death; and a professional evaluation of the underlying health of the animal prior to death. In the process of conducting these examinations, the veterinary pathologist will also search for signs of disease vectors that may indicate a natural cause of death.

Issues that often complicate a cause-of-death determination in an animal (but should not impact the results of a careful and professional necropsy examination) include:

The possibility that the animal may have been struck by additional (non-lethal or crippling) bullets, pellets, or other projectiles on days, months, or years prior to the questioned incident.

The possibility that an illicit bow-hunter shot the animal with a firearm first (because of the difficulty in getting close to an alert animal), and then stuck an arrow into the bullet wound.

The possibility that the animal was killed or fatally weakened by a modern pesticide or poison designed (as the result of environmental protection laws) to decompose rapidly after a few hours of exposure to air or sunlight.

The likelihood is that scavengers will have destroyed a considerable amount of useful blood, tissue, or bone evidence if the carcass was not found and collected in a timely manner (Fig. 21.9).

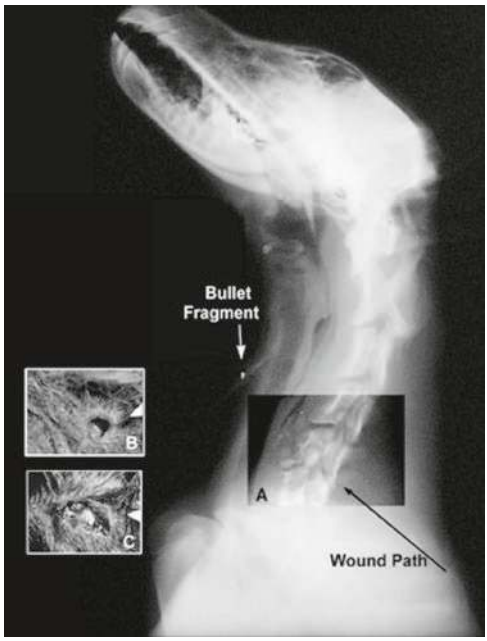

Fig. 21.9 X-rayed wound path in the neck of a wolf found at a wildlife crime scene

In conducting necropsies involving bullet wounds, it is often extremely important that the veterinary pathologist determine the trajectory of the bullet into or through the body. This information may resolve the question of whether the accused hunter was properly defending themself against a charging animal, or illegally hunting a protected species. The information may also be used by investigators, during the interview process, in determining the veracity of suspects and witnesses.

21.6 Digital Evidence

As unlikely as it might seem, illicit hunters have joined the modern electronic era with enthusiasm and imagination. While the idea of a professional poacher hiding their data in a computer might have seemed laughable in the 1990s, modern poachers add digital cameras and video recorders to their lists of equipment, and take hundreds of digital photos to share (over the Internet) with their fellow violators. It is now a rare warrant search of a poacher's residence or business that does not include the seizure of at least one computer, or (often in the case of a business that the investigators are not allowed to shut down) the "mirroring" of the computer's hard drive data into the investigator's portable computer.

21.7 Questions

1. Why is it often difficult to link suspect and victim to a wildlife-related crime scene?
2. Why is July 21, 1975 an important date for Wildlife Forensics?
3. Why is it often difficult to identify the species source of a wildlife part or product?
4. Is it ever legal to kill an Endangered Species animal?
5. What is morphology?
6. Why would a "gut pile" at a wildlife kill site be a useful piece of evidence?
7. What kind of "questioned documents" might be involved in a wildlife investigation?
8. What kind of evidence items from a wildlife investigation would a chemist analyze?
9. Why would stable isotope analysis be helpful for a wildlife investigation?
10. What kind of evidence might a digital evidence examiner find in an active poacher's computer?

21.8 About the Author

Ken Goddard began his law enforcement career in 1968 as a deputy sheriff/criminalist working crime scenes (CSI) and analyzing evidence for the Riverside and San Bernardino County (CA) Crime Labs. In 1972, he was hired by the Huntington

Beach (CA) Police Department to set up a Scientific Investigation Bureau for homicide, robbery, narcotics, and burglary investigations.

In 1979, Ken joined the US Fish and Wildlife Service to design and direct a National Fish and Wildlife Forensics Laboratory to provide forensic support for federal, state, and international wildlife law enforcement agencies all over the world. Finally constructed in 1988, in Ashland, Oregon, the USFWS Forensics Lab was the first – and is still the only – forensic lab devoted to wildlife in the world.

In 2006, Ken was assigned to an international team of marine biologists tasked to develop CSI techniques to investigate damaged coral reefs.

Ken holds a B.S. degree in Biochemistry and a M.S. degree in Criminalistics. He has published nine fiction thriller novels based on his work, including one based on the TV show *CSI*. Ken and his wife, Gena, live in Ashland, OR. Ken's writing web site is www.kengoddardbooks.com

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Appendices

These appendices contain references which will prove valuable in many areas. The reader is director to the National Clearinghouse for Science, Technology and the Law for a myriad of up-to-date resources, http://www.ncstl.org.

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Appendix A

Forensic Societies, Associations, Federal and International Agencies

- AOAC International, http://www.aoac.org
- American Academy of Forensic Sciences, http://www.aafs.org
- American Academy of Psychiatry and the Law, http://www.aapl.org
- American Board of Forensic Anthropology, http://www.theabfa.org
- American Board of Criminalistics, http://www.criminalistics.com
- American Board of Forensic Document Examiners, Inc., http://www.asqde.org
- American Board of Forensic Odontology, http://www.abfo.org
- American Board of Forensic Psychology, http://www.abfp.com
- American Board of Forensic Toxicology, http://www.abft.org
- American Board of Medicolegal Death Investigators, http://www.slu.edu/organizations/abmdi
- American Board of Pathology, http://www.abpath.org
- American Institute of Forensic Education, http://www.educationforensic.com
- American Society of Crime Lab Directors, http://www.ascld.org
- American Society of Forensic Odontology, http://www.asfo.org
- American Society of Questioned Document Examiners, http://www.asqde.org
- Association of Firearm and Tool Mark Examiners, http://www.afte.org
- Australian and New Zealand Forensic Science Society, http://anzfss-vic.blogspot.com
- California Association of Toxicologists, http://www.Cal-tox.org
- Canadian Society of Forensic Science, http://www.csfs.ca
- Council on Forensic Science Education, http://www.criminology.fsu.edu/COFSE/default.html
- Forensic DNA Consulting, http://www.forensicdna.com
- Forensic Nurse, http://www.theforensicnurse.com
- Forensic Science Society, http://www.forensic-science-society.org.uk
- High Technology Crime Investigation Association, http://www.htcia.org
- Institute of Electrical and Electronics Engineers, http://www.ieee.org
- International Association of Computer Investigative Specialists, http://www.iacis.com
- International Association for Identification, http://www.theiai.org
- International Association of Forensic Nurses, http://www.forensicnurse.org
- International Association of Forensic Toxicologists, http://www.tiaft.org
- International Institute of Forensic Engineering Sciences, http://www.ifes.org
- International Society of Forensic Computer Examiners, http://www.isfce.com
- National Association of Medical Examiners, http://www.thename.org
- Society of Forensic Toxicologists, http://www.soft-tox.org
- Southeastern Association of Forensic Document Examiners, http://www.safde.org
- Southeastern Association of Toxicologists, http://www.sat-tox.org
- Southwestern Association of Forensic Document Examiners, http://www.swafde.org
- Young Forensic Scientists Forum, http://www.aafs.org/yfsf/index.html

Appendix B

Granting Agencies

Grants for forensic science research and meeting attendance

1. Forensic Science Foundation – http://www.fsf.org
2. National Institute of Justice – http://www.nij.gov
3. Various forensic societies listed above
4. www.ncstl.org

Appendix C

Degree Granting Programs – Domestic and International

With the demand for forensic services skyrocketing, the educational opportunities are expanding exponentially. The reader is directed to the website of the American Academy of Forensic Sciences for an up-to-date listing of programs for major and minor degrees in forensic science in the United States and International Universities, http://www.aafs.org.

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