EDITED BY
C. Michael Bowers

SECOND EDITION

Forensic Dental Evidence

An Investigator's Handbook

Forensic Dental Evidence: An Investigator's Handbook

Second Edition

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To my wife Cynthia: I could not have done this without you.

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Foreword

Forensic Odontology is a fascinating and challenging field. Technological and procedural advances coupled with the public's increased awareness through media such as *CSI* has made forensic sciences appealing to many, and seemingly infallible to others.

I have known Dr. Bowers for over twenty years, we first made acquaintance in Louisville, Kentucky in 1989 while challenging the ABFO dental certification board examination. Over these years he has earned the respect of all others in this field with his determined dedication to further forensic odontology into a respected discipline of the forensic sciences.

The second edition of *Forensic Dental Evidence: An Investigator's Handbook* edited by Dr. C. Michael Bowers is written for those whose desire the knowledge, background and understanding of forensic dentistry. This book is essential reading and a valuable asset for any investigator, lawyer, medical examiner, nurse, or dentist that has an interest or a role in a forensic dental case.

A highlight of this handbook is the discussion of the wrongful convictions due to erroneous bitemark opinions that have surfaced in the past decade. In the early 1990s Dr. Bowers and others become cautious in the manner in which bitemark opinions were being used to identify specific individuals in an open population. Currently there have been ten exonerations of individuals who have served many years in prison that were falsely imprisoned as a result of faulty bitemark evidence and incorrect opinions. These opinions were not based in science and were without validity or reliability. Dr. Bowers' work as an impartial dental expert coupled with DNA evidence resulted in the exoneration of these innocent individuals.

Dr. Bowers' determined work in educating and informing the forensic community of the need for scientifically validated opinions in the 1990s went largely neglected by board certified forensic dentists. In 1999, the ABFO performed a bitemark workshop to examine the ability of the expert to properly discern the biter from a lineup of unknowns. The ABFO published a paper with the results that reported the ability of the certified forensic dentists to identify the correct perpetrator with moderate accuracy of 86%. What was not reported was the high level of false positives that accompanied these findings. Dr. Bowers' high ethical standards compelled him to uncover the actual findings that revealed a high false positive rate which was not exposed in the scientific paper published by the ABFO.

Recognizing that improvements were necessary in the forensic sciences, Congress directed the National Academy of Science to study the problem. In 2009, the National Academy published a report called "Strengthening

Forensic Science in the United States: A Path Forward" which was a comprehensive review of all the forensic sciences, including bitemark analysis. The findings from this report were the same as Dr. Bowers had been teaching and writing about for years. It was not until after this report was published, did the certified forensic dental specialty group began to acknowledge the need for change. Fortunately, this process has begun and positive changes are currently being made. This handbook relates and discusses all the problems identified by the National Academy of Science.

In the handbook edited by Dr. Bowers, he has partnered himself with many of the world's foremost forensic scientists and dental experts. This handbook offers the latest information available to the forensic community and beyond. It will function to advance the profession and allow justice for all.

David C. Averill, DDS, DABFO
Past President, American Board of Forensic Odontology
Past President, American Society of Forensic Odontology

Preface to Second Edition

The 2010 edition of *Forensic Dental Evidence: An Investigator's Handbook* expands the scope of the 2004 edition with a compilation of new and "just off the press" information that is unparalleled in the forensic dental scientific literature. All chapters highlight forensic cases and technique with a direct emphasis on modern-day methods and protocols.

Forensic Dental Evidence, second edition, contains the compelling forensic issues that challenge investigators in cases dealing with domestic and international human identification, missing person investigations, violent crimes against persons, mass disaster planning, disaster response, and the new threats to urban centers from terrorist attacks. In addition, the text contains chapters on forensic photography, analysis, and legal issues regarding bitemark evidence. All of these topics demand special forensic expertise in forensic dentistry and its related sciences. This book demonstrates that expertise. New scientific topics which premiere in book form are *The Next Level in Victim Identification: Materials Properties as an Aid in Victim Identification* (Chapter 3) and *DNA for First Responders: Recognizing, Collecting, and Analyzing Biological Evidence Related to Dentistry* (Chapter 8). Notable updates are presented in each chapter.

Forensic Dental Evidence is the first book that places criminal investigators within the realm of dental forensics and offers the information necessary to effectively pursue and manage their casework. The advantage of this book over other texts on the subject is its unique timeline of information. It is contemporary in all aspects and intentionally avoids the stale and years-old references seen commonly in print today. Another unique opportunity for readers is its innovative and cutting-edge electronic version. This book contains active hyperlinks that allow the reader freedom to directly and easily travel from references within the text to a large hierarchy of online web-based material. In addition, many of these online references are updated by the accessed website. This self-updating nature of information is new in forensic dental literature and premieres in this book. Readers have access to the latest in reference documentation and now have the option to produce their own online archive of materials they deem important for their needs. In essence, *Forensic Dental Evidence* acts as a springboard into mainstream forensic dental information in real time. As added value, expanded educational information, including the *Atlas of Dental Identification* along with other updates for *Forensic Dental Evidence* are available at www.elsevierdirect.com/companions/9780123820006.

An international faculty of authors who encompass the best in the discipline contributed to this book. They address head-on the challenges of forensic investigation. These authors are seasoned veterans of investigations that span the globe. Highly publicized historic and contemporary cases of all types are presented as examples of real forensic techniques past and present. The authors also include practical suggestions for investigators. The emphasis throughout this book is the necessity of proper scientific methods, the knowledge of their limitations, and the necessity for team training, planning, and multilevel management. The subject matter is purposely presented from various viewpoints by multiple authors in order to glean the wisdom of these internationally recognized forensic experts.

Forensic Dental Evidence, Second Edition, continues its design for readers with an interest in the subject of forensic dentistry. It follows the first edition's precedent of giving up-to-date information and its high educational value through the generous use of high-resolution illustrations.

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Preface to First Edition

This book's purpose is to act as a detailed overview of forensic dentistry as it is practiced in the twenty-first century, and it contains presentations of dental investigation methods. Law enforcement and legal professionals are, in the end result, the clients of the dental expert. This book is written for this audience. Wherever possible, the author has included casework examples to explain the multiple areas in which a forensic dentist can interact with police investigations. The reconstruction of prior events at a crime scene and the activities of the individuals involved is a daunting task. Forensic examiners use dental evidence in this process. Certain suggestions and guidelines are described to raise the certainty of successfully recognizing and capturing vital dental evidence in actual forensic casework.

The development of modern forensic dentistry can be seen in the dental and forensic literature over the last 50 years. Many of these cases are valuable for the innovative problem-based dental techniques used to compare known (K) and questioned (Q) dental evidence. They show considerable effort in answering questions asked by law enforcement and the courts. Interestingly, an independent body of forensic dental science didn't exist before dental identification and bitemark analysis became parts of contemporary forensic investigations. This follows the historical development of forensic pathology during the late nineteenth century in Britain, France, and Germany. Empirical studies in forensic dentistry do exist but still have not answered certain core questions involving human identification based on bitemark analysis that have been posed during the twenty-first century. DNA profiling and digital imaging are recent additions that are being used to increase the reliability of forensic dentists' bitemark opinions that previously used techniques that have varied only slightly during the last 40 years.

Apart from bitemark identification, the use of dental records and accompanying dental/medical radiographs to identify deceased individuals is a common event in the United States and abroad that provides considerable assistance in mass disaster recoveries and cases identifying unknown persons. Beyond this broad overview, the need to properly identify and analyze dental evidence is an ongoing request made of dentists throughout the world. The transient nature of crime scene evidence places considerable pressure on law enforcement to immediately establish possible links between crime and its perpetrators. Mistakes and errors of evidence collection will never be properly remedied by later scientific manipulations in the crime laboratory.

In any criminal investigation, the proof of guilt or innocence is the underpinning focus of forensic efforts. Correct human identification of deceased individuals is vital to both law enforcement and family members. It is just as important to eliminate a homicide or assault case suspect as it is to strongly tip the scale of justice to charge a person with criminal conduct. The cases that are unclear as to guilt and innocence, or at least have weak connections between the crime scene and a suspect, rely even more heavily on physical evidence in order to give the justice system a chance to produce a reliable outcome. When the forensic dental evidence is clear and physically compelling, the truth seems obvious to the judicial system, judge, and jury. When the dental evidence is vague, ambiguous, or otherwise equivocal, it is important for law enforcement and the forensic expert to honestly weigh the value of the evidence against the potential for irrevocable harm to a defendant.

The management of the physical evidence of a crime falls to a series of actors during the entire course of a case. The beginning phase has the managers generally being police officers at a scene. Occasionally the first collection of dental evidence is through the efforts of the forensic pathologist or forensic dentist during a postmortem examination. In a mass disaster, recovery of human remains should be the job of a trained civilian, military staff, or government personnel. In all instances, the persons responsible for detecting, documenting, and collecting the physical evidence are the gatekeepers for the process that follows. The management at any scene should be under the control of prepared, experienced professionals. In the continuum of events after evidence recognition and collection, the forensic laboratory or forensic dentists will obtain control of the evidence and perform their analyses. These forensic opinions will be transferred to the legal arena, where attorneys will introduce the evidence. Their duty will be to translate to their judicial audience the importance of this evidence on the case at hand.

The Logic of Forensic Investigation

The aspects of proper forensic evidence recovery require a knowledge base in the following steps:

- *Recognition (detection):* Teeth and related physical evidence derived from the oral cavity must be observed by responding crime scene and accident investigators. These professionals must also be familiar with common objects that may contain transfer evidence such as saliva or tooth impression evidence. These objects include human skin, clothing, duct tape, envelopes, chewing gum, telephone receivers, and foods such as cheese and various types of beverage containers.
- *Documentation (recording):* Physical evidence obtained from a crime or accident scene should be left in place, properly lighted, and photographed. This establishes its condition and context with the location prior to investigative measures that may disturb or somehow alter its condition. The photographer must take the time to place size-reference scales or rulers in some of the evidence photos. This allows the pictures

and the evidence to be later made into life size via photographic or digital processing. Written notes or log sheets with pertinent descriptions should be kept by the investigator who is responsible for the evidence collection.
- *Collection:* The intent is to capture the dental evidence for later analysis. This commonly includes bagging biological objects (saliva stains, loose teeth, or foodstuffs) in labeled paper bags. Bitemarks in skin, if observed on a victim at a crime scene, should be rigorously photographed and then swabbed. Recreating the position or posture of the person bitten should be considered, but in the absence of a victim's statement or reliable witnesses, all alternatives should be considered.
- *Preservation:* Protocols for the capture and preservation of biological evidence (tissue, blood, semen, or saliva) must be stringently followed. Foodstuffs cannot be preserved for long periods of time without drying and deteriorating. The method of choice for preserving bite impressions in food is to take modeling impressions of the objects as soon as practical after swabbing for saliva. Bitemarks in skin can be impressed with dental molding materials. This permits later creation of a three-dimensional model of the bitten area.
- *Interpretation:* The recreation of a human's identity by their teeth or via DNA taken from a tooth or saliva requires scientific training and should be performed by a board-certified forensic dentist for the former and a biologist for the latter.

Categories of Dental Evidence

The various types of dental evidence can be described as they relate to questions being asked by the investigators.

"Is there direct dental evidence supporting human identification?"

The following types of evidence should be considered:
- A human tooth or tooth fragment
- A fragment of a human jawbone
- DNA obtained from a tooth, toothbrush, cigarette, and so on
- DNA obtained from a swabbing of a bitemark, foodstuff, or object that possesses saliva transfer evidence
- Dental restorations and appliances that can be associated to a particular person through name inscriptions, specific dental material type, composition, or unusual design characteristics

"Is there associative evidence of a person's past presence or activities at a crime scene?"

When investigators ask this question, it extends to the following:
- Does the bitemark in this apple indicate a specific person was present at a scene prior to or during the commission of a crime?
- Does the DNA obtained from this piece of bitten cheese belong to a specific person?

- Does the DNA obtained from the swabbing of this telephone belong to a specific person who was present at the scene?
- Can this "person of interest" be eliminated as a suspect?
- Does the suspect's statement of consensual sexual contact with the victim seem appropriate with the severity of this bitemark?

The following transfer evidence corroboration should be considered:

- Does the saliva obtained from a glass that also has fingerprint evidence contain the DNA of the same individual matching the fingerprints?

This book presents concepts and protocols that are vital to a successful outcome to a criminal investigation that involves dental evidence. One basis for any proven forensic dental protocol is organization and regular utilization. These methods need to be practiced and protocols maintained in order to be available and successful under actual casework conditions. It is my wish that this book will help to improve the body of knowledge available on the uses and importance of forensic dental evidence.

Dr. Mike Bowers
October 1, 2003
Ventura, California, USA

Acknowledgments

I want to acknowledge all of the contributors to both *Forensic Dental Evidence* editions, as well as the following people, each a friend and a mentor, who have been instrumental in my arriving at this point in my professional career: the late Dr. Charles Meyer Goldstein, for setting an incredibly high standard of community and humanitarian service during his 34-year career at the Ostrow School of Dentistry of the University of Southern California; Dr. Warren Lovell, who almost 30 years ago provided the welcome that allowed my forensic science interest to develop; and Dr. Ron O'Halloran, who continues as Chief at the Ventura County Medical Examiner's Office. Finally, I have to thank Dr. Raymond Johansen for his dedicated interest in improving forensic dentistry and for his innovative spirit.

Introduction

Forensic Dental Evidence: An Investigator's Handbook (FDE) has achieved a remarkable readership since its first publication in 2004. Forensic scientists and medical-legal investigators have been amazed by the public's interest in forensics. Forensic dentistry is no exception. Readers of the first edition included college forensic students, high school and dental students, teachers, law enforcement, and forensic investigators. Television media and other entertainment writers used the book to properly insert dental evidence into their plots. The news media regularly refer to dentists evaluating evidence relating to crime, missing persons, and mass disasters. The concept of a "CSI dentist" has come of age in the first ten years of the new millennium.

Scope of Forensic Dentistry

Human identification is the forensic odontologist's primary duty: Who is the victim? This involves the dentist as a team member working along with law enforcement agencies. This team is charged with the responsibility of investigating the evidence from cases involving violent crime, child abuse, elder abuse, missing persons, and mass disaster scenarios. In each context, dental evidence may produce compelling associations to aid victim and suspect identity and to establish facts that can affect the direction and ultimate outcome of investigative casework. Dental evidence can be used to identify both the people who were present during the commission of a crime or witnesses to an accident. The forensic dentist interacts with other forensic and medical disciplines like anthropology, pathology, human anatomy, and biological science. The best international source for forensic dental information and international forensic certification is available at Forensic Dentistry Online ([1]).

Forensic dentistry (aka *forensic odontology* in Europe) has a two-and-one-half-century history in the United States. It is the science and practice of dentistry and its role in modern society. Dental injuries from accidents or assaults must be assessed and treated. Occasionally, the treating dentist or attending forensic dental expert testifies in court proceedings for parties involved in civil litigation. Criminal cases use dentists to testify on dental evidence obtained from a crime scene or crime victims. Occasionally, a perpetrator of a crime leaves evidence at a scene. Bitten food, gum, or chewed objects may be recovered by law enforcement. Autopsy investigations may notice bitemarks on the skin of a deceased victim. Dental experts also testify regarding the quality of dental care (professional negligence) and in cases where dental fraud is an issue.

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[1] *forensicdentistryonline.com*

Teaming Law Enforcement Investigators with Forensic Dentistry

A crime scene will seldom have a dentist as a first responder, nor will one respond with the forensic evidence team or with a major crime or detective bureau. Therefore, it is up to the police to perform certain dental evaluations at a scene. The threshold question for any investigator at a crime scene or autopsy is "What is the dental evidence?" This might seem to be begging the obvious question, but the purpose of this book is to clearly describe the gamut of evidence that is either directly related to human dental anatomy or derived from the oral environment. The survivability of teeth in catastrophic conditions is the feature that makes forensic odontologists regular participants in the autopsy suite. Tooth shapes, appearances, tooth fragments, metal restorations, pieces of skulls, and jawbone fragments may possess features that can be associated with just one person. The robust identification value of DNA, obtained from the inside of teeth and oral fluids, has recently created an entirely new level of identification: the biomolecular identification of individuals.

Knowledge, training, and experience are the keys to successful law enforcement casework. What might be considered as plain good luck in an investigation is really the effect of hard work, thoroughness, and preparation. The purpose of this book is to provide the basis of knowledge and training in forensic odontology that will extend into crime scene investigations and the crime laboratory.

Evidence *identification*, *documentation*, *preservation,* and *collection* are the steps in this process. Identification technicians, crime scene evidence technicians, and investigators must achieve a functional knowledge and the necessary skills to connect this evidence to the case for later analysis by the certified odontologist. The evidence collection process includes knowing the physical parameters of dental evidence that demand special steps in preservation before transportation to the crime lab. If the evidence is properly identified, collected, preserved, and, finally, *transported*, it is also critical that the investigator properly document these steps to ensure *authentication* and a *chain of custody* for all interested parties. The success of later evidence analysis, whether *direct physical evidence* or even *circumstantial evidence*, is directly related to what happens during these first steps.

Specialized materials and methods are used to collect certain types of dental evidence. It is also important for the investigator to know what happens to evidence once it is transported to the forensic technician or forensic odontologist. In that regard, the latter section of this book will demonstrate specialized collection techniques, materials, photographic documentation, and analytical steps involved in laboratory processing and later comparison of physical and biological dental evidence.

Educational Objectives

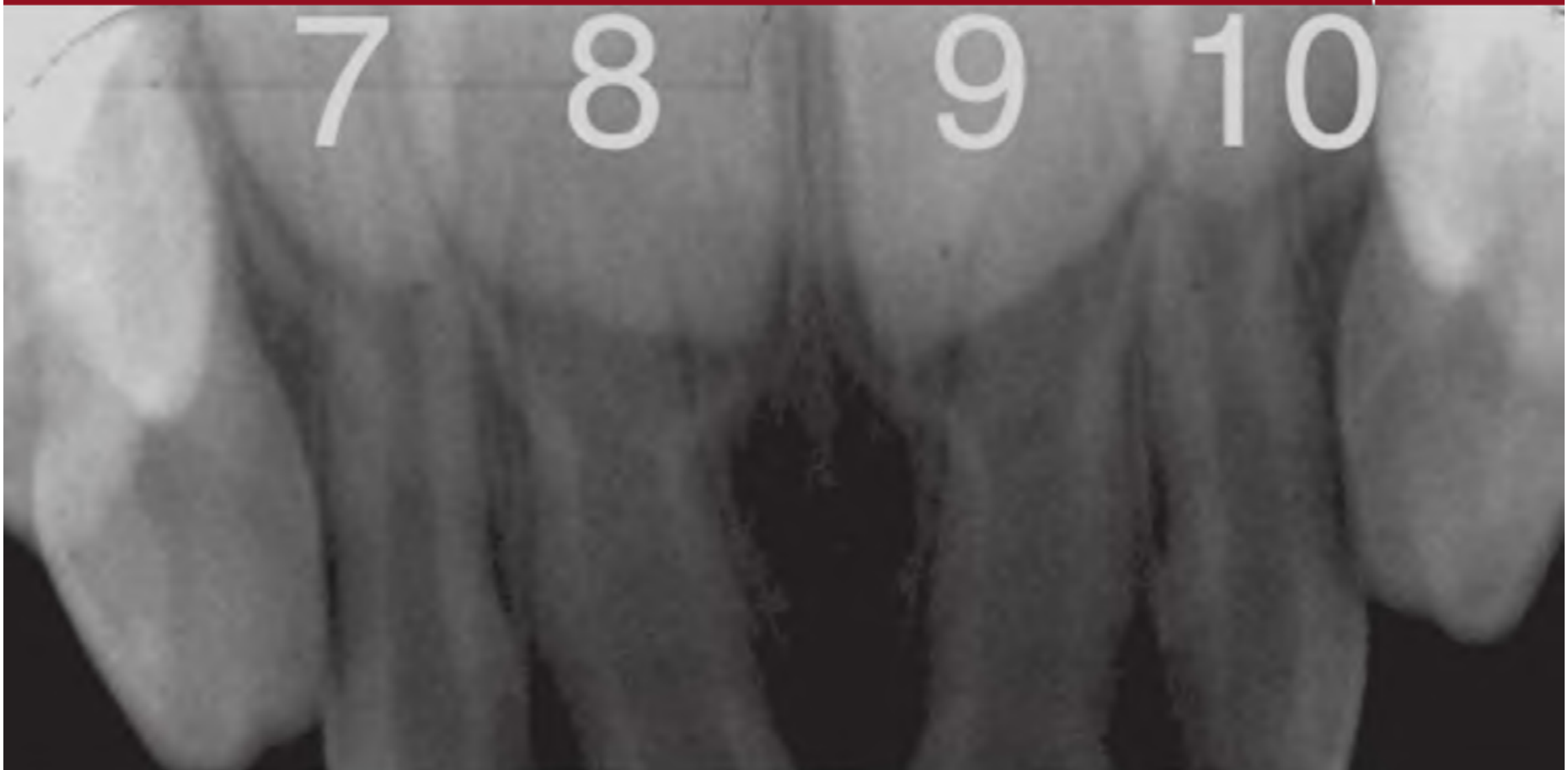
The reader should learn the following knowledge and skills from this book:

- The ability to identify types of dental evidence. This includes the various transfer surfaces and materials that may capture dental evidence.
- An appreciation for forensic identification significance and the limitations of these categories of dental evidence.
- How to properly document, collect, and preserve these categories of dental physical and biological evidence.
- What dental materials and supplies are used in evidence collection and preservation.
- The scientific and evolving judicial requirements regarding evidence collection, storage, chain of custody, and forensic analysis.
- A familiarity with digital comparison techniques via Adobe Photoshop®.

Expanded educational information, including the *Atlas of Dental Identification* along with other updates for *Forensic Dental Evidence* are available at:

www.elsevierdirect.com/companions/9780123820006

CHAPTER 1



Historical Dental Investigations

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Dental Aging Analysis of Ancient Human Remains: *Herakleides* from the First Century AD

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Overview

A death investigation of unidentified human remains requires professional determination of all physical evidence available from the body. The unknown person's gender, age, medical status and cause of death are vital information for a forensic autopsy report. The following case explains details of the life

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and death of a young man whose body was originally found in Egypt. Dental information was important to confirm his age and give insight to his health history at the time of his death.

In 2003, the J. Paul Getty Museum Antiquities Conservation Department initiated the study of a Romano-Egyptian red-shroud mummy (91.AP.6) in the museum's collection. The mummy is known as Herakleides from a painted inscription on top of the wrapped feet. Dating to the first century AD, the mummy incorporates a portrait panel depicting a young man in his early twenties. The mummy, measuring 175 cm in length, was wrapped in one large outer shroud that had been painted red and decorated with Egyptian funerary images. The beautifully executed portrait, the quality of the wrappings, and the elaborate use of gold, on both the panel and the shroud, attest to the prominent status of this individual.

The mummy of Herakleides belongs to a group of Romano-Egyptian mummies called "portrait mummies" and to a subgroup within that category known as "red-shroud portrait mummies." The designation of such complete mummies with added classically painted portraits is credited to Flinders Petrie, the archaeologist who was the first to scientifically excavate and document them in the late nineteenth century. The unique style and color of Herakleides' shroud classifies it as *red-shroud* [1]. These mummified bodies are described as being completely wrapped in a single cloth painted red and decorated with either funerary or daily dress motifs.

The investigation of Herakleides' mummy began with the conservation treatment of the fragile foot area, which was damaged and unstable [2]. The conservation treatment was in preparation for the mummy's first public display at the Getty Villa in 2005, where its presence in the gallery contextualizes the now detached Romano-Egyptian portraits in the collection by illustrating their mortuary function. From here a full study of the body (human remains) and the materials used for the mummification and decoration of Herakleides evolved. The aim of this study was to better understand the person within the wrappings and the ancient techniques employed in its fabrication and adornment process. Imaging technology such as computerized tomography (CT) and infrared photographic techniques revealed secrets such as his complete name and the curious inclusion of a mummified ibis within the wrappings. Examination of the skeleton by orthopedic surgeons and a forensic dentist established his age, health, and height at the time of death. Radiocarbon dating (carbon 14) provided a secure date for the materials used in the mummification process and a likely time frame for when he lived. Motifs and religious iconography were studied and documented to better understand their meaning. The lack of clothing on the youth's shoulders suggests he was an *ephebe,* or adolescent male of social standing. His presumed nudity, a symbol of rebirth, indicates he may have been an initiate in the cult of the Egyptian goddess Isis.

FIGURE 1.1 The mummy of Herakleides: "Mummy and Portrait on wooden panel." © *The J. Paul Getty Museum, Villa Collection, Malibu, California (91.AP.6).*

This study also involved the Getty Conservation Institute (GCI), which scientifically identified and compared the red pigment used on seven of the nine mummies identified within the red-shroud subgroup. The results from the analyses revealed that the composition of the unique red pigment is identical, relating this group to one another even further. The study of Herakleides shows how the collaboration of experts within the medical, scientific, and Egyptological communities can come together to better understand one unique artifact. This supportive exchange of experience, knowledge, and information has opened a window into the life, religion, and ritual of a man who lived almost 2,000 years ago [3].

The Forensic Examination of Herakleides

CT scans of the Herakleides' mummy revealed that, contrary to the usual Egyptian practices of mummification, the 20-year-old man's heart, not his lungs, were removed during embalming. Also uncommon in the scientists' findings was a mummified ibis, inexplicably placed on Herakleides' abdomen under the final layer of his mummy's wrappings.

The Aging of Herakleides

Skeletal Analysis

His age determination was made by examining the epiphyses of his arms and legs. These are "growth plates" seen during teenage and early adult years that gradually disappear at maturity. They were faint in the Herakleides' CT scan but were not completely fused. This is the data that produced an age range of 20 +/– 2 years. This opinion was provided by a radiologist at UCLA, who performed the CT scans, and was corroborated by two orthopaedic surgeons who examined Herakleides' skeleton. There was no evidence of medical pathology (disease) or before-death (antemortem) trauma. A large gash is visible at the back of the skull, but it not clear whether this occurred before (antemortem) or after death (postmortem). The medical team who examined the CT scans believe it was most likely caused during mummification.

Dental Aging

Over the years, development of third molars (wisdom teeth) in adults has been researched in multiple population studies [4]. These studies compare the third molar root growth stages and development in the jawbone to the chronological (real age) of the known people in the study sample. Herekleides' teeth are completely developed (the roots are fully formed) and are at the completed Stage H of full growth [5]. This indicates that he was at least 18 or older when he died. This supports the previous orthopaedic/anthropological opinions of this skeletal age at death.

Acknowledgments

Photo: The J. Paul Getty Museum, Villa Collection, Malibu, California

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The Odontological Identification of Adolf Hitler, Using Cinematographic Documents

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Introduction

A "toothy" antemortem photograph can be invaluable when investigating the identity of unknown human remains. Pictures can show dental characteristics that can be very helpful to the forensic odontologist in comparing antemortem and postmortem data. Such documents can give a lot of information, but how much information is necessary for a positive identification? This paper gives investigators answers to this question from casework that combines both the photographic and dental evidence that is necessary for a positive determination of identity.

Forty-eight members of the sect of the Solar Temple were found dead in two different villages in October 1993. Their guru, Luc Jouret, was among them and was severely cremated. He was odontologically identified, and a picture published by the press was an additional contribution to the identification procedure [1].

The following account is a good example of how photographic documents may contribute to postulate an identity [2]. In October 2001, a Crossair plane crashed near the airport in Zurich, Switzerland. Eleven of the 24 passengers died in this mass disaster. The examination of the dental work of one passenger showed ceramic restorations that appeared unusual both in shape and shade. Before receiving any postmortem data of this otherwise cremated passenger, investigators were struck by an aspect of the dental work that led to the possibility that the remains were of a well-known entertainer. A search on the Internet provided an account of the passenger's travel plans on the day of the crash.

In 1973, Sognnaes and Ström published an article on the identification of Adolf Hitler [3]. The major portion of this article compares more recently released postmortem dental remnants of Adolf Hitler with his cinematographic facial phtotographs. Photographic documents can contribute to odontological identification of human remains, provided that the teeth and their characteristics are sufficiently visible. But how do motion pictures help in the same way? A historical figure such as Adolf Hitler was identified odontologically thanks to information provided by his dentist and radiographic plates found in the U.S. National Archives [3].

A Short Biography of Adolf Hitler

According to Kershaw [4], the first of many strokes of good fortune for Adolf Hitler took place 13 years before he was born. In 1876, the man who was to become his father changed his name from Alois Schickelgruber to Alois Hitler. Certainly, “Heil Schickelgruber” would have been an unlikely salutation to a national hero.

Hitler was born on April 20, 1889, in the little town of Braunau am Inn in Austria. He had three brothers and two sisters, as well as four half-brothers and half-sisters from his father's first marriage. Hitler loved his mother dearly, and he carried her picture with him until his final days in the Berlin bunker. The violence of Hitler's father would turn against him and the rest of the family. His childhood was also punctuated with several moves, and for much of his childhood, he lived in Linz and Vienna, Austria.

Hitler wanted to be a painter, but in 1907 he failed the entrance examination for the Academy of Fine Arts in Vienna. Many members of the faculty were Jewish. He moved to Munich in 1913. While serving in the German army during World War I, he was wounded. He began his political career as an army political agent in the German Workers’ (later Nazi) Party in 1919 and became head of its propaganda arm in 1920.

Hitler was made president of the party in 1921 and began his creation of mass movement and his climb to power. After the abortive Munich (Beer Hall) Putsch in 1923, he served nine months in prison and began writing *Mein Kampf,* a book in which he condemned democratic government and expressed his hatred and fear of Jews.

Throughout the 1920s, Hitler continued to gain strength. He unsuccessfully opposed Paul von Hindenburg in the presidential election of 1932, but he was appointed chancellor in 1933. The offices of president and chancellor were merged in 1934, a move that was supported later by a popular vote. As dictator, Hitler then turned his attention to foreign policy and World War II. His "new order" for Europe called for indiscriminate extermination of entire peoples. The Jews of Europe were the most numerous among his victims of barbarism [4]. Hitler retreated to the chancellory in Berlin in January 1945, and, in the face of impending defeat, he committed suicide.

Hitler's Death

In broad daylight on February 3, a huge American fleet of bombers unleashed a hail of destruction from the skies in the heaviest raid of the war on Berlin, the Reich's capital. Most of the Reich's headquarters were severely damaged. The whole area was a mass of rubble. For a time, there was a complete power failure, and water was unavailable [4].

Hitler's apartments in the Reich Chancellery were largely gutted by incendiaries. He now moved underground for much of the time to the Führer Bunker, a two-story construction deep below the garden of the Reich's Chancellery [5, 6]. The enormous bunker complex had been deepened in 1943, extending an earlier bunker (originally meant for possible future use as an air-raid shelter) dating from 1936, and heavily reinforced during Hitler's stay at his headquarters. The complex was built beneath the Chancellery gardens. It was completely self-contained, with its own heating, lighting, and water pumps that operated from a diesel generator [6]. From now on, it would provide a macabre home for the remaining weeks of Hitler's life.

The bunker was far from the palatial surrounds to which he had been accustomed since 1933. At first, even after he had moved his living quarters into the bunker, Hitler continued to spend part of the day in the undamaged wing of the Reich Chancellery. Over the next weeks, he transferred almost all of his activities to the bunker, leaving it only for occasional snatches of fresh air, to let his dog Blondi out for a few minutes in the garden, or to take lunch with his secretaries above ground. He was there with Eva Braun, his valet Heinz Linge, Martin Bormann, Josef Goebbels, personal adjutants, secretaries, servants, a cook and frequent visitors [7].

During this period, he was constantly informed of the evolution of the situation: the Yalta conference where Roosevelt, Stalin, and Churchill defined the postwar shape of Germany and Europe; the destruction of Dresden; the bad news from the Eastern front; the imminent collapse of the German economy; civilians embracing American soldiers; and troops fleeing or surrendering on the western front.

With both the present and the future so bleak, he had begun to take refuge in endlessly speaking and recalling the "triumphs" of the past, his career, the atrocities of the "Jewish Bolshevism." His physical condition deteriorated sharply during that time. He was haggard, aged, and stooped. His left hand

and arm trembled uncontrollably. He took daily concoctions of pills, potions, and injections that included both stimulants and sedatives. He seldom went out in public.

In his characteristic "either-or" way of thinking, he invariably posed total destruction as the alternative to the total victory for which he had aspired. Ultimately, the existence of the German people—if they showed themselves incapable of defeating their enemies—was less important to him than the refusal to capitulate.

The atmosphere in the bunker on April 20, 1945—Hitler's fifty-sixth birthday—was more funereal than celebratory. The assault on Berlin by the Soviets was imminent. The storm burst on April 22. Hitler realized that the war was lost. He allegedly said, "Es ist alles verloren, hoffnungslos verloren" ("It's all lost, desperately lost").

The next day, Hitler had a discussion with his armament minister, Albert Speer. They both came to the conclusion that it would be better to end his life as Führer in the Reich's capital than in his Bavarian "weekend house." But there was the danger that he would be captured alive. He was afraid that his body might fall into the hands of his enemy to be displayed as a trophy. He gave orders that his body should be cremated. His mistress, Eva Braun, would die alongside him.

Not long after midnight on April 29, in the most macabre surroundings, with the bunker shaking from nearby explosions, Hitler and Eva Braun exchanged marriage vows before one of Goebbels's minor officials, city councilor Walter Wagner. Goebbels and Bormann served as witnesses. Hitler then wrote his private and political testaments. He disposed his possessions to the state, and he appointed Grand Admiral Karl Dönitz as Reich president. Bormann and two emissaries left the bunker on what was to be a fruitless mission to deliver the testaments to the headquarters in Munich.

Early that morning, Dr. Ludwig Stumpfegger, an SS surgeon, distributed to the secretaries, adjutants, and any others who wanted them brass-cased ampoules containing prussic acid (cyanhydric acid). On April 30, Hitler sent for Bormann and told him the time had come. He would shoot himself that afternoon, and Eva Braun would also commit suicide. He wanted their bodies to be burned with gasoline that his chauffeur, Erich Kempka, would obtain. In the bunker were Hitler, Eva Braun, General Burgdorf, General Krebs, Hitler's secretaries, his dietician, adjutants, Borman, and Goebbels, his wife Magda, and six of their seven children. Hitler retreated behind the doors of his study, and Eva Braun followed him almost immediately.

Some 10 minutes later, the valet, Heinz Linge, and Martin Bormann opened the door cautiously. They found Hitler and Eva Braun sitting alongside on a small sofa. Eva Braun was slumped to Hitler's left. A strong whiff of bitter almonds—the distinctive smell of prussic acid—drifted up from her body. Hitler's head drooped lifelessly. Blood dripped from a bullet hole in his right temple. His 7.65 Walther pistol lay by his foot [5, 6, 7].

Within minutes, the bodies of Adolf Hitler and his wife of 18 hours were wrapped in blankets. The corpses were then lifted from the sofa and carried through the bunker, up 25 feet of stairs, and into the garden of the Reich Chancellery. Heinz Linge brought out Hitler's body, his head covered with a blanket, his lower legs protruding. Martin Bormann carried Eva Braun's body into the corridor, where Erich Klempka, Hitler's chauffeur, relieved him of his burden.

Otto Günsche, Hitler's personal adjutant, who had been commissioned with overseeing the burning of the bodies, laid the bodies outside in the garden side by side on a piece of flat, open, sandy ground only about 3 meters from the door down to the bunker. It was a suitable spot, close to the bunker, though extremely hazardous, since an unceasing rain of shells from the Soviet barrage continued to bombard the whole area. Almost 200 liters of gasoline had been gathered in the bunker in readiness. It was swiftly poured over the bodies and ignited. Later, two SS men of the Führer Escort Squad ensured that the bodies had been completely burned and reported it to Otto Günsche.

Little remained of Hitler's and Eva's bodies. The intense bombardment that continued for another 24 hours played its own part in destroying and scattering the human remains strewn around the Chancellery garden. When the Soviet victors arrived there on May 2, they immediately began a vigorous search for the bodies. Nine days later, they showed Fritz Echtmann, a dental technician who had worked for Hitler's dentist, a cigar box containing part of a mandibular bone with two dental bridges and one isolated dental bridge. Echtmann was able to identify from his records the dental work of Hitler [5, 6, 7].

Remains and X-Rays

The death of Adolf Hitler in April 1945 was a mystery until 1968, when the Russian writer Lev Brezymenski revealed documents from Soviet archives established during the identification procedures [8]. This somewhat unprecise book included descriptive information concerning Hitler's alleged corpse, with photographs of remaining dental restorations and some of his natural teeth still in the mandible. The wartime autopsy documents from Soviet archives report the forensic examination of a male corpse disfigured by fire.

The author of this section was able to examine Hitler's remains at the Russian national archives (Figure 1). The photographic documents shown in Figures 1 to 6 were taken by Mark Benecke, a forensic biologist. What was left of the upper arch was a nine-tooth gold bridge with crown, abutments on each of the four remaining natural teeth, one intermediate pontic (replacement tooth), and a double cantilevered pontic (replacement tooth attached to two crowns) at each end. The entire bridge consisted of four upper incisors, two canine teeth, the first left bicuspid, and the first and second right bicuspids (Figure 2).

The first left incisor had a gold crown with a white facing, with cracks and a black spot in the exposed tooth enamel at the bottom. The other teeth of the left side,

FIGURE 1 Hitler's remnants, as kept at the Russian archives in Moscow.

FIGURE 2 Hitler's repaired bridge on the upper arch.

FIGURE 3 The lower left bridge.

as well as the first and second incisors, and the first bicuspid on the right side were porcelain plated. The upper right canine tooth was fully gold-capped. The maxillary bridge was vertically *sawed* off behind the second left bicuspid.

In the mandible, several of the natural teeth were well preserved. On the left quadrant, three abutments (canine, second bicuspid, probably third molar) supported a six-unit gold bridge (Figure 3). On the right quadrant, a three-unit bridge (canine, second bicuspid) bypassed the first bicuspid using an unusual device (Figures 4 and 5). The incisors showed advanced periodontitis as well as signs of buccal erosion and abrasion (Figure 6).

It is not the aim of this section to give a complete list of the comparative conclusions regarding Adolf Hitler's dental condition. This topic has been fully covered by Sognnaes and Ström in 1973 [3]. The American Archives provided the detailed questioning of Hitler's dentist. Dr. Hugo Johannes Blaschke was a dental school graduate of the University of Pennsylvania. He was an outstanding student, graduating fourth in his class of over 100 classmates. From the 1911 yearbook and from recollections of some of his classmates (who called him "the count"), Blaschke was also well thought of as a person and colleague—skilled, meticulous, and dedicated to dentistry. He returned to his native Germany to open his dental practice in Berlin. One of his first well-known patients was Hermann Göring, who introduced Blaschke to Hitler, and in turn Dr. Blaschke also became the dentist of Eva Braun, Bormann, and many other high-ranking Nazis [9]. He treated Hitler from 1934 to 1945. Later that year, he was captured and questioned by U.S. Army officers and also briefly called upon as a witness during the Nuremberg trials in connection with the so-called Pohl process and the Dr. Pook case. After his release in 1948, Hugo Blachke continued to practice as a dentist in Nuremberg. He died in 1957 at age 78 [3, 7, 9].

After his capture in 1945, Blaschke described the characteristics of Hitler's teeth and treatment history, which were found to be compatible with the odontological examination:

- Dr. Blaschke had started a root canal treatment on the lower left lateral incisor.
- A single fixed bridge had been constructed to replace two defective upper left and right bridges.
- No prosthetic treatment was performed by Blaschke on the lower jaw.
- Extensive caries and pulpal involvement had existed for several years on the left central incisor (a "window crown") that could not be properly treated due to Hitler's impatience.
- The existence of a porcelain cement filling on the left lower lateral incisor.
- Due to periodontitis of the upper left second premolar, the distal left portion of the upper bridge was removed in October 1944 by cutting the bridge between the first and the second bicuspids.
- All files and x-rays were lost while being sent by a transport baggage plane from Berlin to Salzburg (April 1945).

FIGURE 4 The lower left bridge, facial view.

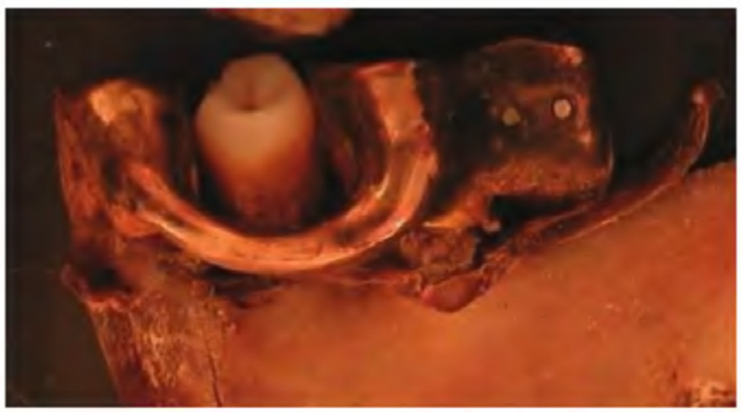

FIGURE 5 The lower left bridge with metallic link, lingual view.

FIGURE 6 The remains of four natural incisors.

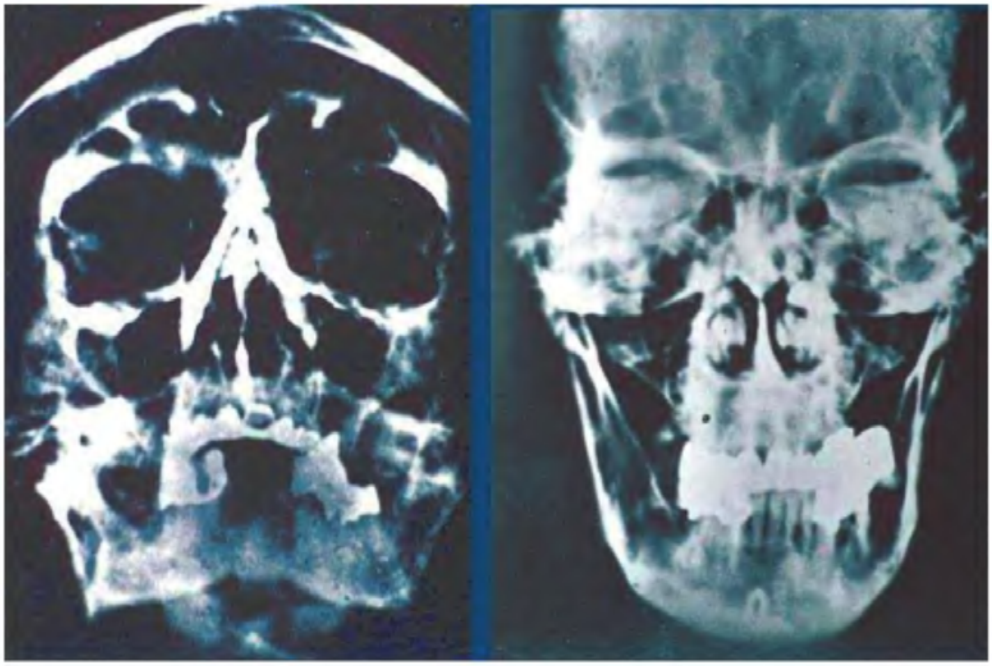

FIGURE 7 X-rays showing dental features.

Five x-rays found in the U.S. National Archives had been taken by Hitler's physicians after the assassination attempt on July 20, 1944, and had been made to assist in diagnosing pain complained of in the sinus regions (Figure 7). They showed findings compatible with those recorded at the autopsy and with the descriptions provided by Hitler's dentist, including the following:

- Most of the posterior teeth on the right side were missing.
- Very radioopaque profiles were observed on the left side of the jaw.
- A striking feature in the anterior portion was a radiolucent zone in the front portion of the upper left incisor, suggesting a "window" crown surrounded by radio-opaque material.
- The metallic link between the lower right canine and the second bicuspid.
- No prosthetic involvement on the lower incisors.
- Signs of periodontal bone loss around the anterior lower teeth.
- Two short metallic posts extending into the root canals of the upper right incisor and the left lateral incisor.
- A shift in the midline relationship between the upper and lower jaw. The midpoint represented by the mesial contact between the upper central incisors intersected with the mesial surface of the lower right lateral incisor rather than with the space between the central ones.

It could be convincingly established from these various data that showed a total of 26 concordant points that is far in excess of what would be required even from fingerprints, that Hitler's postmortem remains had, in fact, been recovered and autopsied following the fall of Berlin in early May 1945 [2].

Cinematographic Documents

The oldest cinematographic document in which Hitler appears goes back to 1920, but there is no opportunity to see his teeth, since the quality of the motion picture is poor and does not contain any close-ups. In the preparation of this article, most of the examined stills or static photographs of Adolf Hitler provided no relevant information because they did not show any "toothy" features. A search in the cinematographic archives of the Swiss National Film Archives (Cinémathèque Suisse) did, however, bring to light documents where Hitler showed his teeth while giving a speech or smiling. On the other hand, in order to examine Hitler's antemortem dental status, it was important to gather documents shot at a time that was not too long before his death.

The documents examined covered the period between 1934 and 1944, when, according to statements made by his dentist, Hitler underwent no further major dental treatment other than that found at the time of his death. The stills were selected from German newsreels, motion pictures on Hitler's life, and Leni Riefenstahl's propaganda films *Triumph of the Will* and *Olympic Games 1936*. Each still selected from the different motion pictures was chosen according to the degree of tooth visibility and was then digitalized by imagery in order to enhance the quality of the documents.

High and Moderate Degrees of Concordance

It must be kept in mind that the questionable quality of the documents examined was due to the visual technology available at the time the films were shot and to deterioration over the ensuing years. Among the different concordant points previously established, those visible on the pictures have been cited and divided into two categories: category A, which is a high degree of concordance, and category B, which is a moderate degree of concordance.

A. High Degree of Concordance

A high degree of concordance is based on the frequency of the appearance of the feature and the relative distinctness of the feature:

1. Upper left central incisor ("window" tooth): most recorded documents show evidence of a darkened tooth (Figure 8)
2. Presence of four natural lower incisors (Figures 9 and 10)
3. Periodontal involvement of the lower incisors (Figure 9)
4. Signs of buccal erosion of the lower incisors (Figures 9 and 10)

FIGURE 8 Evidence of a darkened central incisor.

FIGURE 9 Four natural lower incisors with signs of periodontal disease and buccal erosion.

FIGURE 10 Diastema between second left mandibular incisor and canine.

B. Moderate Degree of Concordance

A moderate degree of concordance is based on (1) a lack of sufficient distinctness of the feature, (2) only occasional appearances of the feature, and (3) compatibility and interpretation in conjunction with previous findings (subjective interpretation):

1. Diastema between second left mandibular incisor and canine (Figures 9 and 10)
2. Reflection of the gold caps of the lower left canine and lower right second bicuspid (Figure 11)
3. Reflection of the gold capping of the upper right canine (Figure 12)
4. Suggestion of a lateral lower left bridgework, (Figure 10)

FIGURE 11 Reflection of the gold cappings of the lower canines.

FIGURE 12 Reflection of the gold capping of the upper right canine.

5. Suggestion of lateral lower right gold capping on second bicuspid and first molar.

There were no factors of exclusion, except for some stills taken from Leni Riefenstahl's motion picture *Triumph of the Will*. This film was made in 1934, probably shortly before Hitler's maxillary bridgework replaced former dental appliances, as described by Dr. Blaschke.

Conclusions

The identification of Adolf Hitler has already been demonstrated by Sognnaes and Ström in 1973 [3], although they never had any access to Hitler's skeletal remnants. These authors used several documentary evidence sources:

1. Complete testimonies by Hitler's dentist and physicians
2. Five x-ray plates taken in 1944 revealing several very characteristic dental features
3. The observations in items 1 and 2 were compared with dental features contained in the Russian autopsy report.

In the present study, cinematographic documents were used, and the findings were compared with previously made observations and Hitler's remnants kept at the Russian archives in Moscow. Because these would have been the only antemortem documents available to compare with the Russian autopsy report, could Hitler's identity be postulated?

The upper left darkened central incisor, the four lower incisors with periodontal involvement, and signs of erosions show high degrees of concordance. Taken together, they show no factors of exclusion, but do they represent enough evidence of concordance? When adding and interpreting the four elements of moderate concordance, there are still no signs of exclusion.

It should be kept in mind that, tempting as it may be, the second category represents occasional appearances, the distinctness of which is not sufficient to make major conclusions. It may also induce subjective interpretation. Thus, though the second category does not add exclusion factors, it does not, by itself, add any certitude either. In other words, based on previous data and on our subjective assessment of their rarity in a reference population, the concordant features support the hypothesis that the odontological characteristics described by the autopsy report, Hitler's dentist's testimony, and the American archives came from Adolf Hitler.

This contribution to the identification of Adolf Hitler using cinematographic documents represents a complementary approach to the methods of investigation used by Sognnaes and Ström [3]. Though it does not by itself provide sufficient data to postulate Hitler's identity with the highest degree of certainty, it reconfirms, with no signs of exclusion, previously made findings and demonstrates the possibility of using cinematographic material as a complement for identification purposes.

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Dental Forensic Identifications: The Beginnings to the Nineteenth Century

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Humans have probably recognized or identified one another from facial features since the origins of the species. While the eyes and nose play an obvious role in this identification, it appears that the mouth, especially the teeth, plays an equally or even more important role. Visitors to the Dr. Samuel D. Harris National Museum of Dentistry in Baltimore, Maryland, can interact with a facial recognition program to identify celebrities based solely on a picture of their smile. Most visitors score very well and are able to identify the majority of presented celebrities just by their smiles.

Identifying family, friends, and acquaintances from facial features occurs predominantly during life, but what happens after a person dies? With an intact body, most of the facial features remain, allowing for those who are familiar with the deceased to continue to identify the individual. However, the soft tissue elements allowing for the identification are absent in instances where the soft tissues of the body have decayed or have been destroyed. Fortunately for the forensic odontologist, the teeth survive, largely intact, through the conditions that render a body unrecognizable.

Hesi-Ré: The First Dentist

When the first body was identified from the remaining dentition is anyone's guess. The first person to be labeled as a "dentist" was the Egyptian Hesi-Ré in an inscription dating to 2650 BC. Egyptian medicine divided most of the body parts and functions into subspecialties of medicine, and Hesi-Ré is described as a physician being "the greatest of those who deal with the teeth." No records exist stating that Hesi-Ré ever identified a body from its teeth.

Lollia Paulina: The First Record of Forensic Dental Identification

The earliest record of a body being identified by its teeth would not happen until the Roman Age. Dion Cassius published his history of Rome over 150 years after Emperor Nero's death, making the record of the identification more of a legend than a transcription of actual events. The story proceeds thusly: Agrippina married Emperor Claudius around AD 49. Agrippina was the mother of Nero and wanted to secure not only her position but also that of her son. Claudius had recently divorced Lollia Paulina. Fearing that Lollia Paulina could still rival her for her new husband's attention, Agrippina persuaded Claudius to banish Lollia Paulina from Rome. Ever paranoid of her position within Roman society, Agrippina decide that the only way to be certain that Lollia Paulina would never have influence over Claudius again would be to have Lollia Paulina killed. Agrippina sent her own soldiers to kill Lollia Paulina, perhaps fearing reprisals from Claudius should he ever find out. Agrippina further instructed her soldiers to return with Lollia Paulina's head so she could confirm the death of her perceived principal rival. Apparently, the ensuing delay in returning with Lollia Paulina's head was enough to render the face unidentifiable based on the soft tissues. Undeterred, Agrippina parted the lips of Lollia Paulina's severed head and identified the head based on the teeth, as Lollia Paulina was known to have distinctive features in her dentition [1].

Dr. Joseph Warren: The First Forensic Dental Identification in the United States

It would be almost two centuries later until another identification based on dental forensic evidence occurred, and this time it took place in a fledgling country by one of its earliest patriots. Paul Revere is well known as an American Colonial silversmith and patriot. Very few know, however, that Revere also practiced dentistry.

Evidence that Revere practiced dentistry comes from announcements published in the *Boston Gazette*. In these, Revere never refers to himself as a "dentist," but he states that he continues the business of a dentist and cleanses and fixes teeth "as well as any Surgeon Dentist … from London" [2]. The ad also mentions that Revere has two years of experience, during which he had allegedly fixed hundreds of teeth.

A few inferences can be made from the ads. Notably, Revere seems to have studied dentistry under an already established dentist, which was only one of three ways to become a dentist before the advent of dental schools. Two years of study, observation, and practice under a preceptor was fairly standard. The other ways to become a dentist were to just start a practice after purchasing the necessary instruments or to practice dentistry in addition to a medical practice. Most trained and degreed physicians also practiced dentistry, with some practicing dentistry almost exclusively. Revere may have trained under John Baker, an English physician and dentist, who was the first or second dentist to immigrate to the United States.

By most accounts, Revere practiced dentistry for only a few years, with the bulk of his practice being what would be called "prosthetic dentistry" today. His mark on dentistry would not have even been a footnote in American dental history except for the fact that one of his patients was Dr. Joseph Warren, a prominent Boston physician.

Dr. Warren was a Harvard graduate and came from a very distinguished family. He was also one of the leading revolutionaries in the Boston area. Dr. Warren was a Grand Master Mason, a leader of the Sons of Liberty, helped to organize the Boston Tea Party, and sent Revere on his ride to alert the militia made famous in Longfellow's poem "Paul Revere's Ride" [3, 4]. Dr. Warren turned down the opportunity to serve as surgeon-in-chief of the Continental Army, instead requesting to be commissioned as a line officer [5]. He was elected a major general, becoming only the second person to receive this rank in the Continental Army [6]. Dr. Warren refused to command from the rear and was present with his men at the Battle of Breed's Hill, more commonly referred to as Bunker Hill [7]. During the battle he received a fatal bullet wound. The projectile entered the left maxilla just superior to the teeth roots and exited the posterior of the skull at the junction of the parietal and occipital bones.

The Battle of Breed's Hill took place in mid-June of 1775 and ended in a victory for the British forces. Due to the summer heat and exigencies of war, the British stripped the deceased Colonials of anything useful and buried them in shallow mass graves. It would be 10 months before British forces withdrew, allowing local citizens the opportunity to try and identify those Colonials who had died in the battle. Dr. Warren's fine uniform had been stripped from his body, making identification almost impossible. The family, knowing Revere had replaced one of Dr. Warren's maxillary bicuspid teeth with an artificial one held in place with silver wire, called upon the silversmith and dentist to identify Dr. Warren's body. Revere went to the area where some of the bodies that could have been Dr. Warren's were located and subsequently identified his patient and friend from the fixed bridge he had inserted just a few months prior [8]. The identification of Dr. Warren by Paul Revere is thought to be the first instance of human remains being identified via dental forensics in the United States.

Edinburgh 1814: The First Use of Dental Evidence in a Court Case

Medical education faced quite a quandary in the early nineteenth century [9]. Medical school professors, especially those teaching anatomy, required human corpses for instructing students. However, the populace, in general, viewed the practice with emotions ranging from mere disdain to open hostility. As an example, the townhouse where the first students of the newly founded University of Maryland Medical School (1807) were viewing and performing anatomical dissections was burned by some of the citizens of Baltimore, prompting the school to build a substantial brick medical school building on "the outskirts of Baltimore" in 1812.

The lack of suitable bodies for study resulted in the digging up of newly interred bodies. "Body-snatching" or grave robbing became a lucrative business for some. Medical students even resorted to the practice, referring to themselves as "Resurrectionists." In June of 1814, Drs. Granville Sharp Pattison and Andrew Russel, along with students Robert Munro and John McClean, were put on trial in Edinburgh, Scotland, for robbing the grave of Mrs. Janet McAllister of Glasgow. During the trial, dental evidence in the form of a maxillary denture was used to support the charge that one of the heads found in the dissecting room operated by Russel and Pattison, as lecturers of the College Street Medical School, was that of Mrs. McAllister.

Dr. James Alexander, Mrs. McAllister's dentist and a witness for the prosecution, testified that a set of her dentures fit one of the heads in the dissection room. However, Dr. John Gibson, a surgeon who had taken care of Mrs. McAllister until her death and who was also a witness for the prosecution, believed that although the teeth fit, the profile of the head was not Mrs. McAllister.

Dr. Watt, a Glasgow physician, testified for the defense that he witnessed Dr. Alexander's attempt to fit the denture to the head, but he felt the denture did not fit very well on Thursday. However, when Dr. Alexander attempted to fit the denture on Friday, it seemed to fit better. Two other area dentists testified that since Dr. Alexander was placing the dentures against soft tissue, an accurate fit could not be determined. One of the dentists also reported that he witnessed light between the denture and the jaw. Upon cross-examination, however, this “expert” informed the court that the fit of the denture could have been altered because they were dry and a more proper fit might be obtained if the denture was kept wet.

The jury returned verdicts of “not guilty” and “charge not proved.” In reviewing the case, it appears that while the dental evidence was questioned, the charges were affected more from the crime scene not being sealed during the investigation. The dissection room that contained all of the evidence changed each day of the investigation in terms of where and the amount of evidence present. Mrs. McAllister's head and other body parts were probably in the dissection at some time during the investigation, but confusion arising from the number of heads and other body parts and their location on subsequent investigative visits left the jury with a reasonable doubt of any of the body parts being those of Mrs. McAllister.

Tooth Eruption Patterns as an Age Determinant

During the early nineteenth century, the Industrial Revolution in England was gaining momentum. Younger and younger children were being forced to work in horrible conditions. The Peel's Act of 1819 forbade the use of children under age 9 from working in certain mills and factories, and children aged 9 to 13 could work only 48 hours maximum. There were two problems with the Act, however: One was that there were no birth registrations in England at the time, so height was used to determine age.

In 1837, Dr. Edwin Saunders examined 1,046 children and proposed that the eruption pattern of teeth was a more accurate age determinant in children than height, and he succeeded in getting the official method for determining age changed from height to an examination of the teeth [10]. Dr. Saunders would receive an honorary Doctor of Dental Surgery Degree in 1845 from the Baltimore College of Dental Surgery (BCDS), the first dental college in the world established in 1840. On page 29 of the college's *81st Annual Catalogue,* Dr. Saunders is listed as "Sir E. Saunders, FRCS, England." This entry indicates that Dr. Saunders was a Fellow of the Royal College of Surgeons and that he had been knighted. He was the first dentist to be so honored. In fact, Dr. Saunders served as Queen Victoria's personal dentist from 1847 to 1883.

Parkman/Webster Murder Trial, Boston 1850: The First Court Case Largely Built on Dental Evidence

Several events had taken place during the intervening years between the McAllister case in 1814 and the Parkman/Webster case in 1850, raising dentistry to the level of a profession equal to that of medicine [11]. As mentioned, previously, the Baltimore College of Dental Surgery had been founded in 1840. It graduated two students in 1842, making them the first persons ever to receive earned dental degrees from an accredited institution. The first national dental organization was also founded in 1840 as the American Society of Dental Surgeons and in 1839 *The American Journal of Dental Science*, the first dental journal in the world, was published in New York.

The 1850 Parkman/Webster murder trial shook Boston society to its very core. The local press followed the case in great detail, the Harvard University Medical College had to be closed due to the large number of sightseers clamoring for a glimpse of the murder scene, and special trains and stagecoaches brought spectators from the outlying areas into Boston, resulting in such a large number that visitors were brought in and out of the courtroom in 10-minute intervals.

Dr. George Parkman was an 1813 graduate of the Harvard University Medical College and a member of Boston's social elite. He had inherited a considerable fortune and, in turn, had given Harvard land while also sponsoring building projects. He was immediately recognizable due to a prominent mandibular prognathism being referred to as the "Chin" by Boston's lower class.

Dr. John White Webster earned both masters of arts and doctor of medicine degrees from Harvard. He was the son of a wealthy apothecary and had attended Harvard's medical school with Dr. Parkman. Eventually he held the chair of Chemistry and Mineralogy at Harvard. Dr. Webster inherited $50,000 upon the death of his father, and, wishing to improve his social standing, built a huge house where he and his wife threw large parties. Maintaining this lavish lifestyle was impossible, however, on Webster's $2,000 annual income.

To maintain the lifestyle to which he and his wife had grown accustomed, Dr. Webster began to borrow money. He borrowed an initial $400 from Dr. Parkman in 1842, but by 1847 he owed Parkman $2,432, even using his valuable mineral collection as collateral for one of the loans. Dr. Parkman, however, was not the only person from whom Dr. Webster borrowed money. He also borrowed money from Robert Gould Shaw Jr., and had secured the loan with the same mineral collection that he had used to secure one of his Parkman loans. Unfortunately for Dr. Webster, Mr. Shaw just happened to be Dr. Parkman's brother-in-law.

It was only a matter of time before Dr. Parkman found out about Dr. Webster's deceitful borrowing practices. After that, Dr. Parkman pursued Dr. Webster incessantly, demanding the return of his money. Dr. Parkman even went so far as to threaten Dr. Webster with having him dismissed from the Harvard medical faculty and discrediting him publicly.

On Friday, November 3, 1849, Dr. Parkman encountered Dr. Webster once again during one of his frequent walks. It was the last day that Dr. Parkman was seen alive. The subsequent search for Dr. Parkman has striking similarities to searches performed today. On Saturday, a wide-ranging search organized by Boston city marshall Francis Tukey was underway. Newspaper notices offered $3,000 if Dr. Parkman was found alive or $1,000 if he was found dead. Several thousand flyers were distributed. Large wooded areas were searched, and the Charles River was dragged. Dr. Parkman owned several apartment buildings in the poorer sections of Boston, and these were searched thoroughly for any sign of the missing doctor. All members of the Harvard Medical School faculty were questioned after two boys reported seeing Dr. Parkman walking toward the medical college.

On Monday, Marshall Tukey searched the medical college along with several officers to rule out the possibility of Dr. Parkman's body being dismembered for use in anatomic dissections. Dr. Oliver Wendell Holmes Sr. was the professor of anatomy and physiology at the medical college, and unlike the McAllister case that took place in Glasgow, Scotland, in 1814, he was able to provide evidence to the investigators that every body part present had been properly ticketed and no unidentified parts were present. Ironically, Dr. Holmes's position had been endowed by Dr. Parkman. He was the Parkman Professor of Anatomy and Physiology. When one of the investigators attempted to open Dr. Webster's laboratory, Webster promptly informed the investigator that the room contained dangerous chemicals that could explode, and the room was never searched. Dr. Parkman's real estate agent even convinced Marshall Tukey to search the medical college, its laboratories, and the lecture rooms a second time, but nothing was found.

The investigation would turn upon evidence discovered by an unconvinced and tenacious janitor. Ephraim Littlefield lived in the college's basement with his wife. While contemplating Dr. Parkman's disappearance, he remembered several events that seemed innocuous at the time but when viewed together brought suspicion upon Dr. Webster. Littlefield had heard Parkman and Webster arguing earlier in the day that Dr. Parkman disappeared. Later that same day, Dr. Webster refused to allow the janitor into the laboratory to clean it. The next day Littlefield had seen heavy smoke coming out of the chimney associated with Dr. Webster's laboratory. He thought that this was an unusual sight, since the medical building was rarely occupied on weekends. Upon investigating, he found Dr. Webster's laboratory door locked once again, and this time he noticed that the water was running continuously.

Littlefield surreptitiously investigated the laboratory when Dr. Webster was away, discovering that the indoor privy was locked and the key missing. Undeterred, he descended into the subbasement and eventually broke through the wall of the privy's shaft, whereupon he discovered two femurs and a pelvis with some flesh still attached.

Knowing that Dr. Holmes would never allow a cadaver to be disposed of down a privy chute, Littlefield informed the police of his discovery. This search, focusing on the lecture rooms and laboratory under Dr. Webster's supervision, uncovered other body parts packed in a tea chest and human bones and a denture inside the assay furnace. Dr. Webster swallowed a strychnine pill upon his arrest, but the poison did not kill him. Afterward, he professed his innocence.

The subsequent 12-day trial of Dr. Webster would prove to be a landmark case in the use of dental forensic evidence to convict a suspect. A total of 121 witnesses were called to the stand. Among them would be several dental professionals. Dr. Nathan Cooley Keep testified that he had been Dr. Parkman's dentist since 1825. More damning for the defense was his positive identification of the pieces of a porcelain denture removed from the assay furnace as being those of Dr. Parkman's denture, which he had fabricated for the victim four years before his death. Dr. Keep detailed how impressions had been made of Dr. Parkman's mouth, and he presented the original models made from those impressions. Dr. Keep went on to demonstrate how all five pieces of the denture recovered from the furnace fit the model exactly. Dr. Keep also testified that the denture must have been placed inside the assay furnace while still in the victim's head because otherwise, since the denture was made from porcelain, it would have exploded in the intense heat of the assay furnace fire. Dr. Lester Noble, an 1850 graduate of the Baltimore College of Dental Surgery [12], who had been Dr. Keep's dental assistant from 1846 until 1849, corroborated the testimony that the recovered porcelain denture pieces fit Dr. Parkman's model.

Dr. Noble was known as a skilled manufacturer of artificial teeth and would become a "demonstrator of mechanical dentistry" at the Baltimore College of Dental Surgery (BCDS) from 1851 to 1852 [13]. Dr. Keep was both a dentist and a physician. As a dentist he was preceptor trained. As a physician he was an 1827 graduate of the Harvard University Medical College. He was awarded an honorary Doctor of Dental Surgery degree from the BCDS in 1843 [14]. In 1868 Dr. Keep would become the first dean of the Harvard University School of Dental Medicine, which was the first dental school affiliated with a university and was also the first dental school to graduate an African American, Dr. Robert Tanner Freeman, in 1869.

Another famous dentist would testify for the defense. Dr. William Thomas Green Morton of Connecticut, a physician and dentist who discovered the anesthetic properties of ether in 1846, testified that he was unable to detect any clues on the recovered teeth that might identify the maker. Upon cross-examination, however, he agreed that the teeth had been ground down after finishing (a point made by Drs. Noble and Keep in previous testimony) and that he could identify his own dental work, admitting that a dentist who takes considerable time to fabricate a denture for an unusual case (Parkman's noted mandibular prognathism) could probably identify his own workmanship. Morton continued to imply, however, that the denture pieces in question could fit another mouth. Drs. Daniel Harwood, Joshua Tucker, and Willard W. Codman, who were also dentists and physicians, all testified for the prosecution, stating that dental practitioners could definitely identify their own work.

In charging the jury, the judge advised them that since there were no eyewitnesses to the crime, the recovered bones alone were inconclusive evidence upon which to base a guilty charge. Therefore, the jury would have to decide if the dental evidence presented was credible enough to render a guilty verdict. Dr. Webster was found guilty of first degree murder after only three hours of jury deliberation. His sentence was death by hanging.

John Wilkes Booth: Identification of the Infamous Assassin

Following John Wilkes Booth's death, his body was sent to the Navy Yard in Washington, D.C., where an autopsy was performed. His body was subsequently "buried nine feet below the surface in the old penitentiary (now Ft. McNair) where the sun would never shine on his grave" [15]. In 1869 the body was disinterred at the request of the Booth family. His brothers identified the body on the basis of a "plugged tooth" [16, 17].

The "Bazar de la Charité" Disaster Results in the World's First Forensic Odontology Text

During the late nineteenth century, Paris's socially elite women held an annual bazaar to raise money in support of their projects for the poor [18]. The venue was a long wooden structure (72 m long by 20 m wide) with poor ingress and egress and a tarred cardboard roof. The structure was lavishly decorated every year, which made for a beautiful event, but all of the fabrics and decorations also made perfect fuel for a fire.

On May 4, 1897, the venue caught fire, supposedly during the refueling of an ether lamp used in a cinematographic presentation [19]. While small in the beginning, the fire quickly spread to the walls, roof, and elaborately decorated vendor stalls. Within just a very few minutes, 126 people had lost their lives. Most of the victims were elaborately dressed women. The bodies were relocated to a hall at the Palais de l'Industrie.

Dr. Oscar Amoëdo, who was a professor at the Paris dental school, in a presentation to the International Medical Congress of Moscow, Dental Section, described the scene at the hall:

> *The hall to which the bodies had been transported presented a terrifying aspect. The corpses, all horribly mutilated, carbonized, shapeless, a great number entirely nude, had been placed side by side upon planks. Some had lost their arms, others had had a leg completely calcined; all bore upon their faces an expression of fearful terror. Many had the cranium entirely denuded and the integuments of the face blackened and hardened by the fire. The skin of the abdomen had burst from the intense heat, allowing the intestines of the unhappy victims to fall out. In one corner lay shoes, and arms and legs detached from their trunks.*

Another witness ended his description with: "… at least only the teeth remained."

Despite the carnage, the identification process proceeded fairly rapidly the next day. Undoubtedly, most of the bodies were identified by what clothing, jewelry, and other accessories had been associated with each body, as these were Paris's elite, and such items would have been many. By midday, only 30 corpses remained unidentified. At this point, the Paraguay Counsel, M. Albert Hans, put forth the idea of having the dentists who were most likely to have treated the victims assist with the identifications. Several dentists were summoned, but the identification process ran into an immediate problem: All of the facial muscles had contracted to such an extent that none of the jaws could be opened, making examination of the teeth impossible. The situation was made even worse by city officials forbidding the sectioning of the faces. Fortunately, each dentist present kept detailed records of their patients mouths and treatments. The dentists pressed their case for being allowed to examine the remaining victim's dentition, and permission was finally granted. Most of the remaining victims were identified through the resulting dental examinations.

Many of the dentists noted during their examinations that many of the gums had been protected from the fire by the cheeks. Amoëdo noted that "the teeth are the parts of an individual that last the longest after all other signs have disappeared. They have a considerable value from the point of view of identification, and the knowledge that the dentist possesses of the dental system of his client, with the register that he keeps, are means of recognition that one ought not to neglect."

Amoëdo ended his presentation before the International Medical Congress of Moscow, Dental Section, with two calls to action. In the first, he called for soldiers and criminals to have their teeth summarily examined, with the data to be used for their identification instead of other physical characteristics. In the second, he charged the dental profession, of all countries, to adopt a uniform universal nomenclature.

Dr. Amoëdo's address was reprinted in the May 1897 issue of *Dental Cosmos*. Further research is needed to determine if Dr. Amoëdo's address is the first delivered on forensic dentistry. During the address he stated, "I obtained much information as to the precise results obtained by these examinations, and I am in possession of numerous documents and the greater part of the registers that they used. These I am keeping for a work I have in preparation." The work to which Dr. Amoëdo refers is *L'Art Dentaire en Médecine Légale,* published in 1898. This book is regarded as the first book on forensic dentistry.

Postscript

The last half of the nineteenth century was propitious for both dentistry as a profession and for forensic dentistry/forensic odontology as a subspecialty of dentistry. By the end of the century, the dental profession saw the formation of accredited dental schools, the publication of scholarly journals, and the formation of national and international associations and societies. Dedicated forensic odontology societies, associations, and journals would come later, but the groundwork had been established; forensic evidence had been successfully entered into a criminal case, the nexus for identifying disaster casualties had been worked out, and the first textbook on forensic dentistry had been published.

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CHAPTER 2

Dental Detectives

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Who Is a Qualified Forensic Dentist? Advice: Use the Best

A critical point arises when a death or major crimes investigator determines that a forensic dentistry expert is needed for a particular case. This book provides an overview on forensic dentistry, but somewhere in the case—sooner better than later—a qualified dentist should be called. Certain agencies outside major metropolitan areas of the United States, Canada, and around the world may not have easy access to board-certified dentists. The informed investigator should know that more complicated identification cases have the best results when an experienced dental expert is used. The investigator also has to ask, "Is this a complicated or a simple identification case?" Certainly any bitemark case should include in the investigation as soon as possible a dentist who has the skill, training, and experience to assess the value of this type of evidence and perform scientifically valid analyses. The simpler case of identifying a deceased subject from dental records may be within the realm

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of any licensed dentist, but the investigator should value the use of a second opinion whenever possible. This does not reflect negatively on those dentists who are developing their forensic skills. This caution is based on the fact that formal undergraduate and postgraduate training in forensic dentistry is not consistent throughout North America and internationally.

What Dentists Do

Hospital emergency room personnel, law enforcement, district attorneys, coroners, and medical examiners frequently develop cases that require dental expertise. The criminal defense bar also uses certified forensic dentists to review and analyze evidence that is relevant to judicial proceedings. The realm of the forensic dentist crosses into all aspects of criminal investigation. The most common cases are missing and unidentified persons (MUPs) cases, where unidentified human remains are found at a crime or death investigation scene. Dental evidence becomes important for such human identification cases when fingerprints are not obtainable from decomposed or skeletonized remains. In the case of "fresh" human remains, the lack of personal effects (e.g., driver's license, credit cards) or surrounding circumstances (vehicle registration or known place of residence) can frustrate the first step in a case. This first step is the identification of who the person *is*.

The September 11, 2001, terrorist attacks at the World Trade Center, the Pentagon, and Pennsylvania required the efforts of hundreds of dentists, some board certified and others willing to help on-site to achieving the goal of identifying the victims. Later chapters in this book provide an immense amount of information regarding what needs to be performed in all types of cases and mass fatality events. When conventional identification means are thwarted, dentistry is generally considered optimal when there is sufficient dental information before and after death. DNA profiling is used for severe body part fragmentation and where dental records are not available. Individual teeth obtained from a crime scene can be used to develop a DNA profile of an unidentified person. The dental nerve and root tissue can be analyzed by biochemical means to recover the person's DNA characteristics.

The second aspect of forensic dentistry is the recognition, documentation, and preservation of bitemark evidence. Teeth marks can be found in food, gum, soft objects, and human skin. The first three may be left at crime scenes, and bitemarks may be found on the bodies of assault victims, both dead and alive. The comparison of these teeth marks to a particular suspected person requires the services of an experienced forensic dentist who has knowledge of the limitations of this type of evidence as it is *not* as reliable as DNA identification technology. The bitemark evidence also may contain saliva that has been deposited on the object or skin during the act of biting or chewing. This saliva can be a rich source of DNA, and protocols must be in place to collect and preserve it early in a case.

Although dentistry is its own forensic specialty, it is important for the investigator to understand commonly used dental terminology and be able to recognize dental evidence. We will provide fundamental terms and descriptions of human adult and baby teeth in this chapter. At the end of this chapter are some cases that illustrate how this information can be used to produce a positive investigative outcome.

What to Do When "a Skull with Some Teeth" Has Been Discovered

The time to find a qualified forensic dentist is not when you get a phone call about a skeleton with an intact skull that has been discovered in your jurisdiction. You should establish a good working relationship with your dental expert *before* you need him or her. Since death and crime scene technicians are tasked with the duty of investigating known or suspected death scenes, you should be aware of the protocols and concepts surrounding the identification of human remains via dental means. The initial realization should be that it is paramount to initiate a thorough and well-documented trail of your investigative steps taken in the field. The material in this book will hopefully provide a backbone for investigators to develop their own protocols if none exist or determine that current ones need upgrading. The following indicates the general case conditions where a forensic dentist is needed as part of the investigation team when condition of the human remains is poor.

A call to a scene—where the first responder indicates a decomposed human skull, body, or a clump of potentially human bones or burned fragments of bones—has to be both an exciting and challenging opportunity for any investigator. This is not the usual case where a fresh, intact or partially intact body is present. Upon arrival, the investigator has to remember that many of the typical human identifiers may not be present. Burn victims seem totally devoid of human features. Fingerprints, definite body parameters of height and weight, eye color and hair color, and the possibility of visual identification will be eradicated. There may be no available personal effects (wallet contents, passport, engraved jewelry, etc.). There are limits to assumptions regarding personal property found on or near a scene, and they must be considered in the totality of other circumstantial and physical evidence. Caution must be exercised. The presence of distinctive tattoos on residual skin found on the body might be present, but skin, although capable of becoming mummified in a proper dry and cool environment, may not be present after prolonged exposure to climatic elements or man-made (e.g., mutilation) conditions. Notable old surgical sites or significant medical history will have to be considered during autopsy and left to the realm of the medical examiner to value in comparison to personal history and medical records associated with a known individual.

The on-scene investigator should know six scenarios in which human remains require dental examination:

1. *Intact body with little to no decomposition found with no identification*. The general sequence of multidiscipline input in this case type has the dead person's fingerprints being taken by law enforcement and then uploaded to regional or national databases. The absence of personal effects will inhibit the association of the body with local information. The absence of a timely missing person's report may inhibit developing leads. The dental exam should be done to allow maximum data collection early in the process. In many of these scenarios, the collection of DNA samples for later testing may occur.
2. *Decomposing human remains*. The possibility of fingerprints will be remote in this case. The use of dental information at the onset of the case may quickly add to the profile of the decedent and should be correlated with personal effects, DNA, or circumstantial information on identity.
3. *Skeletonized human remains*. Law enforcement in this scenario should use both a forensic dentist and a forensic anthropologist. Forensic anthropology is a specialty recognized by the AAFS. These individuals have special training in human osteology (bone science), excavation, and recovery methods and analysis of bones for forensic information.
4. *High-energy accidents, terrorist acts, biological agents*. These events cause severe trauma, dismemberment, and fragmentation of human victims. The forensic team assigned to these cases must include a trained forensic dentist.
5. *Homicide cases*. The autopsy team should include a highly trained forensic dentist to lend experience with analysis of bruises and marks on crime victims that may have been caused by teeth.
6. *Sexual assault and domestic violence cases*. Victims and suspects will bite in the course of a violent assault. The patterns produced by teeth in biting must be photographed and sometimes impressed for three-dimensional modeling by a trained technician or forensic dentist. The analysis of the pattern's possible link to a particular biter (i.e., bitemark identification) is dependent on proper evidence collection at the beginning of the case. An experienced forensic dentist should do this analysis based on the scientific literature.

These types of cases are difficult to quickly or even successfully reach the determination of human identity. This is where the forensic dentist is available for vital assistance to answer the important questions. The dentist can estimate the age of the deceased, help to reconstruct the person's dental profile, and run out leads of potential identities using dental comparison techniques. The dentist can indicate whether the person was dentally healthy or showed sings of self-neglect or indigence. The dentist will also note indicators of the person's appearance. In bitemark identification, answers may be provided as to the appearance of a specific bite pattern in skin or foreign object recovered from a crime scene. In all of the preceding scenarios, it is paramount that the forensic dentist be included in the process from the very first phase in order to optimize results. An incident that has the potential for large amounts of human remains should have a dentist in the disaster plan to assist in the discovery and recovery phases. There will only be one chance to properly process such a scene. A dentist's familiarity with highly fragmented dental and human remains will accelerate the recovery process and help organize the identification process at the morgue or laboratory.

Besides the environmental factors that work to destroy, distort, or diminish the physical characteristics of a deceased body, there may be animal or insect activity that will further degrade the evidence. Fully skeletonized remains require specific steps in ensuring preservation of the human material. The chances of compromising an investigation increase exponentially with the decrease in available forensic information. The steps at the scene must center on preservation of obvious human material and a thorough review of the surface underlying the body part, be it solid ground, brush, gravel, or a muddy stream bed.

Investigators need to know *why* a person died. *Who* that person is allows them to backtrack to *where* the person was last seen or known to be alive. Without the *who*, there is no *where* for the case to go, unless a missing persons report is filed in the same jurisdiction, a nearby jurisdiction, or a jurisdiction that is networked with a functioning and reliable area or national database. *When* the person died is important as well. Case investigators should consider experts of entomology, pathology, and other fields in attempting to reconstruct time since death. The dentist can provide the *who* portion of the puzzle.

All of the preceding factors are not controlled by the investigator. Other people and elements at the scene—the perpetrator, the weather, and so on—take their toll on the outcome. The investigator, conversely, has total control over the scene upon arrival. The following specific areas of control must be maximized:

1. Control your assumptions regarding the *who*, *why*, and *how,* and wait longer than you feel it is necessary to answer those burning questions. Once stated, they are very hard to erase if wrong. Outside pressures from media, supervisors, politicians, and so forth may seem to be overwhelming for an impressionable investigator. To counter this, just keep in mind how bad your feelings and other sensibilities will be if you misidentify the deceased.
2. An equivocal crime scene (whether a natural death, a homicide, or an accident) must be initially treated as a homicide. There is no way to recover from making a mistake at this stage of the activities. You cannot back up if the scene is released too early because of a mistake. Evidence will be lost.
3. The overall conditions of the scene will determine how you will recover the remains and its associated evidence. For example, a scene initially investigated outdoors at night should be thoroughly processed during the day. A wet and marshy area will take special equipment to control

moisture and bacterial contamination of trace evidence. Burned human remains in an incinerated car will require a thorough search of the vehicle for lost teeth (very fragile and brittle) and metal dental restorations (they may be partially melted). Honestly assess your personnel and equipment resources, and be flexible regarding what your plan's limitations may be. If possible, think backward from the final location of the evidence (crime lab or autopsy suite) to the crime scene's original location of the evidence. This will create a better awareness of what needs to be done at the scene. Write your plan using these steps. If you still have questions, ask for help from people who have more experience in successful scene analysis before you process the scene.

4. The documentation of the scene should include all of the basics, including written notes, drawings with measurements, and mapping. This is done before removing any remains or evidence. Put dirt and material removed from around the remains in a specific neutral place near the scene to allow the possibility of a future return and reevaluation. This does not mean throwing the dirt in close proximity to the body over a cliff. Carefully remove it and put it in a safe place. Soil underneath the remains should be sifted. Tag all objects, take photographs, and map before removal. Take orientation photographs of the general scene showing these tags before bagging individual pieces of evidence.
5. Consider how a perpetrator or accomplice may have entered and left the scene, before transporting the remains.
6. Take each step very slowly.
7. An experienced forensic dentist could answer specific questions about dental evidence present at a scene.

Concepts involving recovery of dental remains should concentrate on all of the preceding, as well as the following concerns:

1. Teeth are small and may be broken into smaller pieces by high-energy impacts (plane crashes or automobile accidents).
2. Burned or incinerated teeth are extremely fragile. After documentation, the investigator should spray the tooth with a clear lacquer to help stabilize the ashen tooth structure before removal.
3. Bitten objects must be carefully collected and placed in paper bags that are properly labeled. This type of packaging lessens the chance of bacterial growth on the object, which may inhibit later recovery of salivary DNA at the lab.
4. Metal dental work may be misshapen due to heat damage. Gold crowns will look gray or black, and metal partial dentures can appear twisted and blackened.
5. Bitemarks on skin may look like round or almost circular bruises. The investigator must look for a series of small bruises or cuts that are arranged in a half-circular shape. Many times markings of both upper and lower front teeth will not be apparent. This is called a “single arch” bitemark and is of low forensic value due to its lack of complete dental

information. This may be caused by some object blocking one jaw from marking the skin and also raises the issue of whether the mark is caused by teeth. As always, swabbing of the bite site for epithelial DNA is the best method to identify the biter.

The Use of Teeth by Forensic Science

The investigator should know that during the stages of development from child to adult, humans possess 20 deciduous (baby teeth) and 32 adult teeth. Some of this total complement of 52 teeth may be present in a 1-year-old infant or a 90-year-old person. There is a transition period during the ages of about 6–12 years where adult teeth and deciduous teeth are both present. Twelve is the average age where all deciduous teeth are gone and the adult teeth are present. Wisdom teeth (third molars), if present, may start erupting into the oral cavity at the age of 18.

Teeth may also tell a story. In a real sense, there is a dental profile that can be developed from a person's mouth and teeth. Some teeth can give us an idea of racial characteristics. Asian and Native American populations can have upper front teeth that are scooped out in back (aka shovel-shaped incisors). Teeth can tell us if an unidentified person was lucky enough to have her teeth straightened as a child or as an adult. Orthodontic work in the United States commonly includes the removal of four bicuspids in order to perform teeth straightening. This also indicates a certain social status or income level, since orthodontics is usually an elective procedure. Old gold dental fillings show that the person has received dental work over many years. New dental fillings show recent visits to a dentist. Whitened teeth and white caps show that the person was concerned about his appearance and had the financial resources to receive cosmetic dental work. Gold fillings and caps also show that the person could afford expensive dental care. Large silver fillings show that less-expensive dental care was received. Decayed or missing teeth show that the person was not getting regular dental care. Stainless steel or chrome caps are more economical than fancy porcelain (glass-covered) caps and white fillings. Certain dental metals and materials are used and traceable to geographic regions or countries. Cells in the nerves and roots of undamaged teeth possess the biological makeup (DNA) of an individual. Even teeth fragments may allow investigators to determine an individual's DNA code via genetic testing. The sex of the person is proven by the presence or absence of a Y chromosome (male feature) in a tooth's genetic profile.

The comparison of past x-rays and dental records to the dental features of an unknown dead person is the primary step in dental identification. Finding these old records (both dental and medical) is vital for a completion of any identification case. Communication between the 50 states and the FBI missing person's archive (National Crime Information Centre, NCIC) must be improved regarding missing persons. To date, most missing persons reports in the United States do not include dental information.

Factors that Change the Appearance of Teeth over a Lifetime

Dentistry has been a component of human history for eons. The development of *Homo sapiens* from its primate predecessors eventually introduced new pressures on the health and well-being of earth's inhabitants. The diets and habits of early man created increased wear and tear on teeth and the supporting dental structures of the jaw. Rustic means of grain production produced very abrasive foodstuffs due to incorporation of fine grit. This accelerated attrition, and later breakage, of child and adult teeth. Figures 1–3 show teeth with severe wear caused by dietary habits.

Modern civilization during the last two millennia improved on food production for the segments of society who could afford more refined food. The introduction of sugar and finely milled flour or maize increased the prevalence of tooth decay in these populations. This results in a dental profile much different from primitive society.

FIGURE 1 This is an "ancient" skull that was embedded in layers of hardened mud at a depth of 2 to 3 feet. This indicates a significant time passage since its burial. It was found during a construction excavation and had no accompanying evidence. Supporting this opinion is the severe dental attrition (tooth wear) and the skull being thoroughly desiccated (dried out) and mineralized over time. A "fresh" skeletonized or partially decomposed skull would have a much smoother bony surface and an obvious odor of "rotten eggs."

FIGURE 2 Close-up view of upper front teeth from the excavated skull. The extent of wear seen in "modern" teeth is much less. In this specimen, all of the enamel on the chewing surfaces has been worn away, resulting in exposed root material. The dental nerve or "pulp chamber" in these teeth appear as circular or ovoid areas in the center of each tooth.

FIGURE 3 Close-up view of the skull's molar (chewing teeth) showing severe wear. This wear process may sometimes lead to severe dental abscess formation. These infections cause large amount of bone destruction adjacent to the offending teeth.

Contemporary dentistry has thrived on the existence of tooth decay and tooth loss. The efforts to reconstruct natural teeth that have been lost are recorded in ancient history from Egypt to the present. In modern times the presence of dental restorations and a history of dental treatment can allow investigators to identify deceased human remains. Forensic cases for human identification actually contain multiple specialists. Fingerprint experts, forensic anthropologists, DNA technicians, crime scene technicians, pathologists, and dentists all may have a part in rebuilding the circumstances of a person's demise as well as who that person is.

These man-made changes to the human dentition are a foundation for the modern dental identification of individuals. This investigative profiling focuses on dental work, medical devices, skull features, and tooth changes that have occurred during their lives. These features are memorialized in photographs, dental and head x-rays, and other medical imaging methods produced during a person's life. The assumption is that these features (both natural and man-made) are sufficiently unusual in their totality to make a determination of "possible, probable, or positive" identification. One should realize that a determination of less than "positive" means the body could be someone else.

A negative (i.e., exclusionary) finding is obtained when features are considered dissimilar (no match) or in harder cases where they are similar but are not the same specific two-dimensional shape. In all dental identification cases, the comparisons must be made using x-rays or other radiographic representations of the before and after death dental features. Cases that simply use before-death written medical and dental records for comparisons can never be as certain. The first commandment for the investigator should be *always obtain x-ray records* if there is the possibility of their existence.

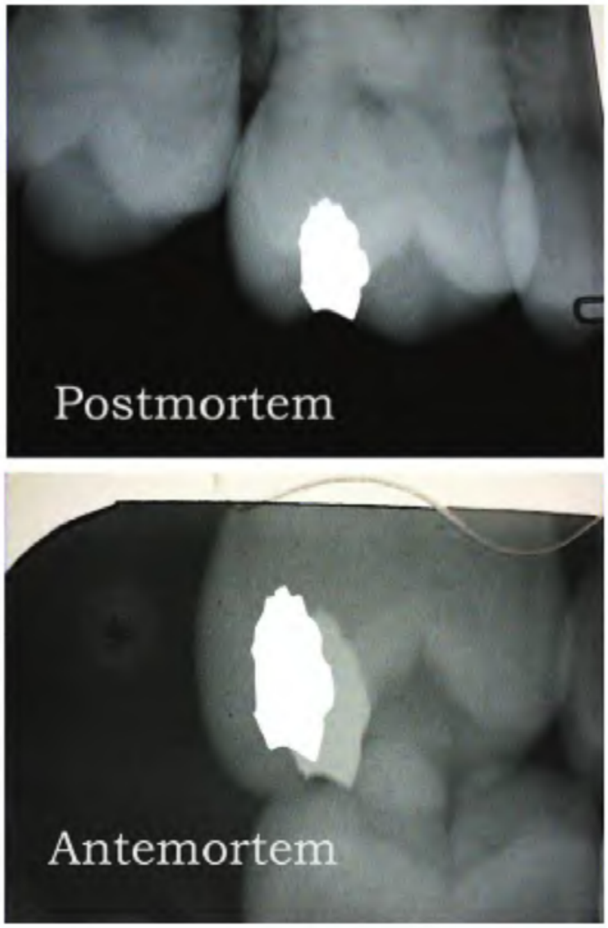

FIGURE 4 Two dental x-rays from an actual identification case. A metal filling in the left x-ray (postmortem) appears as a white shape. The right x-ray (antemortem) was obtained from a missing girl's dental records that were over 10 years old. The tooth with the filling in both x-rays is an adult molar that was filled with a metal restoration. Digital computer correction was then performed to make both images similar in dimensional shape. Finally, the outline of the upper filling was digitally transferred onto the right x-ray for two-dimensional comparison. The shape similarities are sufficient to support a positive dental identification determination.

The following case involved a murdered teenager whose body was encased in a cement-filled barrel and dumped. The remains were recovered weeks after the murder, and technicians were unable to recover fingerprints from the remains. There was significant circumstantial evidence pointing to who the body was, but dental records were used to confirm the identification (Figure 4). This is commonly done when there is adequate dental evidence, since it is faster and cheaper than DNA analysis. In the case of no dental evidence, DNA would probably be the first resort regarding the issue of identity.

The Language of Dental Identification

It is important for investigators to know basic terms used by dentists to describe teeth anatomy and shapes. This will help them to understand dental reports and be able to discuss case specifics. The two main sections of a tooth are (1) the part that shows in the mouth (*crown*) and (2) the part embedded in the gums and jawbone (*root*). Some teeth have more than one root. The front teeth only have one root, while the back teeth can have as many as four.

Each of the five surfaces of a crown has a specific name. The biting surface is called the *occlusal* for back teeth and the *incisal* for the front teeth. The tooth surface touching the cheek and the surface toward the tongue are the *facial* and *lingual*, respectively. The side toward the front of the mouth is the *mesial,* and the side toward the back is the *distal.* These words can also be used to describe tooth position. For example, a tooth may be tipped mesially (toward the front) or crowded in a lingual position (toward the tongue). Restorations (fillings and crowns) are described by the restorative material used and the surfaces involved. An individual silver filling that fills both the mesial and biting (occlusal) surfaces of a posterior tooth is called a *mesio-occlusal amalgam*. These definitions become crucial when charting the dental conditions present.

It becomes obvious that the amount of potential information contained in a person's dental record can be enormous. The quality of an antemortem (before-death) patient file will be directly related to the detail that the dentist included in his or her clinical examination and recorded on paper. The comparison for the purpose of dental identification becomes an impossible task without good records and exam radiographs.

The investigator should be aware of the general terms used by dentists and also be familiar with the shapes of different human teeth (Figure 5). This is to

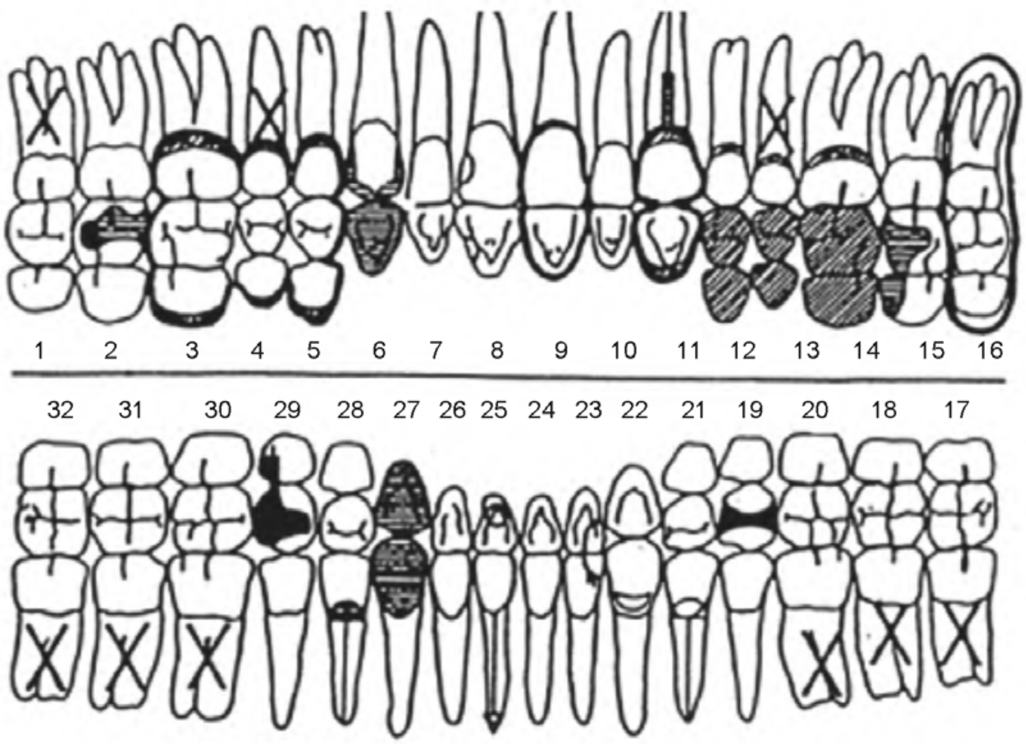

FIGURE 5 This is a dental chart showing all of the human adult teeth numbered in the Universal System that is popular in the United States. The numerical sequence starts with the last upper adult tooth on the right side of the face (#1) and continues to #32. The symbols drawn on these teeth are diagrammatic descriptions of filling shape and location (as in #29), the presence of a crown covering a tooth (#27), or the tooth not being present in the mouth (#17, 18, and 19). The circle around #16 indicates the tooth is impacted (under the gum tissue). Teeth #3, 4, 5 show a fixed bridge. #4 was extracted (hence the "x" on its root) and teeth #3 and #5 were covered with crowns in order to connect a replacement tooth for #4.

be aware of dental evidence and also to understand written dental records obtained in the course of a case. The next two sections include information that should provide basic information.

Tooth Names and Quantity of Teeth in Adults and Children

Tables 1 and 2 describe the number of human teeth and their general shape.

TABLE 1

Tooth Type	Number of Teeth	
	Upper Jaw	Lower Jaw
Deciduous (baby teeth)	10	10
Adult	16	16

TABLE 2

Basic Tooth Shapes	Incisors	Canines	Bicuspids	Molars
General appearance	Front four teeth; all have thin edges; square shaped	"Eyeteeth," cone-shaped	Two cusps	Square; 4 and 5 cusps; largest teeth in jaw

Tooth Terms Used to Describe Parts of Teeth

The following terms are used to describe parts of teeth and jaws:

Crown	Clinical crown—the portion of a tooth visible in the mouth.
Root	The portion of a tooth that normally is embedded in the jawbone. In older persons, the root may also be exposed while in the mouth. After high-energy impacts, the entire tooth, both crown and root, may be fragmented away from the surrounding jaw.
CEJ	The *Cemento-Enamel Junction*—the neck of the tooth that demarcates the crown from the root.
Cusp	Biting edges of a tooth. The front teeth (the pairs of central, lateral, and cuspid incisors) in each jaw do not have cusps. The back teeth (bicuspids and molars) have flat biting surfaces that possess bumps called *cusps*.
Quadrant	Each jaw is divided into two halves that are labeled left and right. The entire human dentition (teeth) has four quadrants.

Incisors	The front four teeth in the upper (maxillary) and lower (mandibular) jaws.
Canine	Commonly known as the *eyetooth*, the canine has the longest root of any tooth. It is located next to the incisors and in front of the bicuspids.
Bicuspids	A set of two teeth behind each canine and in front of the molars. Generally, they have two roots. Also known as *premolars*.
Molars	The large, flat surfaced teeth that have multiple roots located in the back of the mouth.
Incisal	The biting edge of front teeth (incisors and canines).
Occlusal	The chewing surface of back teeth (premolars and molars).
Buccal	Tooth surfaces that touch the cheek. Term reserved for bicuspids and molars.
Labial	Tooth surface that touches the lips. Term reserved for front teeth (incisors). Also known as the *facial* surface.
Palatal	Upper bicuspid and molar surfaces facing the roof of the mouth (palate).
Lingual	Tooth surface that touches the tongue (front teeth).
Mesial	Tooth surface facing towards the midline of the face (line drawn from the nose to the chin).
Distal	Tooth surface facing away from the midline of the face.
Enamel	The hardest tissue in the human body that also covers the crowns of teeth.
Cementum	The root is made of this hard tissue which is much like bone.
Dentine	The softer material that is underneath the outer enamel layer.

Human Tooth Morphology

The ability of investigators and search teams to identify and recover dental evidence is directly based on their education of what the various human teeth look like. Tooth morphology is the science of identifying different types of teeth.

Front Teeth

Human incisors have thin, knife-like crowns that are used for cutting and tearing food. There are two kinds in each jaw (the dental arch). The first incisor is called the *central incisor* and is located directly below the nose or above the chin (midline). The second incisor is the *lateral incisor,* and its position is adjacent to the central incisor. The upper incisors and canines overlap (*overbite*) the lower teeth when the mouth is closed.

Maxillary Central Incisor

This is the most noticeable tooth in the mouth (Figure 6). It has a straight biting edge. Both sides are curved, with the distal being more rounded. *Mammelons* are seen on the biting edges of newly erupted and unworn

FIGURE 6 Adult maxillary right central incisor.

incisors of juveniles and young adults. These are bumps that wear down by the adult years. Mesial and distal aspects present a distinctive triangular outline. This is true for all of the incisors. An important shape variation of the upper incisors is the shovel-shaped incisor. It presents as a large, scooped-out indentation on the lingual (tongue side) surface. This feature is seen in populations of Mongolian racial origins.

Maxillary Lateral Incisor

The maxillary (upper) lateral incisor (Figure 7) resembles the central incisor but is narrower in width. The side surfaces have similar shapes as its two adjacent teeth, the central incisor and canine. The tooth is narrow and can be peg-shaped (smaller and narrow). It is sometimes absent in 1–2% of the population. The back (lingual) surface can have deep pits that often require fillings.

Canines

Canines (eyeteeth or cuspids) are the longest-rooted teeth. This single-rooted tooth is present in each quadrant. The appearance of canines is a genetic trait seen in all carnivores. In color, this tooth appears darker (yellow or brown) than the adjacent teeth. This tooth functions with the incisors to tear and shred food. This may be the final tooth to be lost during life because it has a thick root that is well embedded in the bone. The mandibular canine is noticeably narrower in width than the upper and usually shorter (Figures 8 and 9).

Mandibular Central Incisor

The mandibular (lower) central incisor (Figure 10) is the smallest tooth in the mouth. It is a long, narrow, symmetrical tooth. The biting edge is straight.

FIGURE 7 Adult maxillary right lateral incisor.

FIGURE 8 Adult maxillary right canine.

FIGURE 9 Adult mandibular right canine.

FIGURE 10 Adult mandibular right central incisor.

Mandibular Lateral Incisor

This tooth resembles the central incisor, but it is a bit larger in most dimensions. The biting edge's shape assists in this tooth's identification. The edge is "bent" front to back, reflecting the curvature of the jaw (Figure 11).

Back Teeth

Upper and Lower Bicuspids (Premolars)

Bicuspids (two cusps) are located between the canine and molar teeth. There are two per quadrant and are identified as the first and second bicuspids. The upper have two well-defined cusps: buccal and lingual

FIGURE 11 Adult mandibular right lateral incisor.

FIGURE 12 Adult maxillary right first premolar.

FIGURE 13 Adult maxillary right second premolar.

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FIGURE 14 Adult mandibular right first premolar.

FIGURE 15 Adult mandibular right second premolar.

(Figures 12 and 13). The lower has one prominent cusp and another much smaller (Figures 14 and 15). The larger cusp is the buccal (toward the cheek).

Molar Teeth

Adult molars are located in the back of the jaw. They have the most chewing surface of any tooth and have three to five chewing cusps. Lower-jaw molars have two large roots, and the upper-jaw molars have three roots.

Maxillary Adult Molar

The biting surface outline is square (not as much as the mandibular molars) with four distinct cusps. Some maxillary molars have an extra cusp (Carrabelli cusp) located on the mesiolingual cusp (tongue side of the tooth). There are three roots: two buccal and one lingual, which is the longest of the three (Figures 16 and 17).

Maxillary Third Adult Molar

These are the most often congenitally missing adult teeth. Third molars' shape is also the most variable of all human teeth and is the smallest of the maxillary molars. There are three roots: two buccal and one lingual, which are generally fused together into an ice cream cone shape.

Mandibular First Adult Molar

The lower first adult molar (Figure 18) is the widest of all molar teeth and has two roots. This tooth possesses a five-sided (and five-cusp) occlusal shape that is a classic feature.

Mandibular Second Molar

These have two roots that are shorter than the first molar (Figure 19).

Mandibular Third Molar

The two roots are short, curved, and can be larger or smaller than the other molar teeth. The shapes of this tooth are variable, with the tooth frequently not properly erupting into the oral cavity (impaction).

Tooth Numbering Systems

Any investigator should have a basic understanding of how dentists number and describe features of specific teeth. The United States uses a number system called *Universal* that labels adult teeth from 1 to 32. The baby teeth

FIGURE 16 Adult maxillary right first molar.

FIGURE 17 Adult maxillary right second molar.

FIGURE 18 Adult mandibular right first molar.

FIGURE 19 Adult mandibular right second molar.

are labeled A through T. The first adult tooth numbered is always the upper right back tooth and is #1 and follows to the upper left back tooth called #16. The lower adult teeth start at #17 on the back lower left and continue to the right until #32 located at the back right of the dental arch. The baby teeth are arranged in the same manner, although an alphabetic system is used: A through J for the upper baby teeth and K through T for the lower baby teeth.

The FDI (*Fédération Dentaire Internationale*) system predominates in Europe, Canada, and British Commonwealth countries. The FDI uses a two-number system where the first number is the quadrant (1 through 4) and the second number starts at 1 for the central incisor and continues toward the back teeth. Baby teeth have the numbers 5 through 8 to indicate the four possible quadrants (Figure 20). See Figure 20 for a comparison of these two systems. The upper jaw is called the *maxilla* and is solidly attached to the base of the skull. The lower jaw is the *mandible* and provides the movement when chewing and talking.

FIGURE 20 The Universal System (in blue) contrasted with the FDI System (in white) for the 12 adult front teeth.

The Dental Investigator's Role in Forensic Case Work

Forensic dentists address diverse medico-legal issues that can aid agencies and individuals who have questions relating to dentistry. The author has been contacted by local police agencies, the state attorney general, medical examiners, criminal defense attorneys, private parties, state courts, the Department of Justice, and the National Institute of Justice for dental opinions. The contact usually begins with a phone call.

The identification of missing and unknown persons is a central activity that predominates in a forensic dentistry practice. It is highly advantageous for the dentist to attend the autopsy. Some cases, however, have the initial contact much later in an investigation. A dental identification of an unknown person can involve participation in autopsy examinations at the request of law enforcement, coroners, or medical examiners at local or state level. This postmortem-dental examination of human remains involves charting dental and cranial features, radiographic documentation of these features, and forensic report writing regarding these findings. A second step is the application of these findings to investigations by law enforcement to identify a missing or an unknown person. The physical comparison of autopsy results and antemortem dental radiographs and records completes the process wherein the dentist renders an opinion of either a positive identification, a possible identification, no identification, or inconclusive results.

Collecting and Preserving Useful Evidence

Law enforcement plays a pivotal role because of police officers' early presence at a crime scene, accident, or involvement in death investigation. This book's intention is to give the officer or technician arriving at a scene or an autopsy sufficient information to identify and collect dental evidence that comes across their paths.

Case Types that Can Possess Dental Evidence

1. Homicide
    - Sexual assault with bitemarks.
    - Unknown victim of a crime found in a skeletonized or decomposed condition.
    - A deceased attacker may have bitemark injuries that can be used to corroborate the victim's statement.
    - A deceased child may have bitemark injuries that indicate current or past physical abuse. The identity of the biter may be supported by a dentist and by obtaining swabbings of the injuries for DNA analysis of deposited saliva.

2. Child abuse
3. Spousal abuse
4. Elder abuse
5. Mass disaster
6. Age determination of a juvenile offender

Who Qualifies as a Dental Expert?

The courtroom use of an experienced forensic dentist is recommended for obvious reasons. In the United States and other countries, using a dentist with no forensic training and experience is generally acceptable, but it can raise the issues of the *value* or *legal weight* given to opinions given in the court. The expert must be someone who understands the significance of the relationship of law and dentistry and can explain the complexities and subtleties of dental evidence to the courts. Technical expertise in forensic odontology is not based on the current curriculum available in traditional dental education. In a practical sense, the U S. courts accept testimony from anyone who will aid the court in areas beyond the knowledge of laypeople. The court considers the combination of education, training, and experience and the relationship to the case currently at trial when permitting a nonforensically trained dentist to testify.

The forensic odontologist not only must be an experienced practitioner of clinical dentistry but someone who is also able to observe, record, gather, preserve, and interpret dental evidence. The next task requires concise and balanced communication to law enforcement, prosecution and defense counsel, the court, and the jury.

Courtroom Uses of Dental Evidence

The admission of expert testimony derived from dental evidence is a compelling factor in criminal cases where assault, abuse, homicide, and physical evidence reveal tooth marks in skin and objects or genomic DNA obtained from trace saliva samples, tooth pulp, and roots. The historical uses of tooth mark impressions (*bitemark analysis*) and *dental identification* have recently been augmented with *biomolecular* techniques (DNA) used in other areas of human biology. The early role of a relatively small number of dentists in court proceedings has progressed substantially over the past 25 years. This is due in part to the general acceptance of the forensic odontological community that questions of reliability of methods and opinions are satisfied by the years of experience, credentials, some empirical testing, and considerable anecdotal reporting. Cautions regarding bitemark opinions must be emphasized at this point. Chapters 5, 6, 7, and 8 present this information. There is little doubt in judicial case law that dentists play a role in determining questions of fact relevant to criminal and civil proceedings.

Child, Spousal and Elder Abuse

In the last three decades, the unfortunate prevalence of violence perpetrated against domestic partners, children, and the elderly has necessitated the involvement of the forensic dentist in its recognition and documentation. In most states, all custodial adults' medical and dental professionals are mandated reporters in the suspicion of child abuse. A patient may visit the general practice with dental injuries that are not consistent with the clinical findings. The parent or guardian may avoid discussion about the events surrounding the injury, or the injury may be one in a series of "accidents." Head trauma, neck trauma, and oral and facial injuries are common to child abuse situations. Severe or repeated incidents are suggestive of abuse. See Chapter 11 for more information regarding this topic.

Jurisprudence

Another area of activity is expert testimony in civil litigation involving dental issues such as personal injury law, workers' compensation, professional malpractice, and disputes regarding aspects of the dentist–patient relationship. Injuries to the oral structures may result from auto accidents, falls on private or commercial property, or an accident in the workplace. Litigation may follow. Both sides require the interpretation of an expert who is familiar with the legal and clinical terminology related to diagnosis, treatment planning, procedure, and sequelae (postoperative complications).

Employment

Experienced forensic odontologists generally have formal appointments or consulting relationships with coroners, medical examiners, state and local government agencies, and branches of the military. Reimbursement is on a fee-for-service or contractual basis.

Scientific Dental Investigations

The subject matter of forensic dental investigations can be as simple as being asked to compare two sets of dental radiographs for common features. Alternatively, a series of scientific studies may need to be conducted relating to specific questions pertaining to a case. In this instance, it is mandatory that the odontologist involved uses methods that have been reliably tested and that others can reproduce. This form of ad hoc experimentation is affected in that the experimenter already knows the facts of the case and is generally employed by only one of the involved parties. The basis of an expert dentist's opinion should not involve personal opinion, assumptions of untested hypotheses, and overstatements of the value of the original evidence.

The Most Famous Bitemark Case of the 20th Century

A particularly well-known bitemark case in the United States is the dental evidence brought against executed serial murderer Theodore (Ted) Bundy (Figure 21) in a Florida court. The case involved a double murder and aggravated assault that occurred in 1978. The dental evidence centered on a skin injury on the body of one of the murder victims. The prosecution dental experts considered these marks to have been made by human teeth. Defense experts considered the bitemark evidence to be nonspecific for Bundy's teeth (Figures 22–24). Other physical evidence

FIGURE 21 Ted Bundy is suspected of having abducted and murdered over 30 women over a 10-year period.

FIGURE 22 An intraoral photograph of Ted Bundy. The lower front teeth proved to be useful at trial to link him to a bitemark found on a murdered college student.

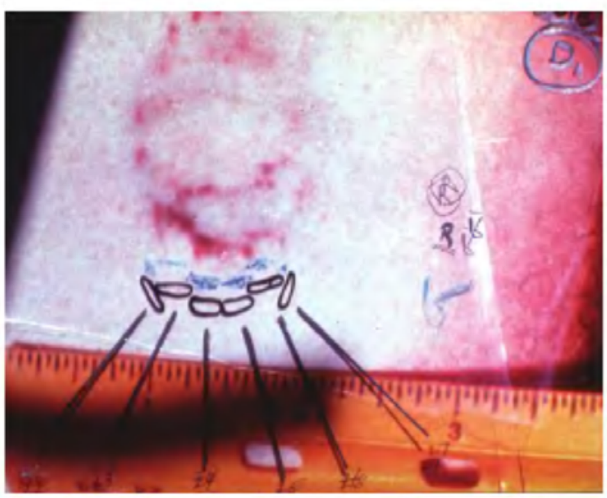

FIGURE 23 Courtroom exhibit showing the injury pattern is actually two bitemarks nearly superimposed in the same area. The wooden ruler was used to allow the picture to be enlarged to life size. Two hand-drawn outlines of Bundy's lower teeth are placed just below a corresponding portion of the bitemark.

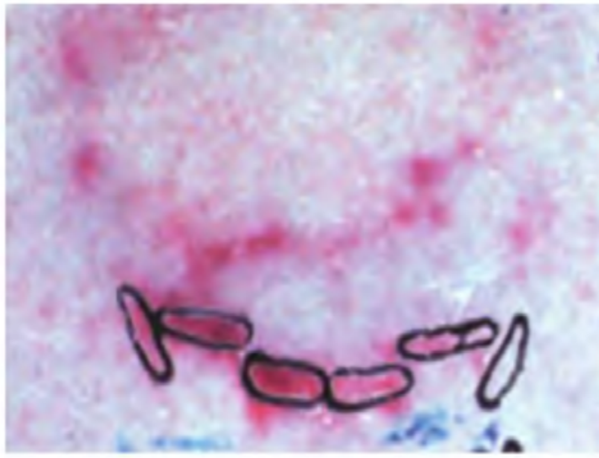

FIGURE 24 Close-up view of the bitemarks with the outline of the lower teeth digitally superimposed on the lowermost injury pattern. The arrangement of five of Bundy's lower six teeth coincides with the reddened bruises.

obtained from Bundy and later associated to the crime included hair samples from one victim's bedroom. The jury, in reviewing the evidence, convicted Bundy of murder. They attested that the bitemark evidence was very compelling. This case occurred before the advent of DNA analysis from saliva taken from bitemark injuries.

Woman's Identity Confirmed by a Missing Tooth

A skeletonized female body was found in a ravine behind a biker bar in California. The remains had few personal effects, but police had a missing person's report that provided a lead. Figures 25–27 show the dental evidence available in this case.

FIGURE 25 The missing person's report included a photograph of the young woman. The investigator thought the woman's front teeth "looked odd." There were no formal dental records available for this woman, as she rarely had dental care.

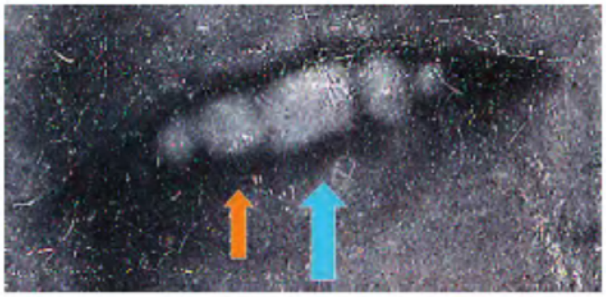

FIGURE 26 The forensic dentist confirmed that the woman was missing an upper central incisor (front tooth #8) sometime in the past, as there was no residual space or gap. The adjacent teeth had moved together to give a relatively normal appearance. The orange arrow points to tooth #7, and the blue arrow points to tooth #9.

FIGURE 27 Digital enhancement of original autopsy image. The skeletonized head shows two front teeth missing after death (open sockets of #9 and #10) but no socket for the long-time missing front tooth (#8). The dental evidence confirmed the dental profile of the missing woman. It is unlikely that the body is someone else due to all the circumstances and supporting evidence comparisons.

The Next Level in Victim Identification: Materials Properties as an Aid in Victim Identification

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Introduction

This chapter is intended to promote awareness of advanced techniques used to detect, document, and identify the nonbiological forms of dental evidence that may be associated within the jaws, such as dental materials and dental prostheses (appliances). Dental prostheses can include crowns, posts, dentures, partial dentures, bridges, and implants. Techniques will be explored that can be used to facilitate victim identification, especially in extreme circumstances.

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As previously described for victim identification by dental means, the principal comparison tool has been x-ray imaging, in which analysis of ante- and postmortem sets of radiographs are compared. The two sets are inspected for concordant features. These features can consist of biological form as represented by trabecular patterns, root morphology, tooth position, and missing teeth. The presence or absence of other bony structures will be noted as well. Another component of the x-ray comparison technique includes assessment of the nonbiological materials present in the dentition. These materials may play a large role in making a positive identification. The shape, location, and position of restorations such as fillings, posts, and crowns can add significantly to the ability of the forensic dentist to make identifying statements based on radiographic interpretation.

Whether whole-body, head, panorex, or bitewing, the radiograph will show features that depend on the transmission or absorption of x-rays. The typical dental radiography system is designed for an exposure with film or digital detector that reveals a contrast in the resulting image of bone and teeth from other materials present. When describing x-ray images, either on film or digital, features are depicted as radiopaque (brighter than surrounding tooth or bone) or radioloucent (darker than surrounding bone or tooth).

The field of dental radiography has developed to reveal subtle differences in densities of tooth structure that may indicate the presence of decay (radiolucent), other pathological conditions, or the nonbiological dental materials (radiolucent or radiopaque). Thus, a radiograph is a black-and-white image that has contrast based on the elemental composition of the materials present in the image. Substances that are composed of high–atomic number elements absorb x-rays and appear bright in a radiograph (such as tin and mercury in amalgam). The quantity of these elements in the material will determine the level of contrast seen. Dental products are made up of varying compositions of these elements. The contrast in a radiograph, then, should give the investigator a clue about possible presence of different materials.

When nonbiological materials are in the field of view of the radiograph, there may be a wide range of contrast in the image that may contain important information about the nature of the restorations. As just stated, dental amalgam will appear consistently white, but dental resin (tooth-colored filling material) will have varying degrees of radiopacity. This is due to the variation in elemental makeup of these substances.

Dental resin is typically more radiopaque than dentin, but it can be very similar to enamel. Fillings that are entirely within enamel or that extend into dentin a slight amount may not be seen on radiograph. It should be noted that some manufacturers do not add high–atomic number elements to their products at all. In this situation the dental restoration may appear radiolucent as compared to the tooth structure. This might be misinterpreted as dental decay rather than a restoration. Thus, there is potential to miss these restorations on radiographic inspection. With the range of dental materials available today, radiography may not infallibly reveal all nonbiological materials. Furthermore, there may be circumstances when traditional x-ray comparison is not possible, such as in situations of fragmentation. Once the structural relationship of the teeth in the jaws is lost, this method of assessment may not be feasible. In these cases, advanced methods, together with comparison of dental materials to the written dental chart, may yield more useful information.

The complexity and variety of dental materials have increased dramatically in recent years, with many new classes of materials introduced to the market. At the time of this writing, for example, on the U.S. market there are over 60 brands of tooth-colored fillings alone [1]. Add to that the different brands of cements, root canal sealers, ceramic crowns, posts, and orthodontic materials, it may be recognized that there is a potential for further confirmation of identity should it be known which brands of materials exist in the dentition postmortem. This information could then be compared to the notation in the victim's dental chart.

Fortunately for the forensic investigator, many dental materials manufacturers use different formulations for their products, and it is possible to identify most of these products by brand based on their physical and chemical characteristics [2–5]. Therefore, it is a logical extension from simply noting the presence of a restoration on both ante- and postmortem radiographs to asking the question "What is the composition and therefore the brand of that restoration?" The answer to this question could potentially add another level of certainty to the identification process, should that level of certainty be required, or in situations when few clues remain to allow the investigator to confirm identity, such as cases of fragmentation, disarticulation, or incineration in which the structural relationships of the dentition may be lost.

The National Academy of Sciences (NAS) produced a report in 2009 that included a critical review of forensic science—in particular, pattern or impression evidence. Dental identification involves a pattern recognition process through inspection of radiographs. Although dental identification was not seen as a controversial area, the authors of the report appeared more comfortable with forensic evidence when proven scientific laboratory methods are used rather than an expert witness' pattern recognition skill. Thus, exploration of scientific methods as outlined in this chapter would appear important in lending scientific weight to the identification process.

Modern Challenges, Radiography, and Fluorescence

In order to use dental materials as an aid in victim identification, it is first necessary to be able to detect their presence upon visual examination. Modern dentistry has created some challenges in this regard because it

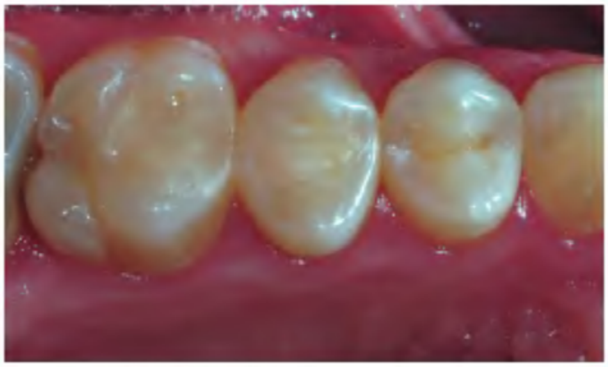

FIGURE 1 It is difficult to tell where the dental resin is in this photograph. *Photo courtesy of Dr. Camila Sabatini, Restorative Dentistry Department, State University of New York at Buffalo School of Dental Medicine.*

is becoming increasingly more difficult to visualize tooth-colored filling materials. Well-placed, well-color-matched restorations can be virtually indistinguishable from tooth structure. As such, they can be easily missed upon postmortem charting (Figure 1).

Furthermore, the current trend in dentistry is to use the smallest fillings possible, in what is described as *minimally invasive dentistry*. In this procedure very small fillings are placed that typically do not penetrate the enamel layer of the tooth. The rationale for this procedure is to eradicate decay at a very early stage. This combined with the excellence of modern tooth-colored fillings in mimicking tooth structure makes detection of these fillings very difficult when using the combined traditional techniques of radiology and visual inspection. In many circumstances it may be impossible to tell with any certainty if a filling is present or not. Erroneous omission or inclusion can impede victim identification, since the antemortem and postmortem charting will not coincide.

The question then becomes "How can you be sure such restorations are properly documented?" Fortunately, many manufacturers add a fluorescing agent to their products. Tooth structure naturally fluoresces under near-UV illumination, with dentin fluorescing with a higher intensity (brighter) than enamel. As natural daylight includes UV light, some dental materials manufacturers have recognized this important feature and incorporated fluorescing compounds in their formulations in order to mimic natural tooth properties. This will impart a lifelike quality to the filling by increasing its vitality. It is important to note that while many resins fluoresce, some do not. The result is that different brands have different brightness under UV illumination. Investigators can use this fluorescent property to their advantage to help locate the material.

When illuminated with a light of a specific wavelength, an object can fluoresce (emit) light at longer wavelengths. This phenomenon has been extensively utilized in forensics and is called alternative light illumination (ALI). Recent developments of LED technology have resulted in the availability of high-intensity flashlights emitting in narrow wavelength bands in the near-UV range (365–400 nm). These flashlights are both affordable and compact, and are ideal for intraoral inspection (Figure 2).

FIGURE 2 Assortment of UV LED lights that can be used for dental material inspection.

The effect of exposure to UV light is comparable to radiography in that the contrast is visible during dental inspection, but fluorescence can easily reveal very small restorations or those that are otherwise difficult to detect. UV inspection can be an essential adjunctive aid to traditional radiography (Figures 3 and 4). UV LED illumination could be considered one of the most useful practical advances in forensic odontology in the past decade [6]. Small LED flashlights are available that emit in various wavelengths. Wavelength selection is important, as there are surprising shifts in contrast with only a small change in illuminating wavelength (e.g., 365–395 nm). A wavelength of 395 nm is ideal for resin inspection, whereas 365 nm is better for porcelain fluorescence.

Figure 5 shows an example of where it is difficult to tell where all of the resins may be. The resin material may be obvious on teeth #18 and 20, but what about tooth #21? The x-ray of this specimen shows a porcelain fused to a metal crown on tooth #19 and an occlusal filling in #20 (Figure 6). In

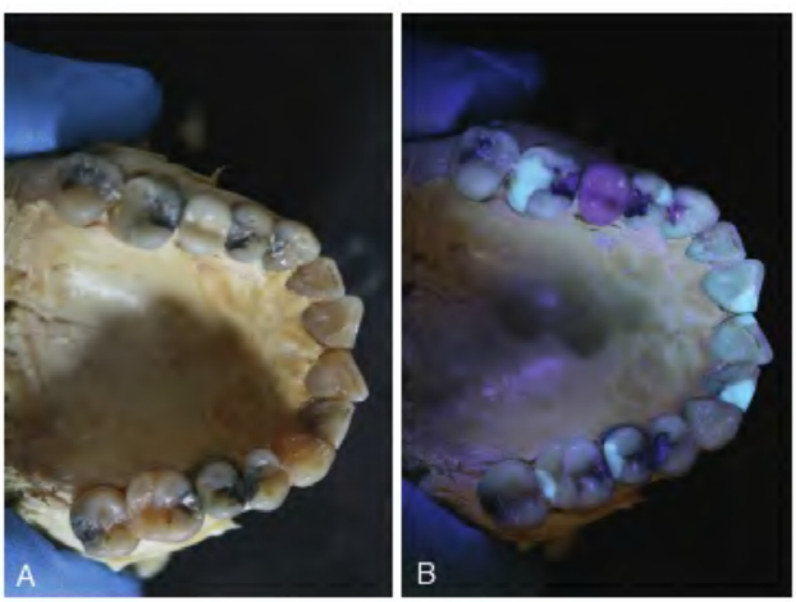

FIGURE 3 (A) In this specimen, it may be difficult to determine where all of the resin fillings may be. (B) With the aid of UV LED light, documentation of the restorations becomes much easier. The resins can be seen as bright portions on the tooth surfaces.

FIGURE 4 (a) As with Figure 3, it is difficult to identify all of the restorative material. (b) The UV LED light reveals composite facial restorations on all of the teeth.

FIGURE 5 In this specimen, the teeth are labeled 18–21. A composite restoration can be seen on #18, a crown on #19, and a composite restoration on #20, but is there a restoration on #21?

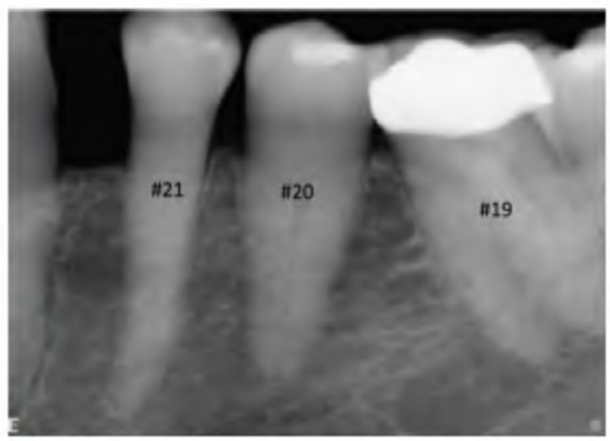

FIGURE 6 Radiographic interpretation is not clearly evident. A slight radiodensity discrepancy can be seen in the distal pit.

#21, there is a slight radiodensity contrast in the distal pit but none in the mesial pit. Inspection with a UV LED flashlight makes visual inspection of the restorations in both the mesial and distal pits obvious (Figure 7). Notice the difference in contrast of the fluorescence of the restoration in teeth #20 and #21 from #18. Once it is certain that a restoration is present, analysis of the material can then be accomplished using laboratory-based equipment such as scanning electron microscopy with energy dispersive spectroscopy (SEM/EDS) or with portable instrumentation such as x-ray fluorescence (XRF).

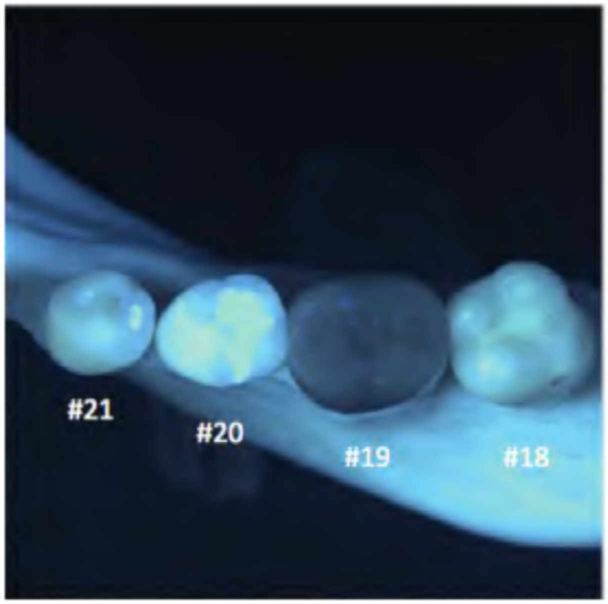

FIGURE 7 UV LED light clearly shows a restoration in both mesial and distal pits.

SEM and SLICE

The SEM produces an image with high spatial resolution, with a magnification range of around 20× to over 100,000×. Different imaging modes in SEM can give information about surface microstructure or chemical phase distribution in a sample. Dental resins, for example, contain glass filler particles with a wide range of microscopic structures that can be readily imaged using SEM. The microstructure of dental materials can be unique to brand. EDS analysis produces an x-ray spectrum that provides an elemental fingerprint for the material in question. An EDS spectrum will contain peaks corresponding to the presence and the amounts of elements in a sample. The technique is reproducible from one instrument to another, allowing data to be compared from laboratories around the world. Quantitative results can be obtained from EDS spectra, allowing percent concentration determination of elements in a sample. The quantitative result obtained can again be unique to brand. Automated databases based on EDS spectra can be used to compare unknown materials to reference collections of spectra. The technique is unequivocal and has been used extensively in forensic identification of unknown materials. Although expensive and laboratory based, SEM/EDS equipment is available in every major educational institution and in a number of crime labs.

One EDS database is the Spectral Library and Classification Explorer (SLICE) database, developed for the FBI [4]. The SLICE dental materials database has been generated at the University of Buffalo and was useful in the identification of several victims of Continental flight #3407 that crashed in Clarence, New York, on February 12, 2009. In this case, microscopic amounts of root canal sealer and dental resins were analyzed and compared to the SLICE database, allowing confirmation of victim identity after reference to the dental charts.

XRF

XRF is similarly a well-established elemental analysis technique. Instruments have been developed that are either laboratory based or portable for field use. As with EDS analysis, the information produced is an elemental analysis of a material, based on an x-ray spectrum. An advantage of XRF over EDS is the ability to measure trace levels of elements in a sample. Portable units typically are operated by small, onboard computers that may have Bluetooth capabilities for transmission of data (Figure 8).

Custom libraries of elemental compositions can be generated for rapid identification of materials, or a spectrum can be inspected and the comparison process completed manually (Figure 9). The information can also be added to dental comparison identification programs such as WinID.

The obvious advantage to the portable unit is direct application in the field for nondestructive analysis. This allows for rapid screening of unknown material. In a matter of seconds, bone, tooth, or restorative material can be sorted from insignificant debris [3]. Also, personal effects can be analyzed, such as jewelry, since the unit can distinguish between metals found (e.g., silver vs. platinum, diamond vs. cubic zirconium). However, this procedure does have a disadvantage, as the portable technique cannot detect elements lighter than phosphorus (P) on the periodic table. These lighter elements require analysis under vacuum as is performed in SEM/EDS.

FIGURE 8 (a) In situ use of a portable XRF unit. (b) Portable computer as part of the unit.

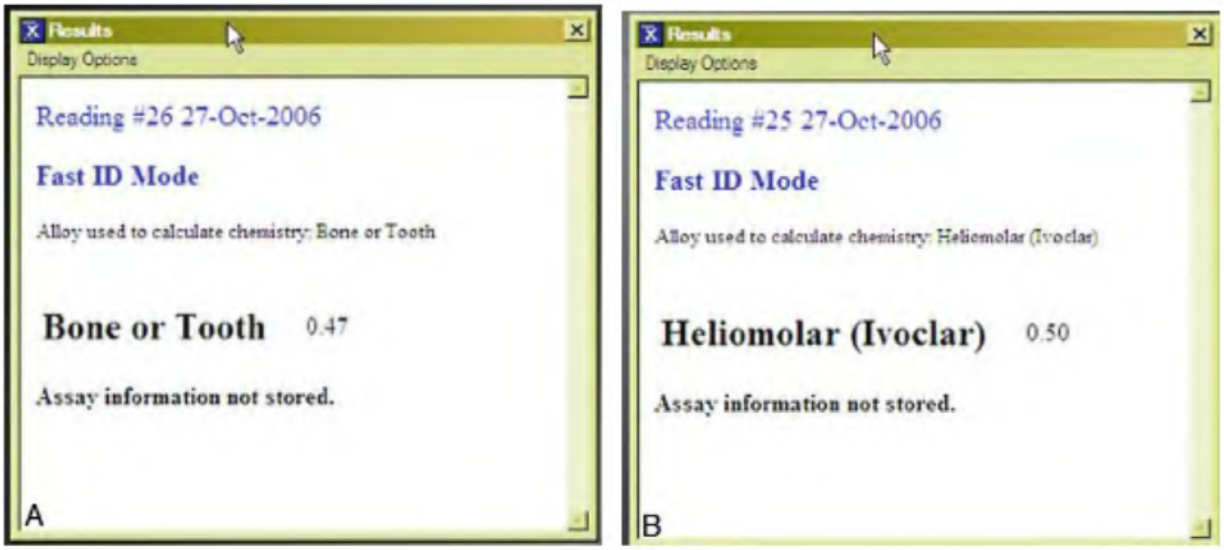

FIGURE 9 (a) The portable XRF unit can determine bone or tooth for other debris. Here the analysis is displayed on the portable computer. (b) The portable computer can also determine resin material. Here it has distinguished Heliomolar brand resin.

Since elements lighter than P will not be detected by portable XRF, this means that silica (Si02), the main component of dental resin fillers, will not appear in the XRF spectrum. Since all dental resin fillers contain silica, brand determination by XRF is based on the presence of additional heavy elements in the fillers. The combination of these instrumental analysis techniques and construction of dental materials databases means that we now have ways to provide scientific confirmation of the nonbiological materials present in the dentition.

Incinerated Remains

Identification of remains that have been exposed to high temperatures can be a difficult task. The amount of damage is related directly to the temperature of the fire and the duration of exposure. Most house fires do not do significantly damage teeth, since many fires do not burn hot enough or long enough [7]. It is not uncommon for most of the damage to occur to the anterior, or front teeth, charring them, while the posterior, or back teeth, are left in pristine condition. Muscles will contract, giving the victim the typical pugilistic or boxer pose. The same muscle contracture will affect the lips, and they will pull back from the teeth, exposing the front (anterior) ones, while the back (posterior) teeth are protected by the skin and musculature of the cheeks [8]. In many instance, the posterior teeth will be in good shape for traditional dental x-ray comparison, while the anterior will be significantly charred or destroyed.

Teeth and bones will go through a progressive color change depending on the temperature and the length of exposure. This color change can be used as an estimate of what temperature the victim was exposed to [7, 9]. Figure 10 shows these changes. At 200°C, the teeth take on a dark yellow coloration, not very different from the creamy yellow hue seen in unburned specimens.

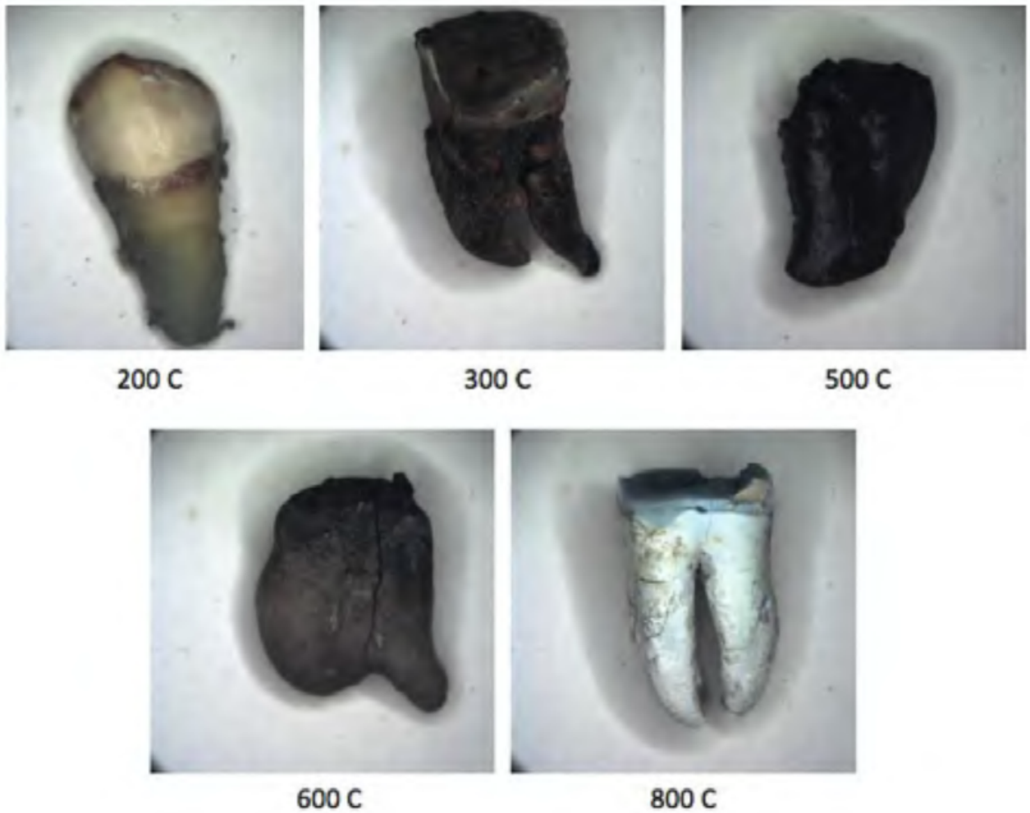

FIGURE 10 Progressive color changes as teeth are heated.

As temperatures increase, a process known as carbonization occurs. When teeth and bone carbonize, all of the organic material except for carbon will be destroyed. This occurs at temperatures between 400° and 600°C. Since carbon is black in color, the tooth will start to darken, progressing to a dark gray and then finally to black. Eventually, with continued exposure to the heat, the carbon will start to burn off and the tooth will begin to lighten in color, fading from black back to gray and finally to white. Once it has turned white, the tooth or bone is described as calcined.

Calcined materials are devoid of any organic material. This typically happens around 800°C. Calcination results after cremation. It should be noted that commercial cremation is performed at temperatures of around 1,000°C for two to two and a half hours and is a two-step process. The high temperature alone does not reduce the body to ashes [3]. When the bones are removed from the cremation oven, much of the macroscopic structure is retained, although the bones are brittle and extremely fragile. In fact, a well-trained anthropologist could probably still determine sex, age, and maybe race [7]. In commercial cremation, once the body has been subjected to the fire for the appropriate amount of time, the bones are removed from the oven and ground through a processor, not unlike a large coffee grinder. This second stage is the means that produces the ashes that many envision when describing cremation.

When victims have been exposed to conditions in which the fire is extreme, producing cremation-like conditions, the victim identification process will become increasingly difficult. Calcined bones and teeth are extremely fragile and break easily, so in these circumstances, enamel will fracture from the underlying dentin surface and dental restorations can be dislodged [2, 3]. Many times these remains will be in a fragmented state, and the utmost care should be taken when handling and collecting remains from incinerated victims (Figure 11). Thorough scene recovery should be performed utilizing techniques such as sieving and sifting with grid demarcation of the area. In these circumstances traditional x-ray comparison may be impossible or give little information because the structural relationship of the jaws is lost. Nevertheless, the remains should still be radiographed, since information may be seen that is invisible to the naked eye.

Dental restorations will maintain their radiopacity, and if a large enough amount remains in the tooth, this will be seen as a bright spot [3]. Figure 12 shows a radiograph of an upper jaw after incineration. Notice the amount of shrinkage of the teeth and bone structure. Also note the fracture of tooth structure. In this image, it can be seen that the majority of the restorative material has been lost, but some remains. The area illustrated by the red arrow

FIGURE 11 Example of calcined remains.

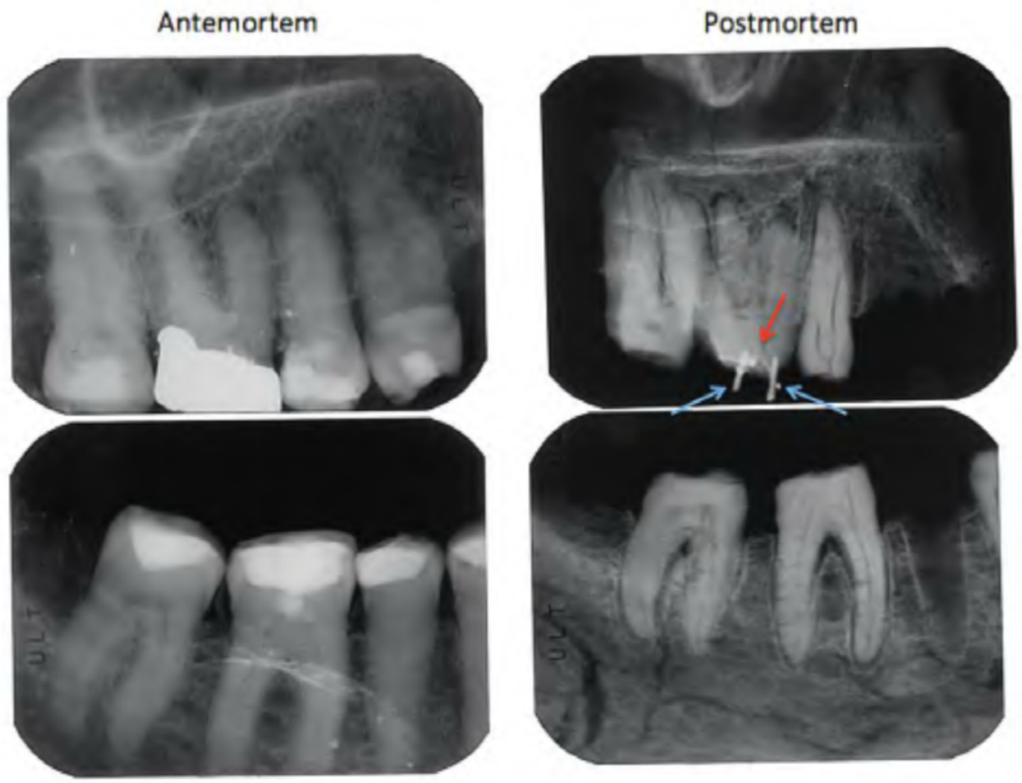

FIGURE 12 Antemortem and postmortem comparison of a cremated individual. Notice shrinkage, loss of tooth structure, and restorative materials. The red arrow points to suspected remaining filling material, while the blue ones show dental pins.

depicts dental restorative material. The blue arrows show metal dental pins. These would be readily seen in the specimen (Figure 13 shows incinerated dental pins). Other techniques for finding microscopic amounts of material are discussed later in this chapter.

It should be noted that calcined bone and teeth can also shrink by a large amount, about 20–25%, thus complicating the identification process [7]. Figure 14 shows the amount of shrinkage that can occur. Notice the difference in size between the two specimens. Prior to burning, the calcined maxilla was roughly the same size as the unburned one.

Victim identification in incineration circumstances can often be aided by analysis of the nonbiological material that may be present within the victim, such as pacemakers, joint replacements, and so forth. The dentition is a rich source of nonbiologic material; dental prosthesis such as crowns and partial denture frameworks are well documented to survive high temperature conditions [10–15]. The metal and porcelain that make up the prosthesis have melting points well above cremation temperature conditions, some as high as 1,800 to 2,000°C [16, 17]. Figure 15 shows a metal/porcelain crown and a partial denture framework recovered from a cremated individual.

FIGURE 13 An example of incinerated dental pins. The arrows point to the pins.

FIGURE 14 Comparison of a noncremated maxilla (left) with a cremated specimen (right). Prior to cremation, both were roughly the same size.

As with the teeth themselves, many dental materials have at least some components that are resilient and that survive even cremation conditions. Not only can a prosthesis be recovered, but dental filling material such as amalgam (silver filling) and resin (tooth colored filling) can also survive. Amalgam brands are not as distinguishable as resin as of the time of this writing, and amalgam fillings cannot be named according to brand if discovered. Composite resin, however, can. This information can be compared against the victims' written dental chart and used as an adjunctive means in victim identification.

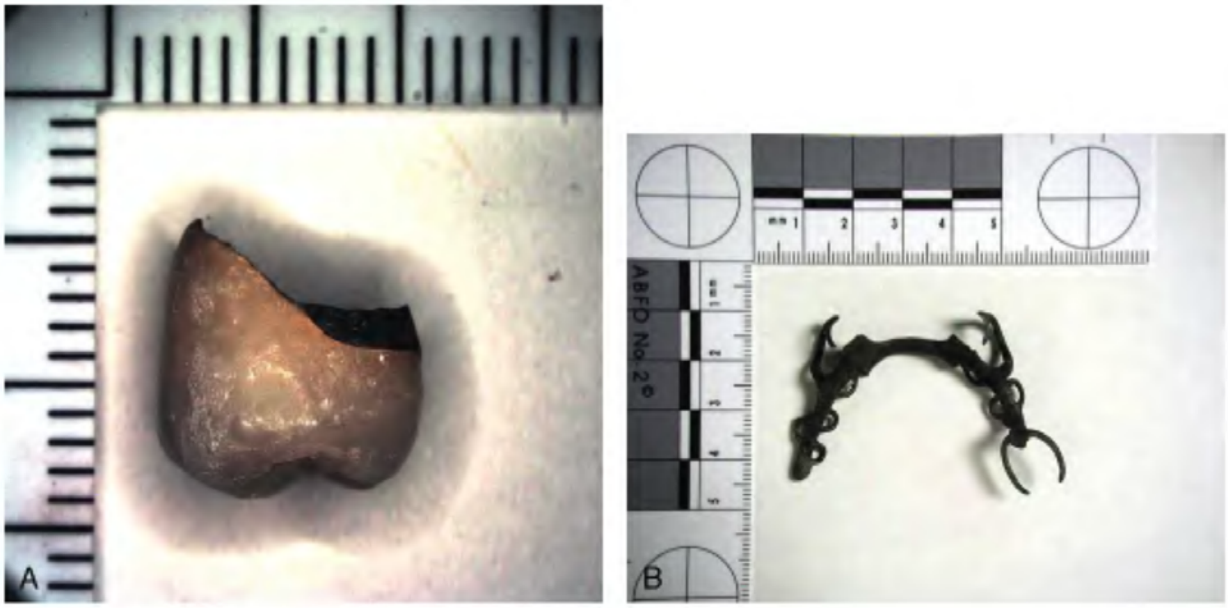

FIGURE 15 (a) An example of a cremated porcelain fused to metal crown. Notice there is very little damage to the crown. (b) An example of a cremated partial denture. All of the acrylic has melted, but the framework is unaltered.

Dental resin consists of an organic resin matrix (methacrylates) surrounding inorganic filler particles. All resins contain silica along with a combination of heavy elements, which constitute the filler portion [17]. Many of the resins contain filler particles of unique elemental composition and size for reason such as radiopacity, handling, and polishing characteristics. These formulas are varied enough to allow identification of resin material by brand.

In incineration circumstances, organic materials, such as the methacrylate component of tooth colored fillings, are consumed by low temperatures, typically by 300°C [18]. Since the inorganic filler particles can withstand cremation conditions, this material can still be identified by brand in this extreme circumstance.

Collection and Analysis

When tooth fragments are found, careful inspection is important. Filling material can often be seen adhering in microscopic amounts to the inside of the tooth or in the prepared surface (Figure 16). It can also be found in dislodged pieces along with the fragmented remains. The material can melt as well and drip onto other surfaces. Figure 17 shows a section of cremated mandible. The black globular material on the outer surface is dental resin.

In any of the preceding conditions, the material can be analyzed and compared to a known sample of the material or to the SLICE database of dental material. The material on the mandible and some that was clinging to a cremated tooth were compared to the dental material database (Figure 18). The unknown material is represented by spectrum 1. The database's first choice is TPH3 (Dentsply, York, PA), and the material documented in the chart was indeed TPH3 (Figure 19).

FIGURE 16 Tooth recovered from a cremated individual with suspected resin adhering to it (arrows).

FIGURE 17 A cremated mandibular fragment. Notice the darks blobs on the side of the fragment. Analysis revealed this to be dental resin

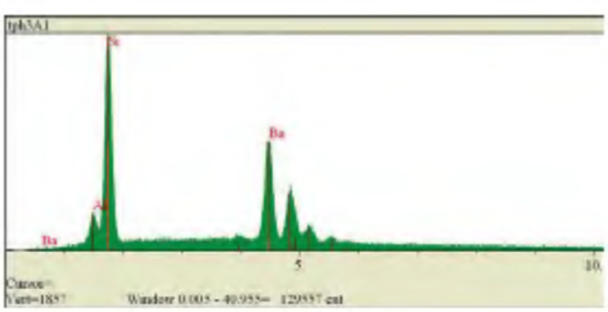

FIGURE 18 Analysis of the material in Figures 16 and 17 reveals TPH 3 resin material.

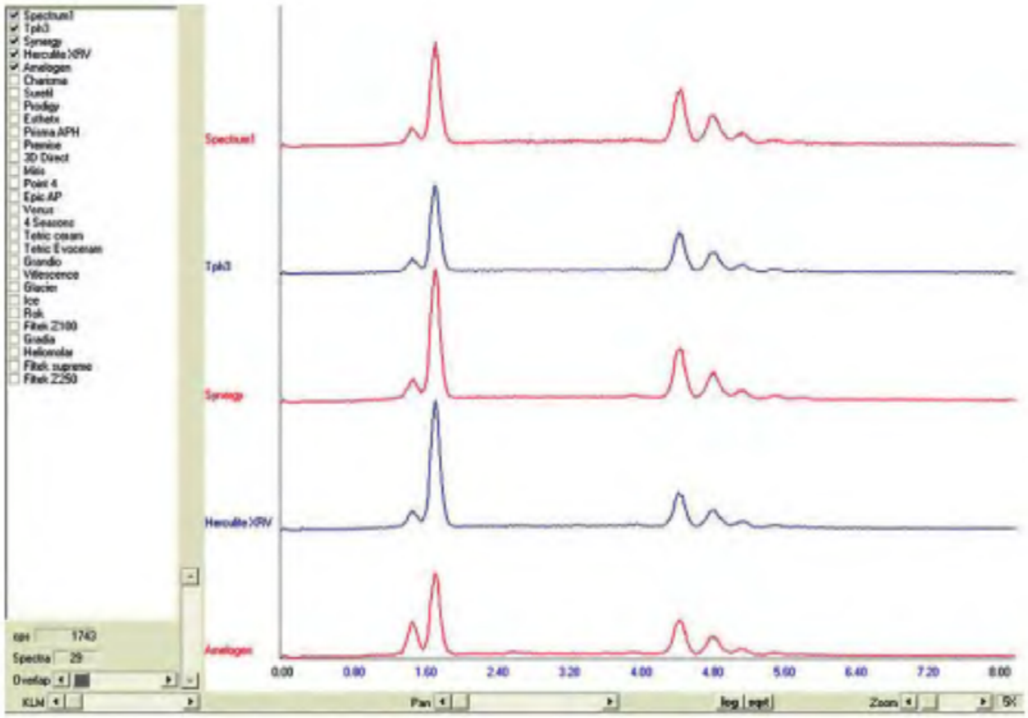

FIGURE 19 Confirmation of TPH 3 with the SLICE database. Specimen 1 is the unknown material. TPH3 was the top choice.

The importance of thorough inspection of all debris cannot be emphasized enough. Figure 20 shows a fragment of tooth recovered from a cremated individual. Note the white color signifying calcination. Small white dots can be seen inside the area within the red circle. The area was examined inside the SEM at 100×. The image now shows something that resembles globular material on the tooth surface. Analysis of the material with EDS revealed it to be Tetric Ceram (Ivoclar, Amherst, NY) (Figure 21).

Resin filling material can be seen in large, discrete particles on the tooth or bone structure or in microscopic amounts inside a prepared tooth surface. Many times the material will dislodge and can be found in large, dissociated pieces, further emphasizing the need for thorough scene search and recovery. Dissociated pieces will not carry as much weight for identification as those still adhering to the victim, but the information can still be used in closed population circumstances.

If specification of the brand of restorative material present in the dentition is to be used in the identification process, then there is clearly another part of the puzzle that becomes very important, and that is specification of the brand in the written chart by the operating dentist. Some dental schools teach their students that recording material brand is important, as knowledge of materials' performance is part of a growing trend known as evidence-based dentistry. This also makes sense in the current market situation in which a large variety of product choices exist. There will be dentists, however, who do not record brands in the chart. Even

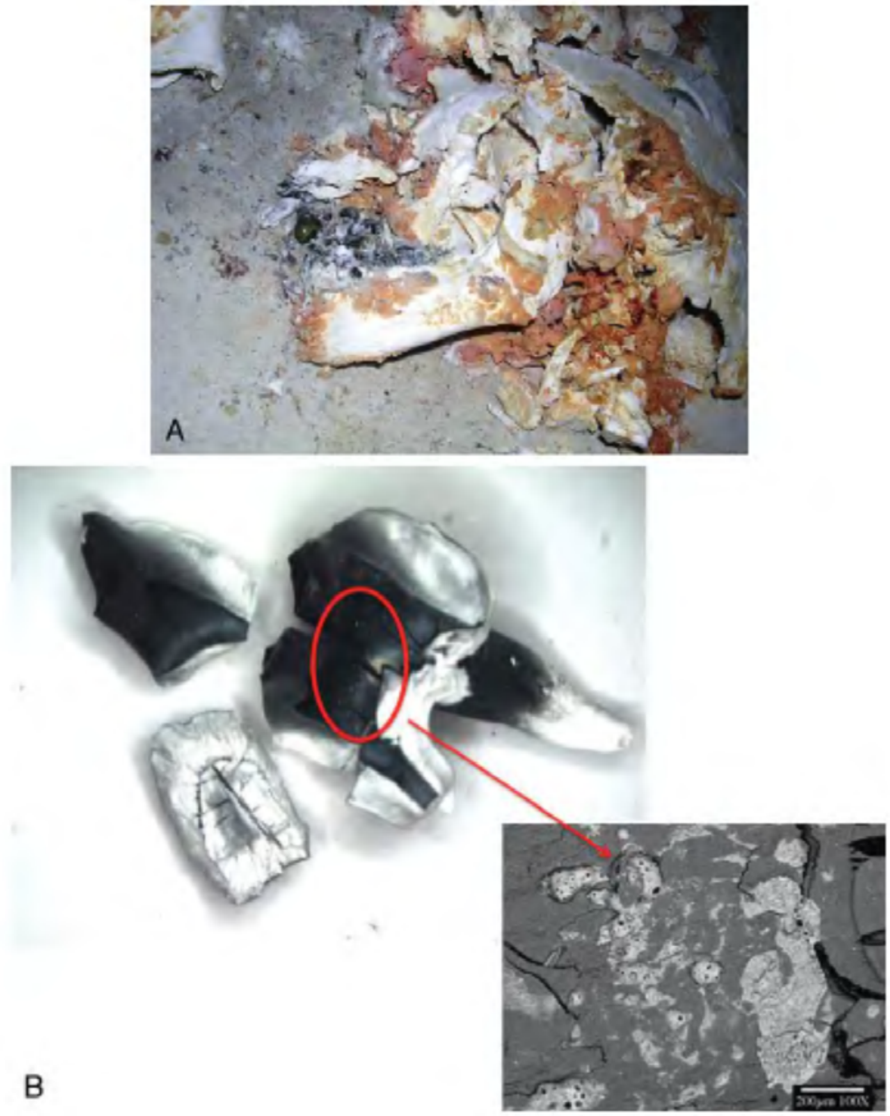

FIGURE 20 (a) Example of a cremated human head. Notice dental debris in the field. (b) Inspection of one of the teeth shows unknown material on the inside of the tooth surface (circle). SEM analysis of the material shows a globular structure (arrow).

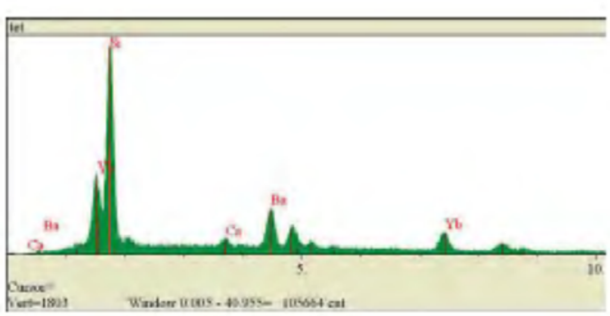

FIGURE 21 EDS spectrum of the material consistent with Tetric Ceram.

under those circumstances, knowledge of brands can provide information if office records indicate regular purchases of specific brands of materials.

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Forensic Dentistry Investigation Protocols

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It is a clear evening in a small housing tract in the outskirts of the city limits. The neighbors are awakened by the sound of a pickup truck crashing into a nearby home and a man yelling obscenities at the house's occupants. Shortly afterward, the truck leaves the scene and races away at a high rate speed down a tree-lined road. For no apparent reason, other than the wish to commit suicide, the driver strikes a large palm tree head on at full speed. The impact sends the unbelted driver through the windshield and onto the truck hood, killing him instantly. Following the impact, the truck bursts into flames, which consume the entire vehicle before the fire department arrives and is able to extinguish the inferno. The death investigators from the county medical examiner's office arrive and remove the body and arrange for transport to their office.

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The following morning, the burned remains are processed for autopsy to determine the cause and manner of death. Body fluids will be drawn for toxicology, and tissue samples will be taken for pathological study during the postmortem (after-death) examination. The pathologist must be able to provide a legal identification for his autopsy report and death certificate. Because of the severity of the postmortem burns, it is determined that the victim's identification will be made on the basis of dental record comparison. The investigator is asked to obtain the necessary antemortem (living) dental records and contact the forensic odontologist on staff to complete the postmortem dental identification. Once the identification has been completed, the decedent's remains can be released to the mortuary for burial.

In cases of this type, forensic dentists are typically the last conventional option among the forensic specialties for postmortem identification. In the county medical examiner's office, the forensic odontologist is not a county employee but is an independent consultant who will assist the pathologist/investigator with the identification of unidentified postmortem remains. Throughout the United States, the vast majority of forensic odontologists are dentists in the traditional private practice setting. The practice of forensic odontology is, in essence, a second career in which the dentist can utilize his or her skills and training in dentistry and apply them to forensics. In other words, the typical forensic odontologist is a general dentist by day, seeing living patients and treating them for various dental ills, and by night, he or she dons a forensic hat and helps solve the mystery of postmortem identification. DNA is also now utilized, but due to its high cost and the extensive time required for analysis, it is used sparingly or when absolutely no other options exist. Other forms of postmortem identification include visual, personal effects, fingerprints, scars, marks, tattoos, and medical radiographs.

Dental Uniqueness

Forensic dental identification has been successful because of the nature of the human dentition. The enamel is the hardest substance in the body and the only exposed portion of the skeletal system. Teeth are very resistant to thermal damage and blunt force trauma, and the dentition remains stable during tissue decomposition. Also, the human dentition is unique to a specific individual. This includes the morphology of the coronal portion of the tooth, the shape and curvature of the tooth roots, pulpal chambers, and their relationship to their surrounding structures (e.g., sinus proximity, mandibular canal proximity, interproximal bony trabecular patterns). With the addition of man-made dental restorations to this list of anatomical features, one can make an identification result that is unique.

Necessity of Dental Identification

There are good reasons to try to identify the deceased (1). A legal certification of death is necessary to consummate legal matters such as life insurance, wills, and so forth. There are family and personal reasons as well (emotional closure for the survivors). In criminal investigations, it is important to establish the identity of the victim in order to proceed with the criminal investigation and help identify possible suspects (2).

In a fire such as the preceding example, the body is often burned beyond visual recognition. Personal effects are also destroyed or can be lost in the fire. Even if personal effects are recovered, they may not be considered reliable due to the typical calamity that surrounds a fire. A forensic anthropologist will examine the remains of the skeletal system and can then determine the age, race, and sex of the victim. Positive identification is best performed by examination of the surviving dentition by a forensic odontologist. In a fire such as a structure fire, where the temperatures are at times very high (1,000°C), even the dental remains may be destroyed. Crowns may fracture or explode, leaving only the roots. The bone may also be completely consumed, leaving only scattered roots with no bony sockets for reference (Figure 1). Even in cases of full intentional cremation, dental fragments may be recovered, which can lead to the identification of the decedent.

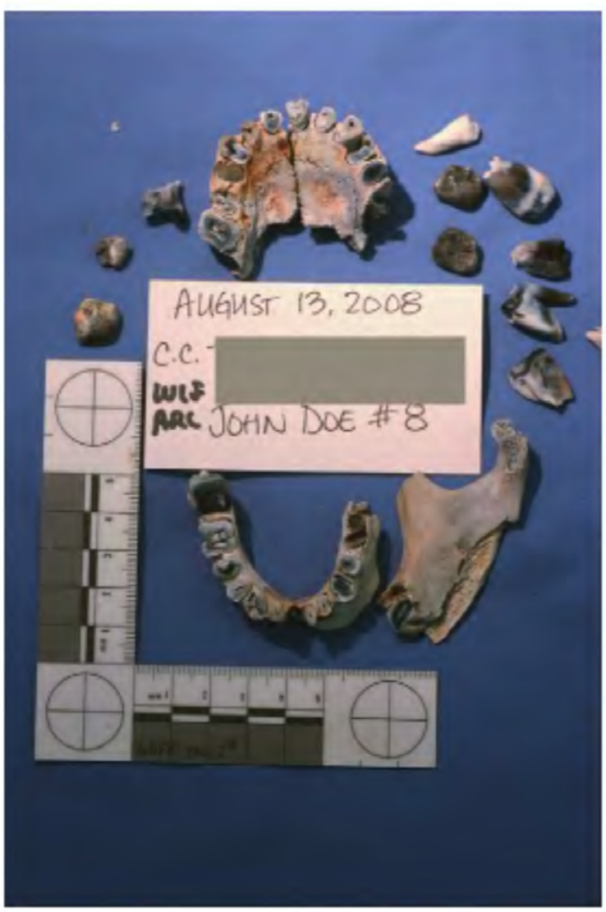


FIGURE 1 Dental remains of a victim of a helicopter crash. The degree of the burns is fifth degree (calcined).

Method of Dental Identification

Forensic dental identification is most often accomplished by the comparison of the postmortem radiographs of the teeth of the decedent (unknown) with the antemortem dental radiographs obtained from the dentist of the suspected victim (known) (Figure 2). Ideally, the antemortem radiographs furnished should be the *original* full-mouth series. Often this is not the case. Children's radiographs are typically only bitewings unless they have orthodontic records as well. Often, duplicate radiographs, not the originals, are sent and have been either poorly duplicated and/or are not labeled right and left for orientation. In addition, the antemortem radiographic image may be of poor quality due to improper operator technique (cone cuts, overlapping interproximal tooth contacts, elongation/foreshortening, etc.) or poor processing (contrast, burned images, etc.) (Figure 3). When poor antemortem radiographs are compared to an ideal postmortem radiograph, the two may not appear consistent. This can seriously hamper the identification effort.

In forensic dental identification, we stress that good quality, properly mounted and labeled, *original* antemortem radiographs are to be sent for comparison. Copies of the victim's dental treatment progress notes should be submitted as well. This allows the forensic dentist to verify dental treatment that was performed subsequent to the date of the radiographs.

In addition to radiographic comparison for identification, other methods of dental comparison have been used with success as well. For instance, photographic comparison using a facial photo that shows the front teeth compared to a postmortem image of the same teeth can show many consistent features, which can aid in identification (Figure 4). Removable prosthetic dental appliances like dentures, orthodontic retainers, and bleaching (whitening) trays have also been used for postmortem comparison and identification (Figure 5). In many states it is mandated by law that any removable denture appliance have a patient identifier (e.g., last name, last four digits of their Social Security number) imbedded in the acrylic base of the denture (Figure 6).

In the United States, when an individual dies, a death certificate must be filed at the time of death. In addition to cause and manner of death, a legal identification must be completed with the decedent named in the certificate. All manners of identification must be exhausted before the medical examiner's office will release a body for burial. The method used for identification will depend on the postmortem condition of the body. If the body is considered fresh with minimal postmortem decomposition (degradation), visual identification, fingerprint comparison, or the use of scars, birthmarks, or tattoos (Figure 7) are all acceptable methods for identification, although visual identification is typically not adequate for a decedent whose death was caused by homicide. If the body is recovered in a state considered other than fresh (i.e., decomposed, burned, fragmented, skeletal, or a combination thereof),

FIGURE 2 A typical set of antemortem radiographs sent by the decedent's treating dentist. Note that there are x-rays from many years. When requesting x-rays, always ask for all of the original x-rays on file. Duplicate x-rays are typically of poor quality.

FIGURE 3 An example of a poor antemortem radiograph. The image is blurred and faded from an improper developing technique.

FIGURE 4 (a–c) Examples of photographic superimposition for identification. (a) A frontal view of the resected maxilla (known). (b) A photo of the decedent that was taken before his death and resized to lifesize 1:1 (unknown). (c) The two images digitally superimposed at 50% opacity

FIGURE 5 The dental identification was completed using a maxillary whitening tray fit to the fragmented remains of the maxilla in a plane crash victim.

FIGURE 6 The patient's last name is imprinted into his dentures for identification purposes.

FIGURE 7 An example of a tattoo on the left bicep of a decedent who was burned in a car fire.

then it will be necessary to complete the postmortem identification via other methods. These methods include the use of medical radiographic comparison of sites such as the skull, long bone, or chest x-rays or radiographs of areas of surgically placed implants or prosthetics such as pins or screws at bone fracture sites, artificial joints (including serial numbers on surgically implanted medical prosthetics), or even artificial heart valves and stents.

If none of the preceding items exist or are available on the decedent, then the next method of comparison for identification is dental. In the United States, more people have visited a dentist at some point in their lives than have had their fingerprints placed on file at some sort of repository (state licensing agency, law enforcement repository, etc.). This is even truer for children and young adults.

Antemortem Record Procurement

Dentists are required by their state licensing board to maintain all of their patient records (treatment charts, radiographs) for a minimum of seven years, but most dental malpractice carriers recommend that dentists retain their records for a minimum of 10 years or for life. When these dental records are needed for postmortem identification, the dentist is required to surrender those records to the proper authorities. The investigator has the authority to procure the necessary records by a legal subpoena.

The dental community is very aware of the importance of assisting authorities with their investigation and most often freely surrenders all of the necessary records to complete the investigation. Recently, the dental community's only reluctance to release dental records has been as a result of the enactment of the Health Insurance Portability and Accountability Act (HIPAA). This federal statute regulates the release of any personal information concerning every patient of record in a practice. There are exceptions in the HIPAA statutes for release of records under the code of law enforcement or legal investigation.

One exemption includes identifying a deceased person. Once the investigator makes a declaration that release of records for identification of the deceased does not constitute a violation of HIPAA, the practitioner does not risk a fine or penalty and then may release the records freely.

Forensic Dental Case Types

The services of a forensic dentist become necessary when all other forms of identification are either exhausted or, because of the postmortem condition of the body, other disciplines cannot be utilized. Events occurring perimortem (at or near the time of death) will often dictate the condition of the remains once they have been recovered by the authorities. For instance, an automobile crash followed by a fire (as described in the opening scenario of the chapter) renders the remains severely charred and will require dental identification (Figure 8). Small plane crashes will often have a similar result regarding charred remains, with the additional challenge of body fragmentation. If the ensuing fire is severe, the remains can be consumed to the point of cremation (calcined) (Figure 9). These remains must be handled very gingerly because they are extremely fragile

FIGURE 8 An orientation view of a burn victim in a car fire (postautopsy).

FIGURE 9 This victim was found in the mountains after a severe wildfire. The remains are considered calcined (cremated).

and the coronal portion of the teeth can easily fracture off, leaving only the root remnants in the sockets. Adhesives like cyanoacrylate or even hair spray can be applied to the dental fragments to stabilize them before removal from the scene and reduce the risk of fracture (Figure 10). Remains that have been incinerated due to extreme temperatures in accidental structure fires or intentionally burned during a homicide have similar challenges regarding evidence preservation. Again, the key to a successful identification result is to handle the calcined remains very carefully.

One of the most common applications of forensic dental expertise is the analysis of skeletal remains. When a body is discovered and the remains are skeletonized, the attempt at identification defaults immediately to dental. Before the forensic odontologist examines the skeletonized decedent, it will be first examined and analyzed by the forensic anthropologist (Figure 11). The forensic anthropologist can sort the skeletal remains and reassemble the bones into their anatomically correct positions. From there they can potentially determine the sex, age range, and biological ancestry of the decedent. Also, they will examine the bones for evidence of trauma, which can assist the pathologist in determining the cause and manner of death. The anthropologist can also be called to examine burned and decomposed remains.

Once the anthropologist has completed this portion of the postmortem examination, the odontologist can now begin the dental examination. It is common to recover only the maxillary portion of the dentition. This is because often the skull has been in the elements for an extended time period and the mandible will become separated from the skull due to the breakdown of the muscle and ligament attachments. This separation can also be caused from animal activity at the scene. It is generally accepted among odontologists that skeletal cases are the easiest cases on which to perform a postmortem examination, because the teeth are readily accessible with no soft tissue to hinder access. Also, there is minimal odor. However, teeth can be displaced easily if the odontologist is not careful handling the jaws. Cyanoacrylate or clay can be used to stabilize loose teeth.

FIGURE 10 Bony fragments as well as tooth fragments are bonded together with cyanoacrylate.

FIGURE 11 Anthropological reassembly of skeletal remains. Dental examination will be the next step in the analysis.

One of the more challenging postmortem dental exam case types are the cases involving decomposed remains. Decomposition is the degradation of the body tissues after death and before skeletalization. There are two types of decomposition: autolysis and putrefaction (Figure 12). In autolysis, or self-destruction, the enzymes of the body tissues destroy (digest) their own cells. Putrefaction refers to decomposition by bacterial or fungal action. Two other types of postmortem changes may occur: mummification (Figure 13) and liquefaction (Figure 14). Mummification occurs when the body is in a high-temperature, low-humidity setting (e.g., summertime in the desert). Liquefaction occurs when the body is in a moist environment (water submersion). All of these types of decomposition present challenges to the forensic dental examination. These cases typically have a putrid odor associated with them. Decomposed tissue is more difficult to handle and manipulate when the jaws are being resected. Teeth may be lost due to the breakdown of the periodontal ligament. The examiner must be careful not to dislodge teeth during the oral autopsy.

FIGURE 12 Decomposed remains showing evidence of putrefaction.

FIGURE 13 An orientation photo of mummified remains.

FIGURE 14 Decomposed remains showing evidence of liquefaction.

Once the jaws have been removed, the extraneous tissue can be excised and the jaws rinsed and towel dried. The body can then be resealed and placed back in the walk-in refrigerator until the case is complete. This allows for a much more pleasant postmortem dental exam. On rare occasions, the forensic odontologist is called in to perform a postmortem identification on a decedent that is considered "fresh" or viewable. This is because no other legal methods of identification are available. This need is usually during a law enforcement investigation such as a homicide. It is common for the decedent to be a child in this instance. The odontologist preserves the facial structures and does not resect the jaws for examination. It is especially important for law enforcement investigators to establish positive identification early on. Identification of the decedent can lead to additional clues and provide an investigative direction in the case. If a suspect is eventually arrested and charged with a crime, proof of victim identification will be critical for later court proceedings.

Dental Autopsy

The dental postmortem examination or dental autopsy is performed in the autopsy examination room of the medical examiner's office. Once the pathologist has determined that a dental examination will be necessary to complete the identification, the investigator assigned to the case will contact the forensic odontologist to schedule the exam. It is imperative that the odontologist be given the case number at this time so he will be able to confirm and reconfirm the number as he or she proceeds with the case. This is also the time that the odontologist should receive necessary permission to remove the jaw structures for the exam. If the case is an identification confirmation, the antemortem radiographs need to be in place at the medical examiner's office as well. If the case is being processed as a "Doe" case, there will be no antemortem records for comparison.

The dental autopsy of a decedent is a complete dental exam that consists of photography, radiology, and a complete dental chart. It is best to begin with orientation photographs before the removal of the jaws. These photos will preserve the facial features intact (Figure 15). The next step is to remove

FIGURE 15 A typical orientation view of the decedent before the jaws are removed.

(resect) the mandible and maxilla. To begin, using a scalpel with an autopsy blade, bilaterally make a pair of horizontal incisions from the commissure of the lips to the tragus of the ear, and then make a cut in the buccal vestibule intraorally from the area of the posterior molar on the left to the right posterior molar both for the mandible and the maxilla. Following these cuts, begin to dissect out the soft tissue until the jawbones become visible. Alternate use of the scalpel and scissors will help facilitate the dissection of this tissue. Once the maxillary and mandibular bones are visible, they can be cut and the jaws removed. The jawbone is cut by one of two methods: electric saw (striker saw) (Figure 16) or with garden pruning shears (Figure 17). The pruning shear method is the preferable method due to its quick speed, lack of dust, and ease of use without an assistant.

For the mandible, the blades of the shears should be placed distal to the last molar at the anterior border of the ascending ramus about midway between the coronoid process and the dentition (Figure 18). The primary concern when making the cut is preservation of tooth structure. For the maxilla, the blades of the shears are placed above the dentition and below the zygomatic bone. One blade is placed inside the nasal cavity and the other is placed outside the bone (Figure 19). Again, the emphasis is on preservation of tooth structure. Finally, before the jaws are completely removed, the remaining soft tissue must be severed.

Once the jaws have been removed, they are then taken to an autopsy room sink where any extraneous soft tissue can be removed. Ideally, we strive to remove all of the soft tissue to simplify the handling of the jaws during charting and radiography. Before the advent of DNA, the jaws were soaked for 10 minutes in sodium hypochlorite (bleach), but that solution is known to degrade DNA, so currently it is recommended not to use bleach but to only rinse the resected jaws in water.

Now that the mandible and maxilla have been removed and cleaned, the odontologist can continue with dental charting, photography, and radiology. The standardized postmortem odontogram chart (Figure 20)

FIGURE 16 The maxilla is being resected using a striker saw.

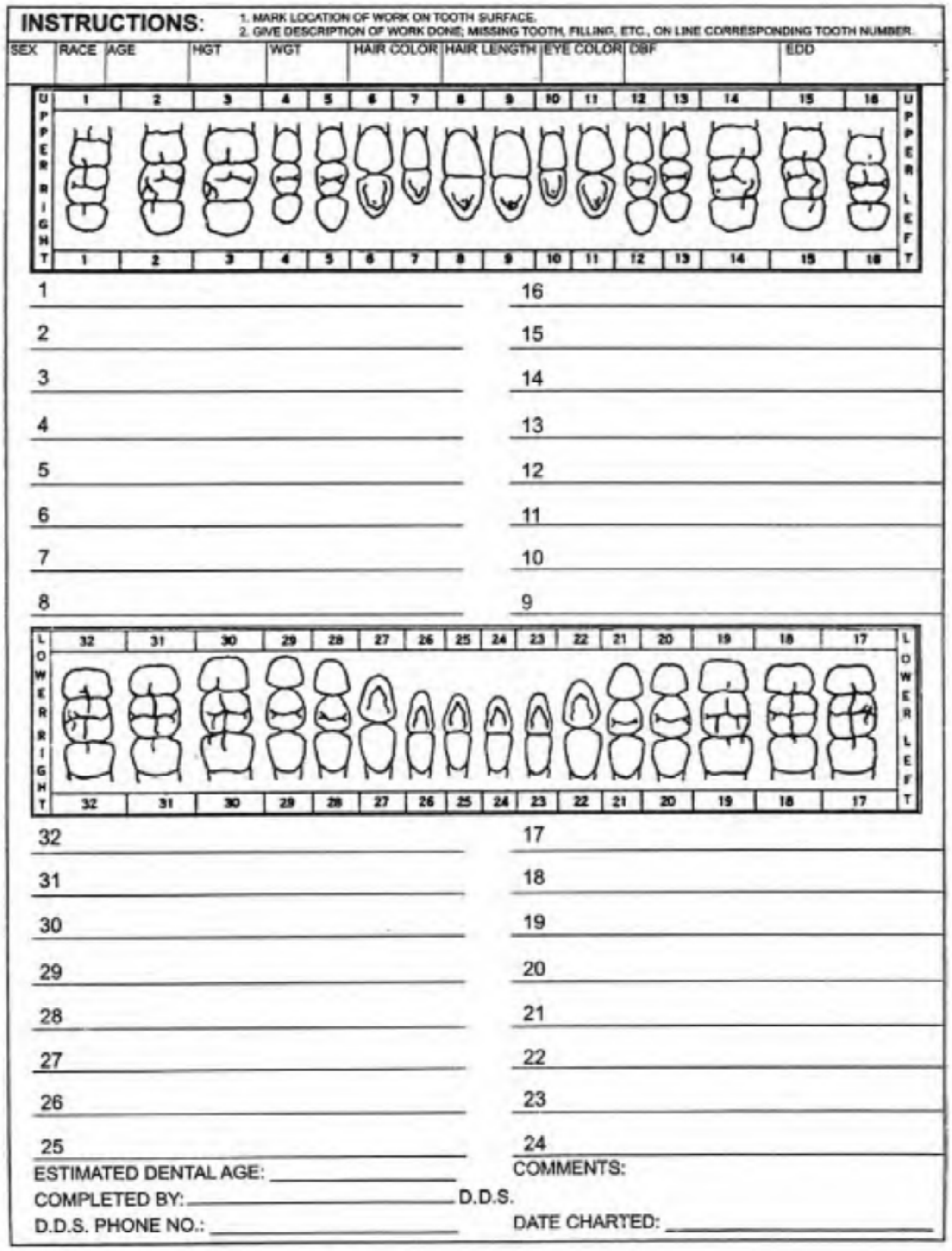
FIGURE 17 A set of gardening pruning shears. This tool is used during the autopsy for cutting rib bones as well as for resecting jaw bones.

FIGURE 18 The pruning shears are being used to resect the mandible. Note the position of the blades high on the angle of the ascending ramus. This is to preserve dental structures.

FIGURE 19 The pruning shears are being used to resect the maxilla. Again, note the position of the blades high in the maxillary sinus through the nares. This is to preserve dental structures.

entries are initially filled out by visual inspection of the jaws. It is imperative that all 32 permanent teeth are accounted for, as well as the 20 primary teeth, depending on the age of the decedent. The dentition is charted based on teeth present, missing (antemortem or postmortem) teeth, and restored surfaces. Any and all anatomical anomalies (i.e., extra teeth) and prosthetic devices, (i.e., dental implants, fixed or removable bridges) must be documented and photographed. Missing teeth must be differentiated as to having been lost antemortem (healed socket) or postmortem (open socket) (Figure 21). This is critical especially if the case will be filed into missing persons as a "Doe" because incorrectly listing a tooth as missing antemortem when it actually was missing postmortem will adversely affect the record search parameter. Once the radiographs have been processed and mounted, the odontogram (a graphic dental profile of teeth, restorations, and other dental features) (Figure 22) can be created with chart entries updated for impactions, root canals, implants, and other radiographic findings.

An important principle of postmortem charting is to never *guess* a tooth entry or feature. If one is not sure of a tooth or anomaly, it is better to list the chart entry as "no information" than to enter the information incorrectly. An entry of no information will not adversely affect a computer-based search for comparisons of the decedent with a missing persons database. Some of the more common computer dental databases include WinId/CAPMI used at the state levels (as well as mass disaster events), NCIC 2000 at the federal level through the FBI, and NamUs (National Missing and Unidentified Persons System), which for the first time brings together two national online databases for law enforcement agencies, medical examiners and coroners, victim advocates, and the general public to search missing persons and unidentified decedent records (*http://www.namus.gov*).


INSTRUCTIONS: 1. MARK LOCATION OF WORK ON TOOTH SURFACE. 2. GIVE DESCRIPTION OF WORK DONE; MISSING TOOTH, FILLING, ETC., ON LINE CORRESPONDING TOOTH NUMBER.

SEX	RACE	AGE	HGT	WGT	HAIR COLOR	HAIR LENGTH	EYE COLOR	DBF	EDD

UPPER RIGHT 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 UPPER LEFT

1 ______ 16 ______
2 ______ 15 ______
3 ______ 14 ______
4 ______ 13 ______
5 ______ 12 ______
6 ______ 11 ______
7 ______ 10 ______
8 ______ 9 ______

LOWER RIGHT 32 31 30 29 28 27 26 25 24 23 22 21 20 19 18 17 LOWER LEFT

32 ______ 17 ______
31 ______ 18 ______
30 ______ 19 ______
29 ______ 20 ______
28 ______ 21 ______
27 ______ 22 ______
26 ______ 23 ______
25 ______ 24 ______

ESTIMATED DENTAL AGE: ______ COMMENTS:
COMPLETED BY: ______ D.D.S.
D.D.S. PHONE NO.: ______ DATE CHARTED: ______

FIGURE 20 A blank postmortem dental chart (odontogram).

Postmortem photography traditionally was accomplished using film-based single-lens reflex (SLR) cameras, but in today's digital world, the digital camera is the accepted standard. The digital SLR camera with a 28- to 70-mm zoom,105 macro lens, and electronic flash (point or ring) is considered the standard camera setup for postmortem photography. There are typically four photographic views that are essential for recording the images of the resected

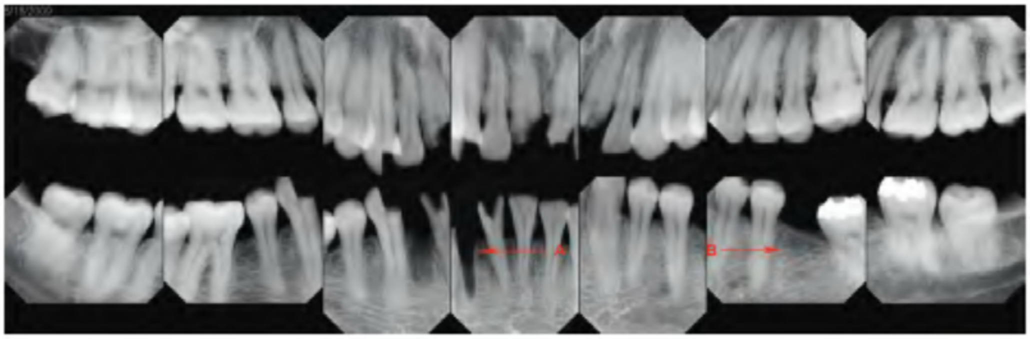
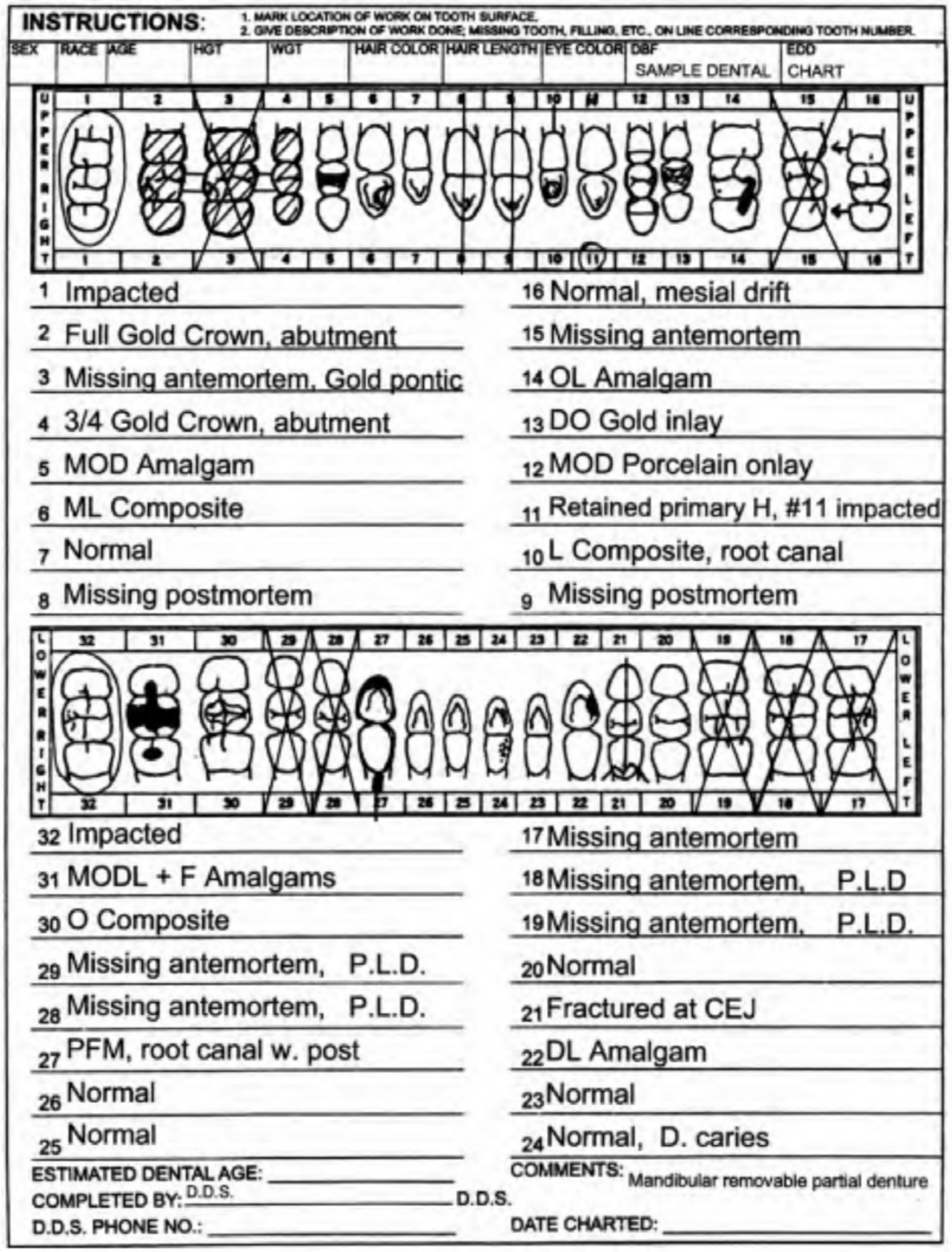


FIGURE 21 The postmortem full-mouth radiograph series shows missing teeth with an "open" or unhealed tooth socket (a), as well as a "closed" or healed socket (b). The open socket is indicative of a postmortem tooth loss.

jaws. The first and most important view is the occlusal or open mouth view (Figure 23). This view shows all of the teeth from the perspective of "looking down" on the occlusal (chewing) surfaces. All of the dental restorations are easily viewed from this angle. The second view is the frontal view (Figure 24). In this view, the jaws are articulated (put together in occlusion), and the photo is taken from the frontal perspective, similar to a natural pose. This view is helpful if the comparison will be to an antemortem frontal (smiling) photograph. Finally, photographs of lateral views of the articulated jaws from the right and left side perspectives (Figure 25) are taken. This angle shows how the teeth intercuspate (orthodontic classification) and shows restorations on the sides of the teeth.

Dental radiology is the final step of postmortem dental documentation. Like photography, radiography was traditionally performed with analog radiographs that were exposed using wall mount or medical x-ray units. Once exposed, the films needed to be processed in a developer and arranged onto an x-ray mount. Double film packets were used so one set of radiographs was always in the examiner's office. Newer technology has led to the use of digital radiographs using computer-based software (Dexis® Digital X-Ray; *www.dexis.com*) (Figure 26) and portable handheld x-ray units (Nomad® by Aribex; *www.aribex.com*) (Figure 27). Though digital technology has revolutionized dental radiography, radiographic technique for x-ray exposure remains unchanged. Eighteen films are necessary to x-ray every tooth covering all surfaces of the teeth when radiographing a postmortem "Doe" case (Figure 28). The x-ray technique used should be "ideal," with no poor x-ray errors included in the final series. In contrast, when performing a postmortem dental comparison for identification confirmation, the postmortem radiographic images should duplicate whatever antemortem radiograph images were received (Figure 29). This includes x-ray type (periapical or bite wing), angulation of x-ray (bisecting or parallel), and reproduction of x-ray errors such as elongation or foreshortening of the image. The comparison of an ideal postmortem radiographic image to a poor antemortem radiographic image can actually appear to be a mismatch even though the x-rays are of the same teeth. It is critical to create multiple exposures of postmortem dental remains in order to duplicate x-ray angulation seen in the antemortem radiographs.



INSTRUCTIONS: 1. MARK LOCATION OF WORK ON TOOTH SURFACE. 2. GIVE DESCRIPTION OF WORK DONE; MISSING TOOTH, FILLING, ETC., ON LINE CORRESPONDING TOOTH NUMBER.

SEX	RACE	AGE	HGT	WGT	HAIR COLOR	HAIR LENGTH	EYE COLOR	DBF	EDD
								SAMPLE DENTAL	CHART

UPPER RIGHT — UPPER LEFT

1 Impacted	16 Normal, mesial drift
2 Full Gold Crown, abutment	15 Missing antemortem
3 Missing antemortem, Gold pontic	14 OL Amalgam
4 3/4 Gold Crown, abutment	13 DO Gold inlay
5 MOD Amalgam	12 MOD Porcelain onlay
6 ML Composite	11 Retained primary H, #11 impacted
7 Normal	10 L Composite, root canal
8 Missing postmortem	9 Missing postmortem

LOWER RIGHT — LOWER LEFT

32 Impacted	17 Missing antemortem
31 MODL + F Amalgams	18 Missing antemortem, P.L.D
30 O Composite	19 Missing antemortem, P.L.D.
29 Missing antemortem, P.L.D.	20 Normal
28 Missing antemortem, P.L.D.	21 Fractured at CEJ
27 PFM, root canal w. post	22 DL Amalgam
26 Normal	23 Normal
25 Normal	24 Normal, D. caries

ESTIMATED DENTAL AGE: ________ COMMENTS: Mandibular removable partial denture

COMPLETED BY: D.D.S. ________ D.D.S.

D.D.S. PHONE NO.: ________ DATE CHARTED: ________

FIGURE 22 A completed postmortem dental chart (odontogram).

Once the postmortem radiographs are taken, the x-ray series can be saved as a single .jpeg file for ease of electronic transmission and file storage. The postmortem x-rays can be compared to the antemortem x-rays to confirm the identification (Figure 30). From this comparison the odontologist can give an opinion.

FIGURE 23 An occlusal view of the resected jaws. In this view the chewing surfaces of the teeth are visualized.

FIGURE 24 Frontal view of the resected jaws. In this view the front teeth are visualized.

FIGURE 25 A lateral, or side, view of the resected jaws. In this view fillings on the sides of the teeth as well as orthodontic dental relationships can be visualized.

FIGURE 26 Postmortem radiography using the Nomad® portable handheld intraoral x-ray device with the Dexis® forensic dental software program on the laptop computer.

FIGURE 27 The Nomad® portable handheld x-ray device.

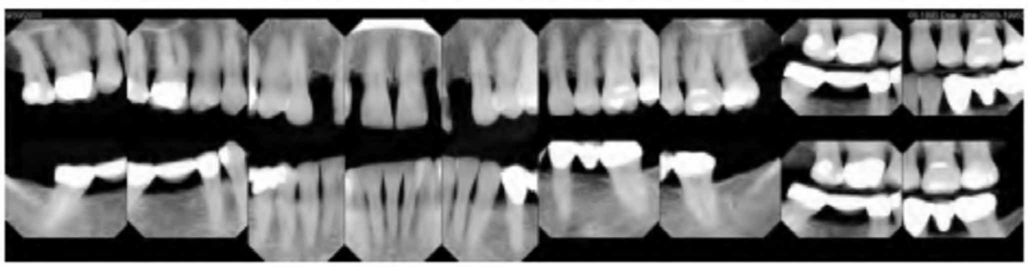


FIGURE 28 A typical postmortem full-mouth (digital) x-ray series.

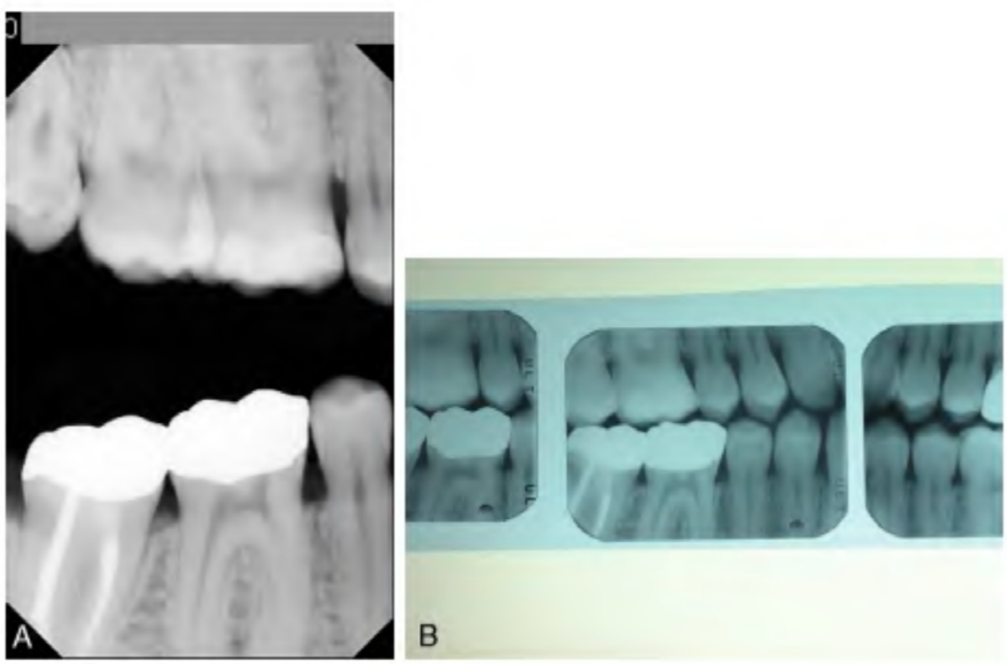


FIGURE 29 (a) A postmortem bitewing radiograph. (b) A set of antemortem bitewing radiographs.

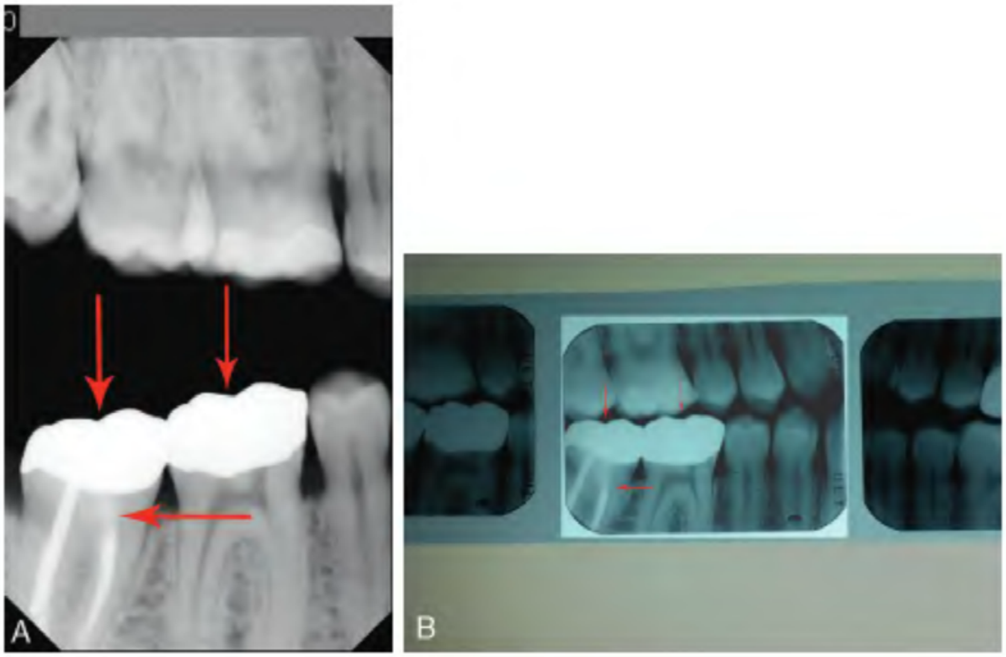


FIGURE 30 The comparison of postmortem to antemortem radiographs for identification confirmation. The red arrows in (a) and (b) show numerous points of concordance of the crowns and root canal.

Terminology for Body Identification (from the ABFO Guidelines, www.abfo.org)

Positive Identification: The antemortem and postmortem data match in sufficient detail to establish that they are from the same individual. In addition, there are no irreconcilable discrepancies.

Possible Identification: The antemortem and postmortem data have consistent features, but, due to the quality of either the postmortem remains or the antemortem evidence, it is not possible to positively establish dental identification.

Insufficient Evidence: The available information is insufficient to form the basis for a conclusion.

Exclusion: The antemortem and postmortem data are clearly inconsistent. However, it should be understood that identification by exclusion is a valid technique in certain circumstances. (Note: The forensic dentist is not ordinarily in a position to verify that the antemortem records are correct as to name, date, and so on; therefore, the report should state that the conclusions are based on records, which are purported to represent a particular individual.)

The Case Report: The final written report should be a summary of the data, conclusions, and opinion (Figure 31). The report should contain the case number, date of examination, name of agency, source of antemortem radiographs (doctors name), and postmortem radiographs and photographs.

June 19, 2010

Office of the Medical Examiner

1234 Anytown, Ca. 91234

County of Anywhere.

AME case #2010-1234

A postmortem dental autopsy and examination was performed on the above listed case on June 19, 2010 at the AME autopsy room facility. The mandible and maxilla were resected using standard techniques. The dental remains were then charted, four photographs taken, and one bitewing radiograph exposed to compare to the antemortem bitewing radiographs. The Anywhere County Medical Examiner's case #2010-1234 and the antemortem bitewing radiographs furnished by John Q. Dentist D.D.S. labeled Johnny B. Goode are of one and the same individual without question. This opinion is based on the bitewing radiographs and the comparison of the full metal crowns on teeth number 30, and 31(mandibular right first and second molars) as well as the root canal on tooth number 31. In addition, the mesiocclusal composite restoration on tooth number 3 (maxillary right first molar) is consistent as well. There were no unexplainable discrepancies between the antemortem and postmortem radiographs. Therefore it is my opinion based on the American Board of Forensic Odontology (ABFO) guidelines, to a reasonable medical certainty, that the identification of the above named decedent is to the level of positive. The decedent remains were charred.

Most Sincerely,

, DDS

Anthony R. Odontologist, D.D.S.

Diplomate-American Board of Forensic Odontology

Chief Forensic Dentist: County of Anywhere

FIGURE 31 A sample written case report of an identification of a decedent using dental records.

The teeth or anatomical structures considered for the comparison should be listed along with the points of concordance or nonconcordance, with explanations as needed. Finally, the opinion is to be stated using the preceding guidelines. At the bottom of the report should be the signature, degree, and title of the examiner. The original, signed report is submitted to the medical examiner. The odontologist keeps copies of all paperwork, charts, radiographs, and photographs for his or her personal records for future reference. Submission of "Doe" reports to state or national databases is the responsibility of the medical examiner.

CHAPTER 5

Recognition, Documentation, Evidence Collection, and Interpretation of Bitemark Evidence

C. Michael Bowers

Associate Clinical Professor, Herman Ostrow School of Dentistry, University of Southern California, Los Angeles, CA

The material in this chapter is meant to provide the investigator with an understanding of the appearance of bitemarks, the characteristics of bitemarks, forensic terminology, and the rationale of bitemark interpretation as it exists in the twenty-first century. Forensic evidence consisting of teeth marks in human skin has been developed from 60 years of forensic acceptance in the U.S. court system. Opposing this judicial trend are the well-known problems and misgivings of bitemark analysis that make front-page headlines in the United States [1]. This area of forensic identification is undergoing a definite paradigm change to science-based proofs driven by DNA technology [2].

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Contemporary bitemark analysis uses materials and techniques that were developed by and are familiar to general dental practitioners, but the determination of identities from bitemarks is not the realm of the general dentist. Specialized expertise is necessary to understand both the strengths and significant limitations of bitemark analysis. These techniques have recently been aided by desktop digital imaging methods that are easily accessible to the forensic expert. Other adjunctive imaging techniques utilizing MRI, CAT scans, or electron microscopy (SEM) will not be discussed here, since they are rarely available to odontologists.

Bitemark analysis is based on the following two concepts or assumptions:

1. The dental characteristics of anterior teeth involved in biting are unique in all individuals.
2. This asserted uniqueness is transferred and recorded in the injury. (Distinguishing features in the patterned injury can be related with some level of certainty to a given dentition.)

A historical question in bitemark analysis has been what, if anything, is "unique" regarding teeth. Recent publications have pointed to the fact that as human beings we share a common biological form and that when considering human populations, tooth positions and shapes can overlap. Thus, dental matches of multiple individuals is a scientific fact in the context of bitemark evidence [3]. In light of this, the concept of dental uniqueness is not supportable.

The notion, however, that a bitemark in skin "could have been made by a particular person" (i.e., someone with teeth like the defendant's) is commonly stated by odontologists to law enforcement investigators, the forensic community, and the court. Another confounding variable in studying bite skin injuries is that most show as only bruises and discolorations, effectively reducing resolution and allowing more than one dental pattern to fit the injury [3]. These issues continue to challenge even the most experienced odontologists and make positive or probable identifications of someone as a biter an unscientific opinion.

The research discussed in Miller and colleagues [3] and Bush and colleagues [4, 5], as well as a 2009 scientific methods review by the U.S. Congress [6] and the use of DNA (see Chapter 8), no longer supports using the old method of trying to "match" teeth to bruises in the skin. In addition to these events, there is obvious proof that bitemark opinions have contributed to the wrongful conviction in 10 cases in the United States in the last decade (see Chapter 7).

The new paradigm is an obvious one. The best identification evidence from a bitemark is DNA obtained from the saliva of the biter [7]. The scientific rationale of DNA typing needs to be adopted by the bitemark community to achieve valid results [8]. This is not a new concept. The assertion, however, that even a bitemark could have or "probably have" been made by one person in particular ignores the problems in the scientific reliability of bitemark identification when DNA has not been recovered from the location of the bitemark [9].

Law enforcement should realize that bitemark analysis is *not* the same as DNA in either function (giving the court reliable proof of guilt or innocence) or scientific accuracy [10]. Also, bite skin injuries often show only as bruises and discolorations, which can make analysis difficult [11]. This chapter presents cases and references that illustrate these challenges.

Bitemark analysis casework strives to connect a biter to the teeth pattern present on an object linked in some way to a crime or event. The general awareness of tooth marks in skin and other objects is high due to popular print, film, and television media. The ability of skin to register sufficient detail of a biter's teeth is highly variable and commonly achieves contradictory results. Bitemark casework and current research indicate that bitemarks do not correctly or completely define detail of known biters in skin. The skin's response to the pressure of a bite causes distortion due to the physical nature of the skin itself. The current opinion of some odontologists is that bitemarks can be useful in including or excluding *possible* suspects. Some consider the ability to identify only a single person as the biter in skin an impossible task. Most recent research considers making any opinion regarding a bitemark to a specific person as not scientifically supported [12]. Numerous cases in the last 10 years have produced exonerating outcomes, long after convictions, that the bitemark opinions supporting the original conviction were erroneous [13]. Bitemarks in other materials such as cheese, gum, and other relatively stable substances possess more potential for identification. Figure 1 shows an item of food evidence obtained from a crime scene.

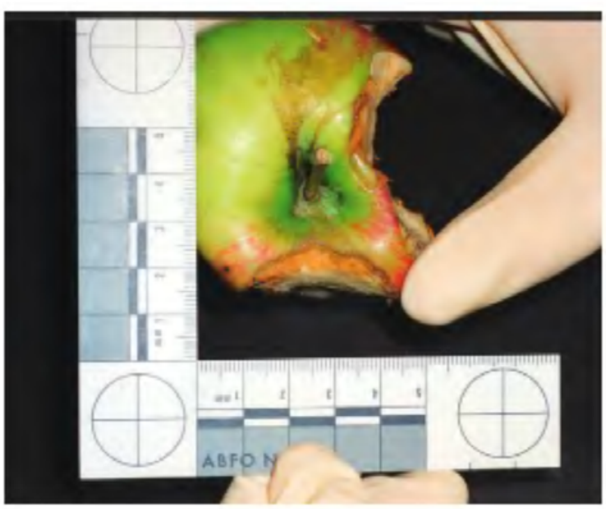

FIGURE 1 This bitten apple was considered valuable evidence and was recovered from a burglary scene. The two types of analyses possible on this apple are (a) DNA swabbing for salivary DNA from the outer surface of the apple and (b) the odontologist's study of the bitten edges of the apple's skin. The time since biting is difficult to determine, but the brownish drying of the edges indicates a passage of time greater than a few hours. Drying of foodstuffs such as this apple also affects the shape of the bitemarks. Because of this, impressions of the apple should be performed immediately after swabbing for DNA.

The History of Bitemarks in the New World

The first reported incident of bitemark identification in the New World occurred in 1692. The trial of Reverend George Burroughs in Salem, Massachusetts, introduced testimony that a bitemark on one of the purported witches was left by Reverend Burroughs. Testimony of his biting was given by one of the women accused of witchcraft. He was convicted of witchcraft by the Court of Oyer and Terminer and hanged on August 19, 1692. The twentieth-century judicial history shows Texas (*Doyle v. State*) as the first appellate court to permit bitemarks into court in 1954. The case involved a bitemark in cheese left at a burglary scene and a police technician, rather than a dentist, performed the analysis.

This area of forensic identification presents some formidable challenges due to factors that are beyond the control of the medical examiner, forensic odontologist, or police investigator. The first factor is skin being a poor impression surface to clearly capture the shapes of teeth making contact with it. The second factor is the common appearance and shape of human teeth. These topics are discussed further in this chapter.

Sequence of Events in a Bitemark Investigation

The flow of a bitemark case involves the following steps:

1. Recognition
2. Documentation
3. Evidence collection and preservation (DNA and physical evidence)
4. Physical dental inspection of the questioned evidence (bitemark)
5. Physical dental inspection, review, and evaluation of the known evidence (one or more suspects). Current research indicates that bias occurs when a dental examiner has only one individual to consider as a suspect. A dental "lineup" of similar yet unassociated individuals' dental models was recommended in the 2009 NAS report.
6. Physical comparison of 4 and 5, which produces one of the following:
   (a) A pattern of common features or an association between the bitemark and the suspect's dentition. Any positive association may, however, be insufficient for a conclusion regarding the identity of the biter.
   (b) No link
   (c) The inability to make a determination because of the poor quality of the evidence
7. DNA profiling from bitemark salivary swabbing evidence and suspect's DNA
8. Communication of results to authorities and legal counsel

Recognition

Recognizing a Bitemark

The general opinion of most odontologists is that many bitemarks associated with violent crime go unnoticed. This rationale stems from the broad range of reporting statistics from diverse areas of the United States. It is apparent that forensic trained individuals in larger jurisdictions are more capable of discovering a bitemark wound or pattern than someone with little or no exposure to them. It is possible that larger communities have better-trained public safety and health personnel. No formal demographics of "biting" activity between different geographic areas are available, but on a per capita basis, larger metropolitan areas generate bitemark cases more than smaller population centers. The reason may be better training or at least a greater chance of recognition due to multiagency or emergency medical/hospital involvement. The responsibility of recognizing a possible bitemark usually falls on either law enforcement personnel or medical staff in hospitals or morgue facilities.

Recognizing a human bitemark is the first task. Figure 2 shows a bitemark with obvious tooth characteristics. The physical parameters of the injury can be

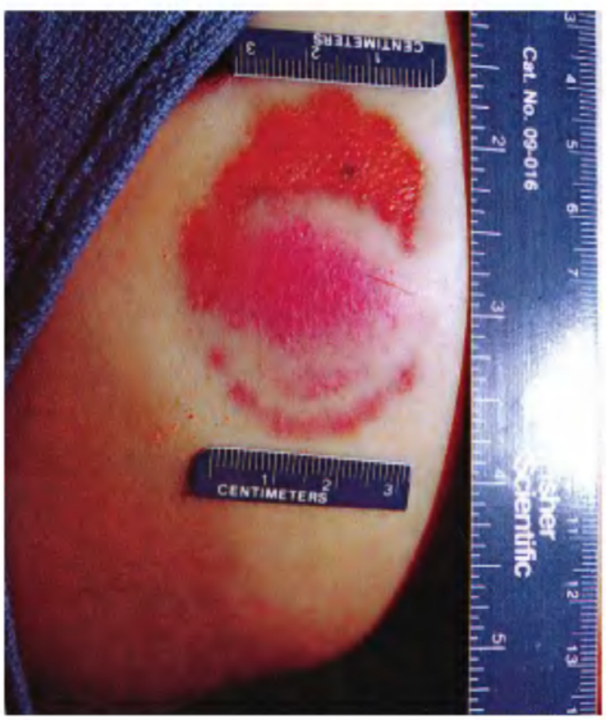

FIGURE 2 This image was taken at autopsy. The injury was located on the victim's back just above the shoulder blade. The placement of multiple one-dimensional scales in the picture closely adjacent to the injury is important in order to properly resize the injury to 1:1 (life size) for later comparison to a suspect's teeth. The picture shows the upper teeth marks on top of the image, accompanied by considerable subcutaneous (under the skin) bleeding in the reddened area below the biting area. The upper teeth show as reddened outlines that give the appearance of a "scalloped edge" along the upper reddened border. The lower aspect of the bitemark (near the smaller ruler) shows the classic U-shaped curvature that a complete arrangement of six lower front teeth can produce. There is enough information in this bitemark to include a defendant as a "possible biter."

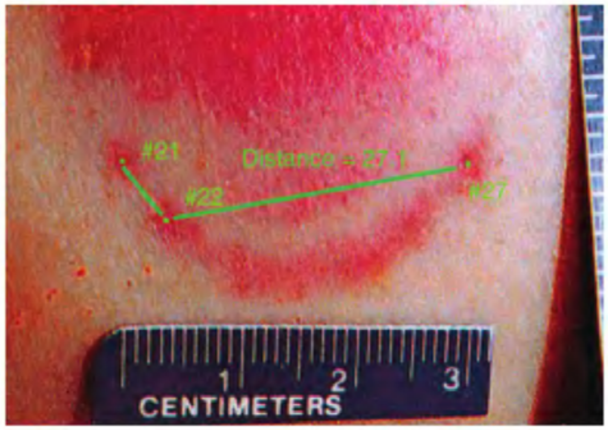

FIGURE 3 Lower teeth were determined to be the cause of this bruising because the shallow U-shaped curve was narrower than the upper portion of the mark (Figure 2). The normally shaped teeth that made this lower mark appear to be similar in size to lower front teeth. Teeth #22 and #27 are cuspids and naturally have pointed tips when not heavily worn from use. The bruising caused by these teeth can be more circular (i.e., round "dots") than the four lower front teeth, which are more rectangular in shape.

measured. Figure 3 shows a close-up view of the lower teeth marks in Figure 2. This is the time to take swabs of the injury. See Chapter 8 for DNA's role in bitemark investigation. The linear distances between teeth #22, 27 and #21, 22 can be compared to a suspect's dental features. Other regions within this injury can also be similarly measured, including angular features. However, caution should be exercised because the latest research has shown that exact metric measurements of any particular dentition do not transfer to the skin [4], and distortion in a bitemark can be considerable [5]. Hospital and law enforcement personnel may have a suspicion about an ovoid skin wound and call in the local dental expert for confirmation. Once it has been established that the injury is indeed a human bitemark, the expert will be expected to document the injury. The final step is the comparison of the characteristics of the injury with those of the dentition of a suspected perpetrator.

The large majority of bitemark cases involve injuries to skin. The individuals who sustained the bites may be either alive or dead. In both instances, the evidence considered by bitemark analysis is subject to changes from the healing process (antemortem) and/or decomposition. Training and personal knowledge of bitemark patterns in skin and soft substances are necessary to achieve reliable recognition of this type of evidence in everyday casework investigations. Investigators should be suspicious of any marks or bruises that have characteristics resembling injuries by teeth. The determination of an injury as being produced from human teeth requires substantial information. Confirmation of the presence of salivary DNA may be subsequently obtained from the bitemark site. This may corroborate or eliminate opinions based on meager evidence such as incomplete patterns or diffuse bruises.

FIGURE 4 This is a superimposition of a defendant's lower teeth edges (the surfaces that would contact the skin) onto the injury. The correlation of the two is good, indicating that the suspect "could have made the bitemark." This opinion has to be tempered with the realization that the arrangement of these teeth is no means "unique." An alternative opinion that is more easily understood by juries is "the suspect cannot be excluded as a possible biter." Therefore, "matches" of this type indicate other people could have made this injury.

Identification of a specific person is best done with biological evidence derived from the same site (Figure 4).

Preliminary Bitemark Examination

The logic tree for the on-scene investigator or autopsy dental examiner involves the following:

1. Is the pattern a bitemark?
2. Could human teeth be the cause of 1?
3. Does the area allow swabbing for salivary DNA?
4. Do the teeth marks present in the evidence possess information sufficient to identify one person? Are the features common to only the human species? What significance are these features in relation to someone else's teeth. Could someone other than the suspect have created the mark?
5. If the answer to 4 is "No": What features (if any) present in the bitemark are sufficient to eliminate specific people from the investigation?

   If the answer to 4 is "Yes": What is the probability of an unassociated person being "matched" with the bitemark evidence?

The importance of this investigative logic tree is to ensure that any bitemark evidence is properly utilized. The current scientific basis for bitemark identification does not give statistical probabilities. Rather, it uses personal opinions regarding the biter's identity. It is possible that more than one person will fit any one dental alignment pattern. As such, bitemark analysis demands a conservative approach by the odontologist. Question 4 means that the "weight" or value of a bitemark must be considered in light of the risk of possibly including an innocent

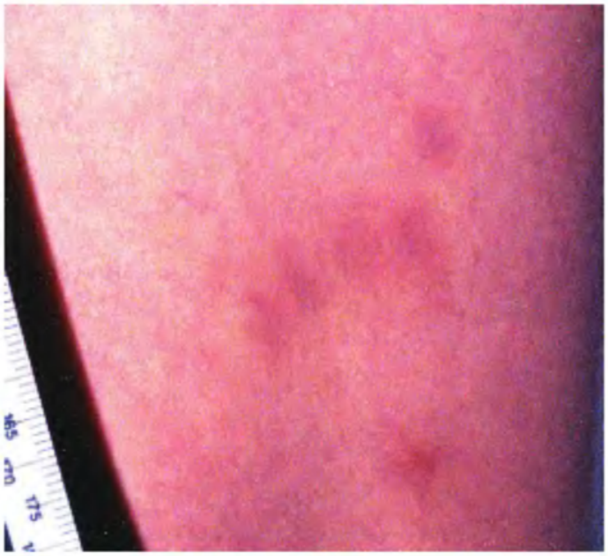

FIGURE 5 This injury was on the inside of a suspect's upper arm. The ambiguous arrangement of these bruises supports an opinion that they could have been made by any number of objects or means besides teeth. At trial, this case had experienced odontologists for the prosecution and defense who disagreed as to what and who had made these marks. Contrast the information available in this image with that of the previous bitemark case.

(i.e., unassociated) person in a criminal investigation based on the odontologist's opinion. In a scientific sense, this type of opinion does not pass an objective scientific analysis.

The first determination of the question "Is it a bitemark?" is subjective, since casework indicates that many skin injuries from teeth are only partial "bites" without showing a complete complement of front teeth as seen in Figure 2. Figure 5 shows a skin injury that is not nearly as detailed as the bitemark in Figures 2–4. This makes a layman's determination of whether it is indeed a bitemark difficult. Even experienced odontologists disagree regarding this question. The idealized or "prototypical" bitemark shows the following characteristics as defined by the American Board of Forensic Odontology's Bitemark Standards and Guidelines (*www.ABFO.org*):

> *A circular or oval (doughnut) (ring-shaped) patterned injury consisting of two opposing (facing) symmetrical, U-shaped arches separated at their bases by open spaces. Following the periphery of the arches are a series of individual abrasions, contusions, and/or lacerations reflecting the size, shape, arrangement, and distribution of the class characteristics of the contacting surfaces of the human dentition.*

Skin Distortions Affecting Biter Identification

According to the older bitemark literature, variations of the prototypical (read: "ideal") bitemark include additions, subtractions, and distortions. Distortion is inevitable in a bitemark due to the physiological principles of skin. Skin is an anisotropic, viscoelastic substance that undergoes a nonlinear response to stress. Anisotropy simply means that skin has different properties in different directions. This tissue exists on the body in a state of pretension, resulting in tension lines that are called Langer lines. Skin will be tighter parallel to tension lines and more relaxed perpendicular to them. Thus, skin is easier to grab in the perpendicular direction. The tension lines not only vary from person to person but also at a single sight on any given individual.

Skin is termed viscoelastic because during normal body movements (rotation of joints), skin moves elastically (it can stretch quite a bit). However, as higher stress is applied, the skin becomes increasing viscous (stiffer). A characteristic of all viscoelastic materials is a nonlinear response to stress, so skin can significantly stretch at low stresses (about 30%), but as the stress increases, this rapidly becomes very limited.

Distortion of the skin is also influenced by the dynamic nature of a situation where one person bites another. The bitten skin surface may be twisted or on a location of the anatomy that is in a postural position that affects the impact of the teeth. The image of breast tissue in Figure 6 indicates how the anatomical location of a bite injury can produce a pattern that is a distorted replica of the teeth doing the biting.

There is movement of both persons during a physical assault with the victim's struggles being incited by the discomfort of the injury. Additions and subtractions mean that in this dynamic situation certain teeth may

FIGURE 6 This image is of a homicide victim's right breast. The nature of breast tissue is readily apparent as the examiner's hand can move or change the shape of the small cuts seen underneath the areola.

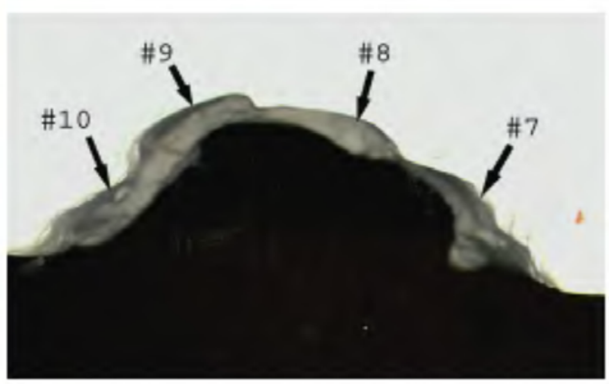

FIGURE 7 The outer edge of this model of bitten cheese shows the continuous outline of the upper four teeth (#7, 8, 9, and 10). Shrinkage from drying out (desiccation) is always an issue with bitten food. Preservation of the bite's details should include accurate impressions taken after swabbing for salivary DNA.

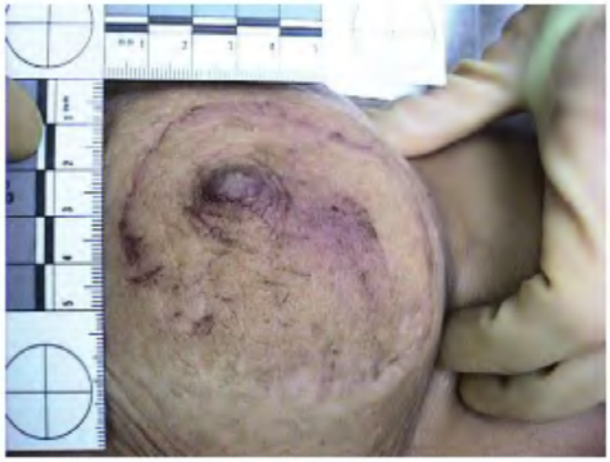

FIGURE 8 This overview image of shallow injuries on the breast shows how the skin surface may capture teeth marks as well as other scratches or small cuts.

not leave a mark, or the same teeth may bite multiple times at or near the original bite site. Figure 7 is a model of a bitemark in cheese. The cut edges of the cheese are extremely clear. This is contrasted with the markings on the breast tissue of Figure 8.

The determination of why certain teeth do not mark in the injury is based on the opinion of the odontologist. The reason for a "missing tooth" in an injury may be any of the following:

a. The biter does not possess that particular tooth.
b. The skin twisted in some way to avoid contact with the tooth.
c. Relative tooth height
d. Factors that influence skin distortion

Either determination is a subjective decision by the dentist, although it is possible to attempt to recreate (b) via test bites in materials (usually wax or silicone putty material). Wax or silicone undergo plastic deformation in response to stress and therefore may only be an adjunctive aid in bitemark analysis, as it is not a suitable substitute for human skin. Wax or silicone undergo plastic deformation in response to stress and therefore may only be an adjunctive aid in bitemark analysis, since it is not a suitable substitute for human skin.

These different scenarios compound the task for the investigator because there are no dental minimums to determine a bitemark. Some dentist investigators have testified that two teeth have made dozens of injuries on the same person. This is an extreme and somewhat illogical opinion, since small abrasions can easily be made by many objects or may be an artifact of postmortem change and environmental insult (i.e., insects).

The following features may also be seen in skin injuries:

- *Central ecchymosis (central contusion):* This is seen in Figure 2 as the brilliantly reddened area in the middle of the upper teeth area.
- *Linear abrasions, contusions, or striations:* These represent marks made by either the slipping of the teeth against the skin or by imprinting of

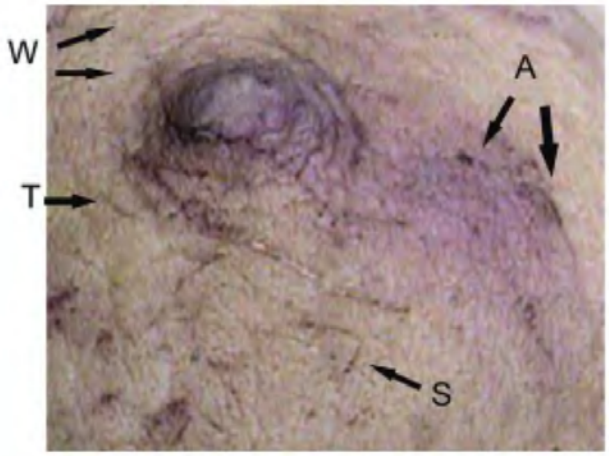

FIGURE 9 This close-up view of the nipple region of Figure 8 shows how normal skin textures lines (T), wrinkles (W), and scratches (S) and abrasions (A) all are present in the same image.

FIGURE 10 A "double bite" case.

the lingual surfaces of teeth. The term *drag marks* is commonly used to describe the movement between the teeth and the skin, and *lingual markings* is used when the anatomy of the lingual surfaces is identified. Another common term is a *radial pattern* (Figures 8 and 9).

- *Double bite*: A "bite within a bite" occurs when skin slips after an initial contact of the teeth and then the teeth contact again a second time. Figure 10 shows a close-up of this type of injury.
- *Weave patterns* of interposed clothing
- *Peripheral ecchymosis:* This is due to excessive, confluent bruising (as seen in Figure 2).
- *Partial bitemarks*: These include one-arched (half bites), one or few teeth, or unilateral (one-sided) marks due to incomplete dentition, uneven pressure, or a skewed bite.
- *Indistinct/faded bitemarks:* As the skin heals, it will gradually affect the appearance of the injury (Figure 11).

FIGURE 11 This is considered a "diffuse" bruising bitemark and is of no evidentiary value for biter identification. DNA swabbing of the injury could direct suspicion on a particular person.

FIGURE 12 A living assault victim's avulsive bitemark injury.

- *Fused arches:* The collective pressure of teeth leaves arched rings without showing individual tooth marks.
- *Solid:* This occurs when the pattern is not apparent because erythema or contusion fills the entire center, leaving a filled, discolored, circular mark.
- *Closed arches:* The maxillary and mandibular arch are not separate but joined at their edges.
- *Latent:* This can be seen only with special imaging techniques.
- *Superimposed or multiple bites:* The Bundy (see Chapter 1) is an excellent example of this feature.
- *Avulsive bites:* This is when tissue or a significant body part (tongue, finger, etc.) is bitten off the victim. Figure 12 shows the damage of an ear being the target of a biter.

Features Indicative of Bite Marks in Skin

Human teeth are arranged in predictable patterns. Because human beings belong to a single species, it is rational to assume that the dentition would fit into finite-shape boundaries. Dimensional variations in tooth size, shape, and position exist among individuals, which can be useful for forensic investigation if the bitemark itself is of sufficient detail and tissue/substrate (e.g., a bite in duct tape) distortion can somehow be controlled. Teeth make it possible for people to properly digest food. The use of teeth over the years produces changes based on personal activity, dental disease, and dental treatment, particularly orthodontic treatment. All of these factors arguably give each person a "dental alignment pattern" that can vary from commonplace to quite unusual.

All these factors arguably give each person a "dental profile" that can vary from commonplace to quite unusual, including the following.

Ovoid/Elliptical Patterns

This consists of a series of "C" (and facing each other) shaped abrasions or bruises that, taken as a whole, appear to have an ovoid outline. This reflects the

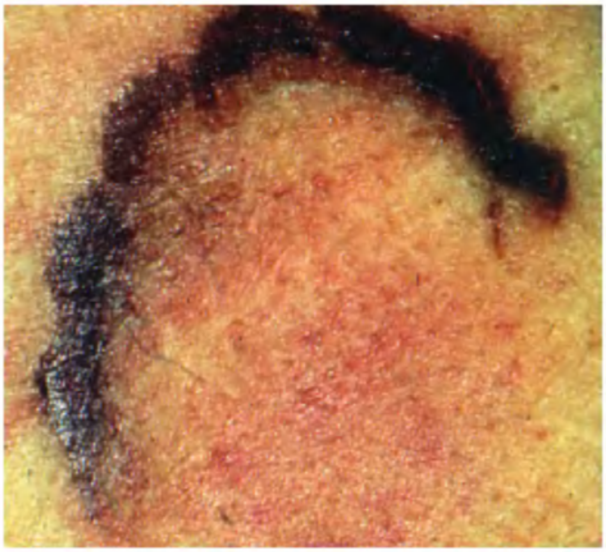

FIGURE 13 This C- or U-shaped injury only showed one dental arch (in this case the upper jaw). You could consider this bitemark to be similar to Figure 2 in detail.

FIGURE 14 A bitemark injury showing a faint curvature of lower teeth.

upper and lower front teeth in both adults and children. Some cases are seen with only a single C-shaped mark (Figure 13). This indicates only one jaw making tooth marks (usually the lower jaw). This reduces the amount of information available to the investigator, since a bite showing upper and lower teeth contains twice as much detail. The absence of the other jaw marking during biting activity is explainable by a number of hypotheses—for example, claiming the clothing protected the skin from the bite. The only way to prove such a claim would be to search the clothing (if available) for saliva and, eventually, DNA. If DNA is present, the analysis of any bruising pattern may be moot.

Interrupted Abrasions

The ovoid appearance of the bitemark can have individual tooth marks that indicate specific teeth. This is not, however, as common as generalized curved bruises, which predominate most skin injuries. Figure 14 shows little in the way of individual tooth marks. The overall curvatures of these lower teeth are quite apparent and could be used to include or exclude possible suspects in this homicide.

Continuous Bruises

It has been shown that curved bruising, which approximates the shape of dental arches, can be a result of objects other than teeth (ECG pads, jewelry, etc.). The diagnosis of a human bitemark, in this category of physical evidence, should be most conservative, since bruising is seldom sufficiently detailed for human identification.

Misdiagnosis

In deceased individuals, skin decomposition and predator (insect) activity create injuries and produce skin patterns. The application of bitemark analysis on skin surface patterns in these cases is speculative unless there are clear and convincing markings in each pattern. What may appear to be a "complex" biting pattern on the skin may actually be a result of postmortem and environmentally

FIGURE 15 A forensic dentist considered the area below the number 2 to be a bitemark. The curvature is certainly a shallow C shape, but the width is much too large for human teeth. Careful analysis of the edges of the wound indicates sharp force injury as the mechanism of injury.

caused changes. Semielliptical injuries mimic the well-described C-shaped patterns seen in an actual bitemark. A prosecution dentist believed that the area labeled "2" in Figure 15 was a bitemark, when it was in fact a knife wound.

Locations of Bitemarks on Humans

The types of scenarios where bitemarks occur can sometimes be categorized from the overall circumstances of the event. It should be noted that the bitemarks themselves do not exhibit features indicating the specific intent of the biter.

- *Sexual assault:* Females exhibit bitemarks on the breasts, nipples, abdomen, thighs, and pubis. Males receive bitemarks on the back, shoulders, and penis.
- *Defense wounds:* Individuals being attacked can receive bitemarks from their attacker on their forearms and hands.
- Animal bitemarks
- Initial animal attacks on humans focus on the legs and then advance to hands, arms, and the head and neck.

Cases that Are Likely to Involve Bitemarks

Bitemarks are generally associated with violent interactions such as sexual assault, child abuse, elder abuse, and homicide. Bitten foodstuffs left at a crime scene may be useful in determining the identity of a burglar or the perpetrator of an assault or murder. Criminals who occupy a crime scene for extended periods of time will use styrofoam cups, food, and other utensils.

Bitemarks on Victims of Violence

Cluster bitemark sites are the common locations where bitemarks are found during postmortem examinations. Bitemarks can be made through clothing, and the clothing should be considered a potential source of *both* physical bitemark impressions and biological evidence from transferred saliva. The biological value of the transferred saliva should not be underestimated, since physical tooth markings on clothing or underlying skin are generally nonspecific for an individual biter.

Victim Bitemarks on Perpetrators

During an assault, the victim may bite the attacker in self-defense. Assuming that a suspect in a homicide is detained for questioning and there is evidence of bitemarks on the suspect, dental impressions of the deceased should be taken.

Homicides

Investigators should know where bitemarks on skin are likely to occur during sexual assaults, child abuse, and homicides. Certain types of homicides usually involve strangulation and/or blunt force trauma, sexual assault, and bitemarks. The initial investigator should ask, "Is this injury consistent with a human bitemark?" This is an important question because if the answer is yes, it initiates evidence collection and victim/witness/suspect interviews. The forensic dental expert will later look at the evidence for similarities and dissimilarities among suspects. Regardless of the dentist's expertise, if the evidence is not collected or is collected improperly, there is less of a chance that this first question can ever be answered.

Sexual activity involves biting activity in many cases. Child abuse (having either sexual or nonsexual contact) bitemarks can be inflicted by adults, siblings, or other children. Sexual biting is seen between consenting or nonconsenting adults. The ability to discern the difference between consensual and nonconsensual biting activity is not well defined in the literature. Certainly, biting that produces severe skin and tissue damage is beyond what a reasonable consenting adult would consider acceptable. In child abuse cases, the child cannot consent to any activity that results in an injury.

Multiple Biting Incidents

Bruises of differing colors that involves new abrasions (scrapes) adjacent to older, scabbed injuries can indicate a series of separate biting events. This category of patterns is seen in ongoing cases of child abuse and elder abuse. In both cases, victims are unable to defend themselves, and the perpetrator repeats the attacks over time. Faint skin injuries may be difficult to see without close examination under various types of light. Ultraviolet light creates an increase in reflectivity from subcutaneous tissue and is used in cases of faint injuries or injuries obscured by healing. Figure 16 shows a faint injury with a

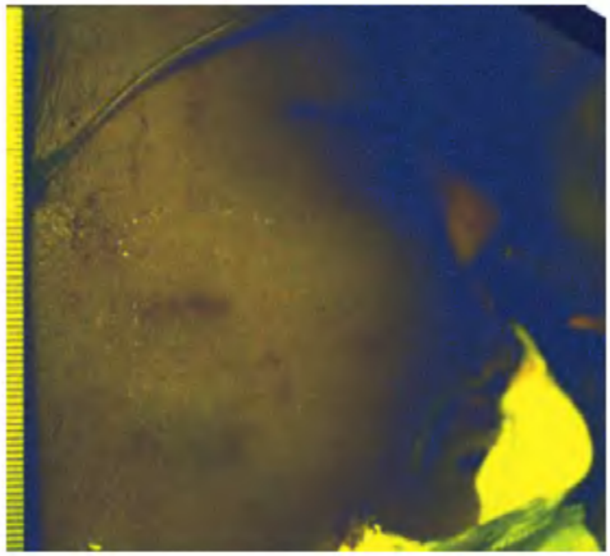

FIGURE 16 This injury pattern has no value for biter identification purposes.

minimum of bitemark characteristics that was taken with UV photography and then digitally enhanced to increase its contrast and brightness.

Time of Occurrence of a Bite

Bruises in the skin of a living person change color as healing takes place. These color changes vary from person to person. Age estimation (aging) of the bitemark is neither a scientific nor an accurate process. It is merely an unsupported opinion.

Adult Versus Child Versus Teenage Biters

Adult teeth and jaws are usually bigger than a child's. A young teenager, however, possesses some adult teeth and is developing toward an adult jaw size. The teenager will become dentally mature by about the ages of 12 to 14, with completion of the growth of the jaws by about ages 15 to 17. At this point, when looking at bruising, the investigator must realize there are limitations in determining a cutoff between adult and teenager biters. An adolescent bitemark, if it is just bruising, can mimic an adult bite when the minor-aged biter is between the age of 12 and 17. This confusion can be caused by the vague appearance of many bruises. Bites in food, gum, and other softer materials are easier to determine.

Variable Appearance of Bitemarks

The limiting factors in recognizing a pattern as originating from teeth are the character of the material bitten, especially human skin, and the power of the biting force. Figure 17 shows the ability of a common styrofoam cup to retain teeth indentations. The use of wax bites (e.g., wax exemplars) by dentists is very useful in reproducing a particular set of teeth edges. The models of a suspect are pressed into the wax when it is softened in warm water. Figure 18

FIGURE 17 A coffee cup collected from a crime scene could easily lead to the identification of a perpetrator. This image shows a bitemark of lower adult teeth revealed in styrofoam. The use of the ruler ensures that photographs can also be made that are 1:1 (life size). The front teeth (inside the colored box) show a misalignment that can be used to include a particular person as the biter. The investigator should also remember that DNA swabbing of this object would also be extremely useful in determining the biological profile of the biter.

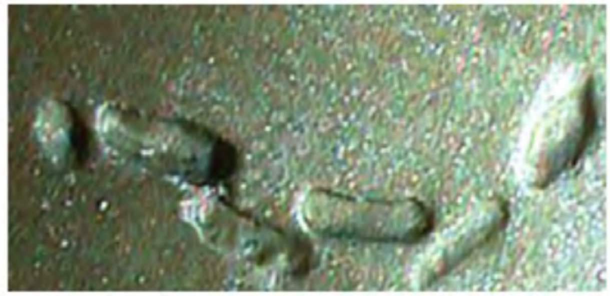

FIGURE 18 This wax impression can be used to capture just the biting edges of a suspect's teeth for later comparison with a bitemark.

shows the detail available from this type of material. Neither wax nor styrofoam have any similarity to skin.

Skin does not consistently or accurately reflect objects that contact its surface. Bruising discoloration results from skin trauma as the dermal vasculature network becomes broken, leaking blood into the surrounding tissue. This both changes and spreads over time. Foodstuffs that are recognizable during a scene search also undergo dehydration and shrinkage over time. Cheese is a very good substrate for teeth marks.

Bitemarks may possess single tooth marks that appear as distinct intricate patterns or present as a diffuse bruise with little detail. Individual marks are considered the features produced by wear or accidental chipping of a tooth's edges. The term *uniqueness* is used in the dental literature regarding these features. This cannot be proven scientifically and should not be used. Bitemarks of high evidentiary value should exhibit markings from a significant number of the six upper and/or six lower front teeth. If fewer than 12 teeth are in a bitemark, it diminishes the identification value of the evidence. Laceration or cutting of skin by human teeth is seldom seen. Animal bitemarks, principally dogs and carnivorous wildlife, possess the dental characteristics necessary for deep gouges and lacerations. Figure 19 shows an arrangement of teeth that is not typical due to the chipping and breaking of a front tooth and the misalignment of the lower front teeth. The wax bite in Figure 18 was made from this person's dental models.

Forensic Identification Value of an Injury Pattern

A human bitemark may have a variety of characteristics and show considerable variation due to incomplete teeth marks without three-dimensional features or because the surface bitten does not register physical indentations

FIGURE 19 These lower teeth are obviously crooked. Also, their biting edges are not all at the same level. The broken upper front tooth (#9) has lost a large part of its chewing surface. Teeth with these features will leave marks in a stable bitten substrate (i.e., a material that does not distort) that show this difference in tooth height (i.e., length). The longer teeth and the corner edges of the chipped #9 produce more damage.

accurately (e.g., skin). Upper- and lower-jaw teeth may or may not be equally or unequally present. A "single dental arch" mark suffers from a serious reduction of information and should result in a guarded consideration as a bitemark. "Single-tooth" marks are subject to considerable disagreement regarding the reliability of a positive link with a suspect or defendant. Physical features may be distorted due to victim movements and jaw movement of the assailant. The anterior teeth are usually more likely to mark. Linear abrasions or stripelike lines due to dragging can sometimes be seen.

Physical Characteristics of a Bitemark Pattern

The following definitions are used for bitemark patterns:

- *Tooth width* is the longest distance along its biting surface (also known as mesial to distal).
- *Tooth thickness* (lip to tongue or labial to lingual) is the distance at right angles to the width.
- *Jaw width* is the length, in the same jaw, from one side to the other. The cuspids (eyeteeth) are the usual landmarks for this measurement.

The fundamental step in bitemark analysis is the determination of which teeth made specific marks. This determination is based on the appearance of the following features.

Tooth Class Characteristics

Front teeth are seen as the primary biting teeth in bitemarks. The incisor types are centrals, laterals, and then the cuspids.

- *Shape differences of the six upper front teeth*. The two upper central incisors are wider than the lateral incisors. The upper cuspids are cone shaped.
- *Shape differences of the six lower front teeth*. The two lower centrals and two laterals are uniform in width. The lower cuspids are cone shaped.

The upper jaw is wider than the lower jaw. A bitemark showing the upper front teeth and the lower front teeth will show a total of up to 12 teeth marking in the skin. The next step in bitemark analysis is the determination of which marks were made from upper teeth and from lower teeth.

Bitemark Class Characteristics

1. The upper four front teeth make rectangular marks, with the central being wider than the laterals.
2. The upper cuspids make round or ovoid marks.
3. The lower four front teeth make rectangular marks that are similar in width.
4. The lower cuspids make round or ovoid marks.
5. Gaps seen between marks can have several explanations, including the following:
   - The suspect is missing a tooth.
   - The tooth in that spot is shorter due to its normal shape or previous breakage.
   - There was an object (i.e., clothing) that blocked the tooth (sometimes more than one tooth) from contacting the skin.
   - Other hypothetical scenarios that relate to tissue movement or biting mechanisms.
6. Areas between known biting teeth that show significantly fainter bruising can be attributed to teeth that did not impact the skin due to some feature present on the tooth. Differences in tissue contours may be another cause. This would be clearly seen in the bitemark photograph. The typical reason is the edge of the tooth is chipped, or the tooth is shorter than the adjacent teeth.

Difference Between Human or Animal Bitemarks

Large carnivore bitemarks are seen in dog bite and mountain lion cases. The bite wounds produced can be remarkable in their depth and amount of damage to skin and underlying muscle. These animals have extremely long canines and a complement of six incisors plus the two canines for a total of

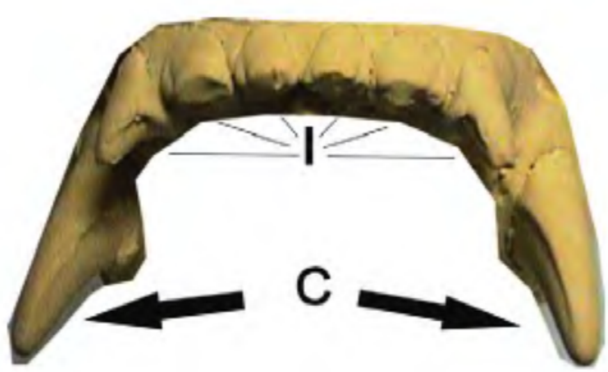

FIGURE 20 This is a plaster model of a dog's upper jaw. This shows the dagger-like canines (C) on either side of the six incisors (I). The dog was involved in an attack on an adult female who experienced severe lacerations from the long teeth seen in this picture. The obvious measurement to exclude a human as the biter is to measure the distance between the long upper canines. The typical distance, even in small dogs, is 50 mm or more. Human canines in the upper jaw are on average 40 mm apart in adults and teenagers.

FIGURE 21 This jaw is from a mountain lion captured and euthanized after a fatal attack on a female jogger. This view is from the inside aspect of the jaw looking onto the skin of the victim. The canines develop the long slashing wounds as seen here. The smaller incisors (six compared to a human's four) left smaller abrasions.

eight anterior teeth. Figure 20 shows a plaster model of a dog's upper jaw. Figure 21 shows a California mountain lion jaw.

Evidence Collection for Bitemarks

Once an investigator has the opportunity to recover bitemark evidence and DNA evidence from saliva, time is of the essence. The person who collects this evidence should have experience and have specialized training prior to doing actual casework. Casework history indicates that most evidence will be recovered by nondental personnel. This is *not* unusual, since there are many jurisdictions without a staff forensic dentist. It is paramount that law enforcement or forensic staff properly prepare for these collection protocols and understand the principles behind these procedures.

Recovery of Salivary DNA

The presence of a bitemark means that the mouth of the offender has made contact with an object. Such contact will almost certainly leave some trace of saliva. This can be an important source of DNA that can be used for identification purposes. Saliva contains skin cells from the lining of the oral cavity. These cells each contain a nucleus that possesses nuclear DNA. The concentration of these cells is quite high in human saliva and allows for recovery of potentially identifying information on whom or what made the bitemark. The presence of a Y chromosome in the resulting profile indicates that a male was the biter. The lack of a Y chromosome and the presence of XX mean that a female was the biter.

The periphery and center of the bitemark are gently swabbed with sterile water, and the cotton applicator tip should be preserved for later laboratory analysis. It is important to use sterile gloves throughout the following procedures. The specific steps are outlined in much more detail in Chapter 8.

Photography

A long-range view should be taken with case number visible in the frame. This is also called an *orientation photo*. The purpose is to reveal the general location of the bitemark on a body or the location of the object being investigated. For close-up views with and without scale, use the ABFO #2 scale if available (www.redwop.com). Make sure the scale is at the same level as the bitemark rather than above or below it.

Impressions of a Bitemark

To make an impression, use dental grade silicon impression material (polyvinylsiloxane: www.pearsondental.com). Place a heavy backing (cotton or plaster) on the impression material while it is setting. This ensures that there will be no distortion of the impression on removal. Take photographs of this process, and make sure the impression is properly labeled and stored in a plastic container for processing by the odontologist.

What the Dentist Does Next

Once all of the available bitemark evidence has be documented, collected, and inventoried, the forensic dentist must render an opinion. This opinion initially must be just on the value of the bitemark evidence until DNA evidence is available.

Analyzing the Suspect's Dental Evidence

It is inadvisable to attempt to create a dental profile of the biter from the resultant injury. Due to the range of distortion possible, it is likely that the overall dental configuration of the biter will not transfer faithfully to skin. Recent research has shown that there can be marked deviation in a bitemark as compared to the dentition that caused it. Bitemark profiling can lead to bias, an inaccurate scenario account, and perpetrator misidentification. This can steer the case completely in the wrong direction while using up valuable time and resources.

Objects Bitten: How Certain Is the Dentist About the Biter?

Human bitemarks that are sufficient to identify just one person are rare because skin injuries are of very low detail or "resolution." These injury types are commonly so vague as to result in multiple sets of teeth of totally unassociated people fitting "better" than a suspect's teeth. Odontologists differ widely in the importance of any type of "match" as a result of the weak details seen in bitemarks. The odontologists using the ABFO voluntary *Bitemark Standards and Guidelines* have three levels of certainty or confidence that a particular person created a bitemark (this may vary due to the ABFO regularly changing its suggested nomenclature regarding bitemark levels of confidence). The biter may be labeled a *cannot be excluded as the biter,* a *possible biter*, a *probable biter*, or *with a high level of confidence is the biter*. These levels of confidence are opinion based, since no supporting data can be used to express the "chance match" of an innocent person's teeth with the bitemark pattern.

This problem is one of the facts that the 2009 NAS report used to determine bitemark evidence in skin as unreliable [14]. The opposite odontological opinion also exists, wherein the biter is "excluded" or eliminated from the investigation. Additionally, the evidence itself may be "inconclusive" as flawed or so fragmentary as to make it worthless for forensic physical comparison analysis. Do not forget, however, that once a bitemark is made, there is transfer of saliva onto the bitten surface, whatever that object may be. This makes the bitemark a dual source of evidence and subject to a physical analysis of the marks patterns and also the subject of biological analysis of the DNA contained in that saliva. Chapter 8 contains more information about DNA processing of biological evidence associated with dental evidence. The DNA results should be considered independent of any dentist's opinion regarding the bite injury pattern.

What the Dentist Looks for in the Suspect's Mouth

Bitemark analysis uses features such as tooth size and shape, chips and fractures, arch shape, tooth alignment, missing teeth, and the lengths of the dentition to identify one person from another. The weight given to these features in establishing a "positive match" is the dentist's opinion. The equivalent features in tool mark analysis are called *accidental characteristics*. The dental equivalent means a change to a class characteristic (a tooth's general shape) due to events such as wear, accident, or unusual dental restorations. The best opinion possible is when the dentist says, "Teeth like the suspect's could have made the bitemark." The dentist then has to explain what is so special about these features seen in both the bitemark and a suspect biter.

Avoiding Bitemark Misdiagnoses

Ringworm, heel marks, defibrillator paddles, insect bites, and animal bites have been mistaken for human bitemarks on human skin. The experienced odontologist should recognize the difference and understand that faint injuries on skin can be ambiguous if the patterns are incomplete or, in the case of insects bites, unusually repetitive in appearance. It is essential that the dentist have a firm understanding of postmortem changes seen in dead bodies as well as skin pattern effects from animal and insect predation. Before or after death, insect bites will *not* exhibit underlying bruises in the subdermal layers. This is only observable through incisions made through the skin by the forensic pathologist.

What Makes a Bitemark Capable of Identifying One Person?

The question of forensic value or "weight" of a bitemark is a personal decision of the odontologist. There are no defined statistics or guidelines that ensure that a bitemark will be equally weighed by multiple odontologists. Expert narratives of dentists testifying that a "positive identification" has been made speak of "distinctive, rare, or unique" features in the bitemark that correlate to a particular suspect. It might be assumed that the mark itself, in these cases, shows a collection of single-tooth marks. As the odontologist's attitude on what constitutes "uniqueness" is not derived from quantitative values or population data profiles, caution must be foremost in the investigator's mind on this subject.

Calibration (consistency of results) of expert opinions on a particular bitemark is low [15]. Adding to bitemark challenges are the layman (jury) and some judiciary having to listen to the words describing the odontologist's findings and then having to reach their own opinion on the question of identity. If a bitemark expert isn't qualified to render a scientifically validated and reproducible opinion, then the jury and the judge behind the bench shouldn't be asked to attempt to solve this dilemma. The range of identification value of skin injuries is very broad. The conservative approach for bitemark analysis considers the limitations to the techniques and the opinions presently available to the dentist. These problems are why DNA testing should override any bitemark opinion in casework. A bitemark opinion may lead investigators to a possible suspect, where DNA sampling and testing might be available. Few believe that a bitemark opinion should be entered into court as a standalone opinion of the defendant's guilt. (See Chapter 7 for a more detailed discussion.)

Investigators should be aware that indistinct bitemarks are the norm, and it is faulty science to interpret a skin pattern duplicating the teeth of just one person. An example of an excellent bitemark case is described in Figure 22. This case shows how a person's crooked teeth can lead to an analysis that corroborates a victim's story of assault by an identified suspect. The picture in Figure 22 is a good "orientation" image. It shows the general anatomical location of the injury. The shape of the injury would slightly change if the victim twisted or rotated her neck. Other areas of the body are even more susceptible to posture-induced shape change. Biceps, legs, and so forth should be photographed in all possible natural postures. The neck picture in Figure 23 shows how the investigator captured a close-up view of this neck abrasion and properly placed a scale. Figure 24 shows another example.

The forensic dentist can make a direct superimposition of the suspect's dental models onto the properly enlarged photograph of the bite injury. Figure 25 shows this procedure. This should not be the only method of comparison due to the plaster models blocking much of the image of the bitemark. The use of an exemplar of the suspect's teeth (i.e., an overlay) and the bite injury is seen in Figure 26.

FIGURE 22 This bitemark victim rendered her attacker unconscious after a short struggle. The suspect was apprehended at the scene. The patterned injury on her neck is digitally enhanced for slightly better contrast.

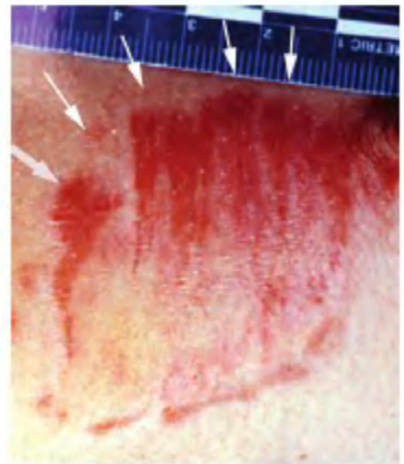

FIGURE 23 The white arrows point to the edges of the abrasion that reflects the arrangement of the biter's upper front teeth. The left two arrows indicate a "gap" or "nonmarking tooth."

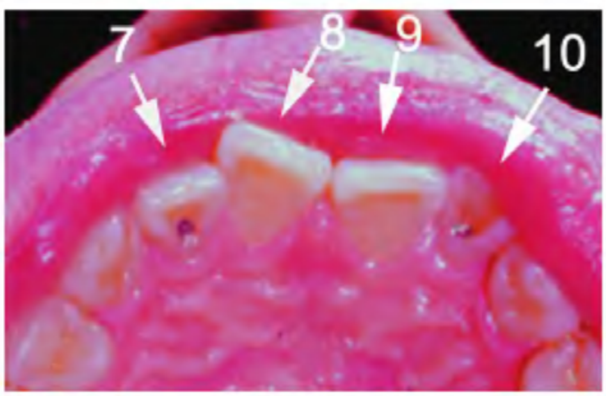

FIGURE 24 This is a picture of the suspect's (later, defendant's) upper front teeth. The picture has been intentionally reversed to correspond to the orientation of Figure 23. The color is enhanced slightly for better contrast. The attacker's upper four front teeth (labeled #7, 8, 9, and 10) show irregular alignment. Tooth #10 is pushed out toward the lip and is shorter than the other three teeth. This feature, where #10 could not make as much damage as #9 or #11, is reflected in Figure 23 along the left arrows.

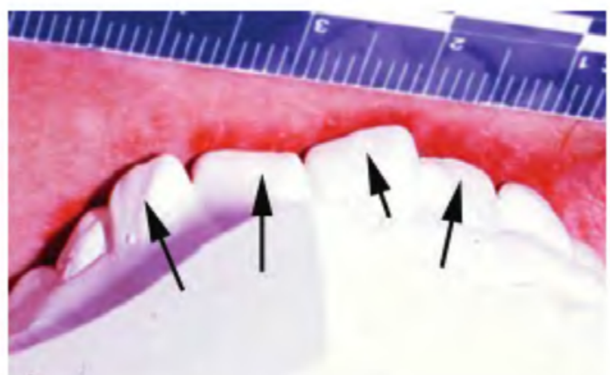

FIGURE 25 This comparison with the dental stone models and the injury has the teeth edges placed slightly below the margin (edge) of the injury. Tooth #10 is indicated by the left black arrow and clearly is above the level of adjacent teeth #9 and #10.

Evidence Collection Protocols

The forensic dental community possesses a detailed protocol for bitemark evidence collection in the *ABFO Bitemark Standards and Guidelines* (*http://forensic.to/webhome/bitemarks*; *forensicdentistryonline.com; abfo.org*).

FIGURE 26 The edges of the suspect's teeth are placed onto the bite injury. This method can be done completely on a computer or may be done by hand drawing the teeth on a transparent sheet of acetate and then reversing it onto the bitemark image. In either method, attention to proper scaling and orientation is paramount.

Anyone tasked with casework involving bitemarks should be familiar with this information. This compilation of steps involving bitemark collection and preservation provides a meaningful and organized checklist for both evidence scene technicians and odontologists. A typical protocol stresses extensive photography with and without scales in view, taking impressions of the bitemark site, DNA swabbing the region, and written documentation of the examination and procedures performed.

Because skin is a viscoelastic organ and changes with injury and healing, the methods of documentation and preservation of the bitemark pattern are of paramount importance. Materials and techniques must be of sufficiently high quality to minimize physical and photographic distortion. Given the curved nature of most areas of the body, camera angulation and lighting are particularly significant when photographing the injury. A scale must be included within the field of view to ensure life-size accuracy when processing the photographs. Black, white, and gray scales should be included to maintain color accuracy. Circular reference targets will reveal off-angle distortion in photographs that can later be corrected. Figure 27 shows what must be done in the situation when a scale is twisted or otherwise distorted during its use.

Initial film exposures of a bitemark should be long-range views without a ruler in order to show direction, position, and body part in perspective and in relation to victim and location (see Figure 22). Subsequent exposures should all include the scale, be close to the injury, and have the bitten object and scale parallel and on the same level. Care should be taken that photo flashes do not obscure the bitemark by “burning out” physical details.

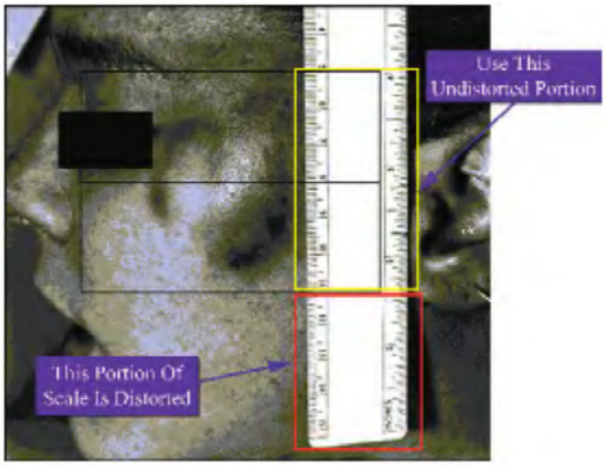

FIGURE 27 An investigator used a straight ruler to photograph the bitemark on the cheek of this victim. The red box surrounds the portion of the ruler that should not be used to enlarge the image to life size. The yellow box indicates the region of the ruler that is undistorted.

Recovery of Bitemark Evidence from the Victim

The collection of bitemark evidence can occur at many stages in an investigation and may be done by a law enforcement technician, morgue technician, pathologist, or dentist. Immediate recovery of this type of physical evidence is required due to potential degradation of the biological and physical evidence over time. Live victims heal, and dead victims are eventually buried or cremated. The evidence must be immediately photographed, impressed (in the few cases that have actual indentations), and documented in terms of location and physical characteristics. Delayed evidence collection and analysis of a "newly discovered" bitemark limits the scope of data available to the examining dentist due to unrecovered information or biological evidence. The reduction in accuracy and reliability of any opinion results from early errors or omissions. DNA collection at the time of autopsy or examination is a vital part of the complete forensic analysis when potential bitemark evidence is of interest.

A living victim with a bitemark is a high priority given the changes that take place in skin as healing occurs. It is beneficial to take additional photographs on days after the incident so changes can be documented and different details recorded.

Photographs of Potential Bitemark Evidence

Traditional forensic photography (color and black-and-white film) should be done before and after DNA collection. The purpose is to visually document the original condition of the evidence and its appearance after the DNA protocol and surface cleansing (removing blood stains) have been accomplished. Interval photography sessions (one, two, or three days, etc.) may be indicated on skin injuries that are both on live and dead individuals. Changes in skin color (from bruising) might improve in detail over time.

Scaled and Nonscaled Photographs

Long-range and close-up pictures of potential bitemarks must be obtained. These pictures should contain a reproducible scale. Proper evidence and scale positioning are important.

Artificial Lighting

Areas in a skin injury may have depth (three-dimensional features). The use of side lighting increases the ability to record these indentations via the use of low-level (rather than directly above) positioning of the flash or other light source.

Photographing Curved Surfaces

The human body has very few flat surfaces. Body positioning and muscle activity also alters the shapes of skin surfaces. The photographer must be aware that pictures of extremely curved surfaces create shapes that are distorted from real life. Incremental positioning of the camera above a curved surface (i.e., a breast) is the only way to control this type of inaccuracy. This is called "splitting the bite," where the camera is placed parallel to portions of the bitemark during multiple film exposures. A reliable measuring scale (L-shape or ruler) must be at the same level as the bitemark area of interest. Figure 28 is an example of a curved surface that will require multiple exposures to ensure accurate reproduction of the bitemark.

This forensic subject demands rigorous adherence to evidence collection, forensic dental standards, procedures, and a mature understanding of the strengths and weaknesses of the subject matter. It is recommended that inexperienced odontologists consult senior members of this discipline when embarking on actual casework. The documentation, collection, and preservation of bitemark evidence contain pitfalls and traps that an uninitiated investigator may fall victim to.

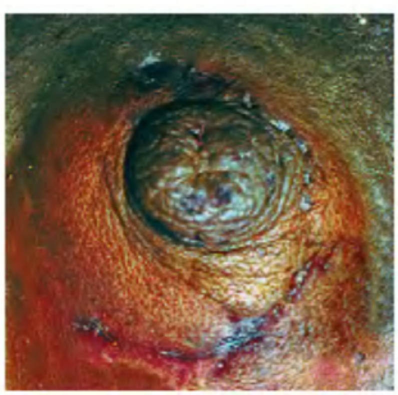

FIGURE 28 The curvature of this small breast is not reproducible in a photograph. This is why impressions of the region as well as multiple pictures with a properly positioned scale are taken. This injury was a major basis for a wrongful conviction of two homicide defendants. See the cases of Harold Hill and Dan Young in Chapter 7.

The primary source of bitemark evidence involves the original photography of the injury pattern. This process requires the use of a stringent photographic technique. Problems with capturing the image of the bitemark can result from flawed placement of the evidence, camera, light sources, and linear scale. Conclusions based on improper photography will be subject to admissibility arguments and possible exclusion in court.

Recording the Topography of a Bitemark

Bitemarks rarely exhibit indentations that can be recorded and preserved via impression taking. This type of bitemark has considerably more information than the typical bitemark that shows only bruising. Special categories of indentation evidence are foodstuffs and inanimate objects (e.g., styrofoam cups) that have surface textures amenable to three-dimensional detail. Contemporary dental impression materials that are silicon-based are highly recommended for this purpose. They have excellent dimensional stability and retain their shape over time and use. These impressions are used to create dental stone (much stronger than plaster) models (exemplars) that are compared to suspects developed in the case. Figures 29–34 show the steps involved in impressing a bitemark injury.

Dimensional Stability of the Impression Material

The impression material used in a bitemark case must be given a reinforced backing before it is removed from the object (skin or food). This is to prevent twisting or other inaccuracies from being introduced through physical distortion. Acceptable backing materials are varied (e.g., acrylic, dental stone, or silicone putty) and can be added during or after the original impression material application.

FIGURE 29 This bitemark contains three-dimensional features that should be preserved with impressions taken with proper dental materials. The use of an adhesive-backed ruler indicates the curvature of this bitten cheek, but it can be difficult to use for sizing the picture (refer back to Figure 27).

FIGURE 30 Close-up view of the bitemark. A canine (cuspid) tooth made the area of deepest skin penetration.

FIGURE 31 Polyvinylsiloxane (PVS) impression material is expressed onto the area of the bitemark using a dental syringe. The setting time of this material is variable based on the ambient temperature of the body.

FIGURE 32 Cotton backing is placed onto the impression material while it is still tacky. This will allow a plaster backing to be attached for structural stability of the impression material.

FIGURE 33 A dental plaster mix is placed onto the cotton backing. Once the setting is complete, arrows can be drawn on it to insure proper orientation.

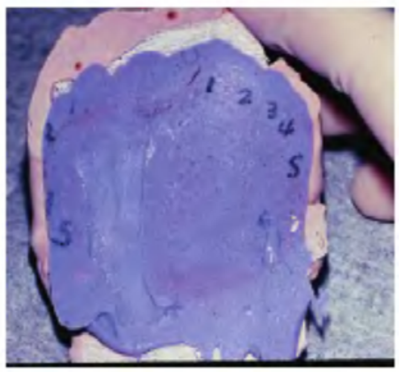

FIGURE 34 The interior surface of the bitemark impression after removal from the skin. Numbering is placed to ensure proper orientation during later analysis. The final step is to pour a dental stone material onto this impression. This recreates actual surface of the bitten skin.

Documentation of Bite Mark Evidence

Proper Record Keeping

Documentation of the location of the bitemark and the impression process includes photography of the bite site before and after taking impressions, markings on the backing of the impression, and notes.

Tissue Removal and Transillumination

The skin tissue and underlying fatty tissue may be recovered and preserved during a postmortem bitemark exam. This procedure requires the approval of the controlling coroner or medical examiner prior to initiation and should be performed after *all* other steps have been completed. The value of keeping the tissue is dependent on the dissection technique and proper stabilization of the tissue before removal. Tissue preservation in a 10% formalin solution is necessary immediately after tissue removal. The size and shape of the tissue, even with proper removal, quite often varies from either enlargement of the tissue or its shrinkage over prolonged storage in solution. Proponents of this method use the excised skin in a "transillumination" process in which a bright light is placed behind it to better visualize bruising detail in the tissue underneath the skin surface.

Live Victim Testimony

The live victim's account of the assault will be important in the analysis phase. The alleged offender may give a differing report regarding relative positions and actions. The injury pattern may show that only one of the scenarios is possible. Close attention should be paid to the position that the victim reports at the time of the assault. This is the position that the victim should assume when the photographs are taken, since posture or body positional changes affect the shape of a bitemark. In a deceased bitemark victim, this type of information is obviously unattainable. Odontologists may attempt to reconstruct the position of the biter and victim via the orientation of a bitemark. In vague or diffuse injury patterns, this is of questionable accuracy and reliability.

Recovery of Bitemark Evidence from a Live Person

Injuries can occur on people who do not die. The biter may be the assailant or the victim. Except for tissue removal, all of the preceding steps apply to every bitemark case. A live subject, however, must consent to the examination in writing or be subject to a court order containing the specific steps to be performed.

Laboratory Analysis of Bitemark Evidence

Serology or DNA laboratory work focuses on the swabbings taken from a possible bitten area. The best way to establish proper protocols is to contact the laboratory in your jurisdiction that will handle your casework. The best way to succeed is to plan ahead and establish collection and transport protocols that meet proper standards. Chapter 8 discusses DNA technology in more detail.

A forensic dentist should perform impressions, photographs, and other documentation of bitemark evidence. The location is usually the morgue or medical examiner facility. Additional procedures may be performed with this evidence at the dentist's own laboratory. Transport protocols and chain of custody must be maintained throughout the process.

Evidence Collection from a Suspect

The collection of dental information and data from a suspect or possible suspect is extremely important. The following is an enlarged checklist that outlines the major elements the investigator and the forensic dentist should know.

Consent of the Subject

Once the injury to the victim has been documented, it may be necessary to obtain dental impressions from any potential or alleged perpetrator(s) or suspects. Either a signed informed consent document or a court order will be necessary in order for the evidence to be admissible later in court. Most jurisdictions require that the form contain specific information on what evidence and how the evidence must be collected. Also, the odontologist should describe the procedures to the subject before performing them.

Collection Protocols

1. *Dental records:* Whenever possible, the dental records of the individual should be obtained. This will aid in establishing the suspect's dental profile and record of treatment. Sometimes a suspect will intentionally have front teeth altered or pulled after leaving a bitemark.
2. *Photographic documentation of the dentition:* Photographs of the dentition should be taken by the forensic dentist or by a technician under the odontologist's direction. A scale such as the ABFO No. 2 scale should be utilized when using a scale in these photographs. Video or digital imaging can be used to document the dentition when used *in addition* to conventional photography. Tripods and/or focusing rails can be used at the discretion of the photographer.
   - *Extraoral photographs:* A frontal full-face view and a view with the teeth in centric should be taken.
   - *Intraoral photographs:* maxillary and mandibular occlusal views of the dentition should be taken whenever possible. Lateral views of the dentition may also be taken.
3. *Clinical examinations:* Extraoral considerations include the following:
   - Maximum vertical opening and any deviations should be noted whenever possible. This measures how wide the person can open his or her mouth.
   - Evidence of surgery, trauma, and/or facial asymmetry should be noted.
   - TMJ (jaw joint) function may be checked in addition to the previous observations.
   - Muscle tone and balance may also be checked in addition to the previous observations.

   Intraoral considerations include the following:
   - Missing and misaligned of teeth should be noted.
   - Broken and restored teeth should be noted.

- The periodontal condition and tooth mobility should be noted whenever possible.
- Previous dental charts should be reviewed if available.
- Occlusal disharmonies should be noted whenever possible.
- The tongue size and function may be noted *in addition* to the previous observations.
- The bite classification may be noted *in addition* to the previous observations.

4. *Dental impressions*
   - Dental impressions, following the ABFO guidelines, should be taken by the forensic dentist or by a technician under the odontologist's direction.
   - Bite exemplars should be obtained in addition to the dental impressions.
5. *Saliva samples*
   - Saliva swabbings should be obtained if appropriate.

Dental and DNA Evidence Collection from a Suspect

In order for models of the suspect's teeth to be created, impressions are first taken. A stone mixture is poured into the impressions, which hardens and duplicates the dentition in question. Photographs, written or audiotaped notes, and wax bite impressions will be necessary to complete the recording process. A DNA sample taken from inside the mouth (buccal swab) should also be considered as a means of collecting. See Chapter 8 for specific details on this process.

Special note is taken of unusual characteristics such as chipped or worn teeth, the presence of developmental mammelons (incisal edge with scalloped appearance), and spaces due to missing teeth, crowding, and position in the jaws relative to the cheek or tongue side. There may also be differences in the plane of occlusion from one tooth to another. Each of these factors will have a bearing on the injury pattern caused by the biter.

Comparison of Injury and Suspect Dental Exemplars

Once all of the documentation requirements have been satisfied for both the bitemark and the dentition of the suspect, a comparison analysis is begun. (Chapter 16 discusses the entire process of comparison via digital imaging.) The stone models of the suspect are compared to the photographs of the bitemark, which have been enlarged to a 1:1 life-size ratio. The general arch size and shape are the first characteristics considered. If there is a discrepancy, the suspect can be eliminated. The analysis continues in the absence of a discrepancy. Offenders may even try to alter their teeth by artificially causing wear or fractures in the hopes that they can eliminate themselves as suspects.

The models are oriented in the direction that corresponds to the position the offender was in at the time of the attack, if credible information is available. No scientific allowances, however, can be made for varying amounts of pressure the skin was subjected to during biting. Dominant features of the dentition are inspected first for discordance with the bitemark. Explanations for discordance (while asserting a bite's identification) cannot be scientifically proven and should be considered bias. The wax bite impressions are used for comparison with the bitemark although they have no relevance to skin and should be understood to be subjectively produced. Overlay transparencies can be computer generated from the models that accentuate the incisal edges and cusps of the teeth, facilitating the comparison process. Digital or photographic rectification of distorted bitemarks' photographs is considered vital in order to control the photographic distortion seen in crime scene and autopsy pictures.

Summary

Bitemark analysis by dentists has 60 years of use in the U S. courts. This chapter hopefully provides a person in law enforcement or other branches of investigation the steps and rationale in the recognition, collection, and preservation of this type of physical forensic evidence. Because skin injuries are of very low detail or "resolution" these injury types are commonly so vague that multiple sets of teeth from totally unassociated people may "fit" better than a suspect's teeth. Odontologists differ widely in opinion concerning the importance of any type of "match" as a result of the ambiguous and vague details seen in bitemarks. Such differences in opinion point to the ambiguous and physically distorted nature of the evidence and the nonscientific nature of bitemark analysis opinions. In response to these limitations, bitemarks should be used only as identifying markers for DNA collection.

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"For example, forensic odontology might not be sufficiently grounded in science to be admissible under *Daubert*, but this discipline might be able to reliably exclude a suspect, thereby enabling law enforcement to focus its efforts on other suspects. And forensic science methods that do not meet the standards of admissible evidence might still offer leads to advance an investigation."

[11] Wisconsin case calls bitemark evidence into question again; http://www.innocenceproject.org/Content/1463.php

[12] Op. cit. 2, 3, and 4

[13] Cases Where DNA Revealed that Bite Mark Analysis Led to Wrongful Arrests and Convictions; http://www.innocenceproject.org/Content/394.php

[14] 2009 NAS Report, 5-36
The NAS report on this topic reads:
No thorough study has been conducted of large populations to establish the uniqueness of bitemarks; theoretical studies promoting the uniqueness theory include more teeth than are seen in most bitemarks submitted for comparison. There is no central repository of bitemarks and patterns. Most comparisons are made between the bitemark and dental casts of an individual or individuals of interest. Rarely are comparisons made between the bitemark and a number of models from other individuals in addition to those of the individual in question. If a bitemark is compared to a dental cast using the guidelines of the ABFO, and the suspect providing the dental cast cannot be eliminated as a person who could have made the bite, there is no established science indicating what percentage of the population or subgroup of the population could also have produced the bite. This follows from the basic problems inherent in bitemark analysis and interpretation.

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Bitemarks in England and Wales

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Introduction

This chapter examines the current status of bitemark analysis in England and Wales. The legal system in Northern Ireland is broadly similar, but readers interested in the evidence collection process in Scotland should consult the Police, Public Order and Criminal Justice (Scotland) Act of 2006. It should also be remembered that although the Scottish legal system employs the same burden of proof as that in England and Wales, the verdicts juries can reach are different. Readers interested in the Scottish system can find out more at the Scottish Law website.

Bitemark evidence is most commonly seen in one of two judicial venues—in either the criminal courts (frequently Crown Court cases) or the family courts—often to decide the future living arrangements of children. Almost universally, forensic dentists are instructed by one of two groups to act: either one of the territorial or special (i.e., transport) police forces or a solicitor acting in the defense of a client. Occasionally, a coroner or other individual may request an examination of a suspected bite injury.

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The Process: Identifying a Bitemark and Collecting Evidence

If an injury has been identified as a suspected bitemark on either a living or deceased victim, there are a number of steps that should be followed in order to ensure that the evidence is recovered correctly and that further assessment will be possible.

Photography

High-quality photography is a key component of any bitemark assessment. Contact should be made with either the Scenes of Crime Officers or the Forensic Photography Unit to determine which officers have received training in bitemark photography. Consent should be taken from a living victim for photography, and initial questioning should ascertain the relative positions of individuals with respect to movement and body position.

All police forces in the United Kingdom now use digital photography, and numerous photographs of the injury should be taken to include both scaled and nonscaled images, as well as the use of special techniques such as UV. Photographic techniques are described in detail in Chapter 15. The British Association of Forensic Odontologists (*www.bafo.org.uk*) recommends that the following views be taken:

- General view of victim and location of bitemark
- View of bitemark without scale
- View of bitemark with rigid right-angled (e.g., ABFO No. 2) scale in same plane as bitemark and parallel to film plane
- Repeat photography (can be daily) until bitemark fades.
- Consider use of specialist film only in exceptional circumstances (e.g., UV light, limited wavelength light).
- If anatomical location of bitemark is susceptible to posture distortion, photograph in range of positional possibilities.
- When curvature of anatomical location prevents a single view of the bitemark, multiple photographs are required of each arch.

Identifying an Odontologist

Photography should be initiated as soon as possible, but the forensic dentist may wish to describe specific views that are required—or even attend to take his or her own photographs. Many police forces will have an odontolgist that they use regularly, while others may use forensic dental advice less commonly.

There have been a number of changes in the United Kingdom forensics regulatory scene over the past five years. For some time now, the Council for the Registration of Forensic Practitioners (CRFP) claimed to provide a list of "approved" specialists in a number of disciplines, including odontology. Those on the list were required to provide examples of casework, qualifications, and continuing professional development credits. Case assessors were charged with examining the submitted materials and permitting or denying the applicant for the list. Plagued with issues from its inception, the CRFP ceased trading in March 2009.

There has not yet been an obvious successor to the organization, but police officers who are looking for an odontologist can consult the following sources:

- NPIA—The national policing improvement authority maintains a list of operationally active odontologists (*http://www.npia.police.uk*).
- The British Association of Forensic Odontologists (BAFO) maintains a list that is available on their website (*http://www.bafo.org.uk/list.php*).
- The Forensic Science Service operates a new range of services under the Natural Justice banner; odontology may be offered in time (*http://www.forensic.gov.uk*).

It should be noted that currently none of these organizations "accredit" the odontologist but simply provide signposting services. The Forensic Science Service does provide assurances on the governance, systems, and operations of the provider. Police officers or instructing solicitors may wish to check that their odontologist is licensed to practice in the United Kingdom. This is a result of being registered with the General Dental Council (*www.gdc.uk.org*), and their registers are available online.

Before contacting an odontologist, police officers should ensure that their forensic submissions department does not have a contracted odontologist and that the necessary administration has been undertaken in order to issue a purchase order or forensic request. Solicitors would normally require a quotation from the provider before making a claim to either the legal services commission or their privately funded client.

Further Evidence Collection

While photography remains the most important component of evidence collection, there are a range of other elements that should be undertaken; the most important of these is the collection of DNA evidence. It is recommended that after photography is completed, the bitemark should be swabbed for salivary DNA evidence. Again, this procedure is described more completely in Chapter 15. A double swab is usually performed in the United Kingdom, where a wet swab is followed by a dry swab. Currently, DNA collection is recommended in all cases, irrespective of likely success of recovery—that is, salivary DNA should be taken from bitemarks present on rape victims who have washed.

While described in the ABFO bitemark guidelines, it is not routine in the United Kingdom to take impressions of the bitemark itself, nor is the collection of postmortem skin for the purposes of transillumination or other studies. This is for two main reasons: First, evidence strongly suggests that skin samples cannot be secured without distortion [1], and second, the Human Tissue Act of 2004 makes the retention of such samples complex [2, 3] and beyond the estate capabilities of many forensic dentists.

It is considered good practice to take a dental impression of the bite victim. This will enable a self-inflicted bitemark to be ruled out, but even if the anatomical location prevents this, a suspect may be found later with a bite injury that is amenable to analysis. It is important to note that this evidence collection can be performed by a general dental practitioner. This is described in more detail in the suspect evidence collection section following.

Opinion

The evidence from the bite victim (who may well be a suspect in the case) should now be properly collected, and this is an appropriate time to gain the opinion of the odontologist before any further steps are taken. For a variety of reasons—usually related to time pressures associated with arrest and charge procedures—further evidence collection may have to proceed without the interim opinion.

Interim Opinion

It is the author's view that an interim opinion is a vital part of the analysis process. Gaining a view at this stage allows *expectations regarding the injury to be managed, unnecessary evidence collection to be avoided, and costs to be reduced*. The images of the suspected bitemark should be provided to the odontologist for a view. Digital images may be sent to secure e-mail addresses—for example, those used by the nhs.net for the transmission of confidential hospital records, sent by secure mail or hand delivered. At this stage, the forensic dentist should be able to render an opinion on whether or not the injury is a bitemark and place his or her conclusion level in the following range:

- *Exclusion:* The injury is not a bitemark.
- *Possible:* An injury showing a pattern that may or may not have been caused by teeth; the injury may have been caused by other factors, but biting cannot be ruled out.
- *Probable:* The pattern of the injury strongly suggests or supports an origin from teeth but could conceivably be caused by something else.
- *Definite*: There is no reasonable doubt that teeth created the injury.

Many odontologists will also provide, at this stage, an assessment of the forensic value of the bitemark—that is, the presence of gross, class, or unique characteristics and the likelihood of the injury being valuable in a criminal or family court. It is important to note that many bitemarks, especially those on children, will commence with a family court matter, where the judicial burden of proof is "balance of probabilities" and may well end up in criminal court where the burden is "beyond a reasonable doubt."

A significance and severity scale can be helpful, as this provides investigators, lawyers, physicians, social workers, and odontologists a scale upon which bitemarks can be classified. Such scales can be helpful for investigators who can understand the limitations of certain injuries and the impact that this lack of forensic evidence has on their subsequent analysis. An example of such a scale is shown in Figure 1. This scale was recently used in research examining the forensic quality of bitemarks where there had been a DNA exoneration; not surprisingly, injuries with low forensic detail were more likely to lead to expert disagreement and potentially a wrongful conviction [4].

It would be usual for an odontologist to be able to state that the injury would be suitable for one of the following:

- No further analysis
- Possible comparison for the purposes of exclusion of a suspect
- Possible comparison of the purposes of inclusion of a suspect

Once the view of the forensic dentist has been sought, an interim statement (if instructed by the police) or report (if instructed by a solicitor) should follow. If further investigation of the injury is recommended, then evidence must be sought from the bite suspect.

The Process: Evidence Collection from the Bite Suspect(s)

This process involves mainly the collection of dental impressions from a bite suspect. Typically, the bite suspect is also the suspect in the case, but there are occasions when a victim has bitten his or her attacker, or a sibling is involved. If the person is a suspect in a criminal investigation, then consent must be taken from the individual before the impressions can be taken. They are considered intimate samples under the Police and Criminal Evidence Act (PACE), so if consent is not provided, the trier of fact is able to take a negative inference. Due to this, lack of consent is rare [5, 6].

Police officers and others who require dental impressions should be aware that any qualified dentist can take such samples. While it may be preferable to have a forensic dentist undertake the procedure, in the United Kingdom, the number of operational forensic dentists and their geographical spread often make this impossible. A local dentist, or one found from calling the NHS Dental Helpline, should be able to attend and take dental impressions. Ideally, these should be in a vinyl-poly siloxane impression material, but, if it is poured quickly, alginate is acceptable.

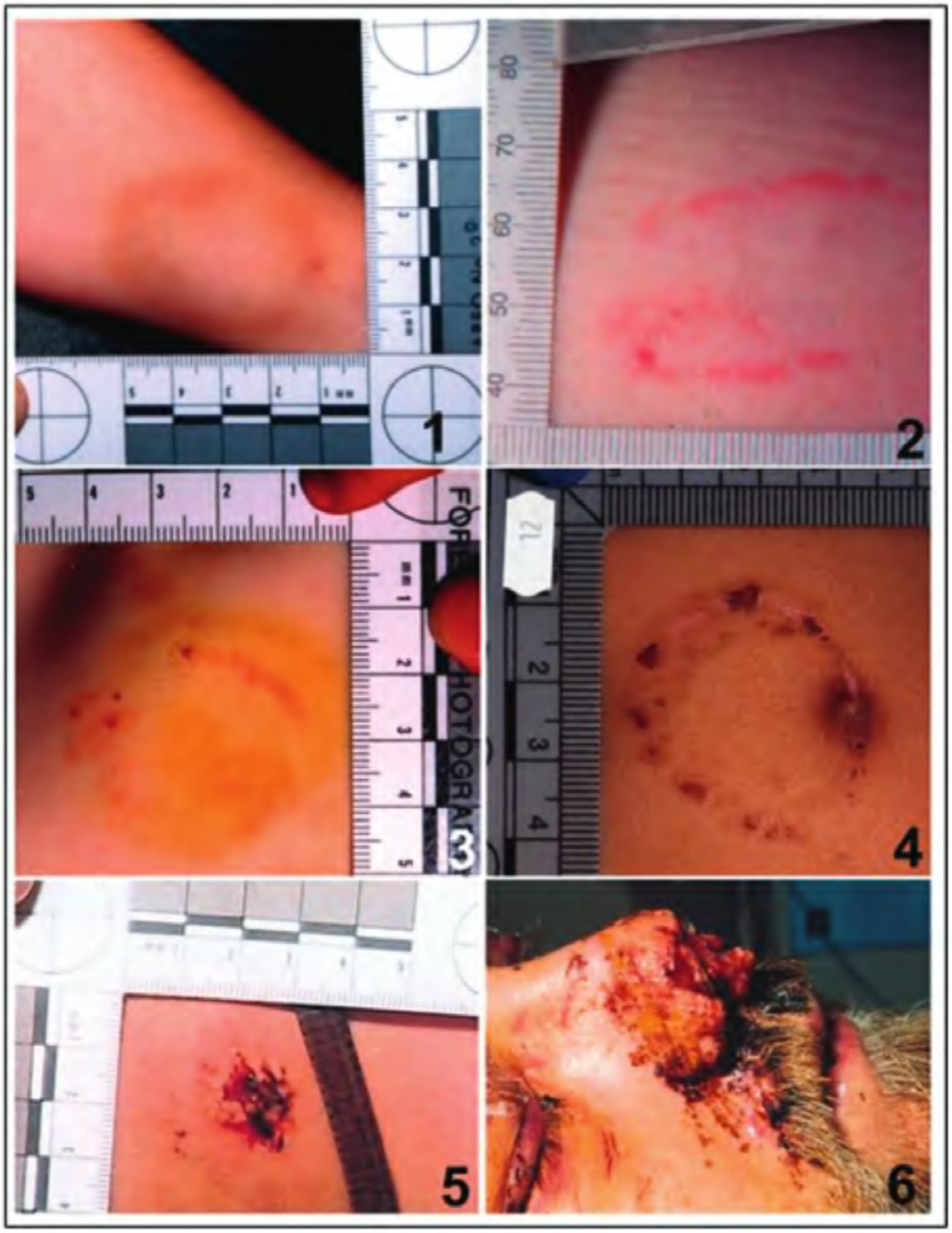

FIGURE 1 This visual scale illustrates an increasing level of bitemark severity, from mild diffuse bruising (1) to an avulsive injury (6). The greatest forensic significance lies at levels 3 and 4.

Most impressions are collected in the medial room of a custody suite or someplace similar. Individuals who are in the family court system or who are not suspects should make arrangements for their impressions to be taken, and dental casts should be produced by their own dentists. In either case, a simple witness statement is required to describe the taking of the impressions, their pouring into plaster models, and their receipt to the investigating officer.

Other items of evidence that should be collected at this stage include photographs of the suspect's anterior dentition (to indicate the condition at the time vs. at trial some months, even years, later) and a wax wafer bite for metric analysis purposes [5, 6]. The suspect should be questioned to determine when he or she last received dental treatment, and any recent trauma or other changes to the teeth should be noted. Again, the evidence collection is identical to that described in Chapter 15.

The Process: Comparison

This process has been the subject of debate in the United States, and now it is increasingly becoming an issue in the United Kingdom and Europe. While the appellate system in the United States is now replete with cases of wrongful convictions linked to bitemarks, there have, to date, been no cases in the United Kingdom where a bitemark assessment has been shown to lead to a miscarriage of justice [7]. However, given that the same physical comparative processes are undertaken, it may just be a simple function of numbers of cases in the two jurisdictions that accounts for the differences to date.

Odontologists are becoming increasingly aware of the fragility of the evidence base for bitemark assessments [8]. The current BAFO guidelines for the conclusion levels to be used in comparative analyses are as follows:

- *Excluded:* There are discrepancies between the bitemark and the suspect's dentition that exclude the individual from having made the mark.
- *Inconclusive:* There is insufficient forensic detail or evidence to draw any conclusion on the link between the suspect's dentition and the bitemark injury.
- *Possible biter:* Teeth like the suspect's could be expected to create a mark like the one examined, but so could other dentitions.
- *Probable biter:* The suspect most likely made the bite; most people in the population would not leave such a mark.
- *Beyond reasonable doubt:* The suspect is identified for all practical purposes by the mark. Any expert with similar training and experience evaluating the same evidence should come to the same conclusion.

These conclusion levels are similar to those previously adopted by the ABFO. They now differ considerably due to the ABFO's attempts to correct its terminology in the face of current criticisms (see Chapter 7). Despite the difference in conclusion level, the analysis techniques employed are identical to those undertaken elsewhere in the world—namely, a metric analysis followed by, if appropriate, a pattern analysis—usually by means of a transparent overlay.

The Process: Report and Trial

Once completed with processing, the odontologist will provide the instructing body with a report that will contain the results of the comparison as well as a detailed assessment of the injury. Reports will typically contain the following:

- An introduction on the case and the request to be involved
- The materials that the odontologist has used and has been provided with
- The timeline of the crime
- Classification of the injury and of the degree of association with the suspect

In the United Kingdom, it is a requirement of civil courts, family courts, and, increasingly, criminal courts that when an opinion is expressed in an expert's report, this opinion is provided on a scale of certainty that adequate reason is provided for that certainty and that the reader of the report is aware of the other conclusion levels available. In essence, the report should place the conclusion into context for the readers.

Forensic dentists in the United Kingdom are broadly similar in demographics to their United States and European counterparts. They are often general dental practitioners working as owners or associates in NHS or private practices. As such, attendance at court proves difficult. The inability to cancel patients at short notice or to jeopardize significant income by blocking out large sections of a clinical calendar has led many United Kingdom odontologists to undertake only identification work.

By working with the court authorities, it is possible to minimize the impact of court on clinical practice. For example, medical and dental experts are often heard out of order during a trial, not only so the jury can hear both opinions back to back but also so the experts can hear one another's testimonies and provide guidance notes to their attorneys. Odontologists may also request to be placed on court notice, meaning that they can present at court within an hour's notice of being contacted. This is very helpful in those cases where a guilty plea is suspected or if a court case is running fast or slow. In short, the Crown Prosecution Service, the Court Service, and the Witness care teams are all eager to ensure that experts are facilitated to attend court.

When giving testimony on forensic matters, odontologists are considered expert witnesses rather than professional witnesses. As such, a discretionary rather than fixed fee is usually awarded, and the hourly or daily court fee of the expert should therefore be determined prior to instruction. The British Association of Forensic Odontology issues a fee guidance document, although odontologists are free to set their own charges, and while many restrict their fees for identification work, there can be considerable cost to obtaining a bitemark opinion.

Summary

The state of bitemark analyses is broadly similar in the United Kingdom and the United States, although the high-profile exoneration cases have not been seen (yet) in the United Kingdom. Despite this, odontologists are increasingly becoming conservative in their assessments of bitemarks. The evidence collection, analysis, and report writing processes share common aspects, although the conclusion levels that are employed differ.

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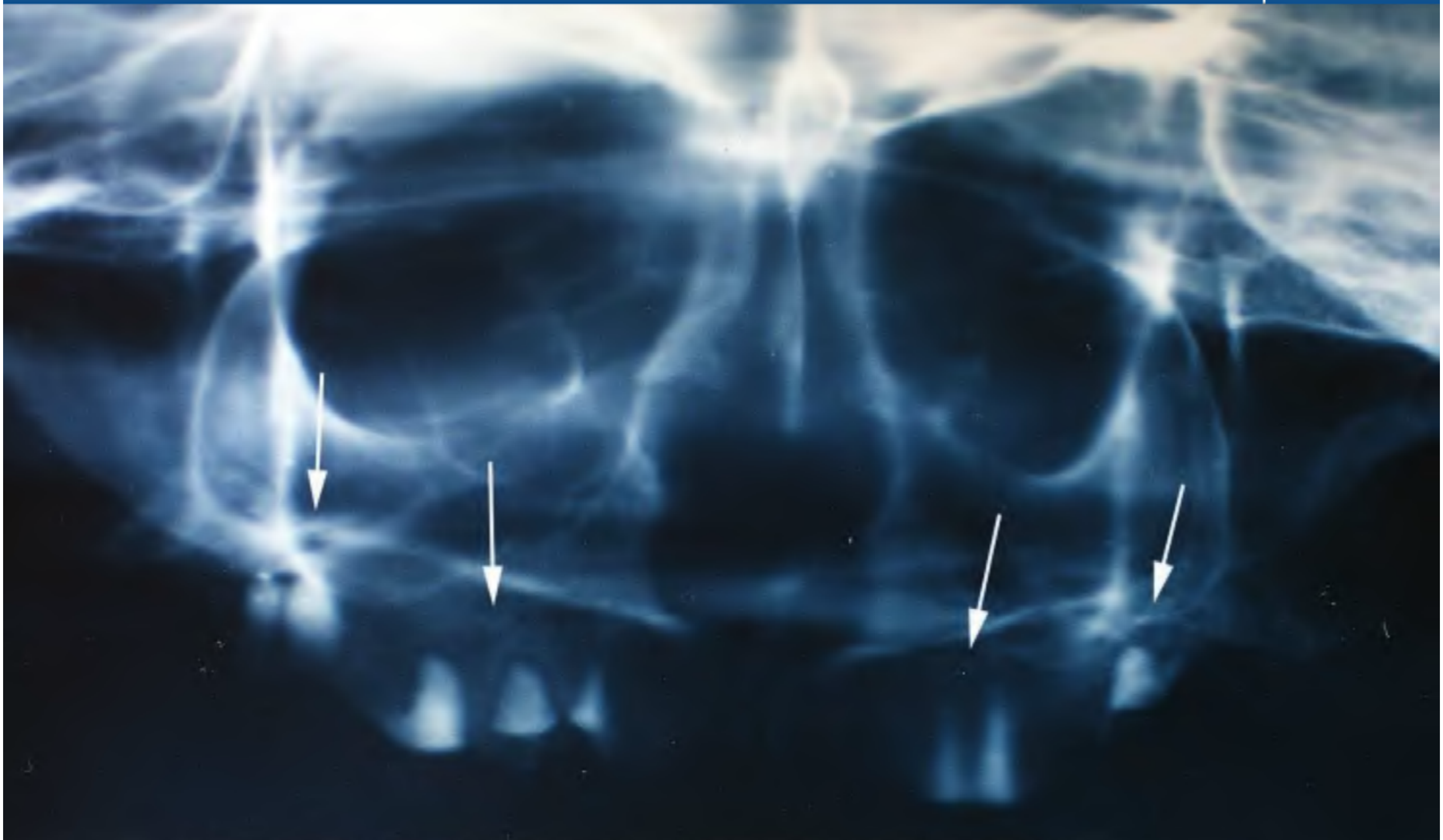

Legal Issues Concerning Bitemark Evidence in the United States

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Law enforcement and other disciplines should understand, in a nonlawyer way, how experts and courts view the acceptance of forensic evidence and the opinions regarding forensic odontology. This chapter gives an overview on these subjects and provides the latest information. Dental identification from teeth (i.e., missing persons) has a history with little legal disagreement. The history of identification from bitemarks shows the need for considerable caution in its use in the legal arena and is a major subject of this chapter. Later in this chapter, there is a review of the odontological literature that

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exists to support what dentists say about bitemark identification. The latest published literature casts doubt that there is any scientific proof that a person can be positively identified from a bitemark [1–3]. Chapter 6 discusses this in more detail.

Legal Factors of Evidence Collection and Its Use in Court

The focus of this book is on collection techniques and methods for forensic investigation involving dental evidence. Just as important are the legal steps necessary to make sure efforts in the field and laboratory are allowed into court proceedings. The typical criminal proceeding in the United States has the prosecution introducing evidence that either directly or indirectly (by assumption) implicates someone as the perpetrator of a crime. It is obvious that the best defense for such accusations of guilt is to get the court to refuse to accept it at trial. This argument regarding inadmissibility is the defense counsel's major strategy even before a trial begins. The defense also has the right to introduce forensic evidence supporting their arguments regarding the innocence of their client.

The legal basis for a motion to deny evidence (i.e., to exclude) from a criminal trial can be that the proponent (the person wanting it admitted) violated the defendant's constitutional right to protection against an unlawful search or seizure by the police. Evidence resulting from this illegal search or seizure is also subject to courtroom exclusion. The general rules regarding this are important for the investigator to understand.

The Fourth Amendment: Arrest Search and Seizure

The Fourth Amendment applies to both state and federal law enforcement. It reads, "The right of the people to be secure in their persons, houses, papers, and effects, against unreasonable searches and seizures shall not be violated, and no warrants shall issue, but upon probable cause, supported by oath or affirmation, and specifically describing the place to be searched, and the person or things to be seized."

The Exclusionary Rule

This is the rule that is argued in court when law enforcement may have failed to follow proper procedure in collecting evidence. The rule states, "Evidence that is obtained by unreasonable search or seizure must be excluded from evidence." Evidence obtained by private parties is not subject to the Exclusionary Rule.

Fruits of the Poisonous Tree

This colorful phrase prevents the state from using *any* evidence remotely derived from other illegally obtained evidence.

Search Warrant Details

The specificity requirement of this rule provides that items to be seized must be described with as much detail as reasonably possible. Obtaining dental evidence from a person falls under this rule. Protecting the evidence involves numerous procedural steps that agencies should already have in place prior to performing any search. Dental evidence at a scene is lawfully obtained via these steps. You must consult these procedures prior to conducting any evidence collection.

Evidence taken from a suspect must also pass muster in the legal arena. The most common means of doing this is to get the subject's written permission (e.g., an informed consent) to obtain evidence or to have a court order approved for the specific types of evidence (saliva swab, dental impressions, etc.) needed. The methods used to obtain this evidence should also be clearly written and described in the consent or court order. Early bitemark cases had subjects refusing to admit to dental impressions. This has not been considered a valid objection in the United States, since the procedure is not invasive (e.g., surgical or dangerous), and the dental information is reasonable and not considered a means of self-incrimination (e.g., the subject being forced to testify against his interests), which would be a violation of the Fifth Amendment to the U.S. Constitution.

Admissibility of Expert Evidence Based on Relevance and Scientific Reliability

In a U.S. courtroom, admissibile evidence is any testimonial, documentary, or physical evidence that is introduced to a judge and/or jury in order to establish or support a question that is being debated. In order for evidence to be admissible, it must be relevant, without being prejudicial, and it must have some proof of scientific fact. For evidence to be considered *relevant,* it must tend to prove or disprove some fact that is at issue in the proceeding.

For evidence to be considered *reliable* enough to be admitted, the party presenting the evidence must be able to show that the source of the evidence makes it so. If the evidence is in the form of witness testimony, the party introducing the evidence must present proof of the credibility of the witness and his/her knowledge of the matters being presented. Statements from people who are not present to testify (hearsay) are generally barred for their lack of reliability. If the evidence is documentary, the party bringing the evidence forward must be able to show that it is authentic and must be able to demonstrate the chain of custody from the original source to the present holder. The trial judge performs a “gatekeeping” role in excluding unreliable testimony. The U.S. Supreme Court addressed (in 1993) the reliability requirement for experts in the landmark case *Daubert v. Merrell Dow Pharmaceuticals, Inc.* [4]. The Court laid out four nonexclusive factors that trial courts may consider when evaluating scientific expert reliability:

1. Whether scientific evidence has been tested and the methodology with which it has been tested
2. Whether the evidence has been subjected to peer review or professional publication
3. Whether a potential rate of error is known
4. Whether the evidence is generally accepted in the scientific community

In 1999, the *Kumho* opinion extended these rules to scientific analysis and testimony [5].

National Acadamy of Sciences (NAS) 2009 Review of Bitemark Evidence

The 60 years of judicial acceptance of bitemark evidence may be experiencing changes due to the NAS report and new research in skin and the human dentition (see [1] and [2]). Later in this chapter, details are outlined of the judicial history of bitemarks prior to this 2009 congressional report and research from 2009 and 2010.

The report was sponsored by the National Institute of Justice at the request of U.S. Congress. The National Academy of Sciences, National Academy of Engineering, Institute of Medicine, and National Research Council make up the National Academies. They are private, nonprofit institutions that provide science, technology, and health policy advice under congressional mandate. The National Research Council is the principal operating agency of the National Academy of Sciences and the National Academy of Engineering.

Report Concerns About Certain Forensic Disciplines

A National Research Council report entitled "Strengthening Forensic Science in the United States: A Path Forward (2009) found the following:

1. Serious deficiencies in the nation's forensic science system and called for major reforms and new research
2. A lack of rigorous and mandatory certification programs for forensic scientists
3. A lack of strong standards and protocols for analyzing and reporting on evidence
4. An inadequate amount of peer-reviewed, published studies establishing the scientific bases and reliability of many forensic methods

This statement considers the reliability of fingerprints, hair analysis, bitemarks, and ballistics [6]:

> *Forensic evidence is often offered in criminal prosecutions and civil litigation to support conclusions about individualization—in other words, to "match" a piece of evidence to a particular person, weapon, or other source. But with the exception of nuclear DNA analysis, the report says, no forensic method has been rigorously shown able to consistently, and with a high degree of certainty, demonstrate a connection between evidence and a specific individual or source. Non-DNA forensic disciplines have important roles, but many need substantial research to validate basic premises and techniques, assess limitations, and discern the sources and magnitude of error, said the committee that wrote the report. Even methods that are too imprecise to identify a specific individual can provide valuable information and help narrow the range of possible suspects or sources.*

Report Concerns About Bitemark Analysis

The section directly addressing bitemark analysis found that there is no scientific research showing any particular uniqueness to human dentition. This is reflected in the bitemark research referred to in the FDE chapter on bitemarks. As stated in scientific literature on bitemarks, even if such uniqueness could be established, it is even less clear that said uniqueness would be transferred when human teeth bite down on human skin. The study finds that due to the elasticity of human skin, swelling and healing, and unevenness of the skin's surface, the marks made from a bite can be physically distorted. The study is even more skeptical of analyses done from photographs of bitemarks, given that photographs allow for further distortion of the marks [7].

The study's authors are also concerned that there is no scientific research showing that the various methods used by bitemark experts are reproducible, both "between experts and with the same expert over time." This is one of the pillars of scientific inquiry—that a scientist's results can be reproduced by other scientists. There are several studies in which bitemark experts plying their craft in controlled laboratory tests have shown "widely differing results and a high percentage of false positive matches" [8].

The authors add the following:

> *As with other "experience-based" forensic methods, forensic odontology suffers from the potential for large bias among bitemark experts in evaluating a specific bitemark in cases in which police agencies provide the suspects for comparison and a limited number of models from which to choose from in comparing the evidence. Bitemarks often are associated with highly sensationalized and prejudicial cases, and there can be a great deal of pressure on the examining expert to match a bitemark to a suspect. Blind comparisons and the use of a second expert are not widely used.*

The NAS study's bitemark section concludes:

> *Although the majority of forensic odontologists are satisfied that bitemarks can demonstrate sufficient detail for positive identification, no scientific studies support this assessment, and no large population studies have been conducted. In numerous instances, experts diverge widely in their evaluations of the same bitemark evidence.*

Bitemark testimony has been criticized basically on the same grounds as testimony by questioned document examiners and microscopic hair examiners. The committee received no evidence of an existing scientific basis for identifying an individual to the exclusion of all others. That same finding was reported in a 2001 review that "revealed a lack of valid evidence to support many of the assumptions made by forensic dentists during bitemark comparisons," which has led to questioning of the value and scientific objectivity of such evidence" [9].

The authors believe that more research is needed to see if bitemark analysis might have *some* probative value—for example, to *exclude* suspects. But there's no reliable research to back up claims that there's any real science behind the idea that an expert can positively match to a specific person a bitemark that is left on skin.

This 2009 report parallels opinions written in the legal literature by this author [10]:

> *A contemporary review of bitemark analysis techniques has summarized certain causes of unreliability in bitemark opinions used in court. These include: changes in suspects' teeth from subsequent dental disease and treatment, examiner subjectivity that overvalues common tooth characteristics poor bias control, lack of forensically relevant population studies to establish the frequencies of occurrence of common dental features, the dimensional accuracy of skin as a substrate for bitemark impressions made by these teeth and the multitude of unvalidated comparison methods and analytical procedures "recognized" and "generally accepted."*

The common debate between sparring forensic odontologists is the identification value of a bitemark and the degree of concordance of the injury to certain teeth of the defendant. The proof of a positive opinion is not based on any formal population studies that state the frequency of a chance random match with other members of a relevant population. The addition of a "dental lineup" of similar sets of teeth to the sample studied by the dentist has never been mandated to avoid expectational and contextual bias. In sharp contrast, larger DNA labs separate extraction and comparison activities.

The issue of interexaminer agreement and accuracy was studied briefly in the mid-1970s, and its findings have not been altered by later research. Using ideal laboratory conditions and evidence, experienced examiners who studied bitemark patterns in pig skin correctly identified the biter 76% of the time [10a]. A recent sampling of 49 actual bitemark cases reinforced the serious lack of agreement in courtroom testimony among odontologists [11].

Types of Dental Testimony by Dentists

Dentists testify in criminal cases about dental identification of the deceased or the identification of biters from tooth marks.

Who Can Testify as an Expert on Bitemark Evidence

The courts consider an "expert" to be a person whose knowledge, training, and experience creates an understanding of facts that are outside the abilities of the average individual. This knowledge must be relevant (be related) to the question being asked in court, such as "Is this injury a human bitemark?" or "Did this particular automobile tire fail and cause the accident?" This knowledge has to help the judge and the jury in rendering a verdict. Using this simple test, people possessing many skills are allowed into the courtroom, such as dentists, automobile tire engineers, police officers, and plumbers. The expert, once admitted, is allowed to render an opinion on matters that occurred outside his or her presence. This is a very powerful and important tool in criminal cases, where quite often both the prosecution and defense counsel have their own experts whose opinions do not agree. Experts actually reconstruct, to the best of their ability, the events that occurred during an act related to a crime. Certainly, regarding dental evidence, the best information for a court is from a certified forensic odontologist.

What Makes a Dentist a Forensic Expert?

Forensic dentistry is not recognized by the American Dental Association as a dental specialty. This attitude varies between countries. The United Kingdom has established a court certification for all forensic experts. Law enforcement, however, has relied on the dentists who assist them to be competent and familiar with forensic protocols.

The typical forensic dental expert is a practicing dentist or a dental educator. Only a handful of dentists work for federal agencies. The U.S. military has active duty dentists forensically trained through the Armed Forces Institute of Pathology (AFIP) at most major bases. The professional forensic organizations where most practicing forensic dentists belong are the American Academy of Forensic Sciences (AAFS) and the American Society of Forensic Odontology (ASFO). The AAFS has an odontology section with a membership of over 300 dentists. Their experience varies from trainee to fellow. The ASFO has a membership of over 400. This includes dentists, dental hygienists, and anyone interested in forensic odontology.

A Short History of Bitemark Evidence in the U.S. Courts

Bitemark analysis is a product of the latter half of the twentieth century. The small number of dentists in early court bitemark proceedings has increased substantially over the last 25 years. The physical evidence available in a bitemark case is challenging and requires the dentists to exercise extreme care in their opinions. The vast array of potential biters can be large due to the fragmentary and diffuse bruising regularly seen in skin injuries. Bitemarks in food, however, have a better potential for tooth detail.

Court Admissibility of Bitemark Opinions

This information deals with the legal acceptance of bitemark analysis in the state of California. Others states and countries have differing histories and legal thinking regarding scientific evidence. In California in 1975, *People v. Marx* was higher-court review of a case where bitemark identification was allowed into court. The higher court's opinion considered it a "new" science and subject to review.

California law requires that before evidence of a "new" scientific technique can be admissible, the person supplying the evidence must show that the relevant scientific community deems the technique reliable. The California Supreme Court in the case of *People v. Kelly* established this rule of law (1976). In the *Kelly* case, the California Supreme Court further refined the rule previously made by the U.S. Supreme Court in the 1923 case, *Frye v. US*.

The *Frye* case involved evidence of a systolic blood pressure deception test that was found by the U S. Supreme Court to be inadmissible because the test had not gained general acceptance in the particular field in which it belongs. The California Supreme Court, in *Kelly*, rejected voiceprint evidence because the evidence in favor failed to establish that the procedure was accepted as reliable by the relevant scientific community. The California court stated that to meet the standard of admissibility, the offering party must establish the following:

1. The generally accepted reliability of the methods
2. The witnesses furnishing testimony are properly qualified by an expert to give an opinion
3. The correct scientific procedures were used

In 1976, the California Supreme Court also stated the following in the *People v. Kelly* opinion:

> *Once a trial court has admitted evidence based on a new scientific technique, and that decision is affirmed on appeal by a published appellate decision, the precedent so established may control subsequent trials, at least until new evidence is presented reflecting a change in the attitude of the scientific community.*

California appellate courts had no problem finding that bitemark evidence is admissible and reliable evidence. One of the first cases to address the issue was *People v. Marx* (1975). In this post-*Frye*, pre-*Kelly* case, the Second District Court of Appeals noted, "The *Frye* test finds its rational basis in the degree to which the trier of fact must accept on faith scientific hypothesis not capable of proof or disproof in court and not even generally accepted outside the courtroom."

In *Marx*, the court's findings were that in the case of the bitemark evidence, the basic data on which the experts based their conclusions—which included models, photos, and x-rays of the victim's wounds and the defendant's teeth—were acceptable to the court and that in making their comparisons and reaching their conclusions, the experts did not rely on untested methods or unproven hypotheses but applied scientifically and professionally established techniques so the court did not have to sacrifice its independence and common sense in evaluating it.

In 1977, the First District Court of Appeals upheld the admissibility of bitemark evidence in the case of *People v. Watson*. In *Watson*, the court relied heavily on the *Marx* case, which was cited as the setting proper precedent.

The next significant case addressing the admissibility of bitemark evidence was *People v. Slone* (1978). In this Second District case, the court found that the bitemark identification evidence admitted by the trial court met the three-pronged test of admissibility laid down by *Kelly*. The court cited the *Marx* case and reiterated its analysis that there is a more trustworthy basis for admitting bitemark evidence than other scientific test evidence. The superior trustworthiness is due to the trier of fact seeing for itself by looking at the material exhibits what constitutes the basis for comparison with a defendant's dentition.

Use of Bitemark Evidence in Jurisdictions Using the *Frye* Standard for Admissibility

Appellate courts throughout the United States have routinely determined that bitemark evidence is reliable and has been accepted as such by the relevant scientific community. Following is a sampling of cases from various jurisdictions that have all approved the admissibility of bitemark evidence.

1. *Doyle v. State* (1954): In this case, the Texas Court of Criminal Appeals upheld the admissibility of bitemark evidence. In that case, before the trial, the dentist examined bitemarks in two pieces of cheese left at the scene of the burglary of a market and compared them as seen in a plaster model of a bitemark made by the defendant in a piece of cheese provided to him by the sheriff. The dentist determined that the same teeth made all of the bitemarks. Similar identification methods had been used for years.
2. *Niehaus v. State of Indiana* (1977): The Supreme Court of Indiana found no error in the trial court's admission of bitemark evidence. In *Niehaus*, a forensic odontologist compared a bitemark in the victim's skin to the teeth of the defendant. The court noted that the method of identification "is simply a comparison of items of physical evidence to determine if they are reciprocal. The methods consist of standardized procedures known to procure accurate models and measurements."

3. *State v. Sager* (1980): The Missouri Court of Appeals presents a thorough treatment of the evolution of bitemarks in its decision in *State v. Sager*. The *Sager* case involved the murder of a 14-year-old girl. The State's evidence included comparisons by forensic odontologists of bitemarks on the victim's body to the defendant's dentition. After a painstaking review of voluminous legal and dental authorities, the Missouri Court determined that "the science of positive bitemark identification has reached the level of scientific reliability and credibility to permit its admission as evidence in criminal proceedings."

All of these and hundreds of similar cases from the 1970s and 1980s show the courts' interest and approval in bitemark identifications. It may be surprising to some, though, that the scientific research necessary to ground such opinions as reliable had yet to be undertaken. The "acceptance by the scientific community" thrust of *Frye*, however, was clearly met by the majority of the forensic dental community of the time.

Little has changed in bitemark analysis appellate opinions since then. Legal commentaries have been critical of bitemark identification since the 1970s but to date have had little effect in eliminating bitemark opinions. The legal analysis of the *Marx* decision from a more scientifically critical position holds that the court's statement was "no established science of identifying persons from bitemarks" was overlooked in their final conclusion ruling bitemark evidence admissible.

This conflicts with the underlying reason that experts are allowed into court, since they know more than the average person does about a certain subject. The tools used in the *Marx* case were considered appropriate, and then the court allowed the reasoning or application of these tools to be admitted, the reliability requirements of *Kelly* notwithstanding. This argument still exists in the twenty-first century, as it is generally brought to court during every trial containing bitemark evidence. The advent of DNA analysis has recently acted as an independent means to support or refute a bitemark opinion. In some cases, it has helped the proponents of bitemark identification, and in other cases, it proves that bitemark identification is subjective and cannot be counted on as being accurate in every case.

Use of Bitemark Testimony Under the Federal Rules of Evidence

The federal judicial system has numerous rules and opinion on the accuracy and credibility of experts and the opinions that they provide in court.* The federal system within the last 10 years has rejected the *Frye*

*Federal Rules of Evidence 702: Testimony by experts, "If scientific, technical, or other specialized knowledge will assist the trier of fact to understand the evidence or to determine a fact in issue, a witness qualified as an expert by knowledge, skill, experience training, or education may testify hereto in the form of an opinion or otherwise."

standard and created a new standard based on the case named *Daubert* (see preceding discussion). The *Daubert* ruling rests on an interpretation of the Federal Rules of Evidence. These rules are not binding on the U.S. state court systems, but a number of states have adopted a similar standard (Table 1).

All of these factors are considered independent determinations by the court and do not have to be met by the expert. What is not satisfied, however, may affect the weight or value of the expert's testimony. It should be noted that, as of this writing, no federal court has reviewed bitemark evidence under these requirements. A few states have done so, with no change in the cart blanche admissibility permitted since 1954. Opinions of dental certainty of a suspect's bitemark identity have been reduced in a number of unpublished Texas Daubert hearings as recently as March 2010. The courts found that experts would be allowed to say a bitemark could be used as a means to include a defendant as a possible biter. This is much weaker than an opinion stating that the defendant was identified as the biter by the evidence. It is a significant departure from bitemark opinions allowed before the advent of DNA's use in court [12].

TABLE 1 States Using *Daubert*, *Frye*, or Other Admissibility Tests

States Using *Daubert*	States Still Using *Frye*	Other
Connecticut	Alaska	Arkansas
Indiana	Arizona	Delaware
Kentucky	California	Georgia
Louisiana	Colorado	Iowa
Massachusetts	Florida	Minnesota
New Mexico	Illinois	Montana
Oklahoma	Kansas	North Carolina
South Dakota	Maryland	Oregon
Texas	Michigan	Utah
West Virginia	Missouri	Vermont
	Nebraska	Wyoming
	New York	
	Pennsylvania	
	Washington	

Typical Questions Law Enforcement Asks Regarding Dental Evidence

Can a non-board-certified dentist be considered a forensic expert?
The simplest rule to remember is that anyone who can help the court and jury make a decision and has appropriate credentials can be admitted as an expert. What will vary is the importance (weight) the jury gives to the testimony given by a noncertified or novice forensic expert.

How much training does a dentist need before testifying in court?
Law enforcement should know that the traditional dental education fails to provide the dentist with the skills necessary to perform in the judicial system and many aspects of forensic science. Simple dental identification cases of unknown deceased persons require competency skills any licensed dentist should possess. Bitemark evidence, mass disaster management, and determination of child, elder, or spousal abuse should be handled by an experienced forensic odontologist.

Can a specific person be identified from biting something?
The best means of identifying a biter is to swab the bitten object for saliva and then obtain a DNA profile from the biologist. The history of bitemark analysis shows a number of cases over the years where an expert's confident positive bitemark identification of a defendant has been proven wrong (see "Wrongful Convictions and Erroneous Bitemark Opinions" at the end of this chapter). Most experienced odontologists say that the ability to positively identify one person from a bitemark is a very rare event. The typical bitemark case contains the argument that a particular person "possibly" or "probably" inflicted the bitemark. New research indicates serious doubts that any bitemark identifications are scientifically valid.

The Scientific Limitations of Bitemark Testimony

The determination of a positive identification by bitemark analysis is limited by the quality of the physical evidence, the variable nature of bruising in skin, and the inability of dentists to scientifically prove that each person's teeth are unique. The following outlines these issues in more detail.

Accuracy of Skin for Bitemarks

In cases of physical assaults having skin injuries, the following variables make each bitemark case challenging:

1. The anatomy bitten
2. The biology of skin injuries
3. Posture of victim during biting
4. Poor bruising detail of the bite injury on skin
5. Anistrophic features of human skin, which results in distortion of a bitemark pattern

Dental Profiling that Cannot Prove Uniqueness

The foundation of bitemark analysis is that the total arrangement of a person's teeth (usually the front teeth) creates a dental profile. There are arguments in the dental literature that each human has a unique dental profile that is discernible in bitemarks. This is now in dispute (see [1] and [2]) because of groundbreaking data from cadaver studies. These assumptions have not been proven valid either by experimental testing or by bitemark casework. Cases having DNA evidence that contradict a bitemark opinion are becoming more common and should act as a indicator that bitemark identification cannot solely give a conclusive answer to the question "Who made this bitemark?"

Bitemark Guidelines

The *ABFO Bitemark Guidelines and Standards* express technique recommendations and establish suggestions on the language and procedures used by forensic dentists. Confidence levels of bitemark identifications have been changed three times in the last four years. This has resulted in considerable confusion due to a lack of accompanying explanations. The author interprets the ambiguity of this situation as a failed attempt at making bitemark opinions more reliable. No testing of these confidence levels has occurred to prove their scientific basis.

On the other hand, investigators should be aware of the suggested dental evidence collection protocols contained in these documents. They are available online at *www.abfo.org*. The ABFO officially still holds to the opinion that bitemark evidence can be as effective as DNA in identifying a biter. This opinion is not considered reliable by all its membership. The last section in this chapter underscores the results of bitemark misidentifications.

Scientific Literature on Bitemark Identification

A literature review on the subject of bitemark analysis was presented at the 2000 AAFS meeting in Reno, Nevada [13]. The material was derived from English-language publications from 1960 to 1999. One hundred and twenty written-contained studies exist of empirical testing (15 %), case reports (40%), technique studies (23%), commentaries (20%), and legal and literature reviews (32%). The 1970s brought out initial articles of first impressions about bitemarks that were later used in the judicial system to justify the consideration that bitemark analysis was scientific. The 1980s were the decade of greatest activity. The 1990s should be considered the period where biochemical analysis of salivary DNA evidence arrived as the first independent means of confirming or eliminating bitemark opinions. As of 2010, the ratios have improved slightly in regards to empirical testing.

The Accuracy of Skin as a Substrate for Bitemarks

The bulk of bitemark cases involve injuries on skin. This is not considered an accurate material to record and replicate the dental impression of the biter [14, 15]. The literature shows, however, that the bulk of experimental studies involve bitemarks in inanimate materials. The Bush [1] and Miller [2] articles present experimental data from bitemarks in human skin that have determined that human skin is incapable of consistently being referenced to a known biter's dentition (due to anistrophic skin distortion) and that dental uniqueness assumptions are not supported by either two- or three-dimensional analysis discrete populations.

Skin has considerable anatomical differences (e.g., breast tissue versus other locations) and also is affected by posture and movement at the time of biting. A 1971 study is the first of only two studies that describe and measured these factors [16]. They found both shrinkage and expansion of the skin at various positions on the body. The maximum distortion found was 60 % expansion at one location. So much variability was observed that the author emphasized the importance of knowing the exact position of the body at the time of biting before attempting an analysis.

Uniqueness of the Human Dentition

Identification from bitemarks is founded on the theories that [1] the dental features of the biting teeth (six upper and six lower teeth) are unique and [2] these dental details can be transferred and recorded in the actual bitemark. These have formed the basis for bitemark admissibility in court. The overall "uniqueness" of dental characteristics is a common statement used in court and in literature as of this writing. This conclusion is generally accepted by dentists and the courts but is subject to considerable criticism and is rejected by recent experimental findings. The reason it is criticized is that it has never been proven, and now there is finally robust research stating the exact opposite paradigm, which is that the human population share biological traits and features that do not allow differentiation or individualization from teeth.

A conservative opinion of a bitemark identification is to say that a person's teeth "could have made this bitemark" or "could not have made this bitemark." Current thought and research now considers those opinions to be risky speculation due to the uncontrolled distortion of skin during biting. The "probability of a mismatch" (as used in DNA results) cannot be calculated. This information is not available to the dentist and renders bitemark opinions unsupportable. The following two studies are 30-year-old papers that are considered the foundation of dental uniqueness.

1. A study of five sets of identical twins occurred in 1982. The separation of one twin from the other by their dental characteristics was the conclusion

of the paper [17]. The authors went on to apply these findings to the general human population.

2. A 1984 paper studied 384 x-ray prints of wax bites that were created and then hand-traced to produce the outline of the original teeth [18]. At the time, the study stated that the assumption of dental uniqueness had been proven. This statement erroneously became the paradigm of bitemark adherents for the next 26 years as somehow confirming that bitemark opinions were valid. The authors commented in their article, "[The question is] whether there is a representation of that uniqueness in the mark found on the skin or other inanimate object." This is not a confirmation that their paper confirmed dental uniqueness was capable of being reliably reflected in actual skin injuries.

A 2010 presentation at the annual meeting of the American Academy of Forensic Science reanalyzed the data from this 1984 paper. The new authors' findings indicated that the original conclusions by Rawson and colleagues were incorrect. The data showed that human dentition actually is quite similar, with physical variations distributed into a normal distribution of subgroupings (not like DNA). The practical application of these results leads to a rejection of the foundation assumptions of bitemark analysis. All human dentitions have a "match rate" with other individuals. Multiple people have dentitions that can create similar bitemark patterns [19].

Analytical Techniques

Testing methods is an essential basis for confidence in forensic procedures. Bitemark analysis is no exception. The wide variety of comparison techniques allowed by the ABFO is based on a consensus of the members of the organization. The array of photographic methods, bitemark, and suspect exemplar production and comparison methods are generally accepted but rarely scientifically tested. Sweet and Bowers tested the comparative accuracy of five generally used transparent overlay methods. Xerographic and radiographic methods are most commonly used. The study concluded the fabrication methods utilizing the subjective process of hand-tracing should be discontinued as being the least accurate [20].

Future Improvements to Bitemark Identification

As a number of legal commentators and forensic researchers have observed, bitemark analysis has never passed through the rigorous scientific examination that is common to most sciences. The literature does not go far in disputing that claim. Definitive research is now invalidating the prior assumptions of bitemark analysis. The following section describes the effects of erroneous bitemark opinions on the lives of 10 wrongfully convicted men in the United States. The 2009 NAS report clearly outlines these deficiencies.

Wrongful Convictions and Erroneous Bitemark Opinions

The Innocence Project/Network

Since the first edition of this book was published, there have been significant events in the legal system regarding exonerations of years-old convictions in the United States. The vanguard of this organized effort has been the Innocence Project of New York, which was founded in 1992. A country-wide alliance now exists called the Innocence Network, which is a group of nonprofit legal organizations in the United States, Canada, the United Kingdom, Australia, and New Zealand that are dedicated to proving the innocence of wrongly convicted people through the use of DNA testing and the reform of criminal justice systems to prevent future injustices [21].

As of January 21, 2010, 249 defendants who were previously convicted of serious crimes in the United States had been exonerated by DNA testing. Almost all of these convictions involved some form of sexual assault, and approximately 25% involved murder [22]. On February 4, 2010, Innocence Project client Freddie Peacock became the 250th person exonerated through DNA testing in the United States

Erroneous Bitemark Opinions that Were Overturned by DNA

In nine U.S. cases, individuals who were mostly convicted due to bitemark evidence have subsequently been exonerated. The tenth case of judicial exoneration decree is currently being appealed by the San Bernardino District Attorney. Descriptions of these cases are provided by the New York and California Innocence Projects. These give insight into the faulty use of bitemark testimony and resulting erroneous convictions. The author has been actively involved in six of these exoneration cases.

Willie Jackson—DNA testing exonerated Willie Jackson in 2006 and implicated his brother in a Louisiana rape. The victim identified Jackson as the assailant in a photo array and also in a live lineup. Such eye-witness identification is often associated with wrongful convictions and is an area of increased scientific and judicial scrutiny. Jackson's brother also appeared in a lineup but was not identified by the victim.

The prosecution presented the evidence of a forensic dentist who testified that bitemarks on the victim matched Willie Jackson's teeth. Just days after Jackson was convicted in 1989, his brother confessed to the crime but was not charged. Sixteen years later, Jackson was released based on DNA test results. In addition, a second, independent odontologist argued that the earlier odontological analysis was incorrect and that the bitemarks actually matched Jackson's brother. His brother was already serving a life sentence for an unrelated rape [23].

Ray Krone—Ray Krone was convicted—largely on bitemark analysis—of murdering a Phoenix bartender and sentenced to death plus 21 years. Krone's case became known as the "Snaggle-tooth killer" due to his crowded teeth being said to match the bitemarks on the breast and neck of the murder victim by a senior forensic dentist. She had been fatally stabbed, and the perpetrator left behind little physical evidence, so the bitemark evidence was a crucial component of the trial. There were no fingerprints; blood at the scene matched the victim's type; and saliva on her body came from someone with the most common blood type. There was no semen, and no DNA tests were performed.

First convicted in 1992, Krone won a retrial in 1996 and was convicted again mainly on the same state's expert bitemark testimony. His death sentence, however, was reduced to life in prison. Finally, in 2002, Krone was released after DNA testing proved that he could not have been the perpetrator. Instead, saliva and blood found on the victim matched a convicted rapist, and he was ultimately incarcerated [23].

Calvin Washington—Calvin Washington was convicted of murder and sentenced to life in prison in Texas in 1987. It was alleged that Washington—acting either alone or with another male, Joe Sidney Williams—robbed, raped, and murdered the victim. A dental expert witness testified that bruises on the victim's body were bitemarks and that these injuries matched Williams's teeth. A jailhouse informant (later considered unreliable) claimed that he heard Washington and Williams make incriminating statements when he walked by their hotel room one night. The prosecution also produced evidence that the defendants were in possession of the victim's car and had sold items belonging to her. Both Williams and Washington were convicted. Williams's conviction was overturned, and the prosecution declined to retry him. Washington served 13 years in prison before DNA test results exonerated him in 2001. Testing also showed that fluids taken from the victim did not come from Washington but from another man, since deceased [23].

James O'Donnell—James O'Donnell was convicted of an attempted sodomy and second-degree assault. Again, eyewitness identification was employed in both a photo array and live lineup, although a second eyewitness failed to positively identify him. A strong alibi was presented by both his girlfriend (now wife) and her son, but this was discounted by prosecutors. An injury to the victim's hand was said to be a bitemark, and an odontologist stated that the injury was "consistent with" O'Donnell's teeth. Based on the eyewitness testimony and the bitemark evidence, he was convicted. Later, DNA testing was undertaken on fingernail scrapings and saliva recovered from the bitemark, which proved that O'Donnell was not the perpetrator. He was released in April 2000 [23].

Dan Young Jr. and Harold Hill—Dan Young and Harold Hill spent 12 years in prison before DNA testing proved that they could not have been responsible for a murder in Chicago. Their convictions were based on a confession (again, frequently a feature of wrongful convictions) and bitemark testimony that their teeth were similar to bitemarks on the victim. During post-convictions appeals, a defense dental expert determined there was no connection between Young or Hill and this bitemark. Later, in the proceedings, an independent odontologist prepared a report in this case stating that the injury was not suitable for comparison due to a number of postmortem artifacts caused by a fire, which was apparently set to confound body identification and forensic recovery. DNA testing was undertaken from the victim's clothing, and this came back negative for Dan Young's and Harold Hill's profiles. The profile contained a mixture of two unknown men [23].

Kennedy Brewer—Brewer was arrested in Mississippi in 1992 and accused of murdering his girlfriend's three-year-old daughter. He was ultimately convicted of this crime and sent to death row. The prosecution's case was based largely on bitemark evidence that was initially detected by the medical examiner and subsequently analyzed by an odontologist. This analysis described some 19 bitemarks on the body of the victim that "indeed and without doubt" matched the maxillary teeth of Brewer. The defense expert stated that the injuries were unlikely to be bitemarks but rather were postmortem artifacts caused by animal activity in the creek where the body had lain for some time before discovery.

In 2001, DNA testing was undertaken on semen samples recovered from the victim's body, and these demonstrated that Brewer could not have been responsible. This led in 2002 to his conviction being vacated, but the prosecution intended to retry Brewer based again on the bitemark evidence. An international panel of odontologists produced a consensus report on the injuries, categorically stating that these were not bitemarks and thus any comparison to Brewer's teeth was fundamentally flawed. Additional evidence to support this was produced by John R. Wallace, a forensic entomologist, who was able to demonstrate that the injuries to the victim's body, wrongfully identified as bitemarks, were caused by crayfish activity in the creek where the body was discovered. In 2008, Brewer was released some 15 years after his first wrongful conviction An individual who was a suspect in the original investigation, but not pursued, has since confessed to the crime [24].

Levon Brooks—Levon Brooks was cleared of all charges relating to a heinous child murder for which he served 15 years in prison. Brooks was sentenced to life in prison for the1992 murder of his ex-girlfriend's three-year-old daughter after false forensic testimony implicated him in the crime. Another Innocence Project client, Kennedy Brewer, was sentenced to death for a similar child 18 months later. DNA testing on evidence from the crime scene in Brewer's case implicated another man in the crime. The DNA profile matched a local man, who later confessed to killing both children alone. The DNA testing, combined with the confession, led to the release and exoneration of both Brewer and Brooks [25].

Robert Lee Stinson—Prosecutors did not seek a new trial in the case of Robert Lee Stinson, who served more than 23 years in prison for a murder that DNA ultimately proved he did not commit. The University of Wisconsin Innocence Project began working on Stinson's case in 2005 and obtained the DNA testing that proved his innocence.

Stinson was convicted and sentenced to life in prison for the murder of a 62-year-old woman in Milwaukee, Wisconsin. His conviction was based, in part, on the testimony of two forensic bitemark analysts, who said bitemarks on the victim's body matched Stinson's teeth. One of the experts testified at his trial that the bitemarks "had to have been made by teeth identical" to Stinson's and that there was "no margin for error in this." The other called the bitemark evidence "overwhelming" and said "there was no question there was a match." DNA testing conducted in the case at the request of the Wisconsin Innocence Project found a male DNA profile in areas of the victim's sweater that had tested positive for saliva. The profile did not match Stinson, proving another person bit the victim [26].

William Richards—California Innocence Project client William Richards remains in the custody of the San Bernardino Sheriff-Coroner Department despite his 2009 exoneration in the murder of his wife, Pamela, and his release from the California Department of Corrections. Superior Court Judge Larry W. Allen refused to release Richards pending the district attorney's appeal of the decision reversing his conviction. Instead, Allen reduced his bail to $750,000, an amount Richards cannot meet, since he has been wrongfully convicted for the past 16 years and is destitute.

The appeal process is expected to last one year or more, during which time Richards will be held in local custody. Depending on the outcome of that process, the district attorney may retry Richards. Finding that new evidence points "unerringly to innocence," Judge Brian McCarville reversed Richards's 1997 conviction of murdering his wife in their Hesperia, California, home. Richards was convicted for the 1993 murder after two trials ended in hung juries. Two bitemark opinions used at the third trial where the conviction occurred were later recanted by both odontologists. They once considered an injury on the hand of the victim to be a human bite. One dentist now considers the injury to be a dog bite. Both agree that methods and attitudes regarding bitemark identification have become more accurate since their first testimony in 1997. In addition, DNA evidence from an unknown assailant was recovered from the murder weapon in 2005.

Although previously in remission, Richards was diagnosed with a second occurrence of prostate cancer in October 2008. Due to the limitations of the facility, Richards has been denied access to the advanced treatment recommended by his physician. "Mr. Richards may die in prison, even though he has been proven to be innocent by a California court," said Justin Brooks, director of the California Innocence Project. "We are extremely disappointed that Judge Allen could not recognize the injustice in keeping an innocent man behind bars."

The California Innocence Project has petitioned the California Courts of Appeal to grant Richards's release pending the resolution of the appeal of reversal [27]. The district attorney's argument opposing Mr. Richards's release from county jail is based, in part, on the reliability of the original bitemark evidence presented in 1997.

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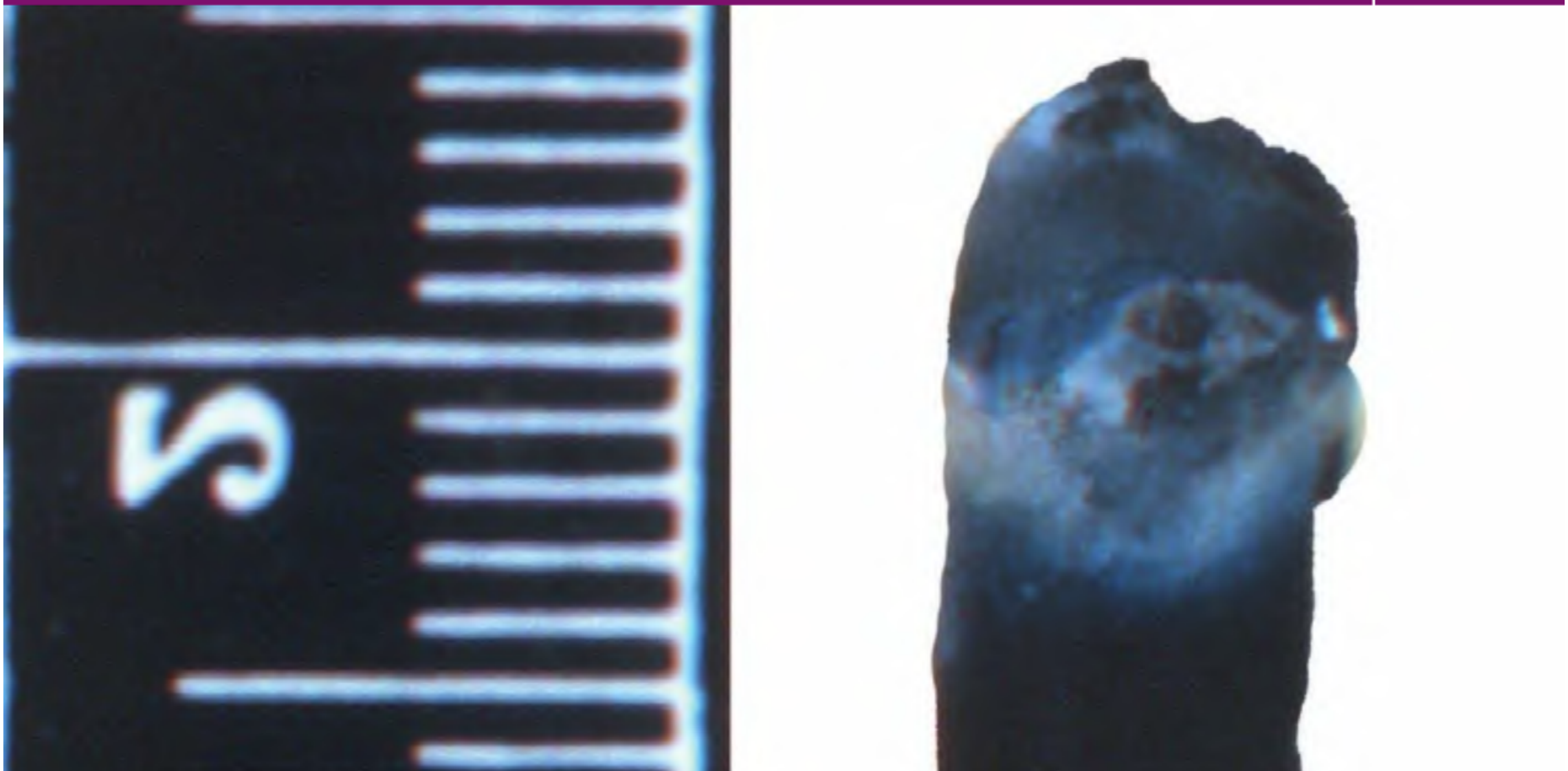

DNA for First Responders: Recognizing, Collecting, and Analyzing Biological Evidence Related to Dentistry

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Why DNA?

Deoxyribonucleic acid (DNA), the genetic chemical of all life, is a polymer of four repeating nucleotide units (G, A,T, and C)—similar to a four-letter alphabet that can be arranged to produce a seemingly infinite number of "books of life." From single-cell bacterium to the largest mammals, DNA is nature's conserved code for life. The human "book" has been completely read, if not translated, after a monumental sequencing effort. Today we know that the 3 billion base-pair human genome that is distributed among 23 chromosomes actually houses fewer than 30,000 genes (codes for protein),

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representing less than 5% of its length. The project confirmed what scientists had already known: that the noncoding regions of the genome contain, among other things, tracts of highly repetitive sequences.

Even prior to the completion of the human genome project, scientists recognized the potential of DNA as a tool capable of answering the important human identification questions. The answers, they realized, could come from analyzing and comparing regions within these repetitive, highly variable sequences. In fact, the first truly useful and widespread “DNA fingerprinting” technique began 25 years ago with the introduction of restriction fragment length polymorphism (RFLP). Now strictly historical, this initial unwieldy method quickly gave way in the 1990s to polymerase chain reaction (PCR) methodologies that had the advantage of being able to amplify DNA. After numerous refinements to the PCR-based tests, each of which represented an incremental improvement, the forensic community came to a consensus on short tandem repeats (STRs). As the current gold standard for human identification, the choice of PCR amplification of STRs was based on their applicability to degraded evidence, power of discrimination, and amenability to database applications [1]. Although there are additional DNA markers in use, STR typing is the method of choice for most forensic laboratories, and given the investments in infrastructure, training, databases, and accreditation, it will be for the foreseeable future.

DNA Applications in Forensic Dentistry

Bitemark analysis and identifying human remains are both common functions of the forensic odontologist and where the expertise of the forensic DNA analyst may be brought to bear. Investigators utilize a multidisciplinary approach whenever possible by incorporating the independent opinions of relevant forensic experts. When warranted, DNA may be utilized to provide additional circumstantial evidence to odontological (or anthropological) evidence.

Identification of Deceased

Comparative dental techniques on human remains will undoubtedly comprise the bulk of the case work garnered by the forensic dentist [2]. It offers a reliable, relatively quick, and economical identification methodology that often makes it the death investigator's method of choice. When the technique fails, it is often as a result of the lack of antemortem dental records, and, although a DNA analysis can also be stymied by the lack of comparative reference samples, the ability to utilize personal effects and/or various relatives offers alternatives.

A suicide case presented by Sweet and colleagues (1999) illustrates this point. Human remains of an adult skeleton that exhibited extensive, complex dental restorative treatment were discovered in a wooded area in North Vancouver, Canada [3]. Associated personal effects provided a tentative identification of the victim as someone of Japanese origin, but an extensive search for antemortem records in her home country failed to produce them. The identification effort shifted from dental to DNA as the coroner was able to acquire Pap smears from the local cancer agency. Ultimately, this was the first individual in Canada who was positively identified through a comparison of DNA (from restored teeth) and a Pap smear and highlights the importance of a multidisciplinary approach to human identification.

Bitemarks

Although comparative dental identifications generate little controversy with respect to reliability, the same cannot be said about bitemark comparisons, even among the experts themselves [4]. Not surprisingly, the act of biting can deposit saliva, a potentially viable DNA source, and standard (forensic odontology) operating procedures for bitemark analysis recognize this fact with appropriate swabbing recommendations [5]. The procedural approach underpins the important complementary roles of these disciplines, and when independent expert opinions coalesce, the investigator has powerful support for his or her proposition. In cases of convictions with dubious bitemark evidence, however, DNA has provided exculpatory evidence in support of the wrongfully convicted [6]. This is not unlike that seen with some hair identification cases in Canada [7].

Sample Collection Techniques

Overview

The work performed by the forensic DNA analyst usually starts at the laboratory door, but the determinants of success for any case begin at the scene or morgue. If mistakes are made there, it impacts all subsequent testing, with little possible remedy. The first responders are the first link in the chain that begins the controlled process from scene to court. The current PCR technologies, with the power to amplify DNA from only a few human cells, dictate the required contamination control measures. Safeguarding biological evidence requires careful consideration of sampling procedures to minimize: scene-to-sample, person-to-sample, and/or sample-to-sample contamination.

- *Scene-to-sample* contamination refers to the inadvertent cross-transfer of DNA from some part of the scene to an evidentiary item collected from the scene.
- *Person-to-sample* contamination refers to the inadvertent cross-transfer of DNA from the investigator to an evidentiary item.
- *Sample-to-sample* contamination refers to the inadvertent cross-transfer of DNA from one evidentiary item to another.

The collection process is facilitated by having the proper equipment and taking precautions that, if adhered to, will minimize the potential of contamination. Additional helpful tips are also available on-line for first responders [8].

With respect to personal protective gear use, disposable coverall "bunny suits" with booties (i.e., *Tyvek*™), masks, and disposable gloves (changed with each new piece of evidence collected) must be used. A specific DNA kit should be constructed that contains all of the required collection, packaging, and documentation materials to accommodate the collection of the most common types of evidence (questioned and reference samples). Use single-use items when possible. When reusable items such as scissors, scalpels, forceps, and so forth are required, they must be cleaned in between each use.

Although the list of what constitutes potential DNA evidence is long, common collection techniques are applied such that any long-term storage ensures the integrity of the evidence. There are a myriad of packaging materials of all shapes and sizes available, but most are made of a "breathable" material to prevent moisture retention, which facilitates DNA degradation through microbial action. It is generally advisable to avoid plastic packaging if a DNA exhibit is to be stored at room temperature. The exception to this rule, however, is when wet biological evidence must be transported safely from a scene. In this case, plastic is warranted to prevent cross-contamination. After transport to the police station or laboratory, the evidence should be unpackaged, air-dried, and repackaged in a breathable material. All evidentiary items must be packaged separately. Unprocessed evidence can be stored for extended periods of time if kept in cool and dry conditions. The following sections will focus on the collection of DNA samples of most relevance to the field of forensic odontology.

DNA Sample Collection from Human Remains for Identification Purposes

If DNA analysis is the method of choice for an unidentified remains case, the decompositional state of the remains will dictate the choice of questioned sample. Lessons learned with respect to DNA analysis from mass fatality incidents are instructive, and many of the same recommendations are applicable to routine case work [9]. For remains showing minimal decomposition, a blood sample collected at autopsy is often sufficient. For maximum convenience *FTA*™ paper (a chemically treated card designed to safely store biological samples like blood and saliva at room temperature) is recommended. Alternatively (or in addition to a blood sample), a deep skeletal muscle tissue sample is recommended, although most tissues will yield usable DNA if not decomposed. If decomposition is advanced, bodily fluids and soft tissues should be avoided due to obvious DNA degradation concerns. In such cases, hard tissues must be collected, because their hard structures offer maximum protection of endogenous DNA from taphonomic changes. Most protocols recommend collecting/sampling of a dense cortical bone (i.e., femur) or a tooth (i.e., canine).

Bone sample selection is an important consideration, but in partial remains cases, one may not have access to their preferred sample(s). Although DNA typing success rates appear to vary depending on the skeletal element tested, bones from head to toe have yielded useable results [10, 11]. A study by Mundorff and colleagues in 2009 of DNA preservation in skeletal elements from the World Trade Center after 9/11 revealed high success rates of identification stemming from patellae and foot phalanx [11]. These samples can be easily excised from remains with a scalpel rather than cutting into long bone and thus minimizes cross-contamination concerns.

Teeth are also known to be potentially good sources of DNA, and like bones, their structure helps to preserve viable DNA for many years [12, 13]. It is thought that the number of roots and size of the pulp chamber affect the amount of recoverable DNA. Canines are often recommended because they offer a balance between ease of extraction (due to the single root) and size. It is recommended, however, that duplicate samples be taken and should include at least one molar. Like bones, tooth selection is important, but for partial remains the choice might be limiting, and one must be prepared to sample what is available. Usable results have been observed from all tooth types (incisor, canine, premolar, and molar), including teeth with restorations.

With respect to packaging of samples collected from the deceased, the choice of material will vary depending on the type of sample collected. Any sample (soft tissue, bone, or tooth) that is wet should be stored in a leakproof container and stored frozen (−20°C) prior to testing. Skeletal elements that are completely dry can be stored in breathable packaging (paper, box, etc.) and stored at room temperature.

The pathologist or forensic odontologist may extract teeth from the body in the morgue so the coroner can submit them to the forensic DNA laboratory for further testing. For dry, skeletonized remains, it is not uncommon for the coroner to submit a mandible or entire skull (with associated dentition) directly to the forensic DNA laboratory to allow the DNA analyst to excise a suitable tooth for analysis.

Reference DNA Sample Collection

Like other forensic disciplines, a forensic DNA analysis is a comparative process requiring profiles from the questioned as well as known source. The identification process can not advance until the forensic DNA analyst has both components available for evaluation. This comparative process is often achieved through targeted investigation to identify the source of a known sample but increasingly occurs via cold hits from a DNA database (convicted offender or missing person index).

The source of a reference sample, like a questioned sample, requires careful consideration of the case at hand. This choice has less to do with the biological sample selected (the majority of samples consist of a drop of blood, buccal swab, and/or sometimes a hair sample) and more to do with consideration of the individual needing to be identified.

Crime Scenes—Suspect Comparisons

Most criminal cases require the identification of a suspect from a crime scene sample via a direct comparison process (targeted or database search). An unmixed (single-source) crime scene sample is expected to be identical to that of the suspect. Reference sample collection from a suspect will usually consist of a blood or saliva sample provided voluntarily or via warrant. Again, there are a myriad of products available to accomplish this, but *FTA*™ paper is one of the most common and can be used to preserve a drop of blood from a finger poke or a saliva sample from a buccal swab dabbed on its surface. Alternative devices for buccal swabs are available and consist of a sterile, single-use swab that has its own container that suspends the sample inside and allows some airflow. Regardless of the method used, the same general precautions should be taken—namely, samples should be stored dry and protected from moisture and contamination in a cool, dry environment until submitted to the laboratory.

Human Remains—Personal Effects and Kinship Comparisons

Many cases require the identification of found human remains, and two approaches are available that impact the choice of reference sample: direct and indirect comparisons. A direct approach utilizes a comparison between the deceased sample and a sample thought to have come from, or been used by, the deceased. An indirect approach utilizes close family members in order to make an identification. Both methods can provide very strong DNA evidence in support of identification.

- *Direct comparisons* use personal effects or samples thought to have come directly from the deceased, such as personal hygiene items (toothbrush, razor, contact lens, etc.) or medical sample (blood, semen, biopsy sample, etc.). Confounding results can be introduced with personal effects collected from a missing person's home because there is always a possibility that someone else has used the item. As such, it is recommended that a familial sample (see below) be collected to confirm the source of such an item. Once this is confirmed, the personal effect profile can be used for identification purposes.
- *Indirect comparisons* use a parentage or kinship approach requiring careful choice of family members. First-degree relatives (parents, children) are the most reliable choice because they are expected to share half of their genome if related to the unidentified individual. Although identification can be supported with a single such reference sample, additional samples add statistical weight to the conclusions and should be collected if available. Note also that if a putative child of the deceased has been collected, then the biological mother should also be included if possible to complete the mother-father-child "trio" for added statistical strength. In a targeted investigation where a tentative identification is available (as opposed to "trolling" a missing person database), an indirect approach with as little as one of the preceding reference samples may be suitable.

Investigators should apply caution when faced with trying to make an identification with only a reference sample from a putative father. Although relatively rare, the rate of nonpaternity (discrepancy between social and biological fatherhood) is high enough, estimated to be 2% to 3%, to pose a concern to investigators [14]. As such, whenever possible such samples should be augmented with the mother's sample.

The reader may be wondering why it is necessary to collect a personal effect for a direct comparison if one also has access to a familial sample. Why not simply use the latter, which is often less problematic anyway due to the lack of degradation? The reason stems from the widespread use of DNA databases for human remains and missing person identifications. In our experience it is very common to have access to only a single parent (or child) of a missing person. A search of an unidentified remains database with such a sample will inevitably result in fortuitous hits (unrelated individuals that share genetic features like that of a parent-child). Often these hits result in very weak statistical support for identification but nonetheless require some attention by the investigator. The same search of unidentified remains conducted with a confirmed personal effect is not expected to produce as many fortuitous hits.

- *Siblings* have also been used for identification purposes, and although siblings tend to share genetic features, a lack of sharing is not grounds for exclusion [15]. There are times when investigators have no other sample options, and in that case the sibling should be sampled. If more than one sibling is available, then it is recommended that they all be sampled. In a targeted investigation, this may be sufficient, but the lack of shared genetic features can make database use problematic.

The collection of DNA samples from living relatives of deceased or missing persons can follow the same scheme just outlined for suspect sample collection. When collecting a personal effect, the same general precautions should be taken—namely, samples should be stored dry and protected from moisture and contamination in a cool, dry environment until submitted to the laboratory.

DNA Sample Collection from Bitemarks

Given the nature of this text, the collection of DNA samples from bitemarks is presented separately, but much of what was presented previously still applies. The deposition of saliva during the biting process has the potential of leaving DNA evidence within or near the demarcation of the mark. This makes bitemark evidence somewhat unique compared to other types of evidence by requiring separate comparisons: physical and biological. These comparative analyses should be completed separately to eliminate any undue bias.

Pretty (2008) describes in detail the accepted practices associated with bitemark evidence collection and analysis, including the biological aspect [5]. It is common when dealing with bitemarks on skin or nonhuman substrate to utilize a double swab technique in order to maximize the DNA recovery [16].

The technique involves an initial swab of the area of interest using one wet, sterile cotton swab (moistened with distilled water) followed by a dry swab. The swabs should be air-dried and then packaged together as a single exhibit. Although most protocols do not ask for it, it is a good idea to also collect a reference DNA sample from the bitemark victim as an elimination sample. It is possible for samples taken from a bitemark to result in a mixed DNA profile consisting of the biter and the victim. Having the victim's profile available allows the DNA expert to essentially "subtract out" this profile and thereby increase the significance of any match to a suspect.

Behind the Laboratory Door

This section introduces the theoretical and practical aspects of the forensic biologist—namely, the identification of biological evidence, the application of current DNA technologies, and data evaluation for the purpose of human identification. The reader will get an understanding of the molecular biological techniques utilized in the development of a DNA profile in an attempt to open the "black box" of the discipline.

Forensic DNA Analysis and the *ACE Principle*

"Science has been likened to a game of chess; there are certain fixed rules that must be obeyed in order to play the game." Underlying this comparative process is the same scientific methodological underpinning that applies to any forensic association: the *ACE Principle*. The principle, although often associated with fingerprinting, applies to the comparison of all physical evidence, including DNA [16a]. Scientific method in a forensic science context can be described as a three-step process:

- *Analysis* refers to the determination of the component parts (via observation and/or measurement) of the questioned sample.
- *Comparison* occurs only after the analysis of the questioned sample and refers to analysis of the known sample for the purposes of documenting the similarities and/or differences with respect to the questioned sample.
- *Evaluation* refers to consideration of these similarities and/or differences with respect to the significance of the evidence.

(Note: Sometimes a fourth step (verification) is included in this principle that highlights the importance of a secondary review by another expert to confirm (or refute) the original findings.)

An appreciation of the importance of this principle within forensic science cannot be understated because it begins from a focus on first principles rather than simply a "how-to" approach. With this in mind, however, the reader is ready for an introduction to the process utilized in a forensic DNA analysis: identification of biological evidence, extraction, quantitation, amplification, and, finally, interpretation.

Identification of Biological Evidence

Often the source of biological evidence is obvious—for example, the unidentified body in the morgue. Under less certain scenarios, there exists a myriad of biological evidence screening tests available to the forensic scientist for pinpointing potential sources of DNA. Doing so at this stage saves time by allowing the DNA expert to focus on the most promising evidence first [17]. For example, there are presumptive or confirmatory methods for common biological substances (blood, saliva, and semen), although others also exist for less common examinations (vaginal fluid, urine, and feces). The majority of these tests, however, are not utilized in a forensic odontology context, although the ability to screen for saliva may be beneficial in a bitemark analysis case. Two common presumptive tests are available: alternate light source searching (based on the inherent fluorescence of saliva) and *Phadebas*™ (based on the high salivary concentration of α-amylase). It should be noted, however, that these are both presumptive tests, and a positive result does not confirm the presence of saliva. Conversely, a negative result may not preclude a successful DNA analysis given the sensitivity of the latter.

DNA Extraction Techniques

Forensic DNA evidence can take an almost infinitely variable form, but the laboratory has a finite number of methods to accommodate whatever might be submitted by the investigator. Although there are numerous extraction methods in use around the world, any approach taken attempts to purify DNA from unwanted biological (i.e., all non-DNA-related components of a tissue), substrate (i.e., the fabric on which a stain was found; a swab head on which it was collected, etc.), and environmental (i.e., dirt) components. Two common DNA extraction approaches in use include organic extraction and solid-phase extraction (Figure 1):

- *Organic extraction method*—a very common method that involves the incubation of biological evidence in a lysis buffer consisting of SDS (a detergent to solubilize cellular membranes), proteinase K (to degrade inherent protein), EDTA (a chelating agent to bind divalent metal ions and inhibit nuclease activity), Tris (a buffer to maintain a constant pH 8), and salt (for desired ionic strength). Following what is usually an overnight incubation at 56°C, the supernatant is extracted with a solution of phenol-chloroform to remove unwanted protein. The aqueous, DNA-containing phase is further purified through a filtration device (e.g., Amicon/Centricon-100 from Millipore) in a centrifuge. The filter acts to retain DNA above a certain size and allow impurities to flow through. The DNA can thus be washed and concentrated and left in a suitable solution for storage in a freezer. This method is not amenable to robotic extraction techniques making it time consuming, but it is very good for many types of evidence including skeletal remains.
- *Solid-phase extraction methods*—have been utilized in different formats but are all based on the inherent (but reversible) affinity

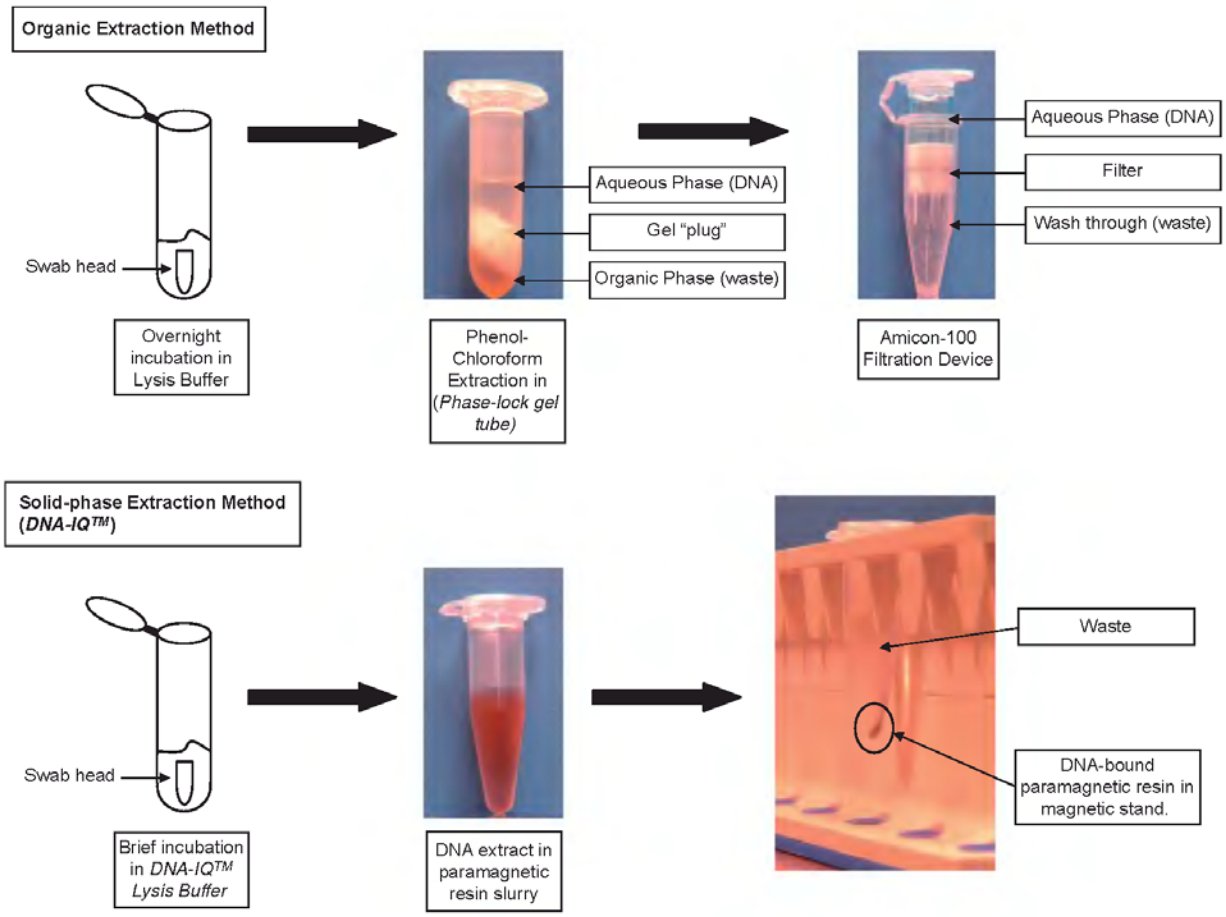

FIGURE 1 A comparison of two common DNA extraction methodologies: organic extraction with filtration device (top) and solid-phase with silica-coated paramagnetic resin (bottom).

of DNA for silica. By selectively binding DNA in solution in order to remove inhibitors (with no such affinity), one has an efficient purification technique. Two recent additions to the field (*DNA-IQ*™ from Promega and *PrepFiler*™ from Applied Biosystems) utilize silica-coated paramagnetic resin that replaces centrifugation with separation on a magnetic stand. Any non-DNA components remain unbound to the magnetic resin and can simply be removed prior to further washing and elution of purified DNA.

These methods add a high-throughput approach because they are amenable to robotic liquid-handling systems and are particularly useful for the more common sample types (swabs, stains, *FTA*™ paper, etc.). Silica-based methods in addition to a manual organic extraction method provide the DNA analyst with the ability to extract DNA from any sample type that he/she may come across.

It is worth discussing in more detail the approaches taken to initiate the isolation of DNA from the most challenging samples type (skeletonized remains) due to their prevalence in casework. Unlike other sample types (liquids, swabs, stains, etc.), teeth and bone samples must be cleaned and pulverized prior to DNA extraction. Skeletal remains are prone to surface DNA contamination from handling, and this must be removed. Bleach is a common decontaminant and is used routinely for soaking intact teeth and also for bone fragments by some laboratories [18]. Alternatively, bone surfaces can be sanded to remove the top layer prior to subsectioning for further grinding. Intact teeth or bone fragments are often cryogenically ground in a freezer mill to produce a powdered sample amenable to extraction [12]. Some protocols will incorporate a demineralization process using high levels of EDTA to completely dissolve the bone powder in order to maximize recovery of DNA [19].

DNA Quantitation

Before DNA amplification can be attempted, one must determine whether the extraction technique successfully isolated human DNA from the evidentiary item of interest. There are a number of approaches that have been used over the past two decades, but regardless of the approach, it must be sensitive enough to detect levels of human DNA common to forensic evidence [1]. The most common approach today utilizes a human specific, real-time polymerase chain reaction (PCR) approach. A common commercial quantitation kit, *Quantifiler*™ (Applied Biosystems) utilizes the power of PCR to measure the amount of amplifiable DNA in a given sample by comparing to a standard curve [20]. Evidentiary samples that fail to amplify at this stage due to degradation, lack of DNA, and/or the presence of inhibitors that have coextracted are unlikely to amplify in subsequent DNA profiling stages. The utility of this test is its ability to detect picogram (pg) levels of DNA, below the sensitivity of many of the subsequent DNA typing tests. Just as important, this kit includes an internal control to detect inhibitors, the presence of which may necessitate further purification steps.

The amount of human DNA detected in the quantitation stage dictates downstream PCR-based testing. If standard STR-based typing is to be performed, approximately 1,000 pg (1 ng) of nuclear DNA is required—the equivalent of approximately 170 cells. Even more sensitive, mini-STR methods (see following) push this optimum threshold to 200 pg (0.2 ng) or lower.

DNA Amplification and Typing Techniques

The ability to accurately copy and thus amplify DNA in vitro is the Nobel Prize–winning accomplishment of Kary Mullis. The polymerase chain reaction (PCR) has been likened to a "Xerox machine" for DNA, and although not invented specifically for forensics, it appears to be tailor made for the field. Its ability to copy short fragments of DNA of limited quantity permits the analysis of degraded, trace biological evidence. The method effectively mimics natural DNA replication processes but does so via successive cycling through temperature changes in the presence of a few key components: DNA (evidentiary sample plus two short primers to initiate the copying process), DNA polymerase, nucleotide building blocks, buffer, and magnesium.

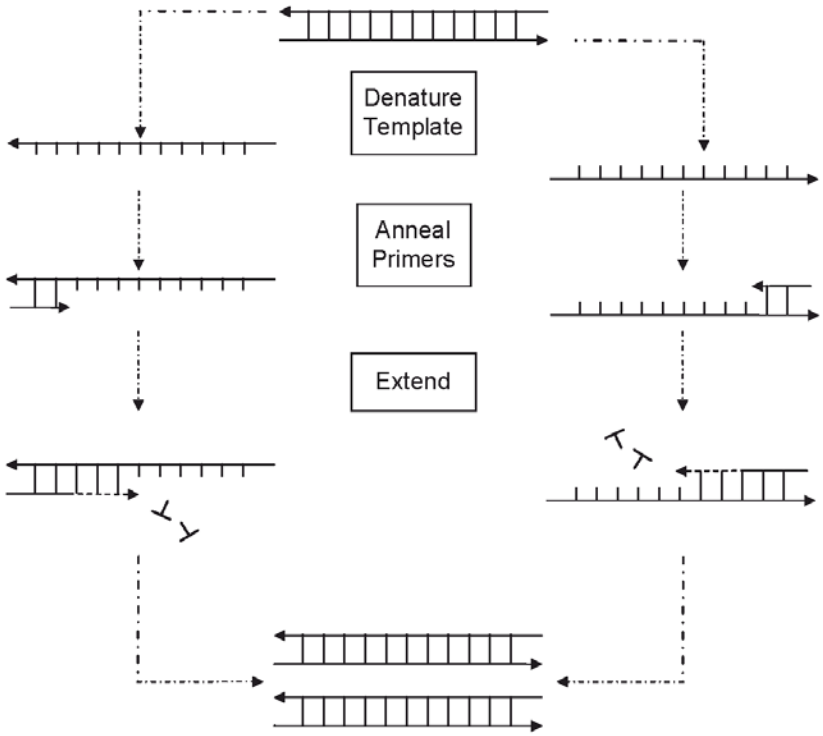

FIGURE 2 A single cycle of polymerase chain reaction (PCR) showing a single copy of the starting DNA template: denatured (at 94°C) into two single strands; annealed (at 59°C) to two short, custom made primers designed to bind on either side of a region of interest; extended (at 72°C) in the presence of a polymerase (not shown) and nucleotide building blocks. The original copy has been successfully amplified (duplicated) to form two new copies. Each cycle of PCR doubles the number of copies.

A successful amplification results when at least these minimal components are placed in a thermal cycler and cycled through three temperatures: 94°C (to denature the template DNA), 59°C (or another primer-specific temperature that allows annealing), and 72°C (optimum temperature for the polymerase to extend from the primer, read the template, and build a new complementary strand of DNA) (Figure 2). As such, after each successive round of PCR, the amount of product doubles; after 28 to 30 cycles there are tens of millions of new copies from each of the original starting templates. The fragments of DNA generated by PCR can be separated according to size and visualized with modern capillary electrophoresis instruments.

With the correct design of the short, custom-made primers, PCR will amplify any region of interest from any species. For example, PCR can amplify forensically significant regions within the mitochondrial and nuclear genome.

Mitochondrial (mt) DNA Markers

Although the bulk of the human genome is contained within the nucleus, a small, circular molecule of DNA, 16,569 basepairs in length, is located within the mitochondria [21]. In fact, there are potentially hundreds of copies of the mtDNA genome in every cell (versus only two copies of the nuclear genome per cell—one from each parent). This trait allows mtDNA to persist and provides another investigative avenue after nuclear-based testing has failed. The sequence of the mtDNA genome can vary between unrelated individuals, particularly in the small hypervariable region. However, this unique marker is maternally inherited (with no paternal contribution), meaning that an individual's sequence will be identical to their siblings, mother, grandmother, great-grandmother, and so on (barring a mutation). Normally one's mtDNA sequence will not be the same as one's father's. Although this inheritance pattern prevents individualization, distant intergenerational comparisons are possible with mtDNA.

Case Scenario

Skeltonized remains were discovered in a heavily forested region of the Pacific Northwest, and due to extreme degradation, no nuclear DNA was detected in duplicate testing (molar and midshaft femur). However, the analyst was able to successfully amplify the hypervariable regions of the mtDNA and produce a complete DNA sequence. Additional circumstantial evidence at the scene provided tentative identification leads, and three surviving family members, the father and two siblings (brother and sister), were located. Because mtDNA was being utilized the father was not tested, but both siblings were, and, if related to the deceased, would be expected to have the same mtDNA sequence (barring mutation). In this case both reference samples from the siblings produced identical mtDNA sequences to the deceased, and the result was interpreted as a "failure to exclude." The significance of this finding was assessed by searching the sequence against a database of unrelated individuals, a technique called the "counting method."

Had the sequence of the deceased and siblings differed at two or more locations, an "exclusion" would have been warranted, and the investigator would have concluded that these individuals were unrelated. Due to the higher mutation rate of the mtDNA genome, a single mismatch would have been classified as an "inconclusive" result.

Nuclear DNA Markers

Based on our current knowledge of the human genome, it is clear that the vast majority of the genome is noncoding in nature (does not act as a code for protein). Large tracts of the noncoding regions are highly repetitive and variable (polymorphic) in nature, a quality that has made certain regions ideal for human identification. The classification of repetitive DNA varies depending on the size of the repeat, but short tandem repeats (STRs) are currently the industry standard for forensic applications. As the name implies, an STR marker is short—consisting of the same four or five basepairs arranged tandemly to produce a repetitive stretch 100 to 400 basepairs long. Figure 3 illustrates an STR position called "D7S820." STR loci (positions) are found throughout the genome and can be further distinguished by their location on the Y (male) or autosomal chromosomes.

Y-STRs are a specialized class of STRs located on the Y (male) chromosome, and, like mitochondrial DNA, they are passed unchanged (barring a mutation) from one generation to the next. They too offer distant intergenerational comparisons, unlike autosomal STRs (see following), which are "shuffled" each generation. Because they are male-specific, their application in violent

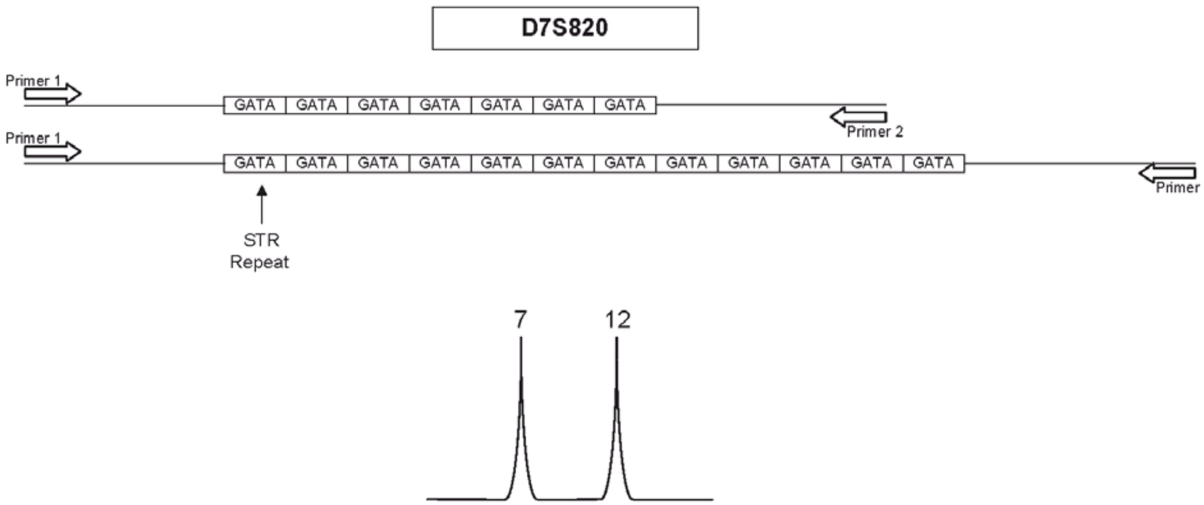

FIGURE 3 An idealized depiction of a short tandem repeat located on chromosome #7, specifically D7S820 (top). This individual has 7 and 12 repeat units that can be amplified (via PCR), separated and visualized (via capillary electrophoresis). The result would be a double peak pattern typical of a heterozygote individual (bottom).

and/or sex-related crimes is often invaluable when the female DNA may also be present (and in great excess). Y-STRs can also provide additional evidence in support of identification for human remains cases. Like mtDNA, individualization is not possible because a male's Y-STR profile is expected to be the same as any paternal relative (barring mutation): son, brother, father, uncle, grandfather, great-grandfather, and so on.

Case Scenario

A forensic dentist is called to the morgue to assess a potential bitemark on a female victim. He notes that the region has what appears to be bloodlike stains within the margins of the bite—possibly from the victim herself. Nonetheless, as part of the standard operating procedure, the dentist swabs the bitemark, and these swabs, along with a reference sample from the deceased, are submitted for DNA testing. The analyst was able to isolate sufficient human DNA to proceed with standard (autosomal) STR analysis and produced a profile of mixed origin: a major contributor consistent with the victim and a minor male contributor of little forensic significance. The analyst proceeded with additional Y-STR testing and produced an unmixed profile. Ultimately, the male suspect profile was found to be identical and could not be excluded as the donor. Analogous to mtDNA comparisons, the significance of this finding was assessed by searching the Y-STR profile against a database of unrelated males to determine how common this profile is in the population

Autosomal STR Analysis

The majority of the DNA typing conducted within a forensic DNA laboratory uses STR analysis of loci found on autosomal (nonsex) chromosomes. An accepted panel of 13 STR loci is used that allows national (and international) standardization of testing procedures. The choice of agreed-upon loci has facilitated the national DNA database efforts known as CODIS (Combined DNA Index System). Numerous commercial kits—dominated by two manufacturers, Promega and Applied Biosystems—are available, but they all utilize a multiplex process that allows multiple PCR amplifications of numerous loci in a single tube. This requires careful primer design, the use of fluorescent tags, and sensitive separation and detection technology. Figure 4 illustrates a typical STR profile produced from *AmpFlSTR Profiler Plus*™ (Applied Biosystems)—a multiplex consisting of nine STR loci plus amelogenin (the sex-determination position). Each locus is labeled, and a close look at each

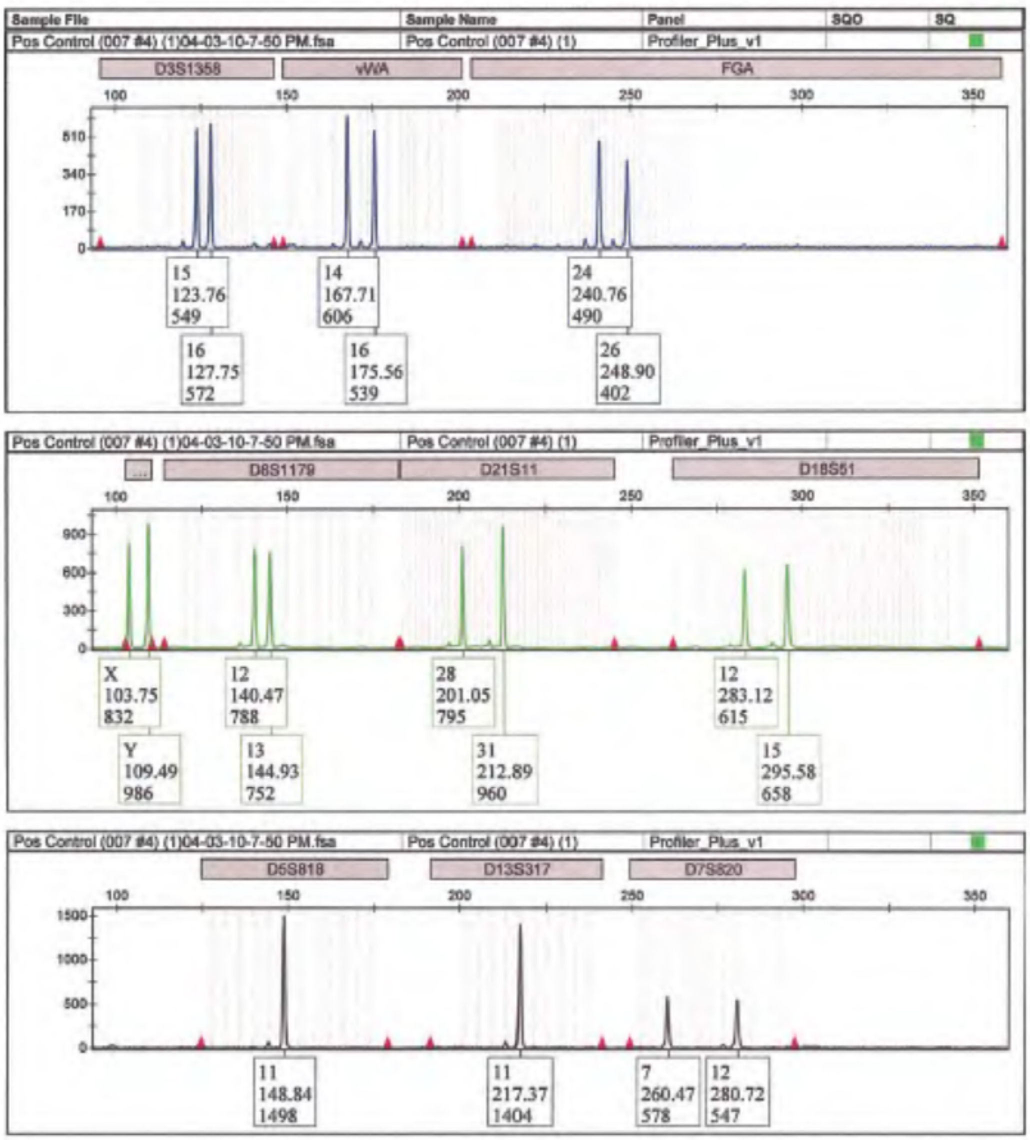

FIGURE 4 An example of a DNA profile generated using Applied Biosystem's *AmfFISTR Profiler Plus*™, a PCR multiplex run on a capillary electrophoresis unit. Each peak is a PCR product and is labeled with the allele call (representing the number of repeats), the size of the fragment (in bases), and the peak height (in relative fluorescence units). Note this individual is a male, as seen by the "X" and "Y" peaks at the amelogenin position.

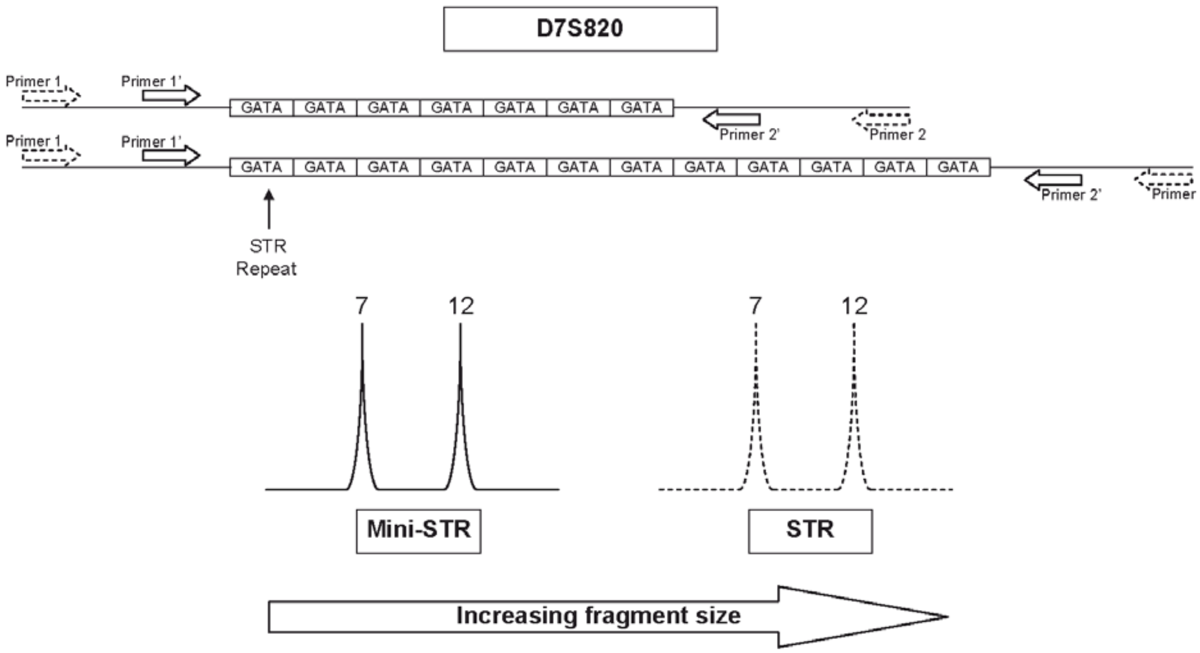

FIGURE 5 STR versus Mini-STR. By redesigning the original STR primers (dashed line), new primers can be produced (solid lines) that can bind closer to the repetitive region and thus target even more highly degraded DNA. The same double peak patter is produced but smaller fragments are produced (bottom).

reveals either a single or double peak pattern consistent with homozygote (identical alleles from the parents) or heterozygote (two different alleles from the parents) inheritance, respectively.

Standard multiplexes like *AmpFlSTR Profiler Plus*™ are very sensitive, with an optimal input amount of approximately 1 ng of DNA. Many types of biological evidence, even highly degraded, can be amplified with this system and produce forensically significant data. More recent advances in STR multiplex design have pushed the limits even further with the introduction of mini-STR systems that can generate usable profiles with approximately 0.2 ng (or less) of DNA. Although the DNA profiles produced look essentially identical to standard STR profiles, the underlying technology is much more sensitive. The added sensitivity of the mini-STR systems is gained by redesigning the primer sets to bind as close as possible to their respective repetitive regions (Figure 5). The result is a PCR multiplex that targets and amplifies even more highly degraded DNA samples. The impact of mini-STR technology on forensic casework was almost immediate [21a].

Case Scenario

Figure 6 illustrates the additional sensitivity of a mini-STR system available to the analyst for challenging human identification cases. A portion of long bone yielded a trace amount of human DNA that produced a very poor STR profile with *AmpFlSTR Profiler Plus*™ (Applied Biosystems). Reamplification of the same sample with *AmpFlSTR MiniFiler*™ (Applied Biosystems) produced a

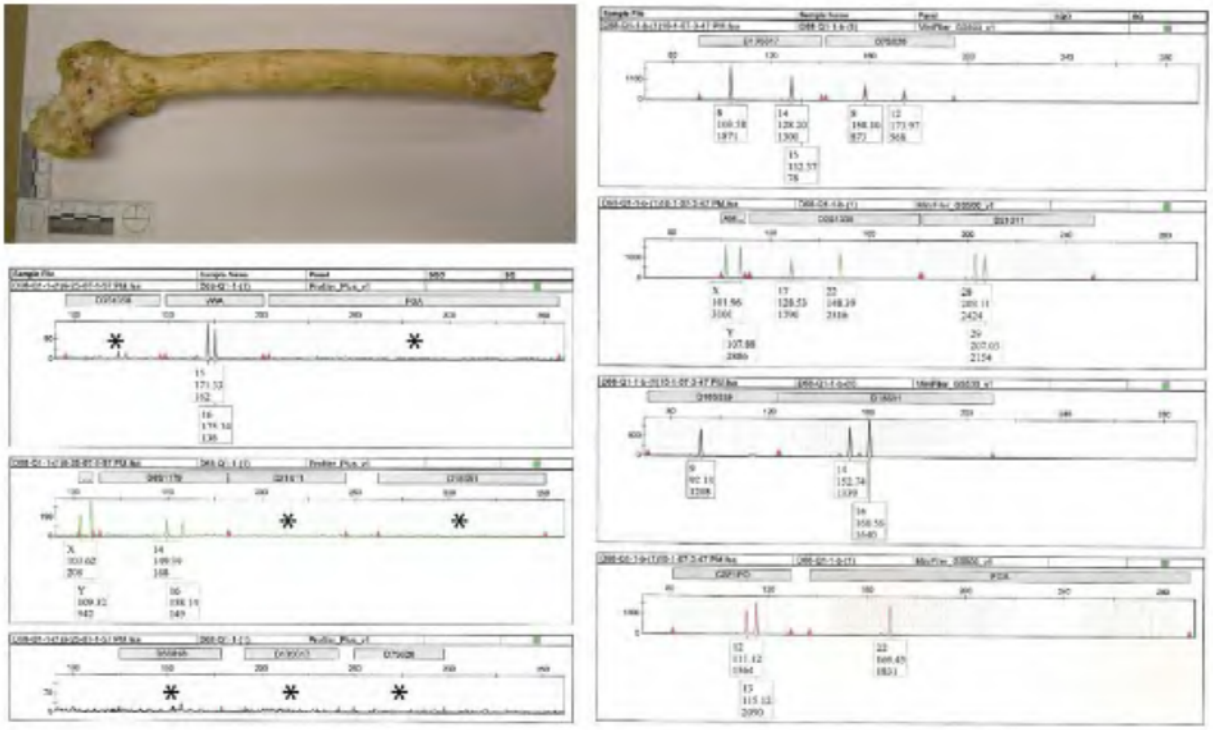

FIGURE 6 Case example illustrating the use *AmpFlSTR Profiler Plus*™ (left) and *AmpFlSTR MiniFiler*™ (right) on a bone sample. An (*) indicates loci that failed to yield genetic information with the former.

full profile. This profile is suitable for comparison purposes should a reference sample become available.

Interpreting DNA Evidence

After completing the analysis procedures on the questioned sample(s) followed by comparison to the relevant reference sample(s), the DNA expert begins the data evaluation phase. It is this phase where the DNA evidence in its entirety is interpreted and conclusions are drawn. The complexity of this process varies but in some cases may represent the most challenging aspect of the case. Ultimately, a DNA case will yield an inconclusive finding, exclusion, or match (aka inclusion or failure to exclude).

Ultimately, DNA has the power to not only convict the guilty, identify the dead, and resolve questions of parentage/kinship but also to exonerate the innocent. Every forensic science student is introduced to the concept of exclusion for what it is—an extremely powerful piece of information, particularly if you are the one being accused of a crime. Exclusions are also usually straightforward to interpret and require no statistical analysis. Declaring a match, however, requires that further statistical evidence be performed to describe the significance of this match, for without it. the interpretation is incomplete and potentially misleading [22].

Direct Comparisons

In the simplest of scenarios, like a single-source (unmixed) profile that matches a reference sample at all loci tested, a statement related to the random match probability (RMP) is common. Direct comparison examples could include the match between a bitemark swab and a suspect or the match between a skeletal sample of the deceased and a medical sample or personal effect from a missing person. The RMP is an estimate of how common a given profile is in a given population or, in other words, the probability of selecting at random from this population the profile of interest. Calculating the RMP is straightforward [1], but it requires the following:

- A single-source DNA profile of interest with associated allele numbers determined.
- A suitable population database (e.g., White, Black, Hispanic, etc.) with the allele frequency information available.
- A basic understanding of Mendelian Genetics and Hardy-Weinberg Equilibrium that underpin the use of p^2 and $2pq$ to calculate the homozygote and heterozygote genotype frequency, respectively, at each locus of a profile. (Note: The NRC-II recommended approach for calculating the homozygote genotype frequency utilizes $p^2 + p(1 - p)\theta$ to account for population subdivision. A conservative value of θ (0.01) is used for large populations [22].)
- A basic understanding of the product rule: the RMP is calculated at each STR locus and then multiplied to produce a combined RMP that is reported.

Table 1 illustrates how the combined RMP is calculated using the nine-locus profile shown previously (see Figure 4). An example of an accompanying statement may take a form such as "The DNA profile from sample Q1 (swab of bitemark) matches sample K1 (B. Mowers). The probability that a randomly selected individual unrelated to B. Mowers would coincidentally share this profile is estimated to be one in 5 trillion." Declaring a match does not mean that both samples *did* come from the same person but rather that they *could* have originated from the same person. The RMP is a statement related to the probability that someone other than the suspect could have this profile and is therefore conducive to the presumption of innocence.

The preceding example highlights the approach for a single-source (unmixed) profile, but mixed samples are prevalent in forensics and can add complexity to the evaluation process. There are different approaches utilized in the forensic community to handle mixtures [23], but in some circumstances an RMP approach can still be used. For example, a two-person mixture with a major and minor donor may allow the former to be unambiguously dissected and utilized like the preceding situation for a single-source profile.

TABLE 1 Example of a Random Match Probability Calculation [a]

	D3S1358		vWA		FGA		D8S1179		D21S11		D18S51		D5S818		D13S317		D7S820	
Alleles	15	16	14	16	24	26	12	13	28	31	12	15	11	11	11	11	7	12
Allele Frequency [b]	0.2896	0.2287	0.1311	0.1860	0.1463	0.0183	0.1616	0.3354	0.1555	0.0945	0.0945	0.1799	0.3476	0.3476	0.3018	0.3018	0.0183	0.1280
Formula [c]	$2pq$		$2pq$		$2pq$		$2pq$		$2pq$		$2pq$		P^2		P^2		$2pq$	
Frequency	0.1325		0.0488		0.0054		0.1084		0.0294		0.0340		0.1208		0.0911		0.0047	
1 in	7.55		20.49		185.16		9.23		34.01		29.41		8.28		10.98		212.77	
Combined Frequency			1.9569×10^{-13}															
1 in			5.11×10^{12} (5 trillion)															

[a] *Based on the profile from Figure 4 (Amelogenin omitted)*

[b] *Based on the Canadian Caucasian population (www.csfs.ca/strdnadata)*

[c] *For simplicity $\theta=0$ for homozygote frequency calculations (D5S818 and D13S317)*

There is an alternative approach to describe the significance of the match just outlined that utilizes a likelihood ratio (LR). The LR method requires two alternative and mutually exclusive hypotheses to explain the evidence in terms of the odds in favor of one or the other events. The LR, like any statement of odds, is simply a ratio of two probabilities. For example, the prosecutor's hypothesis (H_p) may state, "The suspect left his DNA on the victim during the attack," and the defense's hypothesis (H_d) may state, "An unknown person left his DNA on the victim during the attack." Using the same profile as previously, the LR then becomes the probability of observing this genetic evidence given H_p divided by the probability of observing this genetic evidence given H_d. Under the prosecutor's hypothesis, the probability of observing this profile if the suspect left his DNA on the victim during the attack is certain (100%), making the numerator of the odds equal to 1. Alternatively, under the defense's hypothesis, the probability of observing this profile if an unknown person left his DNA on the victim during the attack is simply the RMP (the probability of selecting this profile at random from the population). The LR therefore is 1 over the RMP or 1 in 5 trillion, the same number as previously. An example of an accompanying statement may take a form like "The genetic evidence is 5 trillion times more probable if the suspect left his DNA on the victim versus an unknown individual."

Indirect Comparisons

The likelihood (LR) approach is also employed to evaluate the significance of DNA evidence when parentage or kinship is in question. Although the derivation of the formula utilized in these evaluations is beyond the scope of this book, the logic is straightforward. In criminal cases, questions focus on suspect identity, but in parentage/kinship cases, for example, questions may take the form "Who is the father?" or "Who is the brother?" Although an industry has been built upon answering the former question via the paternity index (itself a LR), similar questions play important roles in identifying the dead. In such cases, individual LRs are calculated at each locus, using the appropriately selected formula, and then a combined LR is calculated using the product rule.

Table 2 illustrates the LR approach for the identification of human remains under three different scenarios where the deceased's profile is compared to a putative brother or a putative mother, or a putative mother and brother. The first hypothesis (H_1) may take the form "Individual 1 is related to the deceased," and the second, alternative hypothesis (H_2) may take the form "Individual 1 is unrelated to the deceased." A likelihood ratio greater than 1 supports relatedness. In this example the genetic evidence is 150 times more probable if Individual 1 is the biological brother of the deceased versus being unrelated. Alternatively replacing the putative brother with the putative mother of the deceased produces a LR of 83,000. One need not calculate individual LRs for each putative relative but rather calculate an overall LR that takes into account all of the genetic information (deceased, mother and brother) and in this case

TABLE 2 Identifying Human Remains (Likelihood Ratio Examples)[a]

	D3S1358		vWA		FGA		D8S1179		D21S11		D18S51		D5S818		D13S317		D7S820	
Deceased	14	16	16	18	22	23	10	14	30	30	15	17	13	15	8	12	9	12
Scenario 1 (Deceased and Putative Brother)																		
Putative Brother	14	16	17	18	21	24	13	14	30	30	13	15	11	12	8	12	9	12
LR	5.80		0.91		0.25		0.91		8.48		0.94		0.25		6.51		9.63	
Combined LR	150																	
Scenario 2 (Deceased and Putative Mother)																		
Putative Mother	16	16	16	18	21	22	14	14	29	30	15	17	12	15	8	12	9	10
LR	2.19		2.67		1.09		2.65		2.41		3.61		83.33		3.55		1.91	
Combined LR	8.30×10^4																	
Scenario 3 (Deceased, Putative Mother and Brother)																		
LR	9.24		1.33		0.55		1.32		7.02		1.80		41.67		6.26		8.40	
Combined LR	2.47×10^5																	

[a] *Allele frequencies (not shown), based on the Canadian Caucasian population (www.csfs.ca/strdnadata)*

results in a LR of 247,000. Software packages are available to assist the DNA analyst with these calculations (24a, b). An example of an accompanying statement may take a form like "The genetic evidence is 247,000 times more probable if Individual 1 and 2 are the biological brother and mother of the deceased, respectively."

The preceding scenarios illustrate some important aspects of human identification cases. Using a sibling as a reference sample can be problematic because although biological siblings are likely to share alleles, a lack of shared alleles does not result in an exclusion. This is unlike comparisons to a parent where allele sharing is seen at every locus, barring a mutation. The strength of the genetic evidence tends to increase, as seen by higher likelihood ratios, when one uses a parent compared to a sibling. Whenever possible, it is advisable to collect samples from multiple, closely related family members.

Case Study: The Case of the Missing Pilot

This case, which was completed at BCIT on behalf of the British Columbia Coroners Service, illustrates the impact that the addition of a mini-STR multiplex can have within a forensic laboratory process. In November 1970, during poor weather, a small, single-engine airplane with its sole male occupant crashed in southern British Columbia, Canada. Although the crash site (Figure 7) was not far from the heavily populated Lower Mainland, it was

FIGURE 7 Case example showing a 1970 single-engine plane crash. The plane, with its male occupant, crashed in a heavily wooded area (left). Several skeletal elements were scattered about the wreckage, including the human skull (upper right, center frame). Analysis in the laboratory revealed the extent of the damage and degradation (lower right).

in steep, heavily wooded terrain. The site remained undisturbed until 2007, when a surveyor stumbled across it. The coroner and police processed the scene and collected several skeletal elements, including a heavily damaged skull and fragment of long bone.

Evidence from the plane provided a potential lead with respect to the identity of the pilot, but a DNA comparison to a putative daughter was required for confirmation. Even after exposure for 37 years to the harsh conditions of this area, usable DNA evidence was generated. Although no DNA was detected in two sampled molars, sufficient DNA was isolated from the long bone (not shown) to proceed with STR analysis. An initial amplification with *AmpFlSTR Profiler Plus*™ yielded a partial (male) profile with two of the nine STR loci exhibiting dropout (data not shown). Analysis and comparison to the daughter using kinship software (24) yielded a combined likelihood ratio of 118. Additional testing with *AmpFlSTR MiniFiler*™ yielded a complete (male) profile with no dropout observed at the eight STR loci amplified. Overlapping loci were consistent between the two multiplexes, and the combined genetic data resulted in a total of 12 usable STR loci and combined likelihood ratio of 4953. The end result was a strengthening of the reported concluding statement from "strong" to "very strong" when describing the strength of the genetic evidence in favour of identification [25].

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Missing and Unidentified Persons: The National Crime Information Center Dental Enhancements

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The Function of the Dental Enhancements

The dental enhancements to the Missing, Wanted, and Unidentified Persons files in the National Crime Information Center (NCIC) were developed to assist law enforcement agencies in the resolution of person cases. After the dental information is entered in NCIC, a dental crossmatch ($.M) report is generated, ranking the matching candidates in order of probability that the dental profiles are of the same individual. The dentition is the most resilient identification media that can be found in the human body. It is extremely resistant to deterioration from exposure to almost all of the elements that can be found on earth. The use of the dental "profile" of an individual to

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compare with that of living or deceased individuals is often compared to the use of mitochondrial DNA (mtDNA) sequence comparison for the development of an identification [1]. Unlike mtDNA sequence comparison, which is considered circumstantial evidence, the final comparison of adequate dental information is able to establish a positive identification. The dentition, with 32 adult teeth and 20 primary teeth, has physical features that are often unique to an individual. Teeth can be present or absent and, if present, restored or unrestored, which creates a combination of conditions that are extremely valuable in establishing a list of possible candidates for further identification [2].

The NCIC dental enhancements are designed to give the investigator a list of possible candidates that are easily reviewed by a trained examiner. It is not designed to establish a positive identification but rather a resource to point the investigator to possible candidates for further investigation to establish an identification. Analysis of the crossmatch report ($.M) also readily eliminates individuals from further investigation in a particular case, thus saving the agencies significant time tracking bad leads. The final identification is established by a qualified individual following the comparison of the available dental records that have been obtained by the investigating agencies.

To facilitate the analysis and expedite the process of the resultant NCIC reports, the Federal Bureau of Investigation's Criminal Justice Information Services division (CJIS) has established two programs. One is Dental Coding Workshops in regions across the country to explain to interested dental personnel how and why the system works. These individuals are trained in the proper analysis and coding of the dental information so the NCIC system is using consistent data in its comparison functions. They are trained in the proper analysis of the resultant crossmatch reports ($.M's). CJIS has also established the National Dental Image/Information Repository (NDIR), which is located online and accessible by members of the Law Enforcement Online (LEO) site. The NDIR contains the available dental information and images used for the process of identification or elimination of possible candidates, thus reducing the time it takes to get the available information needed to establish an identification.

The NCIC system is not designed to be a first responder type of system for the identification of victims. It is an ongoing tool for the investigation of missing persons, wanted persons, and unidentified remains that cannot immediately be identified. When the recovery operation for a mass fatality incident is completed and there are remaining missing and unidentified individuals, the NCIC system should be used for entry of the dental information regarding those cases that remain open. The information regarding these particular cases is then stored indefinitely in NCIC and the NDIR. A good example of this would be those remaining missing persons and unidentified remains that were lost and/or recovered following the initial response to the Hurricane Katrina disaster.

History and Development of the Dental Functions in NCIC

The dental comparison features in NCIC pertain strictly to the persons files. The Wanted Persons File was developed in 1967 and contained no capability of entering dental data. The Missing Persons File was added to NCIC in 1975 and also did not allow the entry of dental information. In 1983 the Unidentified Persons File was added, and, along with the Missing Persons File, dental data were incorporated into the entry fields for both persons files. A comparison program was established that weighted the physical, demographic, and dental information in order to develop a list of possible candidates for matching the missing persons to the unidentified persons. Unfortunately, the dental information was weighted much less than the physical information when developing the list of possible matches. This decision to put more importance on physical attributes than the dental characteristics resulted in matching reports that did not match missing persons that had identical dental profiles to unidentified person records [3].

Another significant problem with this system was the complexity of the coding and the entry form. The coding that was developed for this system contained 56 codes, many of which were subjective. The coding form used for entering the dental information contained 256 fields. The combination of subjective codes and complicated entry fields led to coding interpretation errors and entry errors when the information was entered in to the NCIC system. These problems and the resultant ineffectiveness of the system to generate accurate leads for investigation remained unchanged from 1983 to April 4, 2004 [4].

While the dental information was being added to the NCIC person files in 1983, the U.S. Army Institute of Dental Research (USAIDR) was developing a program that would use dental characteristics as the primary comparison information to identify mass casualty victims: the Computer Aided Postmortem Identification (CAPMI) [5]. Significant research went into the perfection of the logic involved in this program [6–10]. It is a DOS-based program, and further updates of the program ceased soon after the Armed Forces Institute of Pathology (AFIP) took over the project around 1990. The final version of the program is CAPMI4 and has, until the past few years, been successfully used by military and civilian agencies to assist in the investigation of missing and unidentified persons cases. The basic comparison logic and rudimentary intelligence developed for the CAPMI program is now the basis for the logic in the NCIC Dental Enhancements, WinID, and the Centralized Accounting Repository and Information System (CARIS) used by the Joint POW/MIA Accounting Command Central Identification Laboratory (JPAC CIL).

Practical use of the CAPMI4 program to match missing persons to unidentified persons was implemented by the Washington State Patrol's Missing/Unidentified Persons Unit (WSP M/UPU) in the late 1980s. Following the successful resolution of several "cold cases" using CAPMI4 as the primary investigative tool, testing of the then NCIC dental comparison algorithms was accomplished. The results of this test were published along with another publication expressing the problems of the NCIC system at that time, which led to the reactivation of the CJIS Dental Task Force to resolve the problems of the existing system.

In 1997, the Criminal Justice Information Services Division (CJIS) of the Federal Bureau of Investigation reconvened the CJIS Dental Task Force (DTF), which was first established in 1983. The DTF was made up of forensic odontologists, police investigators, medical examiners, representatives from the National Center for Missing and Exploited Children (NCMEC), and representatives from the Royal Canadian Mounted Police's Canadian Police Information Center (RCMP CPIC). The recommendations of this task force were approved by the CJIS Advisory Policy Board in 1999. The recommendations included the reduction of dental codes from 56 in the old system to 10; the redesign of the data collection guides to change the old form from 256 dental fields to 32 fields; the implementation of the basic CAPMI comparison logic in the NCIC matching algorithms; and the addition of dental information to the Wanted Persons File in NCIC. These improvements were implemented on April 4, 2004. The recommendation that a national repository be set up for the digital storage of dental images and information became reality with the establishment of the National Dental Image/Information Repository (NDIR) in 2006.

By the end of 2006, almost all of the technical-related problems of the old NCIC dental comparison issues had been rectified, and an efficient system had been developed to retrieve the dental information needed to resolve cases using dental information. As of this writing, the system is underutilized by many agencies. At any given time over the past several years, on average there are about 100,000 active missing person cases stored in the NCIC Missing Person File. Of these, only about 6,000 have dental information entered. There are currently about 7,000 unidentified persons stored in the NCIC Unidentified Persons File. Currently, the actual number of unidentified persons in the United States is estimated to be closer to 40,000. Of the approximately 7,000 unidentified records in NCIC, 5,000 have dental information entered. There are approximately 1,800,000 wanted persons entered in NCIC, and of these virtually none have dental information available for comparison to the unidentified persons on file. To achieve its potential, it needs trained individuals to (1) assist in the collection of dental information; (2) accurately and consistently code the collected information; (3) preserve and submit the information in a digital format; and (4) review the crossmatch reports generated by NCIC.

In 2007, CJIS implemented training programs for interested dental professionals to aid investigating agencies in the use of the NCIC Dental Enhancements. The training has been scheduled in different regions of the country and occurs three times per year. As of this writing, 450 dental professionals have attended the training, and 240 have volunteered to aid interested agencies. Their contact information is located on the LEO website. These individuals are a valuable asset for the investigating agency to use, as they are familiar with the system, coding, and analysis of the resultant crossmatch reports. Even though the system is much simpler than it used to be, it still requires knowledgeable individuals to ensure that the information is accurate and consistent to prevent the "garbage in, garbage out" problems with computer programs. Given the number of trained individuals willing to assist investigating agencies in their missing, wanted, and unidentified persons cases, it seems reasonable for agencies to enlist their help.

Collection of Dental Information

One of the biggest problems in the utilization of the NCIC Dental Enhancements is the lack of active records in NCIC that have dental information. Mostly this is a resource problem. Law enforcement agencies have neither sufficient money nor the manpower to track down and collect dental information regarding all of their missing and wanted persons cases. These issues are hard to overcome, but many agencies have employed the assistance of trained dental personnel to assist them in this task.

The Health Insurance Portability and Accountability Act (HIPAA) of 1996 has not been helpful in the task of collecting dental information needed to develop an accurate profile of dental characteristics for entry in the NCIC missing persons file. HIPPA is not a problem for the release of dental records in active investigations of missing persons. It often does create added work because many dental clinics may require an official document requesting the records when in the past a phone call usually would be all that was needed. A common form on official letterhead can be generated that lists the information needed from the dental clinic.

Missing and Wanted Persons Dental Records

The investigator should request the following dental information to get the most accurate dental profile possible from the available records for missing and wanted persons. The collection of the dental evidence regarding a missing/wanted persons case can be accomplished by personnel employed by the investigating agency. With this information, a dental clinic should be able to produce the necessary dental information. The analysis of the material for completeness and quality should be accomplished by a trained examiner. Dental nomenclature and abbreviations are not readily or accurately interpreted by nondental personnel. The radiographs received may not be complete or of diagnostic quality. Additional records may be available from dental specialists that are noted in the treatment record.

Legible Copies/Originals of the Written Treatment Notes

The treatment notes are needed to establish what kind of treatment has been rendered and the extent of the treatment. Frequently, restorations (fillings, crowns, etc.) are accomplished after the radiographs have been taken. Some practitioners note the extent of existing fillings which is sometimes impossible to determine by just examining the two-dimensional radiographs. If the records use any kind of color coding, then one should obtain either the original treatment notes or a color copy of these records, with a legend explaining what the different colors mean.

All Available Original Radiographs

All of the available radiographs are needed, since older radiographs may show more detail in some areas than just the most recent radiographs. The original radiographs are much preferred over copies. Copied radiographs lose detail, and frequently it is hard to determine right and left orientation. Original radiographs are preferred for scanning to digital format. Many clinics are now using digital radiographs. The digital radiographs should be submitted in a TIFF or JPEG format. All of the digital radiograph systems have the ability to convert their proprietary images to either or both of these formats. Do not accept proprietary image files, as they cannot be universally viewed and will not comply with the NDIR record submission requirements.

Intraoral and Extraoral Photographs

These types of dental photographs are often associated with orthodontic treatment and are extremely useful in not only the accurate coding of the dental characteristics but also for anatomic identification when restorations are not present. With the advent of intraoral cameras, many general dental practices also have, usually digital, close-up pictures of the patient's teeth.

Dental Casts

The dental casts are plaster or stone models of the individual's teeth and are used in identification processes in much the same manner as photographs. Storage of this type of dental evidence becomes difficult. If dental casts are received, they can be photographed or scanned on a flatbed scanner and the original models sent back to the dental clinic.

The investigating agency should also ask for pictures of the missing person. Snapshots or portrait-type photos showing the front teeth of the individual and facial features can be used in the identification process. This is especially important when no other dental evidence is available.

Unidentified Persons Dental Records

The collection of dental information from the deceased or living unidentified individual is very similar to that of the missing/wanted persons data collection and should include the following:

- *A complete written description of the dentition and oral structures.* The examination findings should include which teeth are present and those that are absent; the type of restorations that are present and the tooth surfaces that are involved; a description of any oral appliances or orthodontic hardware present; any unusual oral conditions; and any endodontic (root canal) treatment that has been performed.
- *A complete radiographic series and panoramic radiograph if possible.* A complete full-mouth series of radiographs should be obtained whether teeth are present or absent. If the unidentified person is skeletal or living, it is recommended that a panoramic radiograph be obtained. Radiographs should be obtained even if the individual is edentulous.
- *Intraoral and extraoral photographs.* Photographs should be taken of the dentition whenever possible. These may be useful in the identification process by being able to compare anatomic features to photographs and/or dental models of missing persons.
- *Dental casts.* This procedure is not commonly performed on unidentified persons. If the unidentified is deceased, many agencies will store the remains until identified. If the unidentified remains are to be interred, it may be recommended that dental casts be obtained to avoid the expensive process of exhumation to confirm dental features. Under no circumstances should unidentified remains be cremated.

Teeth are commonly recommended as a source of DNA. If teeth are to be removed from the remains for DNA sequencing, every effort should be employed to document the anatomic features of the teeth that are to be submitted. It is *not* recommended that anterior (front) teeth be extracted and used for DNA analysis because the anatomy of these teeth is critical when the identification is based on antemortem photographs.

The collection of dental evidence in an unidentified persons case should be accomplished by trained dental personnel. The examination and charting by qualified dental personnel is also critical to accurately describe the dental characteristics and unusual features that will be essential for determining the identification status. The advancement of cosmetic dentistry and its dental materials have created dental characteristics that are not easily observed by inexperienced examiners. Radiographic techniques are also critical and should be performed by an experienced technician. Improper angulations and placement of the film can hinder the comparison process and lead to false negative findings.

The *NCIC Missing and Unidentified Persons File Data Collection Entry Guides*

The new data collection entry guides were revised as of the implementation of the dental enhancements to NCIC 2000. Hard copies and interactive PDF forms of the guides can be obtained by requesting them from the local FBI office or electronically at the LEO website. The first part of these guides primarily relates to medical information and personal descriptors that may be helpful in the investigation. There have been a few modifications in this first section, but primarily it remains unchanged from previous versions. One exception to this is the Body Part Status (BPS) section in the *Unidentified Persons Guide*. This will be discussed later in the chapter. The last part of the guides contains the dental coding instructions. This section has been revised to explain and instruct on the use and entry of the dental enhancements.

At the beginning of both the missing and unidentified data collection guides is a letter to the dental professional that will be filling out the remainder of the form. A checklist of important dental evidence that needs to be collected is also included. It is very important that those that are assisting the LEA and MECs refer to this checklist so they can be sure that all of the information has been collected and submitted to the proper agency. An additional item that is very important but not included on the list is that all dental evidence must be scanned to digital format and submitted to the NDIR after the case has been entered in NCIC. The recommendations regarding the scanning, format, and file naming of these submitted records will be discussed later in this chapter.

The following two forms must be completed in both of these guides.

- **The Dental Condition Worksheet (DW):** The Dental Condition Worksheet incorporated in the *NCIC Persons File Data Collection Entry Guide* is designed to provide additional dental information that is not codable and will not appear on the NCIC persons case record. Its original function was to provide information that would be useful for coding in other dental comparison programs, such as CAPMI4 and WinID. It has become a very useful document to review when analyzing $.M reports, as it contains more descriptive information regarding the dental characteristics that may not be confirmable by the investigator and, therefore, coded conservatively. It allows the examiner the ability to expand on information such as oral surgical elements, orthodontic appliances, removable prosthetic appliances, and oral anomalies that may be useful in the identification process. These latter items can be entered in the section of the NCIC record for Dentist Remarks (DRE). It is important that all fields in the form be filled out completely. A blank could mean either no codeable characteristics were available or the examiner failed to note any characteristics. This document is available in an interactive PDF format so information can be entered, saved, and transmitted to interested agencies (Figure 1).

NCIC Missing Person File
Data Collection Entry Guide

Agency Case #________________

DENTAL CONDITION WORKSHEET
(to be completed by dentist)

You should fill out this chart following your complete review of all available dental records and radiographs. You should number the teeth following the format of the Universal numbering system with tooth #1 being the upper right third molar, tooth #16 being the upper left third molar, tooth #17 being the lower left third molar and tooth #32 being the lower right third molar. In your descriptions of the restorations present, you should include the surfaces involved (M, O, D, F, L), the restorative material used, such as amalgam, gold, porcelain, composite, temporary cement and any other conditions that may be observed such as endodontic treatment, pin retention, orthodontic brackets or bands. You must not leave any tooth numbers blank. If the tooth has no restorations, note it as "virgin" or "present, no restoration." Note other significant dental information at the bottom of this chart or on an additional sheet of paper, which you should attach to this worksheet.

1. ________	32. ________
2. ________	31. ________
3. ________	30. ________
4. ________	29. ________
5. ________	28. ________
6. ________	27. ________
7. ________	26. ________
8. ________	25. ________
9. ________	24. ________
10. ________	23. ________
11. ________	22. ________
12. ________	21. ________
13. ________	20. ________
14. ________	19. ________
15. ________	18. ________
16. ________	17. ________

Additional Dental Information:

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FIGURE 1 The *NCIC Missing Person Data Collection Guide* Dental Condition Worksheet is used to describe the dental condition of each tooth. It also contains a section that can be used for more descriptive information regarding dental conditions and explanations that cannot be coded.

- **The NCIC Person Dental Report (DR):** The *NCIC Dental Report* consists of four sections. For a missing/wanted persons case, the first section contains the name of the individual and the age at the time of his or her disappearance. For the unidentified persons case, Section 1 contains the MEC name and case number. Both

NCIC Missing Person File
Data Collection Entry Guide

Agency Case #____________

NCIC Missing Person Dental Report

SECTION 1

Patient's Name: __________ Age at Disappearance: _____ NCIC #: ________

Completed by: ____________________ Date Completed: ________

Address: ____________________________

Telephone #: ____________ Email Address: ____________

X-Rays Available? ☐ Yes ☐ No   Dental Models Available? ☐ Yes ☐ No   Dental Photographs Available? ☐ Yes ☐ No

SECTION 2 ***DENTAL CHARACTERISTICS***

Upper Right		Lower Right
01 (18)______		32 (48)______
02 (17)______		31 (47)______
03 (16)______		30 (46)______
04 (15)______(A)	(Numbers in parentheses	29 (45)______(T)
05 (14)______(B)		28 (44)______(S)
06 (13)______(C)	represent FDI System.)	27 (43)______(R)
07 (12)______(D)		26 (42)______(Q)
08 (11)______(E)		25 (41)______(P)
Upper Left		**Lower Left**
09 (21)______(F)	(Letters in parentheses	24 (31)______(O)
10 (22)______(G)		23 (32)______(N)
11 (23)______(H)	represent deciduous	22 (33)______(M)
12 (24)______(I)		21 (34)______(L)
13 (25)______(J)	dentition.)	20 (35)______(K)
14 (26)______		19 (36)______
15 (27)______		18 (37)______
16 (28)______		17 (38)______

SECTION 3 ***DENTAL CODES***

X = Tooth has been removed or did not develop
V = Tooth is unrestored or no information (Default Code)
M = Mesial Surface Restored
O = Occlusal/Incisal Surface Restored
D = Distal Surface Restored
F = Facial or Buccal Surface Restored
L = Lingual Surface Restored
C = Lab Processed or Prefabricated Restoration
R = Endodontic Treatment
/ = Tooth present but clinical crown missing (i.e., fractured)*

(*The codes V and / are used differently in the Missing Person Dental Report than in the Unidentified Person Dental Report.)

SECTION 4 ***DENTAL REMARKS***

☐ ALL (All 32 teeth are present and unrestored)   ☐ UNK (No dental information available)

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FIGURE 2 The *NCIC Missing Person Data Collection Guide* report is used to enter the appropriate codes and information needed for entry of the dental information in to NCIC.

the missing/wanted and unidentified persons, DR has the contact information of the person that did the analysis and coding for the case along with simple check boxes to indicate what dental evidence is available—for example, x-rays, dental models, and dental photographs (Figure 2).

The second section of the DR contains 32 fields that correspond to the teeth positions normally found in the human dentition. This section is where the examiner enters the codes for the dental characteristics that will be entered in the appropriate fields in the NCIC case file. Both the Universal and FDI tooth numbering systems are noted on the form. Primary teeth positions are designated using the Universal System alpha codes. By reviewing the DW, it is an easy task to fill in the appropriate tooth fields with the most accurate dental characteristic codes.

The third section contains the acceptable dental codes that can be entered in the teeth fields, along with a brief definition of the individual codes. It is important to note here that the codes "V" and "/" are used differently when coding missing/wanted persons versus unidentified persons cases. Explanation of why there is a difference is explained in the Dental Section of the data collection guides for the type of case the examiner is working.

The fourth section contains a free text field where the examining dental professional's remarks can be noted and entered in the NCIC record. This field may be restricted to 50 characters/spaces in some state systems, so one needs to be aware of this when entering information in the section. Key words work well such as *complete denture, orthodontic appliance, surgical plate/screws,* and so on. Although the DRE comment field is not incorporated into the automated comparison function of NCIC, it does give investigators more information on a particular case in the NCIC case. This field is searchable using the NCIC help desk. Additional check boxes are available in this section to indicate that all teeth are present and unrestored, in which case the system will enter all "V" codes in the Missing, Wanted and Unidentified Dental Characteristics teeth fields. The other available check box indicates that no dental information is available. In this case the system will enter "/" in all teeth fields, and an automated comparison will not generate a dental crossmatch report.

The National Dental Image/Information Repository

In 2006, CJIS established the National Dental Image/Information Repository (NDIR) in the online website of Law Enforcement Online (LEO). Although not electronically connected to NCIC, it is a very important tool for the resolution of missing, wanted, and unidentified persons cases. LEO is a secure website dedicated to the dissemination of information that would be helpful to law enforcement personnel. Applications for access to LEO can be obtained online at *www.leo.gov*. Those dental professionals who have undergone the NCIC dental enhancement training can gain access to this site following the review and approval of their LEO user application.

The NDIR contains the following:

- Instructions for submitting missing and wanted persons information
- Instructions for submitting unidentified persons information
- Volunteer dentists with contact information
- Instructions on how to retrieve the information stored in the NDIR
- The Missing and Wanted Persons Case repository
- The Unidentified Persons Case repository
- Downloadable interactive forms for missing, wanted, and unidentified persons
- Contact information for assistance and recommendations

Submission of case material to the NDIR is completely voluntary. LEAs are not required to submit information, but there are two important reasons for their participation: The NDIR provides ready access to information that can efficiently assist in the process of analyzing the possible identification candidate lists ($.Ms) generated by NCIC. Second, every case that is submitted to the NDIR is reviewed by an individual that has been through the NCIC Dental Enhancement training. This review by qualified examiners ensures that the coding is accurate and conforms to the protocols that are needed to ensure that the interpretation of dental characteristics is consistent. This again is totally voluntary by the submitting agency, but ignoring this free service can lead to inaccurate or incomplete information that could be very important in the resolution of cases.

Comparison Logic

To be a successful, a dental comparison program must have certain features. The program should be specific enough in the dental characteristics to render a manageable number of possible candidates when comparing large databases of individuals. Some programs use what is called a generic coding, which involves coding dental characteristics of the teeth as either present, missing, or present and restored. This type of generic specificity works well in small databases. When dealing with the numbers of NCIC persons cases, this generic specificity yields too many candidates to effectively assist the examiner. Using too many dental characteristics, which was a feature of the previous version of NCIC, yields candidate lists that are too restrictive and increases the frequency of interpretation and entry errors, which does cause the elimination of good candidates for investigation. The current NCIC Dental Enhancements incorporate eight primary codes used for the ranking of records and two secondary codes that are strictly descriptive and are not employed in the matching algorithms.

The second feature that the program must satisfy is the possibility that the dental records available for analysis and coding, specifically concerning the missing or wanted person, do not represent all of the treatment that was rendered to the individual. The program must identify those dental characteristics that are possible matching differences due to treatment that is not noted or available in the records analyzed. This rudimentary artificial intelligence must be incorporated into the program so dental record omissions or unavailable records do not create an exclusion determination by the examiner.

One progression of treatment is not reversible. For instance, a tooth can be present and then extracted. The available dental records may indicate that the tooth was present, but there may be no record recovered indicating that the tooth was subsequently extracted. When a missing/wanted persons record indicates the presence of a tooth and the unidentified information indicates that the tooth is missing, the program designates this as a possible matching characteristic. This is a nonexclusion finding when analyzing the crossmatch report. On the other hand, if a tooth is recorded as missing, it cannot suddenly appear in the unidentified person profile as being present. The program designates this as a mismatch or nonmatch. Depending on the reliability of the records and accurate interpretation and coding of these records, this can be an exclusionary finding.

The NCIC program compares the dental profile coding of the missing/wanted persons files to that of the unidentified persons profiles. It ranks the records in order of the most exact matches (M) of dental characteristics, the most possible matches (P), and the least number of mismatches (N). There are 32 tooth fields that are compared. Those with the highest number of M codes are then ordered according to the most P codes and finally ordered using the least number of N codes.

To the untrained analyst, the process of reviewing the resultant list of possible candidates may seem to be a simple one. The analyst would simply eliminate all of those candidates who had any N scores. Unfortunately, this cannot be done so simply. Most cases that have been resolved using the NCIC system have had at least one mismatch in dental characteristics. There are several reasons for this, and the major one is that law enforcement agencies (LEAs) and medical examiner/coroner (MEC) agencies use untrained dental personnel for the analysis and coding of the dental records. Another reason is the lack of complete, high-quality, and accurate dental records collected by the LEA and MEC for analysis. It cannot be stressed enough that the collection, coding, and analysis should be accomplished with the assistance of a trained dental professional.

Such individuals have been exposed to those types of records and thus the resultant coding that may yield false negative findings. Many of these situations have been identified, and coding rules have been established to handle these characteristics to minimize the possibility that they will generate an N score. For example, one of the most common restorations that generate N scores is the fillings on the front teeth. When placing a filling on a front tooth a dentist usually accesses the cavity from the tongue side of the tooth to restore a cavity that is located between the teeth. Some dentists note this treatment as a two-surface filling, and some note it as a one-surface filling. This also applies to those dentists who are collecting dental information from an unidentified person. A trained dental professional who is familiar with the NCIC system would code the missing/wanted persons record as a single-surface restoration unless there is significant involvement to the tongue side of the tooth. A trained dental professional analyzing the unidentified dentition would code the same type of restoration as a one- or two-surface filling, depending on the extent of the tongue side involvement. These rules of coding will result in either a score in the M or the P column but not in the N column.

The missing/wanted coding is always conservative and should only be those characteristics that can be confirmed by x-rays and/or dental records. When there is any doubt concerning the existing characteristics entries, conservative coding is used. The unidentified coding is considered to be the more accurate dental profile, since the examiner has the actual dentition to examine. This may not be the case for unidentified remains that have already been disposed of or are not readily available for direct examination where only the documentation and hopefully x-rays are available for analysis and coding. For these cases, a more liberal coding is called for. The main concept in coding is to provide the most accurate dental profile and at the same time recognize and code those conditions that could create false N scores.

The NCIC Dental Crossmatch Report ($.M)

Every morning, CJIS generates a crossmatch report that compares the dental characteristics that have been entered or modified in NCIC the previous day. The investigating agency (ORI) of the record that was entered or modified (key record) receives a dental crossmatch report ($.M) that lists the top 35 candidates (object records) that could possibly be matched to their case. The total score is 32, and the records are ordered by the highest number of exact matches (M), the highest number of possible matches (P), and the lowest number of nonmatches (N). The ORI of the object records is sent a message that their case is a possible identification candidate to the key record. By doing this, NCIC is ensuring that both ORIs involved in the matching report have been notified of the possible identification. It is then their responsibility to analyze the information in both the key and object records to either eliminate or pursue further information to determine the identification status. This process should again be handled by a trained examiner. Just as no one expects the LEA investigators to analyze fingerprints or DNA results, they should not be expected to analyze dental $.M's (Figure 3).

The LEAs can use certain items in the NCIC record to eliminate possible candidates. "Packing the record" is a term that is often used by NCIC trainers when they speak to LEAs. There is a MIS comments field for entry of any kind of information available regarding a particular case. One of the most valuable types of information that can be entered here is the circumstances surrounding the disappearance of an individual or the circumstances surrounding the recovery and conditions of an unidentified person. For instance, if information is noted that a person went missing as a result of a boating accident off the

```
YOUR RECORD WITH NIC/M123456789 OCA/10-0307  IS A POSSIBLE MATCH
WITH THE FOLLOWING RECORD(S). "Key Record"

THIS SEARCH WAS INITIATED BY THE ENTRY/UPDATE OF NIC/M123456789.

                     "Object Records"
                 SEX/ EYB/
NIC           ST RAC  YOB  DBF/DLC  HGT WGT EYE HAI MATCH DATA  M  P  N
U000000011 NY M/W  1953 20050215 107 499 XXX XXX              26 03 03
U000000021 CA M/W  1964 19941023 509 168 BLU BRO              26 01 05
U000000031 CA M/W  1959 19990331 509 499 XXX BRO              26 00 06
U000000041 FL F/W  1965 19840418 501 100 XXX BRO              25 03 04
U000000042 FL M/W  1966 19890811 511 165 XXX BRO              25 03 04
U000000051 AK M/W  1961 19920906 405 250 XXX XXX              25 02 05
U000000061 WI F/W  1960 19850219 508 132 BRO BRO              25 01 06
U000000062 CA F/W  1957 19840827 502 138 BRO BLK              25 01 06
U000000063 CA F/W  1944 19870228 502 250 XXX BRO              25 01 06
U000000064 FL F/W  1976 20031229 503 499 XXX RED              25 01 06
U000000071 CO M/W  1951 19890815 509 155 BRO RED              25 00 07
U000000072 CA M/W  1966 19941113 511 175 XXX BRO              25 00 07
U000000073 TX M/W  1965 19870701 511 155 XXX BRO              25 00 07
```

FIGURE 3 A dental crossmatch report ($.M). The information at the top of the report indicates the "key record" NCIC number that has been compared to the "object records" listed below. An NCIC number that begins with "M" indicates that it is a missing person record. An NCIC number that begins with "U" indicates that it is an unidentified person record. There are usually 35 object records. The score of matches (M), possible matches (P), and no match (N) is noted on the right side of the report.

coast of South Carolina, the LEA investigator can reasonably assume that it is not a match to a body that was recovered hanging from a tree in Washington State. On the other hand, a missing person noted to be in a state of depression and who was last seen in a location near the remains found hanging from a tree might be a person of interest for further analysis. Any circumstances surrounding the disappearance or recovery are extremely important when reviewing $.M reports and can save the investigator and dental personnel a lot of time in the analysis of possible candidates (Figure 4).

Another issue that should be reviewed is the Body Part Status (BPS) field. The refinement of this field was also a recommendation by the latest CJIS Dental Task Force and was implemented at the same time as the dental enhancements. The BPS field is extremely important in validating other physical characteristics that the LEA and MEC investigators can use to eliminate possible identification candidates listed in the $.M report. The following codes are used for this field:

N: Not recovered
D: Recovered—Decomposed
F: Recovered—Fresh
S: Skeletal

When the conversion of the previous NCIC data occurred, a fifth code was left over from the previous version: R—Recovered. This code does provide some information but is not as descriptive as those that are currently in use. A review by the LEA and MEC should be done to ensure that the proper codes are currently in the NCIC record for their active cases.

```
MKE/MISSING PERSON INVOLUNTARY
ORI/WA0000000 NAM/LAST, FIRST MIDDLE  SEX/F RAC/W POB/WA DOB/19570518
HGT/504 WGT/102 EYE/HAZ HAI/BRO SKN/MED
OLN/XXXXXXXXXXXX OLS/WA OLY/1981
MNP/MP DLC/19810102 OCA/81-03072010
MIS/CONTACT MAJOR CRIMES 555-555-5555
FPA/N
DNA/Y DLO/ORI OF LAB TX 00000 Y, DNA TYPE-STR, SPECIMEN CATEGORY-BIO MOTHER,
DLO/CODIS SPECIMEN ID-UNTHSC-FXXXX-1
ORI IS   ANY COUNTY SHERIFFS OFFICE

DENTAL CHARACTERISTICS
DXR/Y MPA/N DRE/2 BWS AND 2 PAS ONLY
TOOTH
       01X              32X
       02MOL            310
       03MODL           300D
       040D             29V
       05V              28V
       06V              27V
       07V              26V
       08V              25V
       09V              24V
       10V              23V
       11V              22V
       12V              21V
       13V              20V
       14MODL           190
       15MO             180
       16X              17X

DENTAL IMAGES FOR THE SUBJECT OF THIS RECORD ARE AVAILABLE ON THE LEO NDIR
NIC/M123456789  DTE/19810304 1305 EDT DLU/20070516 1045 EDT
```

FIGURE 4 A missing person NCIC record. This is a typical report printout of a missing person record. The field information has been altered to allow publication. Please see the acronym list at the end of this chapter to provide explanations of each of the data fields.

The codes, D, F, and S provide information to the investigator as to the death interval, meaning the time from death to discovery. This information can be helpful in determining the validity of a possible candidate depending on the date of last contact (DLC) for the missing or wanted person. The BPS field is extremely useful for validating some of the other personal descriptor fields for the LEA investigator when determining candidates who can be readily eliminated as identifications. For example, consider a body that has F entered in all BPS field places. We then can reasonably assume that the sex field is accurate, and thus any mismatch in the sex and, more cautiously, RAC fields between the key and object records can be safely eliminated without any further investigation. Height (HGT) and weight (WGT) fields should be used very cautiously in the elimination process, as the antemortem information may not be that accurate. A complete recovery, using any of the preceding codes, should allow the examiner to eliminate those with discrepancies in the sex field. This process and logic can be automated, but as of this writing, it has not been implemented in the dental comparison algorithms contained in NCIC (Figure 5).

```
MKE/UNIDENTIFIED PERSON DECEASED
ORI/NY0000000 BPS/SSSSSSSSSSSSSSS SEX/M RAC/W EYB/1950-1956 EDD/19950000
DBF/20050101 HGT/UNK WGT/UNK EYE/XXX HAI/XXX
FPC/NANANANANANANANANANA OCA/10-03072010
MIS/SKELETAL REMAINS OF A WHITE MALE,AGE ESTIMATED AT 50 YRS  WAS FOUND IN
MIS/ANISOLATED-WOODED AREA OF THE SOMEWHERE STATE PARK IN THE TOWN OF MINE
MIS/NEARTHE NEW JERSEY STATE BORDER   THE REMAINS APPEAR TO HAVE BEEN IN THE
MIS/WOODS FOR 5 TO 10 YRS
CRC/U FPA/N
BXR/N CDA/U UNKNOWN CAUSE OF DEATH
MAN/
MAL/NYSP FIC, ALBANY, NY MAT/555-555-5555
DNA/N
ORI IS STATE POLICE

DENTAL CHARACTERISTICS
DXR/Y MPA/Y
TOOTH
       01X              32V
       020              310
       030              300D
       04MODFLCR        29V
       05F              28V
       06V              27V
       07V              26V
       08V              25V
       09V              24V
       10V              23V
       11V              22V
       12V              21V
       13V              20V
       14MODFLCR        190
       15MO             180
       16X              17X
NIC/U000000011 DTE/20050922 1205 EDT DLU/20090602 1054 EDT
```

FIGURE 5 An unidentified person NCIC record. This is a typical report printout of an unidentified person record. The field information has been altered to allow publication. Please see the acronym list at the end of this chapter to provide explanations of each of the data fields.

After the elimination of object records due to physical and demographic issues, the LEA or MEC should provide the remaining object and key records to a trained dental examiner. A complete printout of the NCIC records for both the key and the object records should be included in the material. The examiner can then compare the matching, possible matching, and nonmatching dental characteristics. With the knowledge of common coding errors and misinterpretation issues, the dental examiner can often make further eliminations to the list of possible candidates and then investigate those that remain by examining the actual dental records that are available for comparison. If these records are stored in the NDIR, this final process can take as little as a few minutes to establish the identification or eliminate the candidate. If they are not stored in the NDIR, this final process could take days, weeks, months, or never, depending on the ORIs involved and their ability to retrieve the necessary dental records.

NCIC Offline Search

Occasionally, an investigator may want to receive and analyze records that contain specific information about a missing individual or unidentified case. The Investigative Operations Assistance Unit (IOAU) at CJIS is responsible for responding to these types of requests. By using the IOAU, the investigator can receive a list of cases that satisfy specified parameters developed by the investigator. For instance, the investigator can request a list of all missing white females with a DLC from January 1, 2003, to March 6, 2005; an HGT between 5'5" and 5'10"; blonde hair; a laboratory processed crown in tooth #3's position; and dental implants. Depending on the workload at the IOAU, the results of these requests will be returned in 24 hours or usually no longer than a few days. This tool can be very useful if the examiner has been diligent in the entry of unusual dental features in the dentist remarks field (DRE). For further information regarding the manner in which requests for information can be directed, go to *ndir@leo.gov*.

NCIC Records Entered Prior to April 4, 2004

When the NCIC Dental Enhancements were implemented, all existing dental data in the persons files was converted to the new codes. This was possible because the previous codes were much more detailed, so the information was easily machine-converted to comply with the new coding system. Only the tooth field information was converted along with any coding dealing with root canal treatment and lab processed restorations. This eliminated the arduous task of reentering the information for each case.

Because there were thousands of these cases entered in NCIC, CJIS determined that an automatic generation of a dental crossmatch report using the new comparison logic would not be generated for the cases that had been entered prior to April 4, 2004. While this did prevent agencies from being deluged with matching reports, it did not allow the established comparison routines to be used with these older cases. It is likely that the dental enhancements to NCIC, and thus the dental crossmatch reports, would generate good candidates for further investigation. Agencies wishing to have dental crossmatch report generated on these old cases can do so by making modifications to any of the dental fields. This can easily be accomplished by putting the submission date in the DRE field. It is unclear at this time as to whether a modification of any of the physical descriptors will generate a new dental crossmatch report.

Juvenile Runaway Issues

An analysis of the Washington State missing person cases indicates that approximately 70% of the active cases are juvenile runaway cases. A similar analysis of the active unidentified cases indicates that more than 90% of the cases are adults. It is assumed that these are not unusual percentages and are probably very close to those of other states. The majority of cases received for analysis and coding are juvenile runaway cases and often clear within a few weeks or months. There are very strict laws, both state and federal, that require the reporting of missing juveniles, and thus compliance to collecting dental records for these is better than for adult missing persons. A missing adult is not a case that requires follow-up by an investigating agency according to any state or federal law, and therefore, submission of dental information concerning adult missing persons occurs less frequently. The problem is that the vast majority of our unidentified persons are adults. All agencies involved in missing persons cases must utilize their resources efficiently, and case priority becomes a significant issue. When making decisions to utilize resources, they must understand the nature of their cases.

Canadian Police Information Centre (CPIC) Conversion Issue

For years the CPIC system has had dental entries for their person files. They used a generic coding system that basically coded missing, present, and restored coding. This is much less descriptive than the previous NCIC coding. When the dental enhancements were implemented in NCIC in 2004, the CPIC records were machine-converted to the newer NCIC codes. Unfortunately, missing and unrestored teeth were converted correctly, but the restored teeth could not be coded to the surface codes used in the present system of NCIC. The CPIC records of teeth that were coded as restored converted to the "/" code for both the missing and unidentified persons records. The "/"code is not recommended for use in the missing persons record unless root canal treatment is indicated on the tooth and it is impossible to determine what surfaces of the tooth have been restored.

In the unidentified record the "/" code indicates that either there was no information available for determining treatment or the tooth was not recovered with the remains. This discrepancy in the definition of the code converted from CPIC to the current definition of the code in NCIC yields an "apples to oranges" comparison. If CPIC records are observed in the dental crossmatch report, they should not be ignored but will require further examination of the complete NCIC record. During the conversion process, those teeth that were coded as filled in the CPIC system are often listed by tooth number in the Dentist Remarks field (DRE). This can be useful in determining if the record should be further investigated. If the filled tooth pattern is the same in the key record and the object record, then a request for more detailed dental information is justified. One last complicating factor is that the tooth numbers in the DRE field are most often noted using the international numbering system, which can be confusing when the examiner is more familiar with the universal numbering system. Some Canadian records are coded using the appropriate codes for use in NCIC, but as of this writing, the majority of records need to be modified with the proper codes.

Wanted Persons Issues

Investigating agencies can now enter the dental profile of a wanted person. Obviously, with 1.8 million wanted persons in the NCIC database, the investigator will need to choose those cases that may be associated with violent activity. Analysis of the Washington State unidentified persons finds that fully 70% of the unidentified human remains were a result of homicide. This particular percentage of violent deaths is likely close to the national average of unidentified persons' manner of death. The old adage "live by the sword, die by the sword" is appropriate for most of these victims. Their disappearance may not be reported and thus will not be included in the missing persons files and will not be crossmatched to the unidentified persons file cases in NCIC. The family and friends of the wanted person are often uncooperative in providing information that will lead to the collection of dental records that can be used to resolve cases. An assumption can be made that most of these individuals have been handled by the criminal justice system.

Incarceration processes usually involve medical and dental examinations and treatment during the incarceration term. The Department of Corrections (DOC) for most states is a valuable resource for medical and dental information that could be used in the investigation process. Obtaining the dental information is dependent on interagency cooperation. Investigating agencies should establish contacts within their various DOCs so they may efficiently retrieve the necessary information to crossmatch with the NCIC's unidentified persons file. This process can save the agency significant time in tracking down wanted persons if an identification is made with a John or Jane Doe.

Other Missing and Unidentified Persons Resources

There are too many electronically accessible resources for the investigation of missing and unidentified persons to be listed here. Four of the more popular websites are the National Center for Missing and Exploited Children (NCMEC) (*www.missingkids.com*); the National Center for Missing Adults (NCMA) (*www.theyaremissed.org*); the Doe Network (*www.doenetwork.org*); and the National Missing and Unidentified Person System (NamUs) (*www.namus.gov*). All of these systems have the ability to search on various types of information, but only the NamUs system has the ability to search dental characteristics. As of this writing, the NamUs system can search for specific dental characteristics but has not incorporated the basic ranking logic that NCIC 2000 dental enhancements have incorporated in its design and function. The dental coding for NamUs records conforms more closely to the basic or generic coding that was discussed previously. This allows dental information that is entered to be easily converted to the NamUs coding, but the reverse is not true. This has led to two federally funded missing and unidentified tools that can communicate electronically only one direction. This is unfortunate, as it would be ideal if the attributes of both systems could be shared.

Conclusion

Identifying unidentified persons is the most important job for the LEA and MEC, as well as the families and friends of those who are missing. Without it, investigations of violent crimes and missing persons can be hampered and often left open due to the lack of leads. The families and friends go without closure and continue to wonder and worry over the fate of their loved one. All of the tools available should be utilized to their fullest potential to resolve these cases. Fingerprint and DNA tools are well established and do help with a considerable number of cases, but the least expensive and most efficient tool is often underutilized and instead left in the investigative tool box.

The dental enhancements to the person files in NCIC 2000 have established an effective manner in which person cases can be investigated. It incorporates the successful elements of computer programs that have been in use for years, but due to the historical inability of NCIC to effectively use dental information or a lack of understanding of how to use the current enhancements, its potential has barely been realized. The dental enhancements in NCIC 2000 are not static but dynamic. As the future becomes the present, we should see continued improvements to the system that will increase its effectiveness. The law enforcement agencies, medical examiners, and coroners must participate by submitting their case information so the system's present potential can be achieved. The technology problems of the past have been resolved. Resources for assistance in using the system are easily available. All that is needed now is for the investigative agencies to utilize the technology and resources that are available to them. Persons interested in assisting in the realization of the systems full potential can get more information by contacting CJIS at *ndir@leo.gov*.

Acknowledgments

The development of an effective tool to utilize dental information to resolve missing and unidentified persons cases has involved the tireless dedication of so many individuals that it would be impossible to list them all. Those who are close to the issues involving missing persons know that there is a lifelong commitment that is acquired, often not by choice, whether they stay with the particular agency they are working with or have moved on to other work. I would like to name a few who have significantly contributed to the advancement of the tools needed to help bring closure to families as well as those investigating violent crimes. Dr. Lewis Lorton developed the first affective dental comparison program, which has become the industry standard in logic for dental comparison programs. Dr. Norman Sperber was a member of the first FBI CJIS Dental Task Force, which convinced NCIC to include a dental component in its persons files. Dr. Peter Hampl and Timothy Taylor set up the Washington State Patrol's Missing/Unidentified Persons Unit, which was instrumental in the development of the protocols used currently in NCIC and the NDIR. Dr. Bradley Adams, a forensic anthropologist, recognized the importance of dental characteristics and quantified the importance of the dental profile as an aid in the identification process. I would especially acknowledge the current staff at the Washington State Patrol's Missing/Unidentified Person Unit for their complete dedication to the resolution of missing and unidentified persons cases. Finally, acknowledgment goes to those individuals at FBI CJIS, Harry Carlile, Stacey Davis, and Cindy Johnston. These individuals have recognized the importance of the dental information and have tirelessly promoted the use and improvement of the NCIC system. There are many more whom I would like to acknowledge, such as those dental professionals who have volunteered literally thousands of hours to assist law enforcement agencies, coroners, medical examiners, and families in their quest to find answers. We all acknowledge the unidentified, who have no voice, no family, and no life, and dedicate our work to fully utilize the tools available to find your name and know your life and thus give closure to your family and friends.

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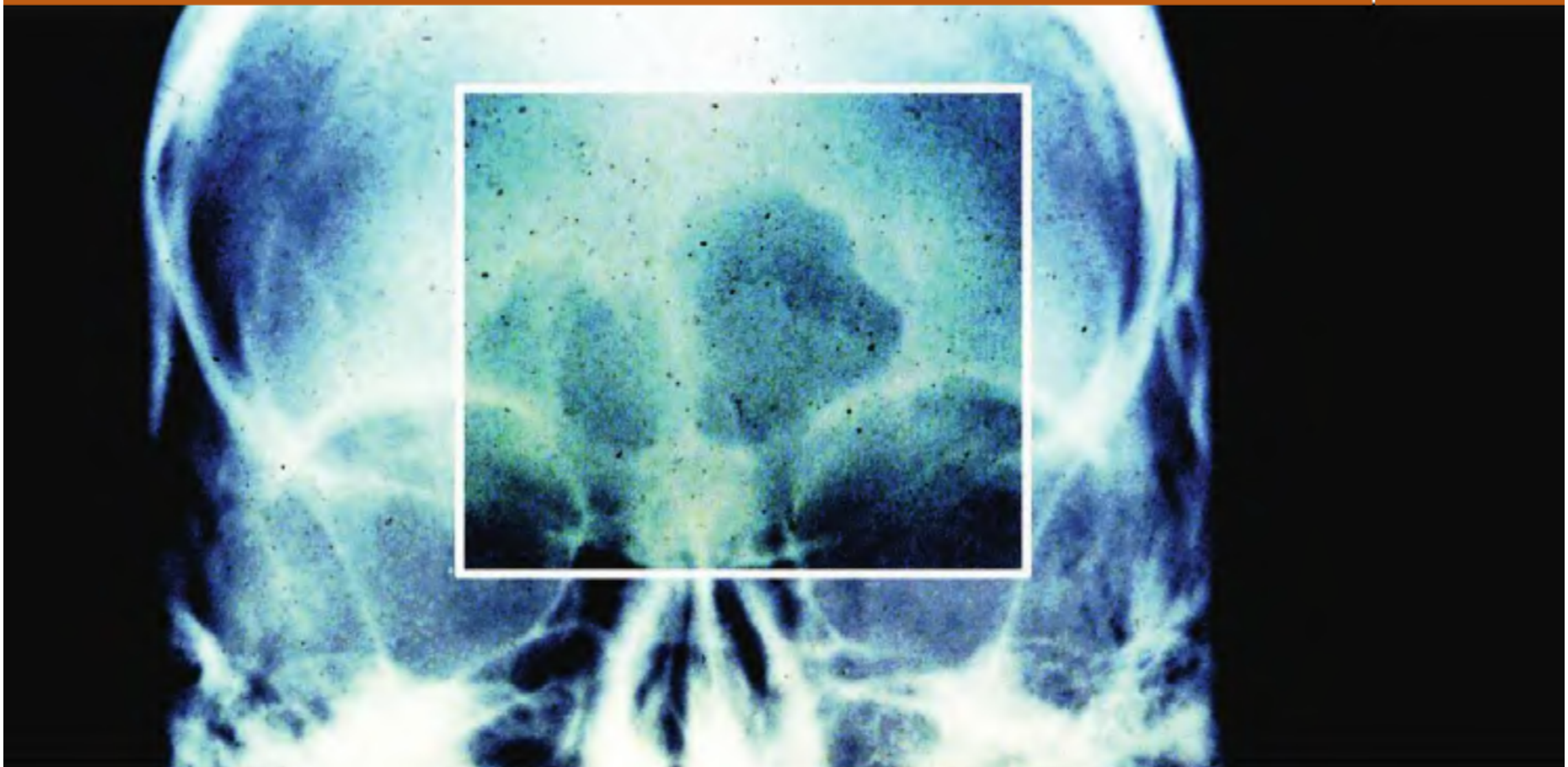
ACRONYM LIST FOR USE WITH NCIC REPORTS

BLT	Blood type	CRC	Circumcision
BPS	Body parts status	DBF	Date body found
BXR	Body x-rays available	DCH	Dental characteristics
CDA	Cause and manner of death	DLC	Date last contacted
CMC	Caution and medical conditions	DLO	DNA location
		DNA	DNA profile indicator

DOB	Date of birth
DOE	Date of emancipation
DRE	Dentist remarks
DTE	Date and time of entry
EDD	Estimated date of death
EYB	Estimated year of birth
EYE	Eye color
FBI	FBI number
FPA	Footprints available
FPC	Fingerprint classification
HAI	Hair color
HGT	Height
JWL	Jewelry description
JWT	Jewelry type
LIC	License plate number
LIS	License plate state
LIT	License plate type
LIY	License plate year of expiration
LKA	Linking case number
LKI	Linking agency identifier
MAL	ME/coroner locality
MAN	ME/coroner agency name & case #
MAT	ME/coroner telephone number
MIS	Miscellaneous
MKE	Message key
MNU	Miscellaneous number
MNP	Missing person record type
MPA	Dental models/ photographs available
MPC	Missing person circumstances
NAM	Name
NIC	NCIC number
NOA	Notify originating agency flag
OCA	Originating agency case number
OLN	Operator's license number
OLS	Operator's license state
OLY	Operator's license year of expiration
ORI	Originating agency identifier
POB	Place of birth
RAC	Race
SEX	Sex
SKN	Skin tone
SMT	Scars, marks, tattoos, and other characteristics
SOC	Social Security number
VCO	Vehicle color
VIN	Vehicle identification number
VMA	Vehicle make
VMO	Vehicle model
VRX	Corrective vision prescription
VST	Vehicle style
VYR	Vehicle year
WAC	WACIC number
WGT	Weight



The Disaster Victim Identification System: Its General Structure and the Swiss Involvement

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Introduction

A mass disaster is an unexpected event that causes serious injury and death to a number of people. Mass disasters may be natural (earthquakes, volcanic eruptions, flooding, tornadoes), accidental (airplane crashes, train crashes, fires), or intentionally man-made (terrorist attacks, warfare). A successful identification process can be defined as a rapid and correct establishment of the identity of a lost person and appropriate communication of this identity to the family and loved ones. There are humanitarian, psychosocial, ethical, and legal aspects to this task.

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Relatives of a missing person must be informed as quickly and accurately as possible if this person is in fact among the victims. The identification of a victim is of paramount importance for a relative. Indeed, it is only after a positive identification of the victim that the process of mourning can begin, eventually enabling the relatives to come to terms with the loss of their loved one(s). The work of the DVI team is also useful and necessary in the context of both criminal (extinction of lawsuits) and civil law. For instance, inheritance and heritage matters can only be legally settled after a reliable identification.

The identification of the victims of a major mass disaster can hardly be done by visual recognition. Other methods are in such cases indispensable to establish a positive link between the victims and the missing persons. Dactyloscopy, odontology, and genetics are the required methods to install databases that will help to obtain a conclusive identification. Nowadays, traveling has become a major source of mass disaster probability, resulting in the deaths of nationals from various countries.

As recently experienced in Haiti's earthquake or in the Southeast Asian tsunami of 2004, one country alone may not have the adequate logistics to deal with mass casualties. Any local or regional emergency structure may be inadequate, damaged, or destroyed and therefore unable to provide an adequate response. It is the responsibility of the international community to offer help and support in the recovery and identification of the victims, thus helping families and the rebuilding of the society. In the event of a terrorist attack, the international community will provide assistance in the identification of the possible assailants.

Today, forensic odontology is a well-established and very reliable method of identification. It is widely used in single-victim situations as well as in mass disasters. Historically, the first recorded use of odontology in identifications associated with mass disasters was at the Vienna Opera House fire in 1849 [1]. In 1897, a destructive fire at the Bazar de la Charité in Paris killed 126 people, 25 of whom were odontologically identified [2, 3].

Later, odontology was used as a means of identification in mass disasters such as a fire in Oslo (1938) [4], during World War II [5], for plane crashes, and for shipping and rail accidents in the 1950s. However, the use of odontology as an identification tool remained somewhat occasional until the 1960s.

Although the FBI in 1940 formed a disaster squad that used fingerprints to respond to a mass disaster situation [6], Norway was probably the first country to develop a model of identification procedures in mass disasters [5, 7], introducing the cooperation of police officers, dentists, and forensic pathologists.

International standards and the use of forensic odontology progressed with the experience of multiple mass fatalities. Identification forms with postmortem and antemortem indications were first used after a plane crash in France in 1950 [8]. In 1979, scenes and body locations were first thoroughly documented in the recovery and identification of the victims of a plane crash in the Antarctic [9, 10, 11].

In 1978, a fuel tank explosion next to a camping ground in Spain that killed 200 people from several countries triggered the development of a standardized and coordinated method to identify the victims of mass disasters by Interpol [11, 12]. A working committee on Disaster Victim Identification was established in 1982. Its objectives were to develop international cooperation, coordination, and response guidelines in massive incidents. A Standing Committee now meets annually at the Interpol headquarters. It reunites specialists from the different disciplines involved in mass disasters, updating analyses and the experiences from responses to the latest incidents. The *Disaster Victim Identification Guide*, first published in 1984, is updated on a regular basis [13].

Interpol and DVI

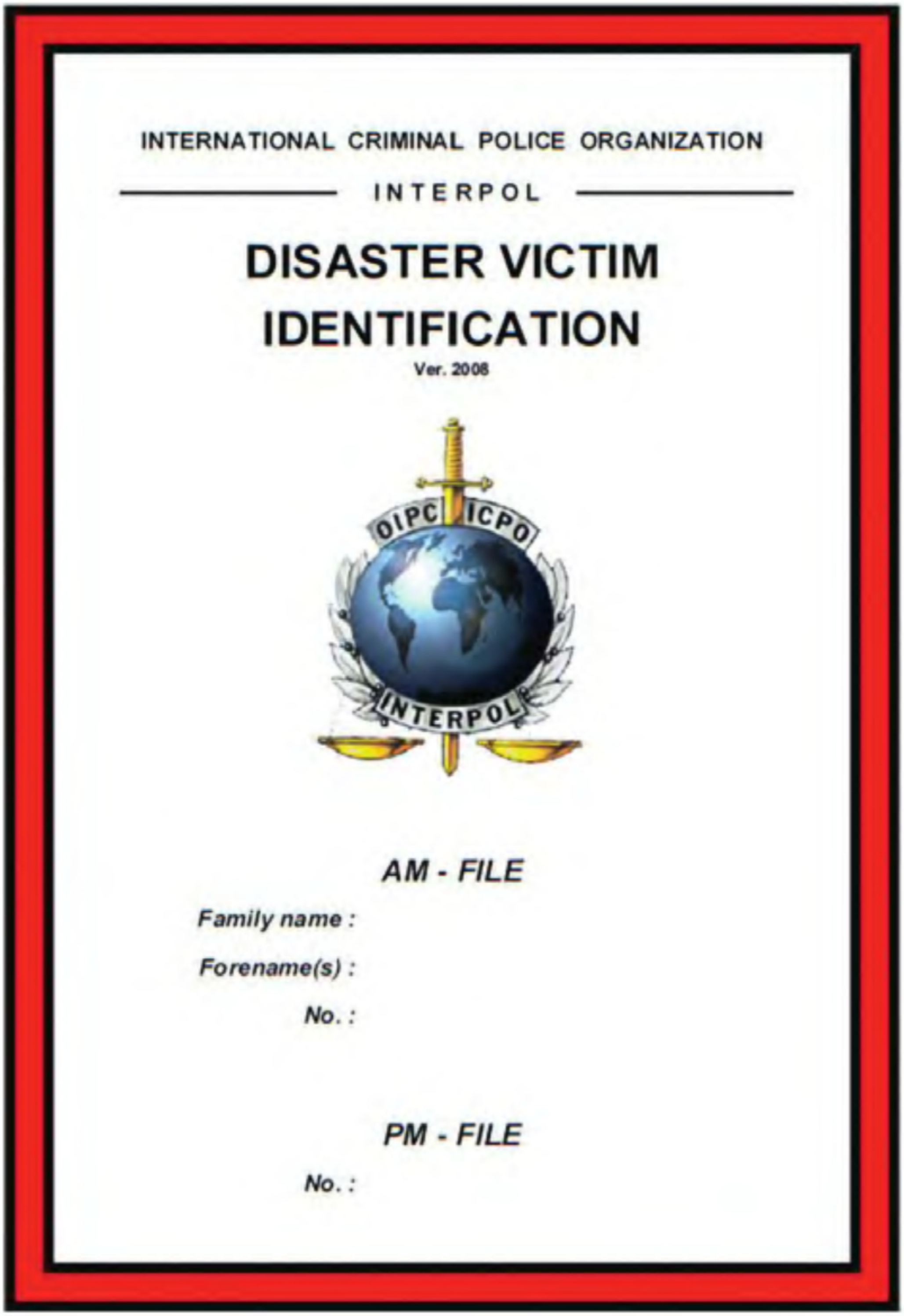
Interpol (International Criminal Police Organization) is an organization that promotes the international cooperation of police corps when it comes to preventing or fighting international crimes. It was founded in 1923 and has now 192 member countries. Its constitution forbids "any intervention or activities of a political, military, religious, or ethnic character." Its activities are focused on public safety, terrorism, criminal organizations, crimes against humanity, piracy, corruption, illicit drugs production and trafficking, weapons smuggling, human beings trafficking, financial and high-tech crime, wildlife crimes, and environmental crimes.

The main office of Interpol is located in Lyon (France), and there are seven other regional offices in the world, as well as a representative agency at the United Nations in New York and at the European Union in Brussels. Each of the 188 members has a national office that corresponds with other countries to provide assistance in their investigations abroad and in the tracking of criminal fugitives. Interpol now employs staff from approximately 80 countries, including specialists from all fields of law enforcement. The four official languages of Interpol are Arabic, English, French, and Spanish [14].

In 1978, Interpol put together a commission to standardize the international forms on which personal information of the people involved in mass disasters had to be filled in: the antemortem and postmortem forms. The first Interpol manual on *Disaster Victim Identification* was published in 1984 after a two years' preparation by the organization's Standing Committee on Disaster Victim Identification. It has been regularly reviewed and revised with the experience of previous disasters in mind. It is designed to encourage the compatibility of procedures across international boundaries [15].

The *Disaster Victim Identification Guide*

The *Disaster Victim Identification Guide* is based on practical experience and provides basic recommendations, underlining the importance of preplanning, training, and awareness of the many potential demands and difficulties that the participants may have to face [16]. Every member of a team should conform to national and regional laws and regulations, or to religious or organizational practices. The objective of any DVI mission remains the establishment of the identity of every victim by comparing and matching accurate antemortem and postmortem data, using the DVI identification manual (Figure 1).



INTERNATIONAL CRIMINAL POLICE ORGANIZATION

INTERPOL

DISASTER VICTIM IDENTIFICATION

Ver. 2008

AM - FILE

Family name :

Forename(s) :

No. :

PM - FILE

No. :

FIGURE 1 DVI Interpol form set.

The DVI operations can be summarized in phases:

1. Scene investigation and recovery of the bodies
2. Collection of postmortem data
3. Collection of antemortem data
4. Debriefing
5. Comparisons
6. Reconciliation

The disaster handling procedures insist on the need to adapt the measures to the workload involved and the available resources. Every team should be directed by an investigator in charge, who keeps contact with public relations and coordinates with the following:

- A director of communications: telephone, radio, fax, computers, telex, and so on
- A director of rescue operations: security, rescue, casualties, uninjured, property, evidence
- A director of victim identification: recovery, photography, morgue station, identification experts, postmortem teams, antemortem teams

The communications center should be established at once and located at a major police headquarters with suitable premises, communications equipment, staff, and other essential facilities. It will be expedient to set up the missing persons unit at or near the communications center, and all inquiries and information concerning potential victims should be directed to that unit. The release of information to the media will be the charge of the director of communications. For instance, no victims' details should be released to the media before the families (or perhaps embassies) have been informed so relatives do not learn through the press that a family member has been involved.

The rescue operations start immediately and provide medical care. Difficulties in locating survivors should be anticipated. All property, wreckage, bodies, and so forth must remain in situ if at all possible. Accurate identification methods are performed by matching antemortem and postmortem data obtained from the following:

- Circumstantial evidence (personal effects such as clothing, jewelry, pockets contents)
- Physical evidence provided by:
  - external examination—for example, general features, specific features (fingerprints)
  - internal examination—for example, medical evidence, dental evidence, and laboratory findings

Visual recognition of a body may be the only criterion accepted in some countries for victim identification. The results are nevertheless considered as inaccurate and may lead to distress and embarrassment. Descriptions of personal effects may assist in correct identification but should never be considered as a proof.

The external examination is undertaken by a medical expert and a police officer who has experience with obtaining descriptions. General features include gender, estimated age, height, build, color of skin, and so on. Specific features such as scars, moles, tattoos, and abnormalities are often unique and thus extremely important if they can be matched with antemortem data. Fingerprints are specific external features and may constitute the safest identification means available. They should always be recorded by an expert.

An autopsy may be necessary for gathering additional data for the identification and for establishing a cause of death. Dental evidence is a particularly important and effective method of identification and can often be so accurate that it will positively identify an individual by itself. The examination of teeth and jaws can only be properly carried out by a forensic dental expert who will perform the oral examination. Because of the exacting detail that can be obtained from this examination, it is an accepted procedure for dental experts. When necessary, dentists may remove teeth for sectioning and age evaluations or remove jaws (complete or in part) for maceration and radiography, perhaps at a forensics dental laboratory.

X-ray equipment can be very helpful for both internal and dental examinations, particularly when an estimate of a victim's age is required, and also to discover fractures or other unique identification information. X-ray examination is also a very effective method of locating and identifying evidential material such as bullets or bomb fragments. X-ray equipment, preferably portable, should always be made available in the mortuary.

Genetic identification techniques make it possible to link an individual directly to family members. These techniques are currently in use to complement other methods commonly used for disaster victim identification, especially when a body has been severely mutilated. The method is especially useful for the attribution of fragmented body parts to a specific individual.

The collection of antemortem data belongs to the antemortem teams, who systematically collect documented information of missing persons from relatives, friends, and so forth. These procedures are performed by assigned specialists using the Interpol DVI Ante Mortem Forms (yellow) (Figure 2). They include interviews of potential relatives or acquaintances; the collection of medical and dental records, descriptions of personal properties worn by the victim, recent photographs, buccal smears or blood samples for DNA, and objects with fingerprints.

Careful and thorough collection of records and samples and the identification of the donors (direct family members) is a prerequisite for matching reference samples to a specific missing person. Obvious errors before data entering should be corrected as needed. The postmortem evidence collection first requires the cooling of bodies to slow the progress of decomposition and the establishment of a morgue station

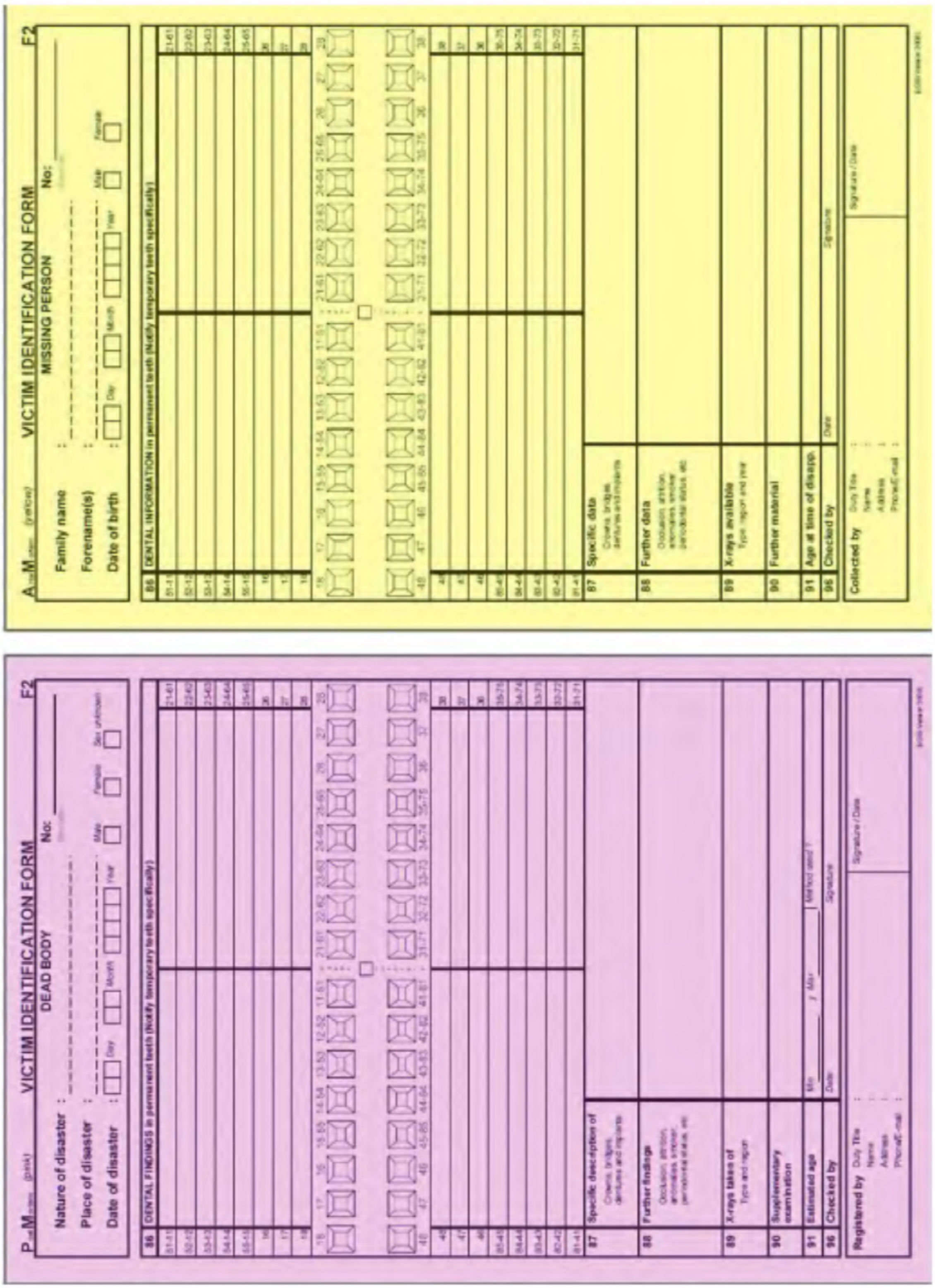


FIGURE 2 Postmortem and antemortem dental forms.

with restricted access. The morgue serves for the reception and storage of the bodies. The bodies and fragmentary remains are numbered and examined (fingerprints, photographed, radiographed, examined by forensic pathology, odontology, and quality control). All of the data will be recorded using the Interpol DVI Post Mortem Forms (pink) (see Figure 2).

The dental status is recorded on the specific Interpol DVI forms, using internationally harmonized terms, codes, abbreviations, and nomenclature. Jaws should be removed only in exceptional circumstances with the authorization of the director of the postmortem unit.

Reconciliation and identification teams first compare the collected antemortem and postmortem findings. The director of the reconciliation team has a basic grasp of all aspects of the identification process. The organizations of the teams include fingerprint, dental, DNA, and secondary identifying features sections. The methods of evaluation include the following:

- Collection/review of antemortem and postmortem findings
- Collective classification
- List of antemortem key markers and postmortem key markers
- First matching
- Individual comparison
- Identification/rejection

Care and assistance involve humanitarian considerations for relatives of mass disaster victims (assistance program), as well as care for operational personnel (health risks management, support, equipment). To ensure a successful DVI operation, some basic recommendations should be considered:

- A DVI team should train together, and the members should know one another.
- A team should be composed of professionals who are used to dealing with bodies.
- Members must be available at least 24 hours before departure.
- Members with personal problems at the time of the disaster should stay home.
- The daily workload should allow sufficient recovery and rest.
- The team members need regular information sessions.
- Psychological support should be offered when needed.
- The duration of the operation should be defined from the beginning and the backup should be organized.
- Members should get some time off before going back to normal activities to prevent stress reactions.
- Positive feedback and some recognition should be provided to the team after their return.
- The team should receive continuing information regarding the progression of the work until the operation has ceased.
- Debriefing methods should be mandatory and offered to the team members.

Using a computer program can be a great time saver. The Plass Data DVI System International software was initiated in 1995. It enables investigators of the 188 member countries to input both antemortem and postmortem data that are then analyzed and compared to accelerate the matching process and assist in the identification of victims. The Plass Data system currently assists in the identification process by matching dental records as well as physical or medical characteristics, such as tattoos or hip replacements, to be matched. The software is installed at the General Secretariat in Lyon so member countries gathering antemortem data on possible victims can have a direct 24-hour point of contact for sending this information via the Command and Coordination Centre [17].

In 2005 the program was used by the control center of Tsunami Victim Identification in Thailand. During this task the system underwent considerable development and improvement in collaboration with DVI groups in Interpol and DVI teams from around the world.

Special operations are related with the operational environment when facing incidents such as exposures to chemical, biological, or nuclear substances. Conducting DVI operations in hazardous environments requires preplanning, training, and the help of specific response agencies (military, scientific, radiological experts, etc.).

Finally, it is important to indicate that all operational enterprises may need the cooperation of international organizations such as the United Nations Office for the Coordination of the Humanitarian Affairs and the Red Cross and the Red Crescent network, which is often involved in emergency operations.

The Swiss DVI Organization

In Switzerland, a DVI team became operational in 2001 [18]. It was meant to be active:

1. In the event of a national mass disaster when the cantons would ask for help to identify victims
2. In the event of an international disaster with Swiss victims if the concerned country asks for help or accepts it. The Federal Police Office coordinates the mission abroad.

Being diplomatically represented by Switzerland in other countries, the Principality of Lichtenstein was included in the Swiss DVI structure in 2002.

The directory board of the Swiss DVI National Committee includes the following:

- One commander
- One operation general manager
- Three members of the Federal Police Office
- Two forensic pathologists
- Two odontologists
- Seven representatives of the cantons' (Swiss states) police enforcements

- One representative of the logistic support team
- Two secretaries and a webmaster

One hundred twenty individuals are members as volunteers and include the following:

- Specialized police officers (investigation, photography, fingerprints, computering, etc.)
- Forensic pathologists, mortuary technicians
- Odontologists
- Psychologists
- Any other needed specialty (logistics, interpreters, etc.)

The DVI specialists are employed in various national police units or university institutes or independent professionals and are available on a voluntary basis in the event of a DVI operation. The directory board is composed of 16 members:

- One strategic leader (police commander)
- One operative head of operations
- One member of staff for International Developments and Crisis Management
- One forensic pathology expert
- Nine police corps members
- Three members of the federal police (BAP)

In addition, another 120 specialists from the police corps and different forensic medicine fields can be recruited:

1. Approximately 90 members of the police corps:
   - Forensic experts
   - Photographers
   - Tracing experts
   - Data administrators
   - Psychologists
2. Approximately 30 forensic medicine specialists, including forensic pathologists, forensic odontologists, and mortuary technicians

The Swiss Disaster Victim Identification team depends on the federal police and is associated with the different police corps of the 26 cantons and the four institutes of forensic medicine of the Universities of Basel, Berne, Geneva, Lausanne, and Zurich, as well as the institutes of St. Gallen and Chur (Figure 3).

DVI's mission is to assist the Swiss cantons, the Swiss Confederation, and foreign countries in the process of victim identification. Requests for a DVI operation are addressed to the strategic leader of the Swiss DVI team through the Emergency Operations Center of the police forces. During crisis management, the back-office staff is located in a Communication Center in Berne.

FIGURE 3 General structure of the Swiss DVI.

The mobilization procedure is carried out as follows:

1. On the strategic leader's order, the emergency operations center summons the operative leader or his representative.
2. The operations center requests from the commanders of the police corps of the different cantons the permission for the immediate involvement of the members of the main team.
3. The strategic leader of the DVI team assumes the command, defines the composition of the main team and of the other teams, and organizes the backup and front divisions.
4. The staff members of the front division move to the disaster zone and organize the involvement of the DVI team with the local authorities in the relevant canton(s).
5. The back-office staff takes quarters in the Communication Center in Berne, which is in charge along with the front division of coordinating the mobilization of the DVI team and organizing the logistics and other tasks carried out by the DVI specialists.

The Swiss DVI team has already been involved in several national and international disasters such as collective suicides (Switzerland, 1994), transportation accidents (Swissair, Halifax, Canada, 1998), terrorist attacks (Luxor, Egypt, 1997; New York, USA, 2001), crashes in a tunnel (Gothard, Switzerland, 2001), genocides (Kosovo, 1999; 2000), massacres (Zug, Switzerland, 2001), tsunamis (Thailand 2005), and so on. The Swiss DVI and the Swiss University institutes of forensic medicine provide regular theoretical and practical training courses in mass disasters for police officers, forensic pathologists, and dentists.

Disasters

In the event of a national disaster, the local police will ask for assistance from the national DVI team. The DVI organization is put on alert and must be able to get to the disaster area and start the operations within the following hours.

In the case of a disaster occurring abroad, the Ministry of Foreign Affairs will decide whether to send a multidisciplined team to the disaster scene. A logistic backup will also be provided to collect antemortem information on missing persons.

The Swiss DVI Team in Thailand After the Tsunami

On-Site Operations

The coastal deluge that was a consequence of a 9.3 magnitude earthquake off the west coast of Sumatra sparked a tsunami that killed perhaps 280,000 people and left about 2 million homeless in 13 countries. By most accounts, the international emergency relief effort in the immediate aftermath of the tsunami was a notable success. A total of 3,009 victims were identified.

On December 28, 2004, in response to a request from the Thai authorities, a team of 30 DVI specialists traveled from Switzerland to Thailand. They joined DVI teams from 14 other countries [19, 20]. The Thailand disaster areas had been divided into three geographical sites of postmortem examinations: site number 1 was located in Khao-Lak, site 2 in Phuket, and site 3 in Krabi. The local back-office for international coordination and information was established in Phuket, and it was at that location that all the collected data were assembled.

The Swiss team was assigned to collect postmortem data on site 3 in Krabi. Some members of the team joined the back-office in Phuket. Site 3 also included other international teams originating from Thailand, Canada, Chile, Italy, Israel, Japan, and Portugal. The postmortem operations were conducted according to a standardized protocol that optimized the collection and interpretation of data [2].

1. To prevent any risk of confusion, a unique identifier was assigned to every examined corpse. This identifier included the telephone country code of the team that examined the victim (041 for Switzerland), the number of the site where it was examined (3 for Krabi), and a four-digit number assigned by the Thai working team—for example, 041-3-0202 (Figure 4a).
2. Photographs and dental x-rays were immediately taken upon the arrival of a corpse. For nonedentulous victims, two bitewings were systematically done [1]. Apical x-rays were selectively performed in case of endodontic treatments, fixed prostheses, and/or implants [2]. A complete dental chart was filled for every case, using the handwritten unified Interpol identification forms [3] (Figures 4b and 4c).
3. To conduct possible subsequent biogenetic analyses, two of the healthiest teeth—usually canines—of each victim were then extracted, placed in a bag, and stored in a refrigerator. DNA collected from teeth limits a potential risk of contamination [4].

FIGURE 4

4. The corpse was then examined by the pathologist (external examination, pregnancy, surgical scars, presence of medical prostheses, autopsy when necessary, etc.) and other investigators (unusual features such as scars, tattoos, etc.). The findings were detailed, photographed, diagrammed, and reported using the unified Interpol identifications forms.
5. The reports of the different specialists were then filed.
6. Finally, a summary report was typed for every examined victim.

An electronic chip allowing rapid localization of the victim was then placed in his or her maxillary sinus before he or she was wrapped and stored in a cooled container.

The Back-Office in Berne, Switzerland

In Thailand, all available information about Swiss missing persons was collected from travel agencies, hotels, and the Swiss embassy and then transmitted to the back-office in Berne. In Switzerland, the police corps of the different cantons contacted families, relatives, and travel agencies to collect antemortem data from all persons reported missing. Such data included photographs, fingerprints, and DNA samples from the victim and/or the family, descriptions of scars and tattoos, personal effects, and medical and dental information.

This information was then transmitted to the back-office in Berne, where it was also assembled. All antemortem data were scanned, introduced into the Plass Data database, and sent both electronically and by diplomatic mail to the back-office in Phuket, where comparative analyses could be performed.

Swiss Victims

Two Swiss citizens lost their lives in Sri Lanka and 110 in Thailand. Among these 112 victims, 107 have been identified, and 5 are still missing to this day. All nationalities combined, 831 victims have not yet been identified and/or are missing in Thailand.

Positive Aspects

Several positive aspects of this operation should be noted:

1. Specialists in all of the needed disciplines were operational three days after the disaster.
2. Excellent teamwork was achieved in the Swiss team, as well as in foreign teams working on the same site.
3. The available equipment turned out to be perfectly adequate for all of the forensic disciplines involved.
4. On-site assistance by professional volunteers was extremely helpful in expediting dental examinations (taking x-rays and hand-processing).
5. The cooperation of the Thai people was praiseworthy both in terms of logistics and hospitality.
6. Remarkable accommodation conditions allowed decent rest after work and for all of the necessary meetings (such as for debriefing).

Negative Aspects

The documentation of any mass disaster inevitably shows predictable and unpredictable unfavorable aspects of its management. Such aspects are usually due to the unexpected character of the event. In the tsunami experience on site 3, the following negatives should be mentioned:

1. Initially, the DVI mission was blocked. The situation encountered was not unusual and could be easily explained by the confusion caused by the arrival of many foreign teams in the chaotic aftermath of a very recent and very disastrous event. There was an initial misunderstanding between the arriving teams and the national local team that could only be cleared by high-level diplomatic measures.

FIGURE 5

2. Because at the time of the disaster most victims were wearing only swimsuits, it was difficult to make preidentifications.
3. The majority of corpses were in an advanced stage of decomposition due exposure to the tropical heat, humidity, larvae, fungi, and delayed postmortem refrigeration.
4. Some corpses, previously fixed in formalin or completely frozen, were very difficult to examine.
5. The intrusive and almost uncontrolled omnipresence of the media put unnecessary pressure on the working teams (Figures 5a and 5b).
6. The antemortem collecting procedures were often slowed down by unclear instructions regarding the protocol to follow.

Conclusions

An estimated 280,000 victims lost their lives in the tsunami that occurred on December 26, 2004. Over 125,000 people were injured, and 2.3 million became homeless. The international rescue response and the help provided by various institutions were formidable. DVI, in particular, was very rapidly operational and ready to contribute to the necessary identification procedures.

Everyone can understand that the magnitude of this particular disaster translates into a tremendous amount of work and stress for the different teams to reach their respective objectives. At the same time, no one can realistically expect high success rates in solving all the problems. In this sense and to some extent, the situation is comparable to that of the Hurricane Katrina disaster in New Orleans in 2005.

For a total of 3,009 identified victims [21], odontology contributed to 73% of the identifications, dactyloscopy (fingerprints) to 24%, and DNA to 3%. Among the positive achievements in carrying out this titanic enterprise was the spontaneous, immediate readiness of several competent international DVI teams to cooperate, reach, and remain on the different locations and to use a coordinated standardized identification program, the Plass Data software developed by Interpol.

The more questionable aspects included the initial chaos that slowed down and sometimes jeopardized optimal action, occasional mix-ups of different nomenclatures, difficulties in finding antemortem records, and the intrusiveness of the media. In spite of the experience and the professionalism of the specialists that took part in this operation, "Expect the unexpected" remained a constant motto. Ideal working conditions are always affected by unforeseen and disturbing events that cause unavoidable problems.

The tsunami experience has clearly shown that a positive and cooperative team spirit is the key to efficiency. At the same time, appropriate mass disaster management cannot rely solely on standardized protocols and excellent skills. It is also important to consider what went well and what went not so well in previous experiences. A critical appraisal of all of the positive and negative aspects of this type of operation is absolutely necessary for improving future missions.

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Recognizing, Documenting, and Analyzing Physical Evidence in Abuse Cases

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Many authors have stated that intrafamily and intimate partner violence (IPV) is epidemic in the United States. Estimates appearing in respected professional and lay literature indicate that somewhere between 20 percent and 50 percent of U.S. households have experienced some form of violence within a home, domestic relationship, or other form of intimate relationship where one or more individuals are dependent on others for their primary source of support. It is not uncommon for many of the injuries associated with inflicted (also termed nonaccidental or intentional) trauma to be visible in the head and neck region. This is especially true in the maxillofacial complex including the oral and perioral soft and hard tissues. This chapter provides information that will be useful when determining if the facial/dental injuries are accidental in nature or if the trauma is more likely to be the result nonaccidental trauma.

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Based on many years of experience in the emergency and nonurgent health care setting, it has been the author's experience that there are a few key features that are can be very helpful in differentiating accidental injuries from inflicted injuries: injuries that are at variance with the history given; injuries that are at various stages of healing; difficulties relating to the history taker, the clinician, or ancillary personnel; and delayed presentation for care.

When presented with injury patterns that might suggest that the presenting injuries are inconsistent with the physical examination and/or the history given by the injured individual or by the parties who are with the injured individual, the treating doctor or investigator should consider that the traumatic injuries might not be accidental in origin. The health care provider or investigator should always keep inflicted trauma in the differential diagnosis.

Equally important to optimum care and the effective progression of the investigative process, all care providers and investigators must remember that all forms of familial and intimate partner violence are potentially interrelated. Whether it involves a young person or an old person, male or female, one form of violence cannot be completely separated from another form. Not uncommonly, the sequelae of violence directly or indirectly affect all age groups living together or any of the persons living in intimate relationships. This is especially true for those persons living together in the same household. The investigation (the individual or individuals responsible for collection and potential analysis of evidence) should not just be focused on the person (or persons) presenting with the instant injuries. It must be remembered that a battered child not infrequently has an abused mother. An abused child might also have an abused father. An elderly person might be emotionally, financially, and physically abused. Additionally, the investigator or treatment provider should consider the possibility that spouse abuse can involve both the male or female partner living together.

Recorded data—whether in written or another means of capturing information—is invaluable in the prosecution of the individual(s) responsible for the abuse or neglect. Law enforcement, protective services, or other agencies responsible for the collection and analysis of data will invariably have published protocols that these investigators should follow. If these protocols are available, the data collected might become less valuable or even inadmissible in civil or criminal proceedings if these protocols are not followed precisely.

As they keep records, health care providers usually follow a treatment record protocol that has for many years been "the standard of care" when collecting patient information. This protocol is identified by an acronym generally known as the SOAP format. When using this format, the letters S, O, A, and P represent a portion of the treatment record wherein specific information is captured for later review and analysis. Information regarding the time, date, and place of examination must be included in the record. It is also valuable to document the individuals present during the examination and treatment of the injured patient.

When using the SOAP format, the letter S stands for subjective data. The subjective data include a wide range of information, including the following:

- Some form of patient identifying data (age, gender, ethnicity, address, caregivers, etc.) including—if available—copies of some form of government photographic identification, insurance information, and so on.
- A record of the patient statement regarding the injured individual's chief complaint (why the individual presented for care). Some readers may be more familiar with a very similar term: *the history of present illness.* In the history of present illness, information is gathered regarding the injury, especially when and how it happened. Whenever possible, this information should be collected from the injured person. Collecting information from the injured person might be difficult when the person is very young, impaired, disabled, unconscious, unable to speak the same language as the caregiver, or otherwise noncommunicative. Careful attention should be paid to histories related to the injury given by others (spouse, intimate partner, parent, guardian, etc.) accompanying the injured party. The history of present illness should be taken in a quiet, supportive, nonaccusatory environment whenever possible.
- A statement regarding the injured party's other pertinent medical and/or oral health care histories. Consistent with federal and insurance requirements, information should be recorded regarding previous injuries, surgeries, hospitalizations or doctors' office visits for similar or related injuries.
- A statement of relationship of the injured person to those presenting to the treatment facility with the injured person. If intentionally inflicted trauma is suspected, a statement from the injured person should include information about the source of the injury or the person responsible for the traumatic event. Some emergency department personnel are trained to ask, "Who hit you?" or, in the case of suspected intimate partner violence, "What did he hit you with?" Again, these questions should be asked in a private, supportive environment to encourage truthful responses.
- When appropriate, a statement describing the family status or personal status of the injured person.

The letter O in the SOAP format stands for objective data. This is the information that is visible, measureable, and quantifiable. Examples of objective data would be the vital signs, injury patterns (i.e., bruises, abrasions, bitemarks, fractured teeth, radiographic evidence of hard tissue injuries), or other forms of hard data. Location and description of the colors (aging) of the injuries are also found in this section of the record.

The letter A in the SOAP format stands for the assessment of the injury patterns described during taking the patient history or discovered during the physical examination. For instance, in the situation when a child patient is incapable of providing a history, does an injury pattern suggest that the source of the pattern is the human dentition (bitemark), or is the source something other than the human dentition? The Assessment section of the record is also the differential diagnosis for the injuries. The differential diagnosis is the rank order of the probable diagnoses based on likelihood (probability) of the cause of the injury or injuries while taking into consideration the diagnostic imperative. The diagnostic imperative is the diagnosis that is so risky to the patient that it cannot be excluded. For instance, after reviewing the history and physical examination, is it more likely that the injury is caused by an accident, or is it more likely that the injury was intentionally inflicted? If inflicted trauma is a probability, then it must be considered first in the treatment plan. Every investigator or health care provider should ask, “Can I reasonably rule out the possibility that the injury patterns I am observing are the result of inflicted trauma?” If inflicted trauma cannot be reasonably ruled out, then further investigation designed to protect the victim from future or additional injuries should be initiated.

The final section of the SOAP format is the P section, which stands for plan. Not only does the plan include the treatment plan (or plans), but the Plan section also includes what further tests are appropriate. For instance, are other diagnostic imaging techniques necessary to reach a definitive diagnosis? Or, if following the history review and the physical examination, is it in the best interest of the injured party to contact law enforcement officials or protective service personnel? Health care providers are reminded that it is mandatory to report a suspected case of inflicted trauma. Utilizing the SOAP format in record keeping applies to all forms of abuse or neglect. The next sections of this chapter will directly address the different types of abuse and neglect that might be encountered by the health care provider.

Although the focus of this chapter is on the violent behaviors seen in Western society, violent behaviors are certainly not unique to those societies. Violent behaviors directed against persons are seen in all developed or developing countries and in the urban, suburban, or rural environments. Violent behaviors and assaults can be found in all religions, socioeconomic groups, and cultures. Although less frequently reported, violent behaviors can also occur within same-sex relationships. It should not be surprising to find that domestic violence and violence within the immediate or extended family—child abuse, spouse abuse, abuse/neglect of the disabled, and abuse of older persons—are common in but not isolated to Western society. Investigators must be cognizant of the fact that intentionally inflicted trauma can result in injuries to the developing fetus, children, adolescents, adults, and the elderly—in fact, no age group is free of the potential for violent acts.

Recent estimates from the Centers for Disease Control and Prevention (CDC) indicate that approximately 25 percent of women have been raped and/or physically assaulted by an intimate partner [1]. Although women are predominantly the victims of violent behaviors on the part of men, some researchers in the field of domestic violence report that men and women are nearly equally involved in assaults. Most reputable publications agree with the CDC when it reports that women experience more chronic injuries and assaults from men than men do from their female intimate partner [1]. More than 40 percent of women who experience intimate partner sexual assaults (unapproved sexual relations within the intimate partner relationship—including marriage) report that during the sexual assault they suffer some form of physical injury [1]. These soft and hard tissue physical injuries can take the form of bruises, lacerations, contusions, gunshot wounds, avulsion tissue injuries, broken bones (including the alveolar bone, jaws, and other bones of the maxillofacial complex), bitemarks, and fractured, subluxated, and/or avulsed teeth.

Intimate partner violence can take many forms to include psychological/emotional abuse (including isolation of the victim), physical abuse, and sexual abuse. Intimate partner violence can begin in the dating relationship, while cohabitating, while married, or when separated or divorced, and can continue into the later years of life. Unfortunately, the violence can often result in death, serious physical injury, disfigurement, and long-term, intergenerational emotional problems.

Injuries associated with intimate partner violence include a wide range of injury patterns by location and severity. These soft and hard tissue injuries should be documented in the record (in the Objective findings section). Whenever possible, photographs should be made prior to treatment like suturing or removal of nonvital tissues. Orientation photographs and photographs with scales in place should be taken. Carefully following generally accepted techniques for photographic documentation of injuries must be followed. If serial photographs are indicated, then appointments should be made to record the changes that occur over time.

The investigator should also consider the value of different techniques for recording injury patterns. Assistance with alternative light source imaging techniques is available from local, state, or federal investigators or crime scene technicians. If not familiar with these techniques or if the health care provider does not possess or have access to these technologies, then local, state, or federal agencies who have trained personnel knowledgeable in these techniques should be contacted.

Radiographs and other diagnostic images (e.g., computed tomography and magnetic resonance imaging) may also be indicated to document hard tissue injuries like dental root fractures, alveolar fractures, jaw fractures,

FIGURE 1 Multiple facial injuries inflicted by the victim's husband. Note the evidence of healing, supporting the diagnosis of delayed presentation of care—one of the features often seen in intimate partner violence.

FIGURE 2 Clinical evidence of a mandibular fracture.

and other fractures of the facial bones. Because previous fractures are often seen in domestic violence cases, careful attention must be paid to the possibility of recent and not so recent fractures when examining radiographic images. The patient history and the clinical examination will often reveal evidence of jaw fractures that indicate the need for radiographs (Figures 1 and 2).

Child Maltreatment

Many jurisdictions utilize definitions of child abuse/maltreatment and neglect that generalize capture the same or very similar criteria for classifying physical or emotionally injurious actions directed against children. One of the most useful definitions comes from the Child Abuse Prevention and Treatment Act (CAPTA), Public Law 104–235. CAPTA defines *child abuse* and *neglect* as "any act or failure to act resulting in imminent risk of death, serious physical or emotional harm, sexual abuse, or exploitation of a child by a parent or caretaker who is responsible for the child's welfare" [2]. CAPTA more specifically defines child abuse as "any physical act (e.g., burns, broken bones), sexual act (e.g., touching, fondling, sexual assault, or incest), or emotional insult (e.g., isolation, belittling, or calling names) [2]. CAPTA defines neglect as when a parent or responsible caretaker fails to provide adequate supervision, food, clothing, shelter, or other basics for a child [2]. All forms of abuse and neglect may result in serious harm to a child (Figures 3 and 4).

In cases where a child is suspected of being abused or neglected, the investigation/ intervention process can begin. One of the most useful algorithms for assisting the abused or neglected child can be found at the Texas Department of Family and Protective Services (TDFPS) website (*www.dfps.tx.us/child_protection*). The TDFPS recommends that once the child is

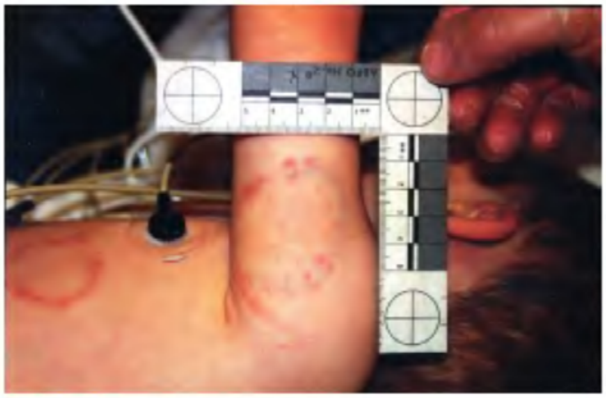

FIGURE 3 A two-year-old child with a bitemark on the right arm. Note the scale used as a size reference on the curved surface.

FIGURE 4 Bitemark on the chest of a two-year-old child. Note the scale place on a relatively flat surface.

identified as being in immediate danger or there is a reasonable likelihood that the child is at risk for being abused or neglected in the foreseeable future, steps must be taken on behalf of the child. These steps might include the following:

- A recommendation for services to address the problem
- Act to open the case for family-based safety services
- Filing of a petition to initiate civil court action to protect the victim
- Actions to include removal of the children from the home and possibly terminate parental rights

Time frames require the caseworker to complete investigations within 30 days from the date the report was received from the agency, unless a supervisor has approved an extension. This "short" time frame should help reduce the risk of further emotional or physical injury to the child.

Also found in the TDFPS algorithm is the provision that "all reports must be referred to the appropriate law enforcement agency for possible criminal prosecution." Clearly, all appropriate evidence collected by the clinician or other investigator must be made available to law enforcement agents for possible use in prosecuting the perpetrator of criminal acts against children. To reduce the possibility of collecting evidence that might later be found to be inadmissible, all appropriate steps should be taken to preserve and protect the evidence collected by the clinician or other investigative personnel. As in all civil and criminal proceedings, chain or evidence must be maintained.

Further provided under Texas state statute is the direction to require law enforcement personnel to accompany Child Protective Services caseworkers when responding to Priority 1 reports of abuse/neglect that involve children who appear to face immediate risk of physical or sexual abuse. Having law enforcement personnel present during the investigative process will protect the investigators from physical harm.

Every clinician must be aware that the possibility is not small for having an abused/neglected child present to their office for care. It has been estimated that in the United States, child protective services' reports indicate that there are approximately 800,000 annual cases of child maltreatment. Childhood exposure to abuse, neglect, and parental violence has been associated with risky behaviors that include smoking, using illicit drugs, and overeating [1]. Depression, suicidal behavior, perpetrating youths, and intimate partner violence, as well as negative outcomes such as heart disease and cancer have also been associated with child abuse and neglect [1].

Abuse During Pregnancy

Even though child abuse/neglect is one of the most common forms of violence, physical injuries can result from behaviors that begin prior to birth (during pregnancy). It is well documented that the effects of alcohol, drugs, poor nutrition, and physical trauma can result in long-term damage to the developing child that can extend throughout the life of the injured person. Assault of the pregnant woman can result in a wide range of emotional and physical trauma, including the potential for injuries that result in death (homicide), perinatal death, low-birthweight live births, and preterm delivery [3]. In two separate studies of nearly 2000 women aged 18 to 65, it was reported that approximately 15 percent of women reported intimate partner violence or abuse during a pregnancy [3,4]. Greater frequency of abuse was associated with increased health risks to the mother and her developing fetus [3]. The Koening and colleagues study reported that women more frequently experienced violence during than after their pregnancy (61 percent of those women reporting abuse during or after pregnancy were abused only during their pregnancy, 21.7 percent were repeatedly abused, and 16.7 percent were abused only after delivery) [4]. The American College of Obstetricians and Gynecologists (ACOG) has produced an excellent publication that describes abuse during pregnancy [5]. The ACOG reports that during pregnancy, the abuser is more likely to direct blows at the pregnant woman's breasts and belly, sometimes resulting in maternal homicide or miscarriage [5].

While some (if not much) of the inflicted trauma is directed at the breast and abdomen, the abusive acts can take many forms, including the following:

- Pushing, which can result in falls, with associated significant injury to the pregnant woman or her developing child
- Hitting with a fist or other object, including attacking with a weapon [5]. This hitting activity is often directed to the head and neck complex.
- Slapping, which can result in injuries to the eyes, ears, soft tissues of the face, and the dentition
- Kicking of any part of the body
- Choking the woman, which results in potentially fatal obstruction of the airway or the great vessels of the neck

- Beatings, which can result in damage to both hard and soft tissues, including the liver, kidneys, and other abdominal contents

These reports of physical injury during pregnancy are alarming, but not every pregnant woman is the victim of abuse. Most women are not abused during pregnancy, and in many cases, women report that the abuse decreased during pregnancy. In at least one study, women reported that they actually feel safe only when carrying a child [5]. Since some of the trauma might be in areas not commonly seen by oral health care providers, dentists, hygienists, and ancillary personnel should be aware that there is a need for medical (or law enforcement) evaluation of pregnant women with maxillofacial injuries.

Physical Injuries During Dating Relationship

Violence in an intimate (including dating) relationship can begin at an early age. Dating violence (also termed physical dating violence—PDV) has been defined as physical, sexual, or psychological violence within a dating relationship [6]. A study of dating violence among students in grades 7–12 found that physical and psychological acts of violence were 12 percent and 20 percent, respectively [6]. These self-reports of violent behaviors indicated that there was hitting, slapping, or some other form of physical harm during the dating period. Students with poorer grades ("mostly Ds and Fs"), African-Americans and non-Hispanic students, and students from the Northeast area of the United States were at greatest risk for dating violence and victimization [6]. In addition to the risk for physical injury and death associated with physical violence during dating, other forms of secondary risk associated with dating violence included sexual intercourse (protected and unprotected), attempted suicide, substance abuse, episodic heavy drinking, and physical fighting (Figures 5 and 6) [7, 8].

Spouse Abuse (Intimate Partner Violence)

Spouse abuse (intimate partner violence) is a major cause of morbidity and mortality in the United States. The Federal Bureau of Investigation (FBI) *Supplemental Homicide Reports, 1976–2004* [9] report indicates the following:

- Approximately one-third of female murder victims were killed by an intimate acquaintance.
- Approximately 3 percent of male murder victims were killed by an intimate acquaintance.
- Of all female murder victims, the proportion killed by an intimate acquaintance declined slightly until 1995, when the proportion began to increase (most reports indicate that the rate has been stabilizing in recent years).
- Of male murder victims, the proportion killed by an intimate acquaintance has dropped during the reporting period.

FIGURE 5 A 24-year-old woman homicide victim who was killed by her boyfriend. Note the multiple facial injuries, with a bitemark on the right neck.

FIGURE 6 Multiple facial injuries on a 19-year-old Hispanic woman that were inflicted by her boyfriend.

- Annually, at least 1,500 women were murder victims from domestic violence.
- Approximately one-third of injuries presenting to the emergency department were nonaccidental—the result of deliberate, intentional acts of violence.
- Approximately one-third of 15-year-old women homicide victims are killed by their husbands, ex-husbands, or boyfriends.

Suicide might also result if the murderer takes his or her own life following the violent act resulting in the death of the intimate partner. It has been reported that 74 percent of all murder-suicides involved an intimate partner [10]. Of these reported cases, 96 percent were females killed by their intimate partner, with 75 percent of these cases occurring within the home [10].

Notwithstanding the physical injuries suffered during violent intimate-partner relationships, there is also a significant financial burden placed upon families. Best estimates indicate that the annual medical expenses associated with domestic violence are at least $3 billion to $5 billion [11]. Businesses lose another $100 million in lost wages, sick leave, absenteeism, and loss of productivity [11].

Crandall, Nathens, and Rivara have reported that women who suffered blunt intentional trauma exhibited very different injury patterns than those who are hospitalized for motor vehicle accidents and falls. The risk for facial injury was much higher among the domestic violence victims than was seen in other mechanisms of injury [12]. Head injuries were also more common in female victims of intimate partner violence [12].

The author's published thesis [13] also found that women who were victims of intentional trauma were more likely than women who were victims of motor vehicle accidents to:

- Present for care on a delayed basis (not presenting immediately after the incident causing the injuries associated with the chief complaint)
- Have had a previous facial/dental injury
- Have had a previous emergency department visit for injuries associated with intimate partner violence

Not surprisingly, multiple injuries have also been reported to be suggestive of intimate partner violence. A study available on MEDLINE indicated that 85 percent of intimate partner violence victims were found to have injuries on more than one area of the body [14]. The most common sites for injury were the eye, the side of the face, the throat and neck, the upper and lower arms, the upper and lower legs, the mouth, the outside of the hand, the back, and the scalp [14]. Injuries to the shoulder and back were less common in intimate partner violence cases than injuries to the shoulder and back in those cases known to be caused accidentally. Of importance to the dentist is that 79 percent of the injuries were in areas clearly visible (injuries to the head and hands) [14]. Very similar patterns were found in a study by Sheridan and Nash [15] and a study by Petridou and colleagues [16].

Intimate partner violence often overlaps in families and those in intimate relationships. An abused child often has an abused mother, and an abused mother often has an abused child. Additionally, abuse might occur at any age. It is easy to extrapolate that violence in a relationship does not begin (or end) at age 65. Persons in same-sex relationships can also be the victims of intimate partner violence (Figures 7 and 8).

Elder Abuse and Neglect

Most authorities on the abuse of adults over the age of 65 (an arbitrary age at which the term *elderly* individual is generally used) define abusive behavior as intentional or neglectful acts that result in or may lead to harm of a vulnerable elderly individual. Although many organizations use similar terminology, the National Center on Elder Abuse (NCAE) definitions are useful in investigations into elder abuse. The NCAE uses the following definitions for the various types of abuse and neglect. The investigator must remember that there can be significant overlap in the types of abuse and neglect that might be discovered in the course of an investigation.

> *Physical abuse:* Use of force to threaten or physically injure a vulnerable elder.

FIGURE 7 A 35-year-old Hispanic male who was beaten by his companion.

FIGURE 8 A 41-year-old white male who was beaten by his male companion. Note the neck injuries associated with choking.

Emotional abuse: Verbal attacks, threats, rejection, isolation, or belittling acts that cause or could cause mental anguish, pain, or distress to a senior.

Sexual abuse (many authors consider this a subset of physical abuse, but for their purposes, the NCAE chooses to consider sexual abuse separately from physical abuse): Sexual contact that is forced, tricked, threatened, or otherwise coerced upon a vulnerable elder, including anyone who is unable to grant consent.

Exploitation: Theft, fraud, misuse, or neglect of authority and use of undue influence as a lever to gain control over an older person's money or property.

Neglect: A caregiver's failure or refusal to provide for a vulnerable elder's safety, physical, or emotional needs.

Abandonment: Desertion of a frail or vulnerable elder by anyone with a duty to care.

Self-neglect: An inability to understand the consequences of one's own actions or inaction, which leads to, or may lead to, harm or endangerment.

Some commonly referenced estimates by U S. government agencies indicate that, at best, only one in six cases of elder abuse is reported. If we assume this statement to be representative of the problem, then it is easy to see why it is difficult to know the exact number of individuals over the age of 65 who are abused and neglected in the United States every year. Notwithstanding the challenges associated with establishing accurate estimates, the best available information from the National Center on Elder Abuse (2005 report) indicates the following:

- Between 1 and 2 million Americans age 65 and older have been injured, exploited, or otherwise mistreated by someone upon whom they depended for care.
- The frequency of elder abuse ranges from 2 percent to 10 percent, based on various surveys.
- For every case of elder abuse, neglect, exploitation, or self-neglect reported to authorities, about five go unreported.
- In the year 1996, nearly one-half million adults age 60 and over were abused and/or neglected in a domestic setting.

According to the National Center on Elder Abuse (extensive information available at *www.ncea.aoa.gov*), potential abusers include spouses, family members, adult children, personal acquaintances, professionals, or other persons in positions of trust, or opportunistic strangers who prey on vulnerable older adults.

Some of the warning signs of physical abuse of an elderly individual might be confusing to an investigator because these injuries can appear to take on many different patterns. Because signs of the natural aging process, dermatologic conditions, or adverse reactions associated with medications can appear similar to inflicted trauma, special attention must be paid to the skin, muscles, and hard tissues of the head and neck complex during the investigation. If the investigator is not familiar with the soft and hard tissues of the head and neck, an individual (most often a physician) must be consulted to assess potential evidence of inflected trauma.

It is important to pay special attention to the head and neck complex during the initial stages of evidence collection because the common signs of inflicted trauma can present in the head and neck complex. Some of the signs of nonaccidental (inflicted trauma) can include evidence of traumatic hair and tooth loss; rope or strap marks, indicating physical restraint; multicolored bruises, indicating injuries at various stages of healing; or injuries suggesting healing "by secondary intention." It must be remembered that evidence of delayed healing can indicate that there might be a purposeful denial of access to care for the vulnerable adult.

The National Committee for the Prevention of Elder Abuse also reports the following additional indicators of elder abuse:

- Injuries that are unexplained or are implausible
- Family members providing different explanations for how injuries were sustained
- A history of similar injuries and/or numerous hospitalizations

- Victims being brought to different medical facilities for treatment to prevent medical practitioners from observing a pattern of abuse
- A delay between onset of the injury and seeking medical care

Not surprisingly, many of these indicators are very similar to those signs and symptoms of abuse/neglect seen in younger populations.

Several authors have reported that injuries to the head and neck area are not uncommon in elder abuse. Zeitler reported that approximately 30 percent of known elder abuse cases presented with neck and facial injuries [17]. Injuries to the oral and perioral soft tissues, jaw fractures, and fractured or avulsed teeth have been reported to be indicators of elder abuse [18]. Because many oral health care providers are aware that signs of intentional trauma are often seen in the orofacial structures, a dentist or otolaryngologist can be especially helpful during the investigation into a potential elder abuse case.

It must be remembered that, whenever possible, the investigation should incorporate the skills of a multidisciplinary team. The clinician/investigator should not hesitate to consult with technicians, physicians, and/or dentists, who can be extremely helpful in diagnosing radiographic evidence of injuries that might be associated with the instant attack or discovering radiographic evidence of previous trauma. Diagnostic images (flat plane radiography, magnetic resonance imaging, and computed tomography) can be just as valuable as photographs in the prosecution of abusive individuals (Figures 9 and 10).

FIGURE 9 An 87-year-old white woman who was struck in the face, resulting in a fracture of the mandible.

FIGURE 10 An elderly man who was struck in the face, resulting in a laceration above the left eye and periorbital ecchymosis (black eye).

Techniques for Recording Evidence of Traumatic Injuries

Varying degrees of injury can result in all forms of intrafamily/relationship violence. Initially, the most important step is to ensure that proper medical/dental attention is directed to treating the injuries associated with the traumatic event. Unless photographs or videorecordings can be made during treatment, evidence might be lost during the treatment phase. During treatment, it is often necessary to maintain an airway, control bleeding, suture lacerations, stabilize fractures, or replace avulsed teeth prior to taking photographs. If immediate intervention needs to be initiated to treat the injuries, treatment takes precedence over evidence collection. If sutures need to be placed, some evidence of trauma might be altered, since tissues must be replaced in physiologic position to control bleeding, reduce scarring, or reduce the possibility of tissue necrosis.

Many excellent references are available in the professional literature about the steps that should be taken to ensure the accuracy of the evidence collected [19, 20]. Independent of whether film or digital imaging is used, the general principles of accurate photography must be followed:

1. Make certain that orientation photographs are taken that clearly show the anatomic location of the injury or injuries.
2. After the orientation photographs, photographs of the injury with a scale in place should be taken. The American Board of Forensic Odontology (ABFO) scale is an excellent reference scale used by many dentists, medical examiners, and other investigators.
3. If available, alternate light imaging (ALI) or/or fluorescent image techniques should be utilized. Many regional crime labs or law enforcement agencies will have cameras or lighting systems that can be used upon request.

If the injury pattern is suspected as being a bitemark injury, trace salivary evidence should be collected prior to cleaning, debriding, or disinfecting the area; making impressions (molds) of the area; or suturing lacerations or other breaks in the skin. Salivary evidence collection procedures should be followed precisely to ensure that there is no contamination of the area with the investigator's/collector's genetic information.

Conclusion

Violence is a widespread problem found in all countries and cultures. Analyses of prison populations reveal that many of those incarcerated are in penal institutions because of their participation in some form of violent behavior. Much of this violent behavior occurred in the home or in intimate relationships. A review of the professional literature confirms what has been believed for many years: most of the injuries associated with inflicted trauma occur in the head, neck, and maxillofacial complex. Because these injuries are often clearly visible, any number of persons might start the intervention process on behalf of the victim. Plans should be in place wherein intervention can appropriately begin on behalf of the suspected victim of violent behavior. Absent a plan, an investigation cannot begin into the cause of the injury patterns discovered. Without an investigation, intervention is not likely to begin on behalf of the victim. If interventional steps are not initiated, the assaults might increase in frequency and severity, potentially leading to serious subsequent violent acts, including homicide [21].

Clinicians and investigators must ensure that they are adequately trained in recognizing the signs and symptoms most often associated with violent behaviors directed against persons (intentionally inflicted trauma). They must further ensure that the evidence they have collected is admissible in any criminal or civil proceeding. Each person must be able to testify that the evidence that was collected is a true and accurate representation of the injuries that were detected.

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Managing a Mass Fatality Incident

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Introduction

The manner in which mass disasters are investigated and processed in the United States has taken a drastic change since the terrorist attacks of September 11, 2001. Prior to this catastrophic event, all aviation accidents and mass fatality incidents were treated as accidents until proven by law enforcement that a criminal act had taken place. Since 9/11, law enforcement treats all mass disaster events, including aviation accidents, as potentially criminal events until proven to be an accident or a noncriminal act. Local, state, and federal law enforcement agencies are called upon to maintain the integrity of aviation crashes, terrorist events, and natural disasters. This chapter gives the basic forensic foundation and framework involved in *mass fatality incidents* (MFI) where law enforcement integrates into the identification process of human remains.

The true definition of a mass fatality incident is when local resources are overwhelmed by the event and the local medical examiner is overworked by the large number of bodies. Depending on the type of disaster, whether a

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man-made event, a natural event, or a plane crash, the roles change drastically for all involved from law enforcement to medical examiner staff. The tragedies of the events of 9/11 have become all too familiar and have become the incidents from which medical examiners and coroners throughout the United States have learned.

In any MFI, the primary response of fire, police, and EMS is to tend to the injured and to initiate search and rescue operations. The search for and recovery of human remains should not be done until all efforts have been accomplished in the search and rescue phase and the incident commander has turned over the scene to the medical examiner.

Often, it is desirable to recover human remains quickly, but the process must be well organized with a clear plan of action, requiring the coordination and dedication of all personnel involved. Agencies should have a disaster manual or plan that will outline the workers' roles and responsibilities. These plans are critical for all agencies involved to maintain order and avoid any unforeseen challenges. Local, state, and federal agencies will have overlapping authority and jurisdiction. In the event of an aviation accident, the National Transportation Safety Board (NTSB) and or the Federal Aviation Administration (FAA) will be involved and will be the lead investigative agency. The FBI, Department of Defense, Department of Homeland Security, INTERPOL, or international law enforcement agencies might also become involved in a mass fatality incident (Figure 1).

FIGURE 1 The high-speed crash of an airplane on an approach to Little Rock, Arkansas, airport. Human remains can be seen entangled in the aircraft wreckage.

Dental Response

Many local medical examiner systems have forensic dentists on staff or as consultants that provide examinations of human remains on a day-to-day basis. However, during a MFI, a full forensic team is needed to handle the identification process. Recently, some states have developed their own forensic identification response teams in addition to the federal Department of Health and Human Services Disaster Mortuary Operational Response team (DMORT). Some private companies, like Kenyon International Emergency Services, Inc., also offer the services of a mortuary response team.

Many forensic disciplines play a part in the identification process and are included on response teams. The disciplines include pathologists, anthropologists, radiologists, DNA specialists, and dentists. Typically the FBI Disaster Team provides fingerprint specialists who are integrated with local and state law enforcement teams. Fingerprints and dental comparisons contribute to the majority of positive identifications, but personal effects and physical features (tattoos, body piercings, etc.) can provide evidence supporting a positive identification.

Temporary Morgues

During a MFI, it is strongly suggested that a temporary morgue be established to minimize the risk of overcrowding and confusion with day-to-day operations of a medical examiner's office. Typically a temporary morgue is established in an airport hangar or large warehouse building that has water, electricity, heating, and air conditioning (Figure 2). It is not recommended that a temporary morgue be established in public facilities like a school gymnasium or a public venue. The facility should be close to the disaster site

FIGURE 2 (a) A temporary morgue with multiple autopsy stations set up with equipment. (b) A temporary morgue with a portable x-ray unit. *Photos property of Kenyon International Emergency Services, Inc.*

if feasible and be secured with nonporous flooring if possible. It is strongly recommended that authorities have predesignated locations written into their disaster plans of temporary morgue sites.

Processing Human Remains

Processing human remains can be extremely difficult and challenging, depending on where the MFI occurs. A coordinated grid system is needed when recovering human remains and can be done either on land or in the water. Total station technology exists where a fixed point is established and a laser from surveyor-type equipment is used to mark human remains and wreckage to provide exact coordinates. The location of human remains along with that of wreckage helps investigators reconstruct a picture of the events that may have occurred at the time of the accident or event. Prior to the removal of human remains (HR), the HR should be photographed and documented, and a consecutive number assigned prior to being bagged and tagged for removal to the temporary morgue. An investigator needs to be very careful not to assume that something is human remains just because it is in close proximity to other HR. All HR should be placed in separately labeled containers and body bags. Some state and federal recovery teams utilize a bar-code system. This type of system is useful when there is a lot of fragmentation.

Although airline manifests and seating plans can supply information about who was on board the aircraft, they should never be used to positively identify an individual based on his or her seat location. Passengers are known to change seats at times before or during a flight. Forensic recovery teams must be prepared to handle multiple types of HR in any type of a MFI. Human remains may be intact, but they can be highly fragmented, burned, crushed, or completely destroyed. The condition of the HR depends on the magnitude of the crash and whether it is a high-impact crash, if a postcrash fire occurred, or if an explosion occurred in flight (Figure 3).

FIGURE 3 A portion of a fragmented body and torso of a victim following an airplane accident. This was not a high-speed crash but a crash with an impact in the terrain. Photo courtesy of Kenyon International Emergency Services, Inc.

The unintentional commingling of HR can result in great confusion during the identification process. Heads should be bagged and carefully placed in a body bag to preserve the integrity of the head and prevent any loss of teeth.

It is very important to have a disaster management plan in advance with trained personnel prepared and trained for when that disaster might occur. The success to managing a MFI is when agencies review, update, and train regularly on their disaster plan. Contact information, agencies, personnel, contracts, and vendor supplier information must be updated regularly. Continuity within the plan must be maintained, especially in jurisdictions where there are elected officials such as coroners and sheriffs.

Identification Methods

A typical disaster morgue operation will include departments for triage, photography, personal effects, fingerprints, radiology, anthropology, dental, pathology, DNA, and embalming (Figure 4). Once the human remains have gone through the entire morgue process, they are held in storage until positive identification is determined and all documentation and records have been checked and reviewed through a quality control process.

Triage

Once the human remains are received in the morgue, they are examined at the triage station, which is the first station in the process. Here, a morgue number is issued, and the remains are escorted to the next station in the process or a station that is open and available for examination.

Photography

All human remains are photographed both at the incident site and at the morgue. Along with full body photographs, photos are taken of the body bag tag numbers and any tattoos, body piercings, specific injuries, and trauma to the body.

FIGURE 4 The triage area of a morgue where human remains are received and examined for commingling, after which instructions are given as to where the remains should go next in the morgue process.

Personal Effects

Personal effects (PE) are categorized as associated, unassociated, and group items. Associated PE is an item that can be associated with a specific individual. Items that are found on human remains or items that are labeled and have specific markings can be attributed to a specific person. Unassociated items are PE that cannot be associated to any particular person. They can be general items like clothing or anything that has no individual markings on it. Group items are those that are found together in a suitcase or bag that can be associated to a specific person. An example would be a women's purse or handbag.

Personal effects need to be handled with care, dignity, and respect just like human remains. Under the Federal Aviation Family Assistance Act of 1996 and Foreign Air Carrier Act of 1997, air carriers are expected to do all they can to return PE to family members. Under the legislative acts, the air carrier must hold onto all PE for 18 months before it can be destroyed. Every effort is made to render the PE safe from biohazards and fluids and return the PE to the family at their request either as is or repaired. For unassociated PE, a catalogue is produced that contains photographs and a description of the PE. Family members are asked to review the catalogue to determine which PE items belong to their loved ones. There are private agencies that are skilled and trained in processing PE from aviation crashes.

If the incident is criminal in nature, then law enforcement handles the PE as evidence, and the process can take months or years before any personal effects are released and returned to family members. The case must go through the court system before the items can be released.

Fingerprints

Depending on the condition of the soft tissue on the fingertips, fingerprints are a very reliable and positive form of identification. There are multiple agencies in which fingerprint records are kept on individuals, such as military records, government and private employment records, criminal databases, and in some states driver's license records. Some countries, like Haiti and Thailand, require their citizens to have a fingerprint on file to get a government-issued identification card. During a mass fatality incident, the FBI Disaster Squad responds with a team of fingerprint specialists to assist local authorities in taking and comparing fingerprints on human remains.

Radiology

In the event of a terrorist act or bombing, full-body x-rays should be taken on all human remains, first to determine if there are any explosive fragments or evidentiary material embedded in the soft tissue. X-rays also help in observing any dental fragments, medical prosthetic devices, any spinal fusions, past traumas, or anything unusual that might help in determining the identification of the individual.

Portable x-ray units are very helpful in the morgue and should be used by trained individuals. All necessary health and safety precautions should be taken at all times.

Anthropology

The anthropologist plays a critical role in both the morgue and the field during the search and recovery operation. The anthropology section is responsible for examining the human remains to determine a biological profile, especially when there are multiple fragments and body parts. The anthropologist will be able to examine the bones to determine if they are human or nonhuman and to establish gender, age, and, in some situations, ethnicity.

Dental Processing

Extreme care must be taken when handling all dental fragments, especially jawbones that contain teeth. In the field it is recommended that heads be wrapped in plastic to prevent the loss of teeth, especially in cases of severe fragmentation. Once the remains are brought to the morgue, they are examined and x-rayed. There are handheld x-ray devices, such as Nomads®, that dentists can use to take an x-ray of the mouth or specific teeth. The quality of the radiographs is very important to compare the postmortem dentition to the antemortem dental records. Several dental software programs are available in which the antemortem and postmortem dental radiographs can be stored and cross-referenced for comparison.

Postmortem Dental Profiling

The oral examination should be conducted by a forensic odontologist (dentist) with the help of a dental assistant. As the dentist examines the mouth and teeth, the assistant records the findings on a postmortem dental chart, where the data are later entered into a computer program to be cross-referenced. All postmortem information is compared to all missing persons and antemortem record information.

Antemortem Dental Profiling

From the moment the incident has occurred and family members are notified of their loved one(s) missing, antemortem dental records must be collected. Family members need to contact all the dentists whom their loved ones visited in their lifetimes. All radiographs, charts, photographs, notes, and anything generated through the course of their treatment must be collected and given to the antemortem collection team.

Dentists on the antemortem team can follow up with the missing person's dentist if questions arise about dental records. Several software programs are available that can be utilized to help facilitate and manage the data that are collected. WinID™ and PlassData™ are two computer software programs that assist the dentist and other forensic disciplines in managing all data and radiographs that are necessary for the investigation.

Comparing Antemortem and Postmortem Dental Profiles

The process of comparing antemortem dental records to postmortem dental records can be very long and painstaking. Although certain computer software programs can assist in eliminating certain individuals, the end result of a positive identification requires the eyes of a qualified dentist or team of dentists to make a final determination.

Once the antemortem team has charted an individual's teeth based on the antemortem records, the postmortem team must do the same on the human remains and charting the teeth on an identical form. For example, if during the postmortem examination it is noted that an individual has a crown on tooth #9, it can be compared to the antemortem records to find the person who had a crown on that tooth.

Dentists are human beings and can make mistakes when charting a patient's tooth. There are at times minor discrepancies in the charting and how an individual interprets a particular finding. These discrepancies can sometimes work themselves out, and the possibility of a wrong identification or misidentification can be eliminated.

With the aid of dental radiographs and the speed of the Internet, most x-rays can be compared electronically without mailing the particular dental chart and radiographs. During a mass fatality incident, time is of great importance, and by sending medical records through the mail you run the risk of records being lost or destroyed. Records received electronically help the dentist in presenting the findings to families and investigators in an accurate and professional manner.

Challenges in Mass Disaster Management

In any mass fatality incident involving large numbers of individuals there will be tremendous challenges faced by the forensic odontologist. Whether it is a high-speed crash of a commercial airplane or the collapse of a building as a result of a bomb explosion, there will always be the chance of fragmentation and commingling of human remains. After 9/11, the risk of passengers flying on airplanes traveling under false names or using false identification was greatly reduced due to positive ID checks. In environments or incidents where there is a large group of people with no manifest or record of the population present, there is a greater probability of getting an inaccurate count of victims.

Communication

Communication in any MFI is critical if the operation is to be successful. In many situations, information is power, and individuals want to hold on to information. However, sharing information is vital whether you are in the morgue or in the field. Information must be shared among the different sections of the morgue and with the teams in the field as well. For example, if one station in the morgue notices something on a medical record or finds something that the pathology section or dental section needs to be aware of, then those sections need to be notified and the information passed on. Too many times, information is not conveyed correctly or to the right people, and this creates problems and unnecessary delays in identifications and release of human remains.

If one link in the process is jeopardized, then the entire operation can come to a complete halt or prolong the operation. If dental information like x-rays is received in poor condition, or if dental charts are wrong or inaccurate, this will eventually lead to tremendous delays in the identification process and possibly lead to a wrong identification.

In some situations, issues develop that are out of the control of the dentist and others working in the morgue. Political, jurisdictional, and sometimes legal issues can all arise that might prevent certain procedures from going forward. One must keep in mind that all MFI are fluid environments, with processes changing constantly. As long as there are working procedures and protocols in place and everyone adheres to and follows these procedures, there should be no questions about the manner in which the operation is being managed. It is important for the management of the morgue to keep everyone positive and to be flexible. Being flexible, adaptable, and open to change during a MFI creates a working environment that is conducive to the needs of the family and the work you are doing.

Data Management

The amount of information received during a MFI, especially what is generated in the morgue and Family Assistance Center, can be overwhelming and must be managed quickly, efficiently, and accurately. How the information is received and stored will play a vital role in the timely process of identifications and release of remains. Everything from recovery of human remains to antemortem and postmortem data to family preference of the funeral home and repatriation must be entered into a single database and managed by a single group or source. Certain scientific information can only be entered by individuals who are trained and experienced in that field. For example, dentists must enter all antemortem and postmortem dental information into the database. This is critical because of the specific codes and different charting methods that are used around the world.

The information collected can be used to help families to complete legal documents for insurance, death certificates, and, most important, the package that the team of forensic specialist will use to determine whether or not human remains are positively identified. Once all of the data are collected, including photos, the information is turned over to the jurisdiction (typically medical examiners) that is responsible for positively identifying the human remains. All information is kept confidential, and access to the data should be limited to personnel who are entering the information, those who need to know the information about the human remains, and the jurisdiction in charge of overseeing the operation.

Family Assistance Center

The Family Assistance Center (FAC) provides support and assistance to families, information to families, site visits and memorials, and information about contacting the proper authorities concerning identifications, notifications, and the disposition of the remains. The FAC itself is a physical building either in a hotel or community center that provides the basic physical needs for the families, including food, shelter, transportation, telephones, and emergency services. The FAC is staffed by trained professionals and mental health providers who are there to listen and provide the logistical support that family and friends need during this tragic time. The FAC becomes an excellent facility for medical examiners and coroner's offices to conduct private interviews with family and friends in order to collect medical and physical history and information on a missing person, along with collecting DNA family reference material if needed in the future.

Mental Health Counseling

During any mass fatality incident, the well-being of both the staff and volunteers is extremely important to monitor. No matter how big or small the incident, the stresses and challenges involved in working a mass fatality incident are immense. There must be continuous monitoring and assessment of staff and volunteers by trained mental health professionals who are skilled in noting symptoms of fatigue and mental distress. The monitoring needs to be continued even after the incident is complete. It is important to have "hot washes," where staff and volunteers discuss the operation's issues and challenges. These are one-on-one sessions and are important for staff and volunteers to be integrated back into their normal daily routines.

Aftermath of a Commercial Airline Accident

At 35,000 feet above sea level, commercial airplanes are settling into their cruising altitude to their final destination. Very rarely do airplanes fall out of the sky or experience severe problems that cause the aircraft to fall into the ocean. That is exactly what happened one evening in October 1999. A wide-body aircraft (767-300ER) crashed about 60 miles (96 km) off the coast of Rhode Island, and 203 passengers and 14 crew members lost their lives in the chilly Atlantic Ocean. All but a few bodies were intact, and most had sustained severe trauma and fragmentation. There are no inconsistencies with the manifest other than one passenger who reportedly exited the plane following a stopover in New York's JFK Airport. It was determined that this person was on company business for the airline and had permission to leave the aircraft on its stopover at JFK from Los Angeles.

A large percentage of the passengers and all of the crew members were from the Middle East, which created many problems during the recovery and identification phases of the operation. It was difficult to obtain medical and dental records from family members, as well as to obtain permission from family members to take their DNA samples due to cultural and religious concerns.

Conventional means of identification from radiographs, medical comparisons, and dental comparisons was going to be difficult and at times impossible and time consuming. Fewer than 20 (9%) individuals were identified by conventional means. This does not include total bodies. Only fragmented remains and those that contained dentition were identified by conventional methods, mainly by dental comparisons. More than 91% of the fragmented remains required DNA testing to determine positive identification.

A small percentage (approximately 10%) of the human remains were recovered in the early days of the operation, including human remains that were floating on the ocean surface or had been removed from the aircraft wreckage as it was recovered. A temporary morgue was set up by the Department of Health and Human Services Disaster Mortuary Response Team (DMORT) in Rhode Island at a former military base. In the early days of the operation, a minimal amount of fragmented HR were recovered, and forensic specialists worked to determine any identifying features on the HR to try and correlate the remains to a passenger or crew. The temporary morgue was in operation for three weeks when it was determined that no additional remains would be recovered from the ocean surface and a plan needed to be developed to recover the remainder of the human remains from the ocean floor.

Two months after the crash, the NTSB leased a commercial vessel to recover the wreckage and human remains that had settled on the ocean floor. Pieces of wreckage were recovered from a depth of approximately 230 feet using a clamshell scoop and a crane. As the wreckage was recovered from the ocean floor and lowered onto the recovery vessel, teams of FBI/ERT agents and NTSB investigators combed through the wreckage to separate airplane parts and human remains. The remains were placed in refrigerated containers, and after the operation at sea was completed, the remains were transferred to the Rhode Island State Medical Examiner's Office for examination and identification.

The challenges in comparing antemortem medical records to postmortem records range from incomplete records received from families to mischarting of dental records to a lack of cooperation from family members. Once it was determined that DNA analysis would be the only method to make a positive identification, family members became agitated that the process would take months to complete. Family members were scattered all over the world, and it took time and cooperation from many governments to assist in helping the medical examiner's office in obtaining family reference material. All DNA material, both familial reference material, and postmortem samples were submitted to the Armed Forces DNA Identification Laboratory (AFDIL) of the Armed Forces Institute of Pathology for testing and analysis. Over a thousand samples were submitted, along with close to 500 familial reference samples.

The final DNA report was received over 14 months after the crash. In the end, all 217 passengers and crew members were identified by DNA analysis. Even the 20 victims who were identified earlier by conventional methods had their identifications confirmed by DNA analysis.

Kenyon International Emergency Services, Inc., was hired by the air carrier to handle the identification, preparation, and return of personal property. The impact of this airplane into the water occurred at a speed in excess of 600 mph at a severe angle of descent, with radar graphs showing water being sprayed almost 1,200 feet into the air. At that rate of speed and angle of descent, it is expected that there would be extreme fragmentation of both human remains and wreckage. Based on the examination of the remains and the wreckage recovered, it is estimated that the force of impact was greater than 300 Gs (gravitational constants).

MFI Recommendations for Medical Examiners' Needs

It is very important for any medical examiner's office to have a protocol or mass fatality plan in place. One can never plan for all possible events or scenarios, but the purpose of a MFI plan is to have a foundation and guideline in place that can be used to fit any type of mass fatality incident.

At the time of an incident, there will be much communication among multiple local, state, and federal government agencies. The medical examiner or coroner is in charge of all fatalities and becomes the incident commander during the search and recovery phase of the incident. The event must be kept separate from the daily operations of the local medical examiner's office. All local, state, and federal resources will be available, but it is at the medical examiner's discretion whether the resources are needed and how they will be used. Most state law enforcement and emergency management agencies have equipment and resources that can supplement the medical examiner operation. Federal agencies like the Department of Health and Human Services DMORT and private companies like Kenyon International Emergency Services, Inc., can provide temporary morgue equipment, supplies, and personnel to augment the medical examiner's team. The FBI/ERT team provides total station capability for documenting the recovery site along with the collection and documentation of evidence if necessary.

All of these resources should be included in the MFI plan, along with additional public and private sector agencies and companies that can support the operation during a MFI. If the incident is an airplane crash, there will be additional requirements that are needed as outlined in the Federal Aviation Family Assistance Act plan of 1996 and 1997. One must think long-term rather than short-term, since it can be weeks or months before the incident is either closed or a process is in place to recover and store all human remains until positive identification is completed.

Inventory Control

All HR recovered from the field should be given a search and recovery (SR) number prior to being photographed, logged, and transported to the ME/C office. The numbering system needs to be simple and start with the number 1 and go in consecutive order. The number is followed through the morgue. This is extremely important when there is a tremendous amount of fragmentation or when the remains are in a poor condition.

Triage of Recovered Remains

One of the first stations in the temporary morgue is the triage station, which is where human remains are examined to see if there are features on them that make them identifiable or unidentifiable through conventional methods. It is the station that sets the pace for the morgue in which human remains are separated.

Probably Identifiable

Large portions of human remains with hands will be processed for fingerprint comparisons or those with teeth for dental comparison, tattoos, and any unique identifiable characteristics on the body that can be compared to a record and positively identified (Figure 5).

Possibly Identifiable

This typically involves larger body parts that don't have anything unique or any obvious characteristics that can be identified immediately.

Probably Not Identifiable

There will always be a percentage of soft human tissue that is not identifiable. A medical examiner is only asking for trouble if she claims she will be able to identify every piece of human tissue. This is just not possible, even with DNA testing.

FIGURE 5 Human remains that are considered probably identifiable due to certain characteristics and physical features of the body that will make a positive identification based on the dental or medical devices present.

DNA Collection

In the early stages of a mass fatality incident, when the morgue is processing human remains, it should be standard practice and protocol in the Mass Fatality Plan that a sample will be taken of all human tissue that comes into the morgue for future DNA testing. There are several public and private laboratories throughout the United States that have experience in testing and analyzing postmortem and familial reference material for positive identification. Under no circumstance should a local or state police crime laboratory be used for DNA testing. The work involved in a mass fatality incident is extremely time consuming and expensive, and it can create a tremendous backlog in the already overburdened police crime lab.

DNA Testing

DNA testing is not always the most effective and efficient way to make a positive identification during a mass fatality incident. It is not always possible or the most definite way to get a positive identification. In some situations, it is very timely and expensive. In the preceding case of the plane crash near Rhode Island, it cost almost $5 million to conduct the testing on the 217 passengers and crew. The decision must be made early on by the medical examiner on whether DNA will be the final method of determining identification. It must be decided which types of samples will be needed, bone or soft tissue. Not all soft tissue is viable for DNA testing. In some situations, depending on the condition of the samples, routine nuclear DNA testing might not be feasible, and mitochondrial DNA might be preferred. This, however, can take days to complete, and it is much more expensive than nuclear DNA.

If the decision is made to profile even the individuals who have been identified via conventional methods, this will increase the expense of the testing, as well as prolong the final results and add to the caseload. The storage of the DNA samples will take up valuable space in the DNA laboratory and/or the medical examiner's office. Families must be made aware that in some situations the entire sample can be consumed in the testing phase. Therefore, the family can be notified that their loved one has been identified, but no remains can be returned to them. In other situations, the family might request that the sample be returned once the identification is determined so the remains can be buried.

Quality Control

As discussed early in this chapter, the decision to take samples for DNA testing should be made very early in the operation. This is important to minimize the rate of decomposition and degradation of the sample. Once samples are taken, recorded, and labeled, they need must be placed in a freezer until they are tested.

Human error can be a major factor in coding and labeling DNA samples. A simple numbering system must be determined and kept throughout the entire process. A bar-code system is usually the best. In cases where there is a lot of fragmentation, commingling of human remains is a strong probability. Recovery teams must be very careful to separate any human remains and place the samples in individual bags. Mixing up human remains can cause problems with the DNA testing. It is extremely important that proper techniques are followed when sampling the tissue for testing. The risk of contamination is greater when proper techniques are not followed, which may result in inconclusive profiles. Only trained DNA technicians should be allowed to take the samples of the human tissue and ensure that the utmost care is taken in packaging the samples for testing.

Public Information

Only the medical examiner/coroner is permitted to release the names of the victims after they have been positively identified. He or she is required to release the names as a form of public record. This should be coordinated with all agencies involved, and family members should be notified that this will happen. In addition, the medical examiner/coroner must report how the identification process was performed, when the remains will be released, and what long-term plans are in place for the recovery of human remains. In an aviation accident, it is important that the names match those on the manifest prior to releasing the names to the media.

Data Management

Regardless of the size of the mass fatality incident and the number of victims killed, maintaining the records, files, and information received on missing persons and victims will be very cumbersome and difficult to process if no system is in place. All of the data that go into the data management system become the property of the medical examiner/coroner. In the case of an aviation accident, the airline involved will have access to the information as well. There must be a protocol in a mass fatality plan that covers record keeping, updating information, control, and management throughout the entire process (Figure 6).

The information that is collected is valuable not only for the investigators in charge of the mass fatality incident but for the families as well. The medical examiner will need the information, and that will be the only source of information to give to the families. In some situations, the DNA process can take months or even years to complete. The data will be the conduit between the medical examiner/coroner and the families.

In the event of an airline disaster, the information that is collected and stored in the data management system is collected from the families in the Family Assistance Center. Once the center is closed, this information is all that is available to medical examiners/coroners and investigators.

FIGURE 6 Data management staff entering data into the computer on specific antemortem information. *Photo property of Kenyon International Emergency Services, Inc.*

Positive Identification

Certain scientific standards are used to determine how valid postmortem identifications can be made. Besides the conventional methods of fingerprints and dental records, personal effects can be useful in leading to a positive identification, although they should not be the only factor in making an identification. In addition to unique pieces of jewelry and specific types of clothing, these can only be considered circumstantial methods of identification. The final determination must be made by the standard conventional methods of identification. Tattoos and body piercings can be very specific and unique as well, and in some situations this might be the only method in which a positive identification can be made on a human remain. If that is the case, everything must be clearly documented and the decision based on the process of elimination.

In airplane disasters, often crew members have a presumptive identification based on the uniform they are wearing: captain, first officer, or flight attendant. This is circumstantial, but it is a start in narrowing down the antemortem medical information. At times families become upset because the circumstantial evidence makes it easy for medical examiners/coroners to make identifications of crew members quicker than passengers. This allows for "probable" identifications to take place quicker than "possible" identifications.

Computer Methods and Software Used in Identifications

Without the aid of computers and the use of identification software programs, the time involved in making identifications would take weeks and months to complete during a major mass fatality incident. Although computers and software programs do not make positive identifications, they aid in narrowing down the most likely and least likely choices. A team of forensic specialists, such as pathologists, odontologists, anthropologists, fingerprint examiners, and DNA specialists, make the decision on whether human remains are positively identified based on the evidence and facts they are reviewing.

Many software programs are available to the global forensic community. WinID™ is widely used in the United States by the U.S. government DMORT teams, and PlassData™ is widely used among foreign law enforcement agencies. PlassData™ is the program of choice for INTERPOL. Both programs have very significant data fields for dental, pathology, anthropology, personal effects, and antemortem medical information to be entered. Many local and state medical examiner/coroner offices are developing mass disaster software programs that are written for their own system and are something they feel comfortable using. The New York City Office of the Chief Medical Examiner developed a program shortly after 9/11 that has become well known in the United States among medical examiner systems.

Record Keeping

Although computers can be used to maintain the files and records on missing persons and to track human remains, there must also be a paper trail in which the data and information are taken from and put into a data management system. All files and records, both antemortem and postmortem, become the property of the medical examiner/coroner after the incident. These records are important because in some situations individuals are being identified by DNA, and it will take days, months, or years before all of the samples are identified. It is strongly suggested that a team of individuals be assigned to perform record keeping, maintain the files, and do quality control checks on all of the files and paperwork received. It is human nature for people to make mistakes, and when a large-scale incident is involved, there are sure to be mislabeled forms and documents, and mislabeled and misfiled photographs. Families are going to expect to receive accurate records of their loved ones and with the highest regard and respect. It is inevitable that legal action will be taken after any mass fatality incident. All records and files should be handled properly, and the chain of custody should be followed on all reports, photographs, and specimens.

When to Stop Recovery Efforts

Making the decision to stop recovery efforts is one of the most difficult decisions a medical examiner/coroner will ever have to make. It is a decision that is not made independently and must be discussed with all parties involved. In an aviation accident, the decision to stop recovery efforts is discussed with the families *before* the work is stopped. In any situation, it is clearly an ethical and political issue that troubles many and makes the decision difficult and more challenging. We live in a modern society that has all of the latest tools, equipment, and technology that should make it possible to recover every piece of human tissue and enough human tissue to be able to identify everyone involved. Unfortunately, that is not always the case, and we can't recover everyone. There are tremendous differences between land- and water-based accidents and MFI that involve building collapses or terrorist events.

In the preceding plane crash case scenario, it was a water-based accident, and it took several months to make the decision to stop all recovery efforts. Technology was used to map the ocean floor using side scan sonar, and a specialized vessel from Europe was used to conduct the recovery. A detailed map and plan were used with coordinates drawn that allowed the recovery to take place in a methodical fashion. After two weeks of working 24 hours per day, the decision was made to stop all recovery efforts. In the end, 80% of the aircraft was recovered, and all 217 passengers and crew members were identified. Although the human remains were fragmented, each victim was returned to his or her family for a proper burial.

The loss of one recovery person's life is not worth trying to retrieve the remains of for someone who has died in an accident. Search and recovery teams do everything humanly possible to find victims and human remains. The work is challenging, difficult, and dangerous. But at some point, it is necessary to stop and say, "We did everything possible to recover all human remains."

It is important to remember that personnel search for human remains to identify an individual, not to identify body parts. Often, families believe that search efforts will continue until all of their loved ones are returned. Unless additional pieces are identified, once a piece of human tissue has been identified as a certain individual, no further efforts should be taken to find that person.

International DVI Teams Cooperating During an Event

There are unique challenges and issues that arise in international mass fatality incidents that are typically not seen or experienced in the United States. Cultural and religious customs in some countries take precedent over the recovery, handling, and disposition of human remains. In addition, there are political and jurisdictional challenges to which governments providing Disaster Victim Identification (DVI) teams to the incident will have to adhere. Finally, there are a variety of ways in which international forensic teams operate and how they follow the international standards or protocols for identification.

When DVI teams are invited to a foreign country to assist in a mass fatality incident, they must be aware of all religious and cultural customs practiced in that country. Their beliefs should never be considered "wrong" or inappropriate. DVI teams should respect the country's customs and perform their duties within the guidelines of that country with professionalism and dignity toward the bodies. For example, in Thailand it is customary for Buddhist monks to provide offerings and hold ceremonies at the morgue where human remains are stored in refrigeration units. This might seem unusual and an exception to the norm, but DVI teams must be accepting of local customs and avoid any unnecessary hardship to family members while waiting for their loved ones to be identified.

International DVI teams must understand that they are invited guests in the country to which they are traveling to provide support and assistance. The team must "play" within the rules of the host country, following their recommendations. In some situations, the political arena of the host country will dictate how the incident will be managed and will coordinate all resources—provided that DVI teams are invited in. When a Helios Airways plane crashed in Greece in 2005, the Greek government would not allow assistance from foreign countries to help in the identifications of passengers and crew. The operation was controlled by the Greek government, and the local medical examiner had to comply with federal regulations and use only Greek resources.

Finally, although there are international standards in the forensic community as to what constitutes a positive identification, these are followed in varying degrees from country to country. The methods of dental charting also differ, depending on the country in which the MFI occurs. When using DNA for identification, different laboratories require varying ranges as to what constitutes a match. The number of required loci for identification can range from 13 to 18, and some laboratories will accept as few as 9 to make a positive match. In some situations, circumstantial or presumptive identifications will be accepted, which goes against international standards. DVI teams must determine what will be the acceptable standard for the MFI, set a benchmark, and work to convince the host country to abide by them.

DVI teams come with a host of knowledge, experiences, and skills. There are varying skill and experience levels within DVI teams, depending on the number of times individuals are deployed to MFIs. Acknowledging that there should be no influence of standards because of their own beliefs and customs, the overall role of DVI teams is to provide identifications on human remains in a professional, ethical, respectful, and dignified manner.

Identifying Victims of 9/11

At the Office of Chief Medical Examiner City of New York

Jeffrey R. Burkes
Chief Dental Consultant to the Office of Chief Medical Examiner of the City of New York, 1979–2005

The task of identifying the victims of the World Trade Center attack in 2001 required all the skill and experience I had obtained in the 26 years I worked at the New York City Office of Chief Medical Examiner (NYC-OCME). In the first days after 9/11, experts throughout the country had predicted that we would be able to identify perhaps 100 victims at the most. Despite their pessimism, my goal, and that of our dental unit, was to identify all of the victims, even though at the time some casualty estimates were as high as 10,000.

On September 11, I was told by the director of Medico-Legal Investigations that our office (OCME) would be issuing death certificates for individuals who were not positively identified in the usual manner, even if remains were not found. This was a new paradigm, since prior to 9/11 no remains were ever released without a positive ID. I can recall several cases of remains that had lingered in the office for a number of months before being sent for city burial because a positive ID could not be established, even though there were

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claims on the remains and we had suspicions that these claims were in fact true. Under pressure to identify victims as quickly as possible, the individual who was in charge over all of the identification units was willing to employ identification methods that were not routinely used previously, such as comparative radiographic images of skeletal anomalies. Deviating from the standard means of identification increased the risk of misidentification.

One such incident involved the use of a radiographic image to make the identification of a firefighter known to have an abnormality of the cervical spine. When the fireman's colleagues brought in these remains, they insisted that they were those of a particular firefighter because of the jewelry and bunker gear found with the remains and the location where these remains were found. A comparison was made between antemortem and postmortem (nondental) radiographs, and both showed the skeletal anomaly. On this basis, the body was positively identified. The body was released to the family, but after the funeral, DNA testing showed that samples from this body matched those from the toothbrush of another firefighter with whom he had worked closely. Ironically, this firefighter had the same skeletal anomaly, a bifurcated cervical spine! The family was then notified that they had received the remains of another firefighter.

I suggested and urged the Director of Identifications and the Director of Medico-Legal Investigations to require two forms of identification (from dental, fingerprints, DNA, visual, tattoos, and others), as in the Pan Am Lockerbie disaster. I was overruled. DNA at this point was just beginning to be used in mass disaster investigations. It became apparent to me that the bulk of the identifications of the World Trade Center disaster victims would be done by dental means, as had been customary when there were many fragmented remains. Later statistics would show that of the approximately 1,600 victims identified in total, 596 were positive dental IDs. Furthermore, some of these IDs were completed by dental months ahead of the DNA identifications, allowing the remains to be immediately released to the families without waiting for the DNA results.

One of the first problems we encountered on 9/11 was the lack of office space to process information coming into the unit. The forensic dentists worked for the OCME as consultants; we had our own private dental practices, and we had become accustomed to working at the medical examiner's office in borrowed space. In the days right after 9/11, we set up computers, records, telephone lines, and view boxes in an abandoned space in the basement of New York University Medical Center, which is adjacent to the OCME. At the same time, we set up multiple processing stations in the autopsy facilities at the OCME consisting of radiograph machines, radiograph developers, view boxes, gurneys, lights, Stryker saws, and other dental instruments used to examine dental remains (Figures 1–5).

I realized early on that this disaster could be an invaluable learning opportunity for the experienced as well as the novice forensic dentist. In 1984 I had organized the Multiple Victim Dental Identification Unit at the

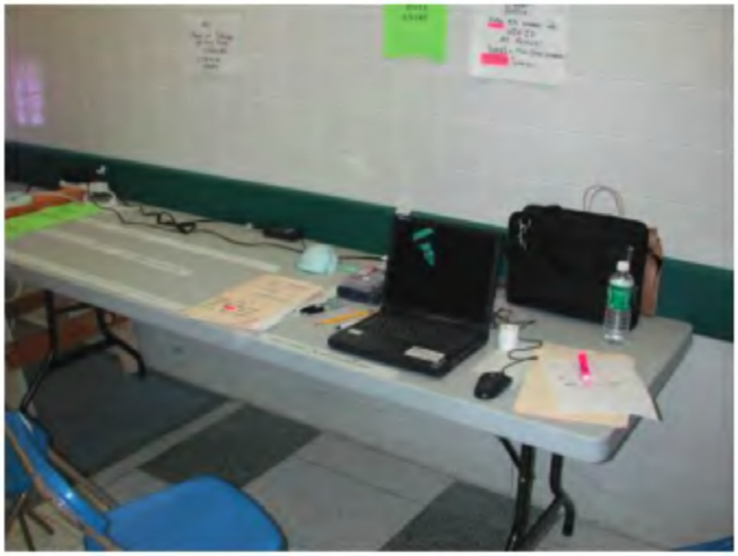

FIGURE 1 Materials used to transcribe data from paper chart to the WinID program in the computer.

FIGURE 2 Computers, networked.

OCME (MVDIU); by 9/11 this group consisted of 40 dentists with varying levels of expertise. While we were an experienced team, having drilled together yearly for mass disasters, we did not have the manpower to run the unit 24/7. I did not want to sacrifice accuracy by using dentists who had little or no experience, so I decided to draw the leaders (we called them tour commanders) from the MVDIU and welcomed volunteers from the tristate area as well as the rest of the United States and Canada. By putting the experienced and less-experienced forensic dentists together, the novices got excellent training, and we did not sacrifice accuracy.

One of the first needs was an administrative staff to oversee credentialing and scheduling of dental teams. Dentists are accustomed to running their own offices and issuing orders, while dental hygienists are excellent team

FIGURE 3 Dental processing stations are set up according to established protocol.

FIGURE 4 Workstations are provided with fixed gurneys—stainless steel trays on sawhorses.

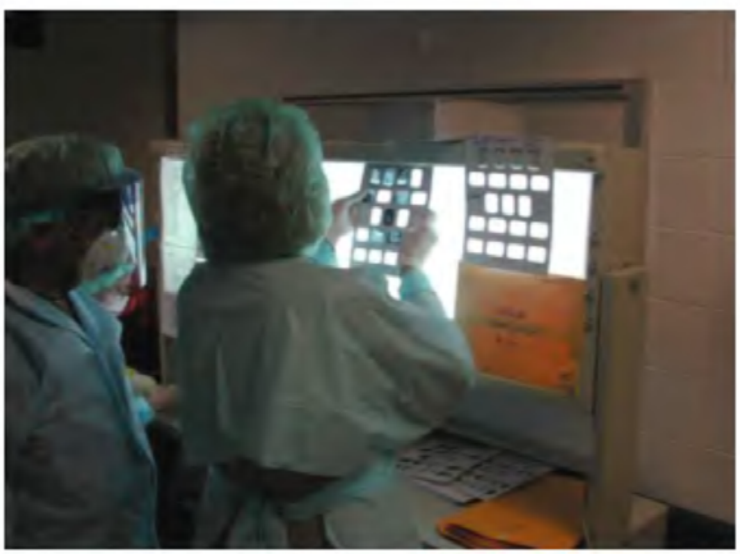

FIGURE 5 Looking at radiographs on the light box.

workers and implementers of procedures. I asked two very capable hygienists to head up this office. They also maintained the protocol that all volunteers were required to read and sign. (This protocol covered all aspects of obtaining dental records and using them to make a dental identification, and it grew from 1 page to 40 pages in length as issues and needs arose.) I asked the hygienists to schedule tour commanders for 12-hour shifts and forensic dentists for one of three 8-hour shifts. This schedule was designed to avoid communication gaps incurred by shift changes; each tour commander's shift overlapped the 8-hour shift changes.

This plan worked very well. The tour commanders were required to fill out written critiques of the forensic dentists working on their tours, detailing the ability and attitude of the participating dentists. All of the tour commanders were required to participate in a weekly conference call in which they would report the strengths, weaknesses, and problems they had discovered to date. This gave me a unique insight into the status of the Unit, as well as rapid input into correction of unanticipated problems my TCs had found.

The response to New York City's disaster from the American and Canadian forensic dental communities was overwhelming. Four hundred and fifty dentists and dental personnel volunteered to come to New York and help with the victim identification. They came at their own expense, leaving behind their dental practices. Initially we had some donated and discounted housing available to them, and meals were always available from "Sal's Café," the Salvation Army trailer that offered breakfast, lunch, and dinner to workers at the OCME on a 24/7 basis (Figure 6). We were all grateful for the refreshment and a brief time to unwind. Sal's was all too conveniently located about five feet from the entrance to the Dental Identification Unit's trailer, where the nonclinical work with the computers was performed and the matches were made (Figure 7).

FIGURE 6 Sal's Cafe.

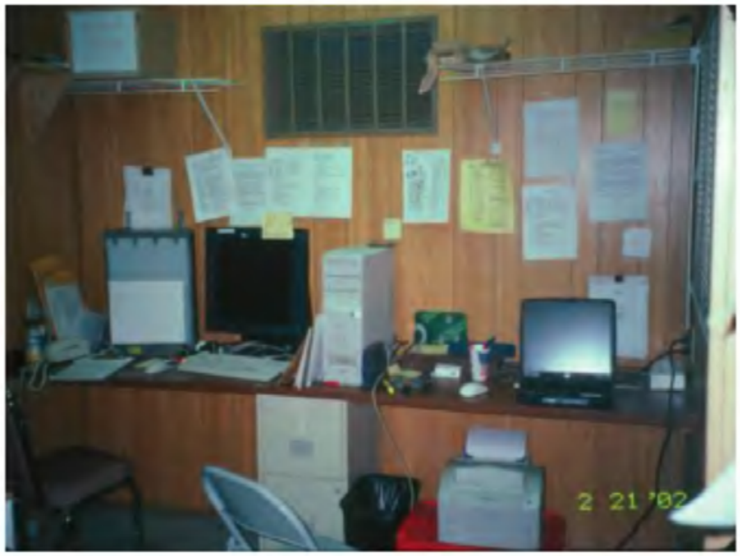

FIGURE 7 Inside the Dental Identification Unit's trailer.

Prior to 9/11 we had performed dental identifications without the need for or use of computers, but now, with 20,000 body parts and an unknown number of victims, we could not proceed without computers. We brought in the WIN-ID dental comparison program and proceeded to enter postmortem data with the help of DMORT (Disaster-Mortuary Operations Response Team) dentists. They worked 12-hour shifts, 20 per shift, from all over the United States. It was reassuring when I would see the familiar face of an experienced forensic dentist whom I knew from the national forensic dental meetings getting off the DMORT bus. As the dental remains were brought to the OCME, the postmortem teams would begin to receive the full-body radiographs taken by the OCME radiologic technicians, expose and develop the dental radiographs, and do the dental charting, recording the results initially on paper (Figures 8 and 9). This information was then transferred to the WinID

FIGURE 8 Radiographing dental remains.

FIGURE 9 Charting dental remains.

system, and the dental radiographs were scanned in. All recorded data were "doubled and redundant," in that two dentists worked together, one calling off observations and the other recording the results, repeating the process after switching roles before obtaining an acceptable level of confidence.

In another room, antemortem teams recorded the antemortem records of presumed victims in the form of a seven-page "VIP" (Victim Information Profile) form, which usually contained dental radiographs as well as a dental chart and/or the name of the dentist of the presumed victim. After information in the chart was clarified and verified by the antemortem team, members of the comparison team began searching for matches from the database that we were amassing from the documentation of the dental remains by the postmortem team. These teams also operated by the principle of "doubled and redundant." We soon learned that the number of victims was greatly inflated because of multiple missing persons reports filed by family members and friends. In fact, there were 60,000 missing persons reports filed. A "Reported Missing" committee was established to make an official list of the victims after eliminating duplicates. This made our job much easier.

The VIP forms were obtained at the Family Assistance Center, eventually located at Pier 94 at West 54th Street and the Hudson River. There, NYPD detectives collected evidence brought in by families: toothbrushes, hairbrushes, razors, photographs, dental radiographs, descriptions of scars or tattoos, and so on. In addition, buccal (cheek) swabs were taken from family members to aid in DNA identification.

The VIP forms were transported to the OCME. One hundred eighty DMORT volunteers transferred the data from paper into our computers. The dental unit extracted the dental information and returned the forms to the Incident Control Center (ICC) so the DNA unit, the medico-legal investigators, anthropologists, and others could look for matches (Figure 10).

FIGURE 10 The Incident Control Center.

Once the remains had been examined by the dental unit, unless there were fingerprints to be taken, the remains went to Memorial Park, which consisted of 16 refrigerated trailers, in two rows of eight, housed under a large white tent (Figure 11). This was a solemn, guarded place decorated with wreaths and flowers, and it served as the final station for the victim's remains before release. Funeral directors and dental team members entered as needed. Before a body was released following ID by a nondental modality, a dentist would be called to rechart the dental remains to be certain they were consistent with the original postmortem record. This was to prevent releasing any body due to a clerical error, which had previously occurred, precipitating

FIGURE 11 Inside Memorial Park.

this protocol. Other errors occurred, which even dental could not correct, including the case of an MOS (Member of Service) who was positively identified by dental means in 2001 but the family was not notified until 2002.

When a dentist felt he or she had made a positive ID, it was reported to the tour commander or another experienced forensic dentist in DMORT, who then reviewed these findings. If they agreed, he would then show it to another tour commander or another experienced forensic dentist in DMORT, and all three would have to agree before it could be signed out as a positive dental match. If the three did not concur, then I would make the final decision at the shift change. The system worked well, as we had no wrong dental IDs among all of the victims of 9/11. This was a higher standard than we had previously used at the Office, which only required the signature of one forensic dentist in order to release the remains.

On November 12, 2001, New York was shocked again as American Airlines Flight 587 crashed just outside JFK Airport with 260 on board and 5 victims on the ground. Most victims were residents of the Dominican Republic. With our shifts working 24/7, we were able to identify the remains very quickly—within 28 days, including both dental and other means of identification. Flight 587 identification had its own set of difficulties: In some cases, entire families died on the flight, and some victims may have been illegal aliens. In both cases, few people came forward to supply information. I appealed to the president of the Dominican Republic Dental Society, located in the Washington Heights area of Manhattan, where a number of the victims lived, to get out the word that we wanted only dental records and were not interested in their immigration status.

Some of the most poignant memories I have surround the remains of the members of service (FDNY, NYPD, EMS, and Port Authority Police). When a body was discovered at the World Trade Center site, and there was a presumptive determination that this was a member or members of service, the remains were placed on a stretcher, covered with an American flag, and placed in an ambulance or the vehicle associated with the MOS's branch (e.g., fire truck, police vehicle) rather than a medical examiner's vehicle. When the ambulance was a few minutes from the OCME, the driver would radio ahead to the police officer in charge, who would then signal the vehicle's approach. Everyone in the area formed two facing rows and stood quietly as the ambulance passed between and stopped at the receiving entrance of the medical examiner's office. The body was then ceremonially removed from the ambulance and placed on a gurney, and the officer in charge called the assembly to attention. The uniformed officers held a salute as an honor guard of police detectives accompanied the body into the building, and they would then stay with the remains through all of the stations of the identification process.

The final number of victims of the disaster was determined to be 2,749. In order to expedite death certificates for victims who had not been identified, the OCME took affidavits from the family members and issued Judicial Decree Certificates. Over the months and years, the OCME was finally able to identify the remains of approximately 1,600 individuals, 596 of which were by dental means. The authoritatively quoted statistic states that the dental unit identified 52 victims. This is misleading, because the dental unit was able to make most of its 596 IDs before any other modality confirmed what dental had determined. However, once another modality, such as DNA, confirmed the dental identification, the record changed to "multiple modality." In each case, however, the body was released as soon as the dental ID was made, which was usually months before another modality confirmed it.

I believe forensic dentistry's response to the challenge of the 9/11 attacks proves the superiority of dental identification over other modalities, such as DNA. One reason is speed: While a dental ID can be done in a matter of minutes, DNA analysis takes days or even weeks. As of October 31, 2001, the dental unit had positively identified 170 victims, while DNA had identified 10. This is partly because there are many more individuals trained in forensic dentistry than in the emerging field of DNA identification but also because antemortem records are usually readily available, and well-established procedures and protocols in dental identification maximize the efficient keeping of records and minimize the chance of mistakes.

Another advantage of dental identification involves casualties where there are degraded or commingled remains. In these situations, the integrity of DNA evidence is compromised, while dental remains—which are extremely durable—are not. Furthermore, forensic dentists are specifically trained in the gathering of remains in casualty situations in order to ensure evidentiary integrity and in obtaining antemortem dental records.

It is also interesting to note that DNA identification relies on probability: Probability analysis can leave room for error. Dental analysis, on the other hand, relies on hard physical evidence where the standards of comparison have been long established and tested. Because of this, dental analysis can usually be apprehended intuitively by the layperson, as in the case of a juror hearing and evaluating evidence in a court case—radiographs, dental casts, photographs, charts—which almost all laypersons will have encountered in their own experience . When the forensic dentist explains the significance of the elements of the graphical materials presented, jurors can relate the information to their own bodies and develop their own sense of veracity of the opinions expressed by the expert before them.

A final, and critical, factor is cost. While in the resolution of casualties such as 9/11 no cost should be spared, the reality is that communities do not have unlimited funds. One DNA analysis can cost thousands of dollars, while the only cost in a dental ID is a minimal consultant's fee.

What is perhaps most telling is that over the course of the entire 9/11 victim identification effort, what few mistakes were made (and reported in the press) were identified and corrected by the dental unit and other modalities. It is gratifying that there have been no reported cases of mistaken IDs by dental means. Dental identification remains the benchmark for mass disasters.

Australasian and Multinational Disaster Victim Identification

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Overview

Although fierce sporting rivals, Australia and New Zealand are geographical neighbors in Australasia and are strategic allies. Cooperation between the two countries' military, policing, and identification personnel is long-standing. Australia has a surprisingly long history of disasters dating from its colonization in 1788. Environmental disasters in Australia have ranged from cyclones, earthquakes, floods, and landslides to heat waves and bushfires. Major transport and industrial incidents have been less frequent, usually involving bus, rail, and light aircraft. To date, the national airline Qantas has not had a fatal crash. Most disasters have involved fewer than 200 dead. The largest loss of life outside warzones remains the pandemic of Spanish Flu in 1918, which caused the deaths of approximately 12,000 people

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[1]. Although New Zealand is noted for both earthquake and geothermal activity, most mass fatality incidents have been transport-oriented with modest death tolls [2].

Regionally, Australia and New Zealand sit in an area of immense geographical and climatic instability, with both natural disasters and man-made incidents occurring on a large scale across the region. The Indian Ocean Tsunami of 2004, which was precipitated by undersea movement of tectonic plates, killed in excess of 200,000 and precipitated a worldwide emergency response [3].

Contemporary Australasian emergency management dates from the destruction of the Northern Territory city of Darwin by Cyclone Tracy in 1974 [4]. Besides responding to disaster scenarios, Australasian Disaster Victim Identification (DVI) personnel have been extremely proactive in developing operation manuals and training courses in Australia and New Zealand and around the region. Four key universities offer postgraduate education in forensic dentistry, providing a wealth of knowledge and experience. This chapter outlines recent Australasian incidents involving DVI dental specialists and provides suggestions for streamlining the identification of the deceased in mass fatality incidents.

Local Incidents

Early disasters in Australian territory included shipwrecks (the sinking of the *Cataraqui* was Australia's worst civil maritime disaster, killing in excess of 400 people in 1845); epidemics (the Bubonic plague from 1900 to 1910, the Spanish flu in 1918, polio 1946–1955); and industrial accidents (coal mine explosions at Bulli in 1887 and Mt. Kembla in 1902) [1]. Disasters in more recent times include those of environmental origins (South Eastern Australia heatwave and bushfires in 2009 and 1983, Cyclones Tracy (1974) and Fife (1991), the Thredbo landslide in 1997, and the Newcastle earthquake in 1989). In 1977 the Granville train derailed and a bridge collapsed, and in 1996, 35 people were killed by a sniper in Port Arthur [5].

The Natural Disasters Organisation emerged in the 1970s after Darwin's Cyclone Tracy experience. The city was devastated on Christmas morning when it was hit by the tropical weather depression Cyclone Tracy. Winds were recorded at 217 kilometers per hour before the Bureau of Meteorology anemometer was destroyed. Sixty-five people were killed and 70% of Darwin's homes were destroyed or severely damaged [4].

Further disaster preparedness planning has revolved around Emergency Management Australia [1], an organization in the Federal Attorney General's Department, and the Australasian Disaster Victim Identification Committee (ADVIC), which is comprised of Australian and New Zealand police and identification specialists [6].

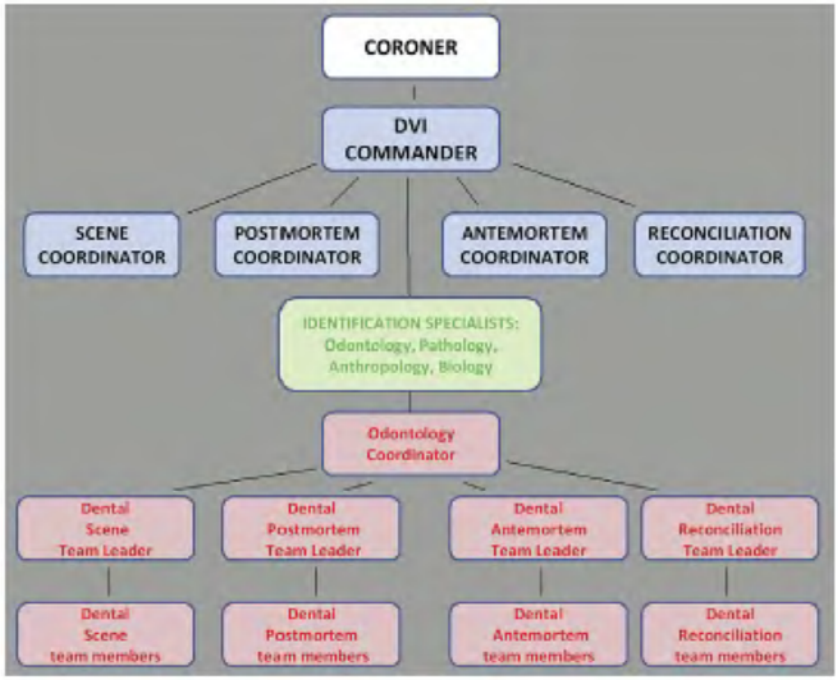
FIGURE 1 Debris from Air New Zealand flight TE901 (© New Zealand Police). The aircraft was flying at about 450 meters above sea level on an Antarctic sightseeing flight in whiteout atmospheric conditions, where the sun is filtered through cloud and reflects light from the snow, making it impossible to distinguish ground from air. The plane flew into the mountainside of Mt. Erebus.

In 1979 New Zealand's largest "local" DVI response occurred offshore when 257 people, predominantly New Zealanders, died in the crash of a sightseeing aircraft into Mt. Erebus in Antarctica [7]. Extreme terrain and weather made the recovery operation difficult (Figure 1), but 213 victims were positively identified.

Australia and New Zealand both have a Westminster-style government. Acceptance of identification and the issue of forms permitting burial or cremation of the deceased fall within the provenance of state and territory coroners [8]. In a mass casualty event, coroners delegate the operational management of the incident to the corresponding police DVI commander. Police and identification specialists work in a clear chain of command that is illustrated in Figure 2. Presumptive matches are presented to an Identification Board and these results are then submitted to the coroner for ratification.

As member countries of Interpol, the world's largest international police organization facilitating cross-border police cooperation, Australia and New Zealand utilize the Interpol Standing Committee on Disaster Victim Identification international guidelines [9]. These contain overarching principles for the management of a mass fatality incident and provide forms for the collation of all relevant antemortem and postmortem data. DVI personnel also use DVI Systems International, a computer program endorsed by Interpol, for storing antemortem and postmortem medical, pathology, odontology, anthropology, molecular biology, physical, and property data [10]. It allows multidisciplinary use and search capacity, with integrated data-mining and comparison across all areas to assist in matching reported missing persons and unknown remains. All aspects of current computer data management are logged in an automatic audit trail, and standardization within the program assists quality management.

FIGURE 2 Australian Operational Structure for a DVI incident. Odontology structure mirrors that of the police, with defined phase leaders and reporting lines.



Forensic odontology experts and interested general dental practitioners in Australia constitute the Australian Society of Forensic Odontology [11] and have developed a *Disaster Victim Identification Forensic Odontology Guide* to document dental procedures and protocols [12]. The New Zealand Society of Forensic Dentists harnesses expertise in New Zealand [13].

Case Study: Operation Phoenix Victoria 2009

An extreme heat wave across southeastern Australia culminated in bushfires across the state of Victoria on and around Saturday, February 7, 2009 (Figure 3). The result was Australia's highest ever loss of life from a bushfire (173 dead, over 400 injured, and 2,000 homes destroyed). Victoria Police coordinated the five-phase DVI operation, with police and identification specialists seconded from all Australian states and territories. Personnel from New Zealand, Indonesia, and Japan were also involved. DVI Systems International was used for the first time in an Australian mass fatality incident. The odontology response was rapid and well coordinated, with incident-specific standard operating procedures (SOPs) in place by the time most of the deceased had been recovered and transferred to the mortuary. The majority of the victims were identified by dental comparison.

FIGURE 3 The resilience of nature—a kangaroo surveys the aftermath of bushfires in Victoria.

TIP: Odontology Coordinator

A dedicated odontology coordinator is invaluable. This person should be readily contactable by the regional DVI commander and should maintain a roster of trained available dentists. When activated, the odontology coordinator administers terms of deployment, sets standard operating procedures and quality assurance standards in conjunction with phase team leaders, and manages dental personnel rosters. The odontology coordinator may also lend expertise to the Identification Board.

TIP: Fragile Remains

For most identification scenarios, the limiting dental factors are location and the quality of the antemortem dental records. In cases of severe incineration, however, it is likely that the quality of postmortem remains will be the limiting factor. Data available at the scene may not survive transportation to the mortuary due to the fragile nature of the remains (Figure 4). In such cases, it is important to have odontologists at the scene to recognize and document dental evidence to supplement the postmortem phase. Charting, photographs, and radiographs compiled at the scene are valuable adjuncts to autopsy information. Lateral oblique extraoral views can be taken without disturbing the fragile structures. Odontologists can also assist with stabilizing the remains for transportation, such as covering the head and hands with plastic bags [14].

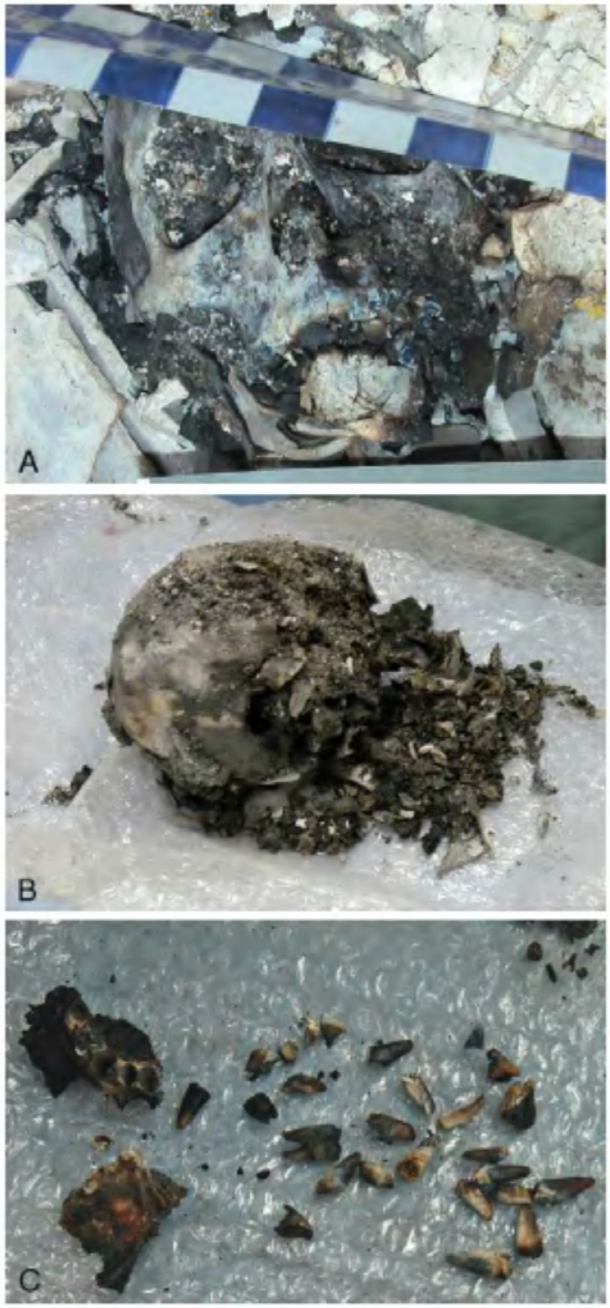


FIGURE 4 Human remains located after the Victorian bushfires. (a) The skull, although calcined, is clearly recognizable. (b) The head was wrapped for transportation to the mortuary, but significant damage has occurred to the fragile remains. (c) Very little dental evidence remains to allow identification by dental comparison.

TIP: CT Technology

The computed tomography (CT) scan is a medical imaging procedure that utilizes x-rays and digital computer technology to create detailed two- or three-dimensional images. Although the equipment is expensive, it is becoming commonplace in state mortuary facilities for routine coronial casework. In the DVI scenario, the use of a CT scanner at phase 2 will allow collation of important postmortem data prior to autopsy, including information about age and gender (Figure 5). Commingled remains will also

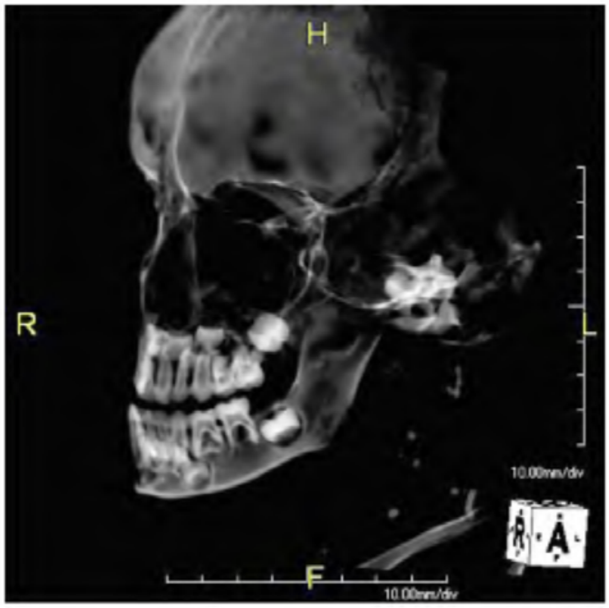


FIGURE 5 A CT scan allows visualization of the stages of tooth development. An estimate of age can assist profiling and targeted DNA analysis. This example shows an estimated age, based on tooth development, of approximately 2 years 6 months.

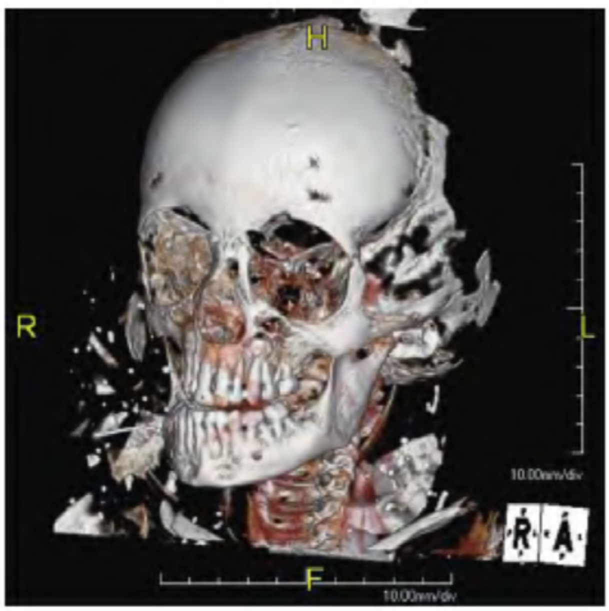


FIGURE 6 A CT scan also allows reconstruction of the skull, which can then be used for a photographic superimposition.

be seen at this triage stage, and bodies can be scanned for metal debris. Skull reconstruction from the CT images can also be used in the reconciliation phase for photographic superimposition (Figure 6).

TIP: File Management

File management is crucial to maintaining the integrity of the data and to avoid recurrent dilemmas associated with mislaid or mixed files. Problems may be minimized by following several recommended protocols.

Transparent zip-lock bags can be used to hold files for each antemortem and postmortem case, and only one file should be open per operator at any given time. Antemortem dental data may come from several different sources (e.g., general dental practitioner, orthodontist, oral surgeon). This data should not be indiscriminately thrown together, since information from a particular origin may need to be validated. Control of file movement among the antemortem, postmortem, and reconciliation sections, and between personnel, is best managed by bar-coding to allow easy tracking and accountability. Exhibit storage areas must also preplan for oversized exhibits, such as medical radiographs and boxed exhibits for dental casts and appliances.

Regional Assistance

Australasian DVI personnel may deploy to regional countries where Australian or New Zealand citizens have been killed or where the host country does not have DVI experience or resources. Deployments have included the bombings in Indonesia of the Marriott and Ritz Carlton Hotels in Jakarta in 2009, the airline crashes of Garuda Airlines Flight 200 in 2007, Yeti Airlines in Nepal in 2008, PNG Airlines on the way to the Kokoda Trail in Papua New Guinea in 2009, and the 2009 tsunami in Samoa (Figure 7). Personnel were also sent to Tonga following the deaths from civilian unrest in 2006.

FIGURE 7 The aftermath of the 2009 tsunami in Samoa. Australian DVI personnel assisted with identification of the deceased.

Experts have also been involved in the identification of service personnel killed in action. Remains dating from World War II (Papua New Guinea and Borneo) and the Vietnam conflict have been located in recent years (Figure 8) and repatriated to Australia. Mass graves of civilians killed in East Timor have also been explored.

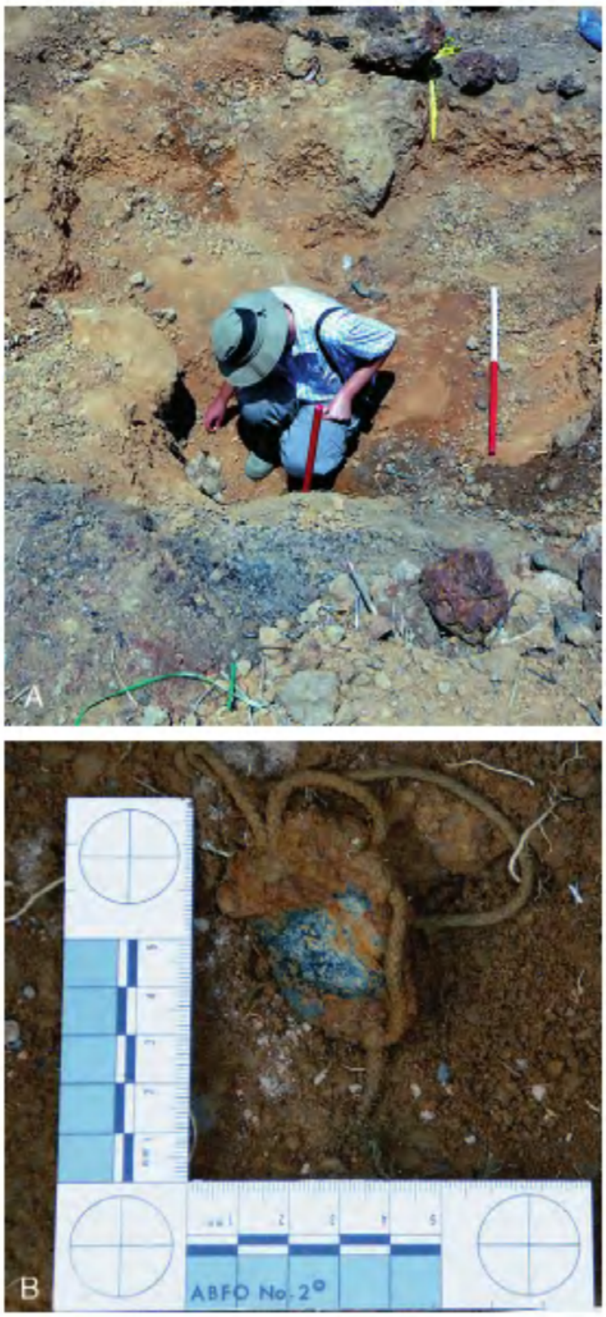


FIGURE 8 (a) Location and identification of Australians killed in action in the Vietnam War. (b) Identification tags worn by Australian services personnel were x-rayed to reveal personal identifying serial numbers.

TIP: DVI Equipment—Take and Leave

Rapid response deployment to disaster-affected areas is simplified if a cache of equipment is assembled in advance and regularly maintained. A notebook computer with DVI Systems International software allows direct data entry to the database program based on the Interpol DVI forms (Figure 9). Alternatively, Interpol Post Mortem (pink), Ante Mortem (yellow), and Reconciliation (white) forms are used (handwritten). Adobe® Photoshop® is a software tool that allows radiographic [15] or facial [16] superimposition. A Nomad™ portable x-ray machine, digital x-ray software, or radiographic film; dental instruments; and personal protective equipment (boots, gloves, eye protection, and masks) are all required. This equipment is frequently left in the disaster-affected region on completion of the work as a goodwill gesture.

Multinational Disasters

In the past decade there have been many large-scale disasters in South East Asia, including floods and landslides in the Philippines, typhoons in Vietnam, and earthquakes in Indonesia. Two of these, the Bali bombings of 2002 and the Indian Ocean tsunami of 2004, required a multinational response. In both instances, the Australian Federal Police were formally asked by the affected country to assist in the DVI process. Many other countries also sent teams, necessitating the coordination of teams with different language skills and methodologies.

Determination of the requirements of the home jurisdiction and lead agency is paramount at the outset, as practices, experiences, and the legal systems are usually vastly different. Decisions about necessary documentation, standard of proof of identification acceptable to the local authorities, cultural and religious issues of particular significance, and quality assurance standards need to be determined rapidly and the relevant information disseminated to all practitioners.

FIGURE 9 A flyaway kit: Notebook computer, with identification program DVI Sys and digital x-ray system, digital camera, and the Nomad™ portable x-ray unit.

Case Study: Operation Alliance—Bali 2002

October 12, 2002, saw three synchronized explosions occur on the tourist island of Bali, Indonesia, resulting in the deaths of 202 locals and tourists. The Australian Federal Police coordinated a response from Australia to assist the Indonesian National Police in aspects of the crime scene and bomb investigations, as well as disaster victim identification. The fragmentary nature of many of the remains, the desire of the authorities to identify the suicide bomber as rapidly as possible, plus the unknown presence of unexploded bomb remnants all made mortuary work complicated. The terrorist nature of the incident also added safety and welfare concerns to the mix for practitioners. In the early days of the response, team members were not allowed to leave the accommodation area alone, but after about five days, it was determined that it was unsafe for personnel to leave the hotel at all unless on official investigative or DVI activities. The potential for personal safety to be compromised in these situations adds additional stress to practitioners, and it is important that management provides frequent and accurate briefings to allay fears and minimize misinformation.

Case Study: Operation Cawdor—Thailand 2004

Countries affected by the devastating tsunami of Boxing Day 2004 included Indonesia, Malaysia, Thailand, Bangladesh, India, Sri Lanka, Maldives, South Africa, Madagascar, Tanzania, Kenya, and Somalia [3]. Most countries buried their dead and rebuilt their communities without standard victim identification procedures. In Thailand, however, where almost 5,000 people were killed as a result of drowning and injuries sustained from debris (Figure 10), the presence of many tourists necessitated a more formal approach to DVI. Thai officials requested help from countries with affected citizens, with the result that teams from over 30 countries were involved in the DVI process. This mix of experienced personnel allowed rapid evolution of the computer program DVI Systems International to cope with situational demand [10], and new techniques in fingerprint gathering [17] were developed, which highlights one of the benefits of such a large group of people working together cooperatively.

Unfortunately, there can be disadvantages to the presence of so many practitioners from diverse backgrounds, and agreement about procedures to be followed proved to be one of these. Even after the implementation and dissemination of SOP, some practitioners refused to follow these practices. Although completely against the spirit of cooperation and outcomes for the better good, lead agencies need to be cognizant of the fact that situations like this frequently occur and have predetermined management strategies devised. The majority of identifications in Thailand were achieved by dental comparison. DNA technology was not prominent, particularly in the early stages of the response.

FIGURE 10 The deceased from the Boxing Day Tsunami, Thailand, were taken to Buddhist temples. Refrigeration of the bodies, particularly given the tropical conditions, was a priority.

TIP: The English Language and Standard Operating Procedures

A common language is needed for multinational communication. Interpol stipulates English as the common DVI language, but it is easy to slip into one's native tongue. An Australian dentist trying to understand what a German thought an Icelandic colleague may have meant, as occurred in Thailand, increases the potential for errors in the identification process.

Standard operating procedures should be determined early by the lead agency. Ask three dentists, and you will get four answers on how to do things! Using Interpol forms helps in this process, but determination of the charting format, the number and type of x-ray views, and which teeth (if any) to take as a DNA sample needs to be clearly specified by the odontology coordinator. Familiarity with SOP, such as those contained in the Australian Society of Forensic Odontology *Disaster Victim Identification Forensic Odontology Guide,* means that odontologists from different states and territories of Australia quickly mesh in DVI teams.

Simplifying Deployments

Although it is acknowledged that there is no panacea for preparedness for the management of disasters, it is accepted that discipline-specific guidelines will help in the training and preparation of practitioners who will participate in the event of a disaster. Part of this preparation and training will include expectations for conditions of the deployment, including contracts and remuneration, code of conduct for behavior, and SOP. Irrespective of this, it is essential that there be a high level of communication and organization at the time of an incident. Practitioners need adequate warning of the need to deploy, a full briefing prior to leaving for the deployment, and an induction on arrival at the incident.

The experiences of Operation Alliance highlight that risk assessment of both the scene and the local environment is critical and must be conveyed to team members. Operation Cawdor emphasized that the outcomes of the operation are more important than the individuals involved and that codes of behavior need to be enforced.

TIP: Communication

DVI team members, particularly dental, are usually present from a sense of community service and goodwill. Although well trained in their discipline and aware of appropriate procedures and behaviors, they are not necessarily fully cognizant of police operational procedures and hierarchies. It is probably impossible to provide these people with too much information, and regular briefing and updates will be appreciated and help the operation run more smoothly.

TIP: Training

Regular short-duration DVI training courses should be arranged for interested personnel, including both police officers and identification specialists. Experience has shown that physical and mental preparation is essential for rapid cohesive deployment [18, 19]. DVI work is not for the fainthearted, nor should it be a training ground for complete novices.

Conclusion

Many of the recent worldwide mass fatality incidents have been manifestations of climate change, involving hurricanes, floods, tsunamis, crop failures, droughts, and bushfires. It is predictable that such incidents will increase in frequency and show no respect for nationalities, time zones, or religions. Governments and DVI specialists must prepare accordingly. The aftermath of the 2010 earthquake in Haiti is a graphic example of a failure to consider and execute emergency management and DVI planning.

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Photography and Forensic Dental Evidence

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Often, looking at photographs is the only way a forensic dentist can evaluate the evidence in bitemark and abuse cases. Law enforcement's reliance on photography is extremely well established, and multiple protocols exist for each jurisdiction. This chapter is not meant to be a substitute for these detailed narrations [1], but the material presented emphasizes aspects regarding dental evidence and focuses on the methods required for its proper documentation. Most examples will point out problem areas in specific evidence photographs.

In many cases, people other than the forensic dentist will originate the crime scene photography. Photography is vitally important, since the original evidence in homicide cases is eventually lost due to postmortem changes, burial, and cremation. In live patients, injuries heal and will fade from sight. It is necessary for law enforcement to be certain that the injuries to skin and other objects are properly documented so they can be reproduced for later analysis. Conventional film photography is still the best, with digital pictures being useful for backup purposes.

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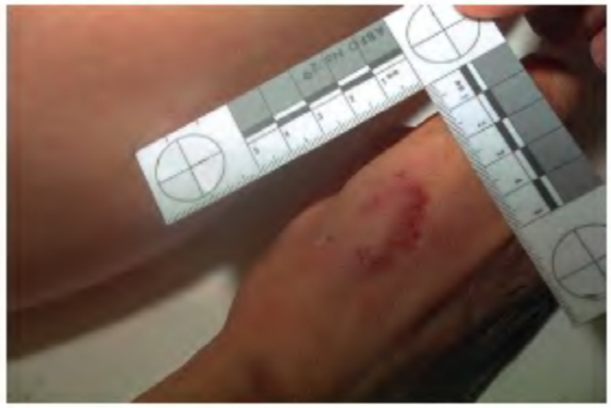

FIGURE 1 This homicide case photograph has problems with (1) camera placement, (2) the placement of the scale, and (3) poor illumination. The camera is showing a considerable off-angle (not directly above the injury) distortion. This is proven by the elliptical circular references (they should be round). The popular ABFO No. 2 scale is not placed parallel to the bruise present in the picture, severely impairing its use to create a life-size picture of the injury. This image cannot be used as a 1:1 (life-sized) image for analysis.

Dentists may take their own pictures during an autopsy to document postmortem dental features, abuse injuries, and bitemark cases. Quite often, however, the dentist is *not* present and simply receives images taken by someone else. This, however, has the following limitations:

1. Poor lighting at the scene or morgue
2. Poor camera positioning in relation to the object photographed
3. Lack of scale or sizing object in the frame of the photograph
4. Misalignment of the scale, camera, and evidence that creates an irreparable distortion in the picture

A well-taken picture far surpasses verbal or written descriptions or drawings. Bitemark analyses require specific dimensional control of the objects being photographed because the dentist takes life-sized models of a suspect's teeth and superimposes them onto the crime scene evidence. Figure 1 is an example of poor photographic technique.

Photographic Duties

Good photographic results are a minimum standard for every competent law enforcement agency. Poor crime scene photography will impact the quality and outcome of every forensic case and reflects negatively on everyone involved. Standardization of equipment and procedures, combined with regular training of personnel, has proven to be the equation for acceptable results. Figure 2 discusses another problem with a scale's placement.

The primary purpose is to photograph evidence *before* it has changed or been disturbed by third parties. The use of videotaping during an autopsy should *not* be a substitute for conventional still photography. Figure 3 demonstrates another example of scale misalignment.

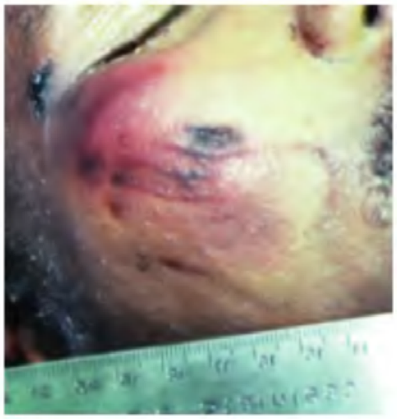

FIGURE 2 The use of the autopsy ruler in this photograph is incorrect due to its misalignment with the injury on the cheek.

FIGURE 3 This ABFO No. 2 ruler has been modified. The lower leg of the ruler has been cut off. The intact upper leg is not on the proper plane with the injury. Checking the circular reference targets proves that the ruler is misplaced. The camera placement, however, appears to be proper.

Logging Photographs Taken

The courtroom use of photographs requires each document to be considered "accurate and representative" of the crime scene and the object considered of evidentiary value. Proof of the photographs' authenticity starts at the crime scene itself. The best way to satisfy this standard is to create a *photo log* that contains the following information:

- Case number of the agency controlling the scene and evidence
- Name of photographer
- Date and time when the evidence was photographed and the date of the incident
- The place where the photograph was taken
- A description of the evidence in each photograph
- Equipment used: the specific camera, flash type, film type, number of exposures, optical filters, settings for f-stops and lens speeds, digital image capture devices, and electronic peripherals used to store and manipulate the image files

Standard Photographic Protocols

Dental Identification Cases—Autopsy Pictures

The first view is the front of the deceased's face as it is seen before the autopsy commences. This documents the condition of the remains when they were first found. The viewable body may be photographed to show later to the deceased's family for possible visual identification. The second view should show the front teeth. In burn cases and decomposition cases, the facial muscles have to be dissected away. The teeth may be so carbonized that later removal during the autopsy may destroy them. If rigor has made the jaws of a viewable body impossible to open wide, waiting 12 to 24 hours rather than dissecting away tissue is recommended. Intraoral pictures may be taken after the jaw muscles relax, or after dissection, the jaws should be independently photographed. The jaws should be placed "in occlusion," which simulates the closing position of the teeth.

Bitemark Photographs: The Requirements for Close-Up Photos

An overall picture should be used to orient the injury on the person or the location of a bitten object at a scene. During autopsy, this would be a picture showing the entire body, unwashed and therefore untouched. This establishes the unaltered condition of the evidence, and only later should a picture with a case card or number be placed in the frame. Figure 4 shows an "orientation" view that tells the investigator the anatomical location of the skin injury.

The next step is a close-up orientation with the scale that is described in the following section. Using both black-and-white and color film is important. This photo will be used for forensic comparison and must accurately detail the color and contrasting black-and-white features of the physical evidence. The requirements for bitemarks are similar to other areas of physical evidence photography, such as the following:

- Fingerprints
- Bloodstain patterns
- Gunshot residue deposits
- Shoeprints and tire prints
- Fracture lines in glass and other materials

The use of natural lighting at an actual crime scene should be attempted while using oblique lighting. The autopsy room, however, usually does not allow such freedom. In that case, artificial lighting and supplementary lighting are necessary. The important step is to avoid "burning out" the bitemark with excessive direct light, flash exposure, and reflections. The use of oblique

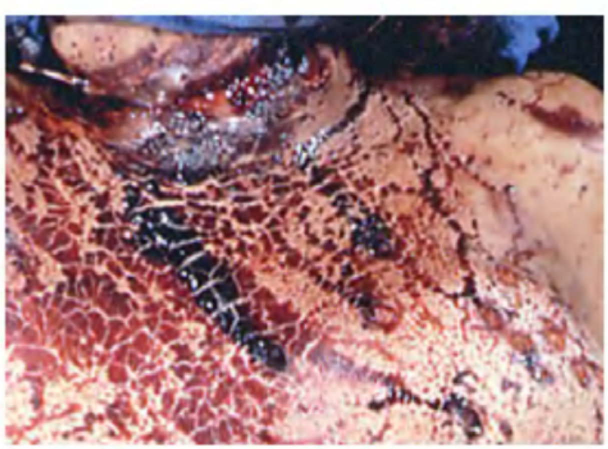

FIGURE 4 This autopsy photograph shows the condition of the homicide victim in the left chest area before the entire body was cleaned. This documents the location without viewing the entire body. Later pictures will document the condition of the skin injuries in closer detail with and without the use of measurement scales.

lighting (light at 45 degrees to the surface) is particularly important to allow three-dimensional (having depth) features to be highlighted as areas of light and shadow.

Proper Use of Scales and Measuring Devices for Close-Up Photography

Placing a scale, measuring tape, or ruler next to the evidence is very important for later use of the photograph for forensic comparisons (Figure 5). The two-dimensional detail and proper size of the evidence item is dependent on the scale's ability to clearly show its linear markings and circular reference targets. Chapter 7 provides advanced information on issues relating to misalignment of scales and photographic distortion. The alignment of the scale to the skin or bitten object is critical. Figure 6 provides a good example. Holding the scale is commonly necessary when dealing with autopsy photos, and someone else can do that for the photographer. Communication between these two parties is important. Figure 7 is an example of an incorrect result in scale placement.

Physical Distortion and Bitemarks

The evidence photographer must understand that skin bitemarks change shape during movement during biting activity. This happens because skin is flexible, and the body changes shapes as the position changes. For example, say there is a bitemark on a person's bicep. This upper arm muscle is quite large and moves a lot when the arm is flexed or extended out straight. Knowing the position of the arm during the biting allows the photographer to duplicate that position. The chances of knowing this, however, are low

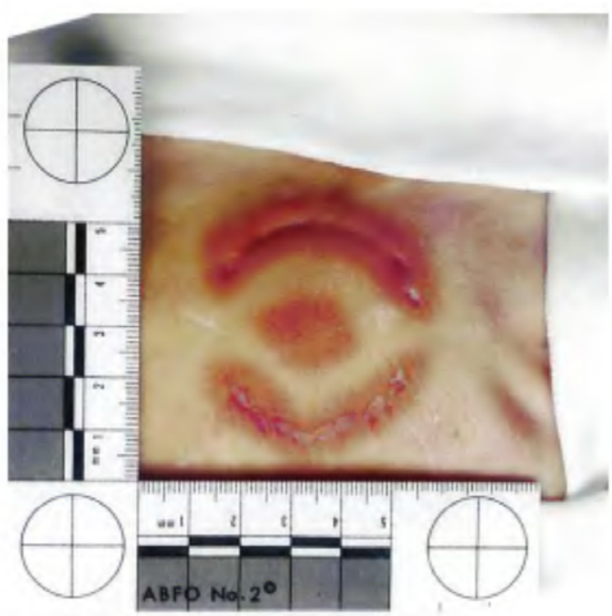

FIGURE 5 This picture shows a close-up view of a human bitemark. The scale used is the ABFO No. 2, which is placed outside the area of the injury but still in close proximity. Previously taken "long-range" and "midrange" pictures were taken without a scale in place to show the areas now covered by the L-shaped ruler and the surrounding cloth drapes.

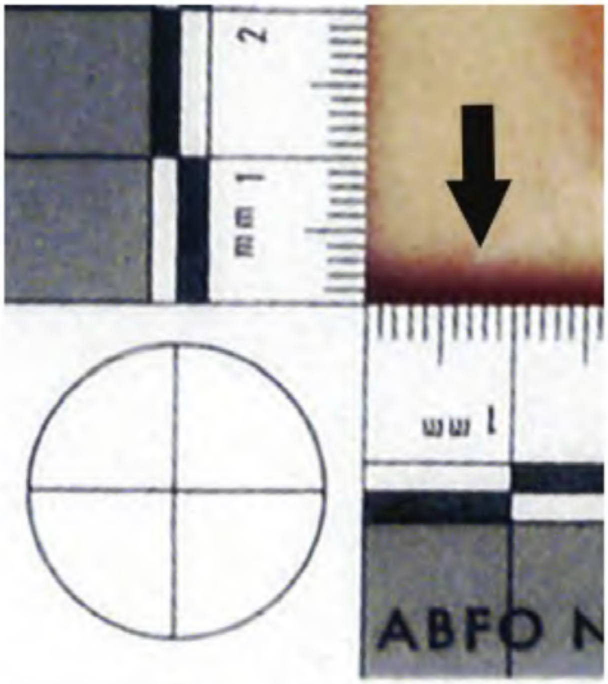

FIGURE 6 The corner of the L-shaped ruler shows the edge of the ruler close to the skin's surface. The curvature of certain bitten surfaces produces positioning problems with the camera/scale/skin alignment. Multiple pictures should be taken using sections of the bitemark to isolate the curvatures. The "circular reference target" in this picture proves that the camera is directly above the scale. Off-angle camera placement is also called "perspective distortion" and distorts the target into an ellipse. This may indicate that the evidence image is also distorted. Correction is necessary before a meaningful comparison can be made.

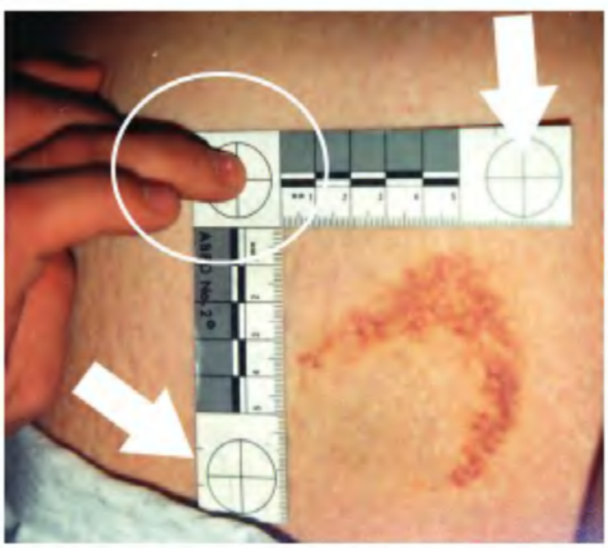

FIGURE 7 The white circle shows fingers covering a circular target reference. The remaining targets (white arrows) show the effects of off-angle camera positioning. The right target is closest to the skin injury and in the correct plane. After correcting for distortion through rectification of the entire image, the right circular target can be used to reproduce the evidence image to 1:1.

unless the victim is alive or a witness can corroborate the information. In the case of a deceased victim, the photographer must position the arm in multiple positions to recreate its full range of motion. For bitemarks on arms, legs, breasts, buttocks, and so forth, the possibilities of alternative positioning should be considered. Figure 8 shows an evidence photo of a live victim.

FIGURE 8 The anatomy of the back is quite stable in shape, regardless of arm movement. Skin has physical properties, however, that create shape distortion of the patterned injury during impact from teeth and other objects. This picture shows good placement of an L-shaped ruler below the area of injury on a back. Teeth did not cause this injury.

FIGURE 9 The physical change produced by the lab assistant holding the breast creates a serious distortion problem. In this situation, the breast should be photographed in as many natural and assisted positions as possible. These photographs should then be digitally analyzed to consider how much shape change occurs between the various positions.

Figure 9 shows proper placement of the camera and ruler. Unfortunately, there is another issue regarding physical distortion that still exists in the picture. Look at the picture, but don't read the legend, and see if you can figure out what the problem is with the photograph.

Suspect Photographs

Using color slide film and black-and-white film is best. The ability of conventional film to reproduce high-resolution pictures outweighs the use of a digital camera at the present time. Informed consent or a court order is needed to take these pictures. The photographs taken should include the following:

- Full face
- Left profile
- Right profile
- Frontal picture with jaws wide open using measure
- Close-up of upper and lower front teeth

Checklist for Forensic Photography

Uses of Crime Scene Photography

1. Record the original scene and surrounding areas.
2. Record the original and unchanged appearance of physical evidence.
3. Physical comparison analysis
4. Court testimony

Judicial Admissibility of Photographic Evidence

1. For a photograph to be allowed into court proceedings, it must satisfy the following requirements:
   a. The object pictured must be material and relevant to the case.
   b. The photograph must not inflame emotions or prejudice the court or jury against the defendant.
   c. The photograph must be free from distortion and not misrepresent the scene or the object it represents.
   d. Digital enhancements must be documented and explained.

Documenting Forensic Observations

Photographs are the only way to record a crime scene and are not a substitute for other records. It is recommended that field notes, photographs, and sketches *all* be used.

Recording the Crime Scene Containing Dental Evidence

1. Secure the scene.
2. Take preliminary field notes.
3. Take overview (long-range) photographs as well as close-up pictures.
4. Make a basic sketch.
5. Record each item of evidence and its location.

Photographs Necessary to Record Items of Dental Evidence

1. Take multiple photographs of each item of dental evidence.
   a. One should be an orientation (midrange) shot to show how the object or pattern is related to its surrounding context. Typically, a bitemark in skin is documented showing the location of the injury in relation to the victim's head or the nearest major anatomical location of the body.
   b. A second photograph should be a close-up to bring out the details of the object (Figure 10).
   c. A third photograph should include a measuring device placed in the same level (parallel to camera lens) as the injury pattern.
   d. Lighting considerations: Block out ambient light and use a strong light source at different angles to find the light angle(s) that shows the best detail in the bitemark. Then place the electronic flash or light source at that angle when taking the photograph. Figure 11 is an example of a poor lighting technique.

FIGURE 10 This close-up of front teeth is meant to show the chips and malpositioning of a suspect's upper teeth.

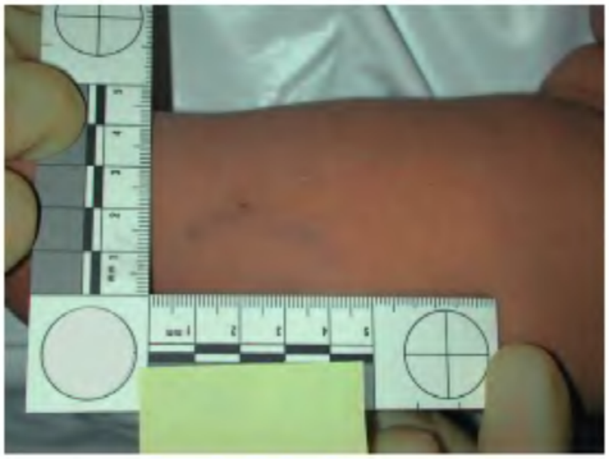

FIGURE 11 This digital photograph is seriously underexposed. The skin injury is very faint, and the poor lighting will require significant digital manipulation in order to restore proper color values. The better alternative would be to take more pictures with additional lighting during the autopsy.

Conclusion

The investigator tasked with photography must be well trained and versatile. Each case presents individual challenges that have to be understood and then overcome. Because most dental (especially bitemark) evidence will disappear or degrade over time, sometimes there is only *one* opportunity to do it correctly. Practice (not actual casework) makes for acceptable results. The hardest failure to admit in court is that your photographs were not good enough to support the evidence you collected at the scene.

Reference

[1] http://www.fbi.gov/hq/lab/fsc/backissu/oct1999/swgit1.htm.

The Use of Digital Imaging in Human Identification and Crime Scene Analysis

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The use of digital formats in forensic photography and analyses has matured through the last 30 years into a recognized forensic specialty [1]. Law enforcement and related investigators should have an understanding of digital imaging methods utilized by forensic dentists and others who use similar methods to analyze physical evidence. This chapter outlines these methods and gives the reader an overview on this subject [2]. While this chapter is moderately advanced and geared primarily for midlevel to advanced imaging technicians, it will give crime scene examiners and law enforcement an idea of some of the capabilities in the realm of digital imaging methods.

Forensic dentists form their opinions on the basis of direct superimposition of questioned (Q; a bitemark or postmortem x-ray) and a known sample (K; a suspect's teeth or antemortem dental x-ray). Courts allow experts to

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present photographs of physical evidence (exemplars) that have sufficient identification value to demonstrate features that support the expert's opinion on the case. Hence, photographic accuracy and dimensional control of images are very important and demand rigorous attention to scale dimensions and the detection of photographic distortion.

The dental comparison techniques used in this chapter are similar to the physical comparison of Q and K evidence in fingerprint, ballistics, and tool mark studies. These disciplines have the criminalist using a comparison microscope to place the Q and K evidence samples side by side. The loops, whorls, striations, indentations, accidental (shape changes from use and aging), and class (general features of a large group of similar objects) characteristics present in the evidence samples may then be visually compared. What can be difficult to assess, both in the crime and dental laboratories, are the dimensional values (height and width) of the evidence samples. In forensic dentistry, the traditional ruler and protractor measurements and shape comparison processes are manually derived from evidence photographs and plaster models of a suspect's teeth. These methods vary between examiners and are not accurate to greater than ±0.1 cm. Digital measurements by multiple examiners have been tested to within ±0.05 cm accuracy during numerous training sessions. Alternatively, some crime lab analysts and dentists ignore size comparisons and focus on similarities in class and individual features. In both situations, the possibility of error arises from examiner-subjective methods and partial selection of the available physical information. Two-dimensional digital measurement of distances and angulations are quite easily accomplished with a desktop computer and high-quality computer monitor, and they can lend considerable determinations of similarities/dissimilarities in physical evidences.

The recent development of digital imaging software and imaging devices such as scanners and digital cameras has created an opportunity to better control some well-recognized photographic variables and allows the forensic examiner to turn the computer monitor into a comparison microscope with the added benefit of the following functions:

- Accurate means of measuring physical parameters of crime scene evidence
- Correction of common photographic distortion and size discrepancies
- Better control of image visualization
- Standardization of two-dimensional physical comparison procedures
- Improved reproducibility of results among separate examiners
- Electronic transmission and archiving of image data

Measuring the Physical Characteristics of Two- and Three-Dimensional Evidence

The steps to create a digital comparison are described in this section. The examples are from forensic dentistry evaluations of bitemark evidence and dental identification of unidentified remains. The application of these methods may also be useful to other areas of forensic investigation that require image comparison information.

Digital Evidence 101

Image File Storage

There are a number of storage systems through which forensic investigators can receive two-dimensional digital images of physical evidence. These include thumb drives, zipped (compressed) computer files, zip disks (100 MB or 250 MB storage capacity), compact disks (CD), e-mail attachments, and, most often, photographic prints, slides, or negatives.

High-Resolution Scanning and Digital Camera Settings

When a picture is in digital mode, as opposed to conventional film, the necessity to print the picture (hard copy) requires a "high-resolution" setting for either the scanner or the digital camera. The detail of a digital image is represented by the number of dots per inch (dpi) for scanners and digital cameras. Computer printers output these images in lines per inch (lpi). The computer storage necessary to store a photographic quality of an 8½" × 11" picture is over 30 MB when 350 dpi is the selected resolution.

Archival Images

Forensic digital imaging demands that the examiner document each original image (i.e., case01original.jpg) and create a duplicate image for later use as a working copy (i.e., case01workingimage.jpg).

Image Magnification Using the Computer Monitor

Adobe Photoshop CS4® is a retail software program that permits a multitude of editing features, functions, enhancements, and metric (distances and angles) analysis. Once a crime scene photograph is scanned and imported into Photoshop®, the initial working image can be enlarged using the zoom tool. Increments of 25% up to 300% and 400% enlargements may be shown on the computer monitor using this tool. This requires a very high-resolution image (300 dpi) to avoid pixellation (fuzziness) of the magnified picture. This mandates that the original image capture camera setting be at high/max setting.

Bitemarks

Digital Control of Photographic Distortion Evidence

The functional tools within Photoshop® can be used to detect and correct for certain angular distortions. This is an extremely important step because it forms the foundation for the comparison procedures that follow. The first issue with Figure 1 is the scale's off-angle position relative to the bitemark.

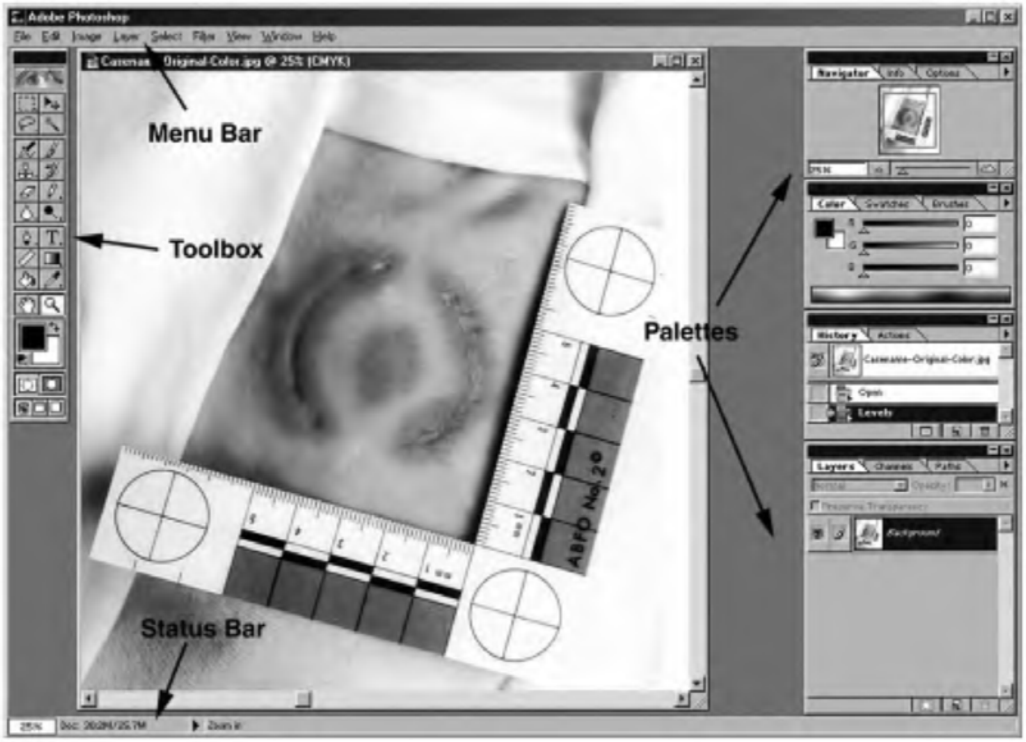


FIGURE 1 The Adobe Photoshop® working screen.

A photograph is a representation of the objects in the range of the camera lens. The degree to which this exactly reproduces those objects is influenced by many variables. When bitemarks are photographed or dental radiographs are used as evidence, attempts are made to carefully control the off-angle camera placement in an effort to obtain an accurate picture of the bitemark or dental restoration for later forensic analysis. A tripod should be used whenever possible. Unfortunately, these efforts are not always successful, and distortion is often introduced into the image from off-angle distortion.

Photography of bitemarks and similar types of two- and three-dimensional physical evidence should have the following features:

- Presence of a scale (or some appropriate measuring device) oriented on the same plane as the bitemark or evidence sample
- The orientation of the camera (or film plane) and the scale is parallel
- The scale is on the same plane as the bitemark, thus eliminating parallax distortion. The scale is used to reproduce a life-sized image of the object. Its displacement below or above the object will make this latter process inaccurate.

Detection of Photographic Distortion by the Forensic Examiner

Correction for angular distortion focuses on the size and shape of the ruler present in the image [3]. If the scale shows no distortion, then the evidence adjacent to it will be undistorted as well. The sides of the scale or ruler must

FIGURE 2 Evidence photograph showing a combination of photographic distortion. Type I distortion exists from the camera being malpositioned over the injury. Type II results from the ABFO No. 2 scale not being completely parallel to either the camera or the bitemark. The red circles indicate the elliptical shape of the scale's top circular reference point and the circular shape of the lower reference point.

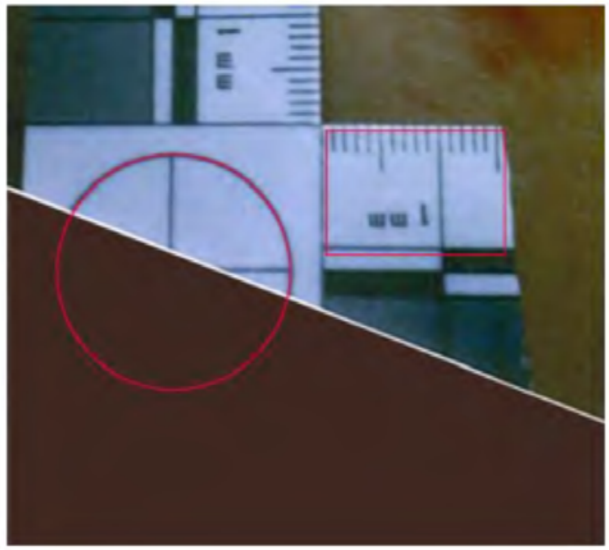


FIGURE 3 In this case, the corner of the ABFO No. 2 scale is in the same plane as the injury pattern. The 1.5 cm portion of the scale's lower edge can be used to establish the life-sized dimensions of the picture.

be parallel, the incremental lines must be perpendicular to these sides and equally spaced, and, if present, any circular reference shapes must be round (not an ellipse). A two-legged scale (a two-dimensional scale possessing an *x*- and *y*-axes) will have a 90° angle created at the intersection of the two legs. An ABFO No. 2 (Lightning Powder Co., Inc.) scale is shown in this chapter. Placing a digital circle over the circular reference target and using it to evaluate the scale's sides, incremental lines, and angles for parallelism can preliminarily check the degree of distortion (Figures 2 and 3).

Simple Rotation and Cropping of the Bitemark Image

The evidence image must have the scale oriented along the *x*- and *y*-axes of the entire image in order to perform later manipulation based on this scale. Excess perimeters in the image may be removed using the crop tool (Figure 4).

Determining Theta

Before attempts can be made to digitally correct the off-angle camera positioning, the amount of distortion should be measured. The examiner evaluating the bitemark photograph should refer to the circular reference shapes present on the scale. An elliptical shape proves the camera-positioning angle was incorrect. The amount of nonparallelism (theta) is determined by doing the following:

1. Measuring a line across the narrowest distance of the ellipse (minor axis A).
2. Measuring a line across the major axis of the ellipse (major axis B).

The angle theta may be determined by solving theta = $\cos^{-1}$ A/B (Figures 5 and 6).

FIGURE 4 The evidence image in Figure 2 corrected to proper 1:1 (life-sized) dimensions. The useable portion of the scale (the lower corner) is dimensionally corrected to 1.5 cm using Photoshop®. This is dependent on the injury pattern being in the same plane as that portion of the scale.

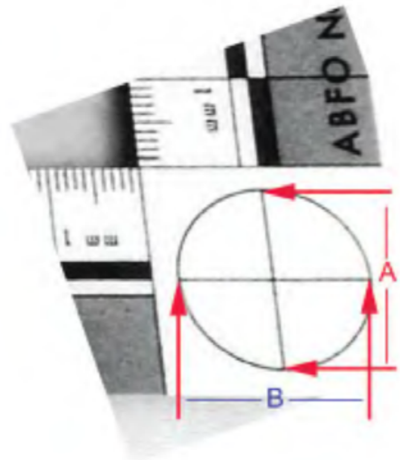


FIGURE 5 Off-angle camera placement has made the normally circular reference an ellipse. Measurements of the A (minor axis) and B (major axis) create a ratio that can be used to determine theta.

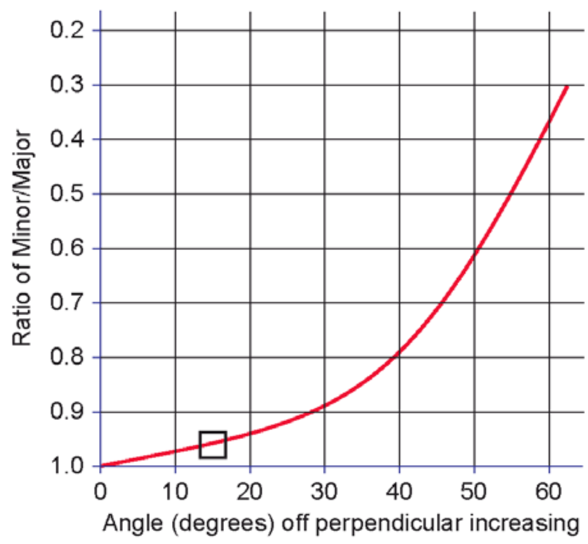


FIGURE 6 Determining theta. The ratio of the distance A (minor axis) to B (major axis) is 0.94. Find this value of the vertical scale of this graph and draw a horizontal line right until it meets the red curved line. The theta value (amount of off-angle camera placement) in this example is about 15° (black box on the red line).

Correcting the Photographic Distortion

If it has been determined that significant distortion exists, it must be corrected before the bitemark photograph is resized and/or enhanced. Only then can a meaningful comparison analysis be accomplished. Correction may be accomplished by an experienced photograph technician or digital imaging technician.

Definitions of Photographic Distortion

- *Type I distortion:* The scale and bitemark are on a plane, but the camera back is not parallel to either (Figure 7). This nonparallelism of the camera can be corrected. When the image of the scale is brought back to its original size and shape, the image of the bitemark will also be corrected (rectification). This assumes that the scale itself is on a single plane and there is no parallax distortion relative to the bitemark.
- *Type II distortion:* If the scale is not on the same plane as the bitemark, rectifying the scale will adversely affect the proportions of the injury pattern. In situations like this, it is best not to try to rectify the scale but to perform the resize (1:1) procedure based on the scale "as is." The amount of parallax distortion present will obviously affect the accuracy of the results. The weight given to the results will contribute to the ultimate decision in the case. The investigator must decide what amount of distortion is acceptable in order to produce a meaningful comparison. Figure 2 is an example of this type of distortion that is still amenable to correction.
- *Type III distortion:* In some cases, one leg of a two-dimensional scale will have perspective distortion, but the other leg will not (Figure 8).
- *Type IV distortion:* In this instance, the scale itself may be bent or skewed. There can be forensic value if the scale is relatively flat in the area directly adjacent to the bitemark. Peripheral scale inaccuracies

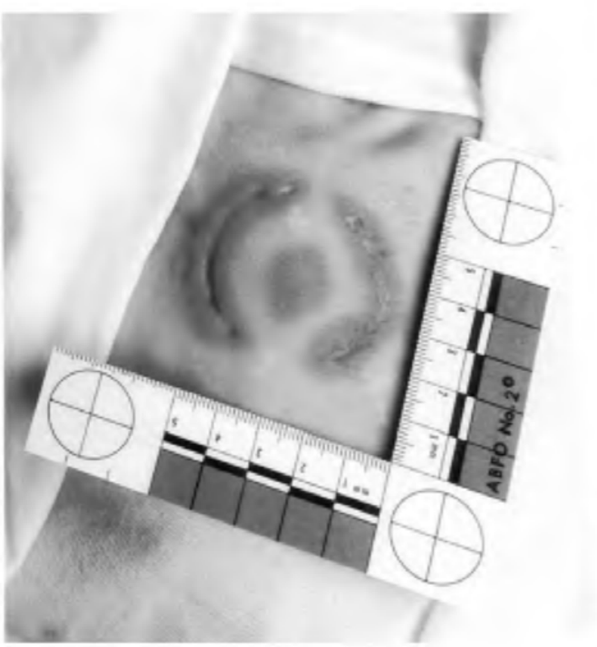


FIGURE 7 Type I distortion.

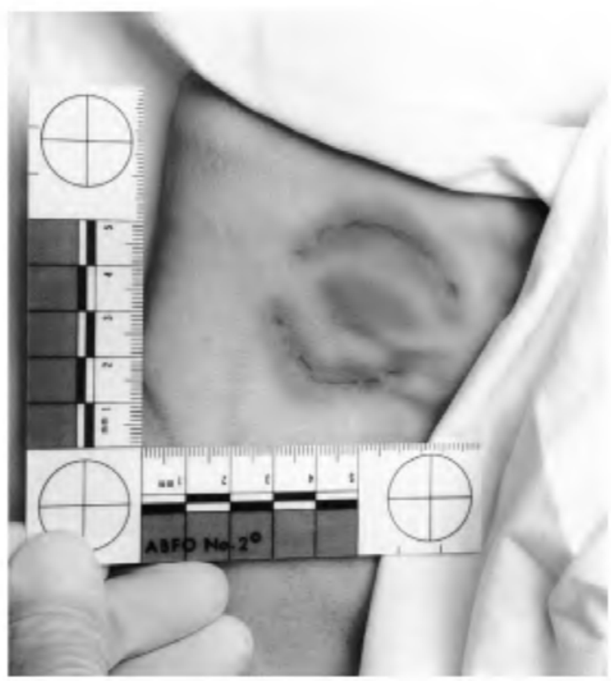


FIGURE 8 Type III distortion.

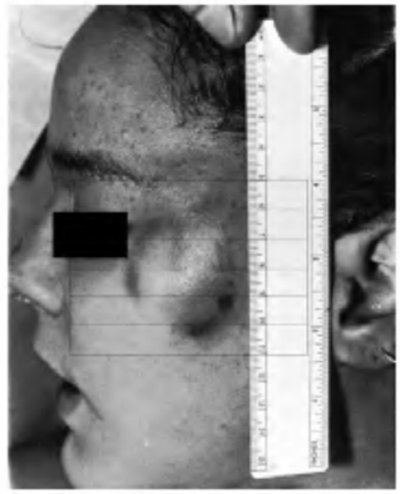


FIGURE 9 Type IV distortion. The bent areas of the scale are not used in resizing the image.

can be discounted. Use only the area next to the mark for the resizing procedures. Do not use the entire scale. There must be at least a 1 cm length of nondistorted scale in close proximity to the bitemark (Figure 9).

Limitations

In some cases, an image is so severely distorted as a result of poor photographic technique that there is no forensic value. The only remedy is to rephotograph the subject matter, but unfortunately, sometimes the physical evidence has changed or disappeared, thus preventing these remedial efforts.

It is important to realize which type of distortion, if any, is present in the original bitemark photograph. This can often be a difficult task and requires some experience. Another concern is the utilization of a two-dimensional object (the scale) to analyze a three-dimensional bitemark. It is a very significant concern with a bitemark on a curved surface.

The variations present in bitemark cases present challenges to the examiner regarding the value of the injury pattern and the relationship to a suspect(s) teeth. Photoshop® can help in a large number of these cases, but, again, it is the investigator who must determine the limits to the use of bitemark evidence and its impact on the strength of the ultimate opinion.

Computer-Generated Exemplars of a Suspect Dentition

Simple Overlay

A major purpose of using digital imaging is to produce a properly rectified (no off-angle distortion), scaled reproduction of a suspect's tooth-biting edges. The term *hollow volume* refers to the outline or perimeter of each biting surface. This product is called an overlay. The final process is to place the overlay on the bitemark evidence and evaluate the physical correspondence between the two. The increased accuracy of this digital process is the chief improvement over the conventional methods of overlay production. The dental examiner uses the computer program to select the dental biting edges

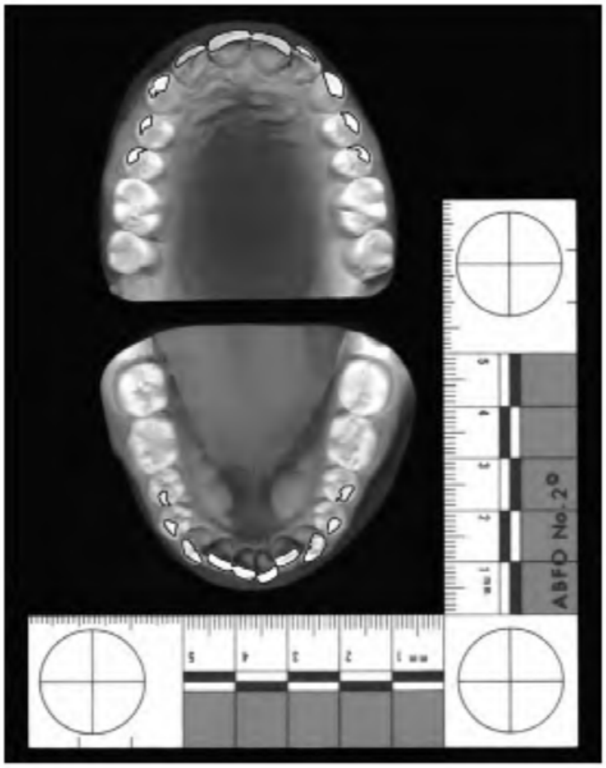


FIGURE 10 Scan of dental models. The outline of the front teeth has been selected as a black outline.

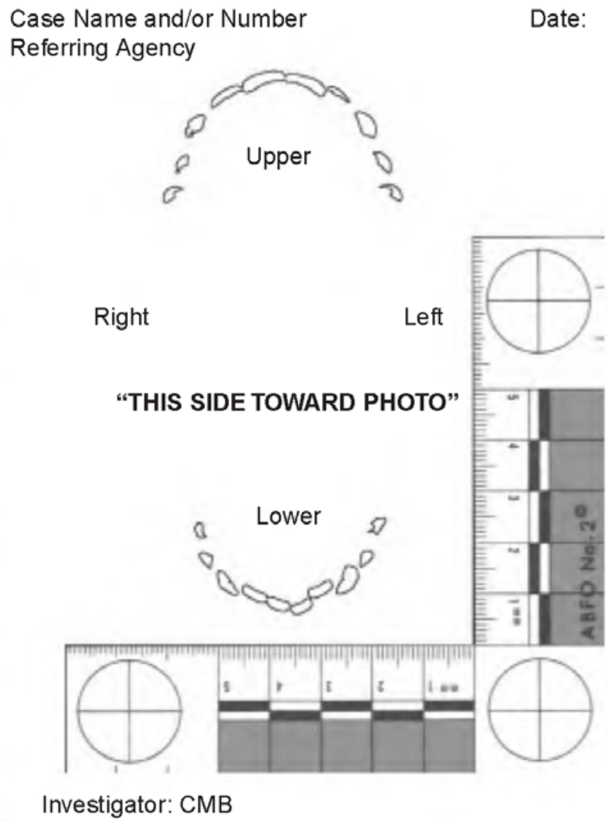


FIGURE 11 The selected teeth outlines and case information can be combined into one document for later superimposition (after being reversed) onto the bitemark.

instead of using hand-drawn tracings of the suspect plaster models (Figure 10). From this selection of the biting edges of the teeth, their outline is used to produce the computer-generated overlay (Figure 11).

Digital Comparison of Bitemark Evidence

Completion of the analysis occurs when the digital overlay is superimposed onto the bitemark image. In this example, the correlation between the two is extremely high. This is because the bitemark was made experimentally and the actual biter's teeth were used for this comparison (Figures 12 and 13).

Metric Analysis of Bitemark Injuries

The use of digital imaging allows the examiner to measure physical data in bitemark cases. The application of certain Photoshop® tools and functions provide the dental examiner with physical evidence data that will create linear and angular information useful to support the final conclusions regarding a case.

Bitemark injuries *and* suspect(s)' teeth possess pertinent physical characteristics that are amenable to digital measurement. The following are some of the most obvious ones:

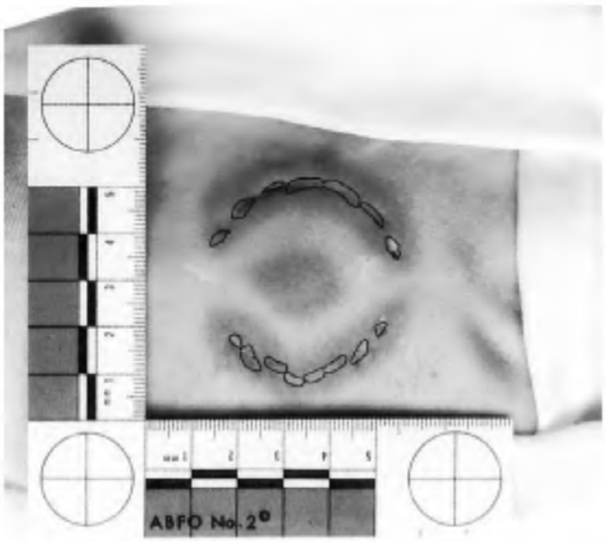


FIGURE 12 The overlay has been reversed and then placed onto the bitemark image. The identification value of this comparison is extremely high. The bitemark was experimentally created, and the teeth used in this comparison are of the actual biter.

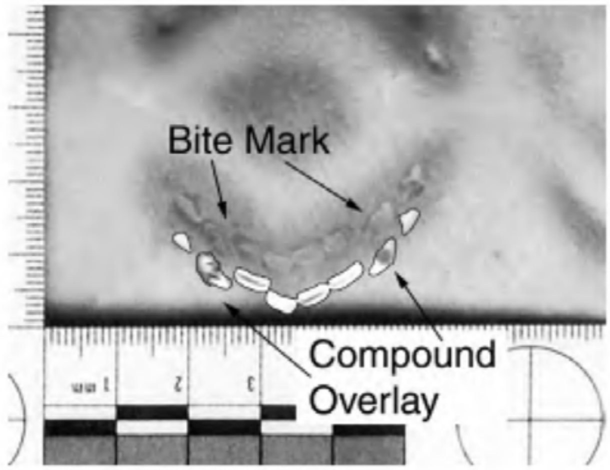


FIGURE 13 The "compound overlay" is more than the outline of teeth. It incorporates all of the two-dimensional image values of the dental models.

- Arch width (distance from one cuspid across to the other cuspid)
- Shape of the dental arch (generally can be described as C-shaped, oval, or U-shaped)
- Labiolingual position (a tooth out of normal alignment front to back)
- Rotational position (twisted)
- Intertooth spacing
- Tooth width and thickness
- Curvatures of biting edges
- Wear patterns and unusual dental anatomy

Step 1: Analyzing a Bitemark Injury

It is recommended that the injury pattern be completely analyzed before the dentition of a suspect(s) is evaluated. This ensures a measure of blindness when features of the injury are vague and ambiguous. This establishes hard data sets for this questioned sample before commencing the analysis of the suspect's teeth (Figure 14). The following should be analyzed:

- Cuspid to cuspid
- *x*- and *y*-axes
- Tooth widths and thicknesses
- Rotational value of each tooth

Step 2: Analyzing the Suspect's Dentition

Identical steps are then performed using the scanned images of the suspect's plaster dental casts (Figure 15). Metric analysis of dentition casts should be done using the following features of each tooth:

- Cuspid to cuspid distance
- *x*- and *y*-axes and intertooth distances

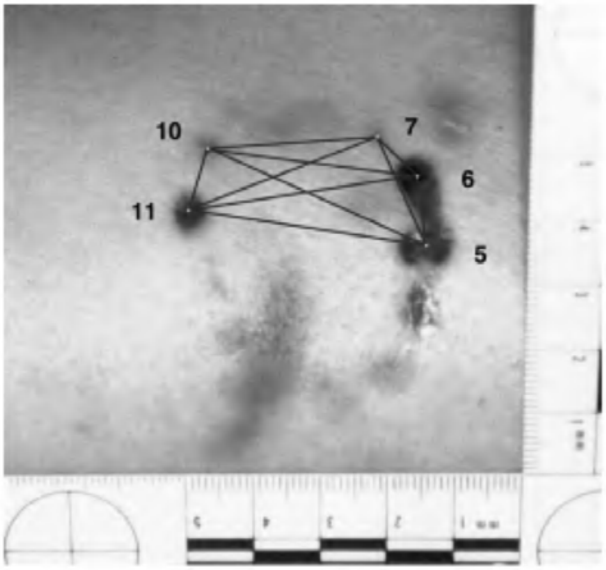


FIGURE 14 An actual case involving a bitemark analysis. The numbers indicate upper teeth that are identifiable in the bitemark. The lines are drawn to measure distances and angles created by these teeth for correlation with possible biters.

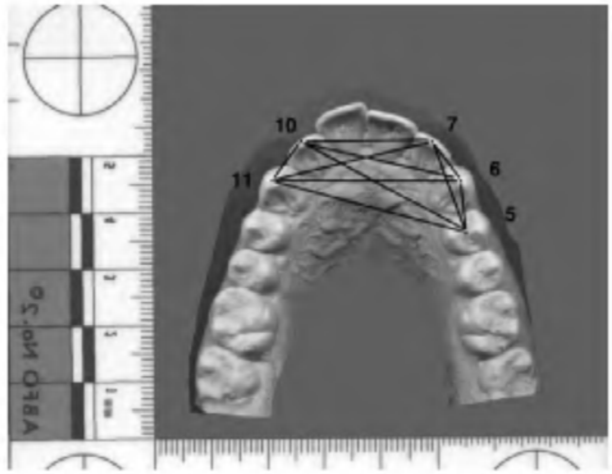


FIGURE 15 Suspect dental analysis. Due to the limitations of information available in the bitemark, the suspect's upper teeth are analyzed in the same manner. There is a correlation between the two evidence samples, but there is not enough data available to make a positive bitemark identification.

- Tooth widths and thicknesses
- Rotational value of each tooth

Step 3: Comparison Data of a Hypothetical Case

Bitemark: Upper Jaw Width	Suspect: Upper Jaw Width
42 mm	42 mm

The examiner should create a total profile of features for both evidence types (suspect and known) to support a comparison in this case.

Dental Identification: The Uses of Digital Imaging

The methods just described may also be applied for the superimposition of dental and medical x-rays that are pertinent to human identification cases. The following case studies indicate the usefulness of digital superimposition [2].

Case One

The unknown adult skeletal remains possessed a complete maxilla and mandible with all of the teeth present. A single silver amalgam filling in tooth #3 (FDI: # 16) was the only observable dental treatment (Figure 16). A missing persons report focused the investigation toward a young woman, and dentistry was considered the best means of confirming the identity of the unknown victim. Antemortem dental records were obtained belonging

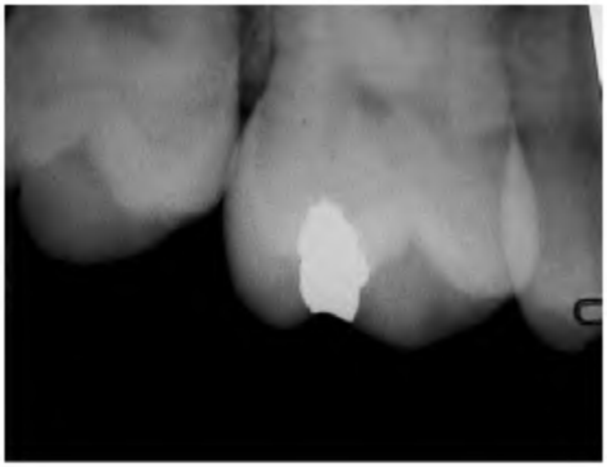


FIGURE 16 Postmortem radiograph of a deceased person showing a metal dental restoration in tooth #3. *Photo courtesy of the family of Nichole Hendrix.*

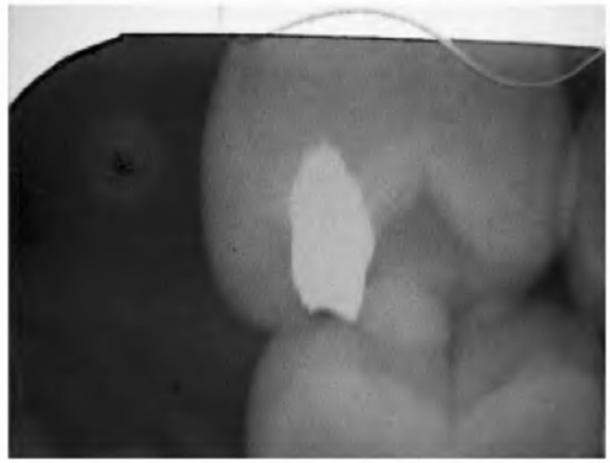


FIGURE 17 Antemortem radiograph of a person showing a metal dental restoration in tooth #3. *Photo courtesy of the family of Nichole Hendrix.*

to a female. They were dated 7 years earlier (Figure 17). The antemortem radiographs (four bitewings) showed a mixture of primary (baby) teeth and all four permanent first molars. A distal pit metal restoration (silver amalgam) was present on tooth #3 in these before-death x-rays. All of the other teeth present in the radiographs were not restored and had no remarkable features. The identification focused on tooth #3 due to the fact that the primary teeth had fallen out over the intervening years, the scarcity of restorations present, and the paucity of antemortem records.

The antemortem radiograph was elongated (distorted) due to the angulation of the x-ray beam. The postmortem radiograph showed a more normal tooth orientation. Despite these differences, the restorations did show similarities in relative shape. A digital comparison focused on these similarities. Then features common to both samples became very apparent (Figures 18 and 19).

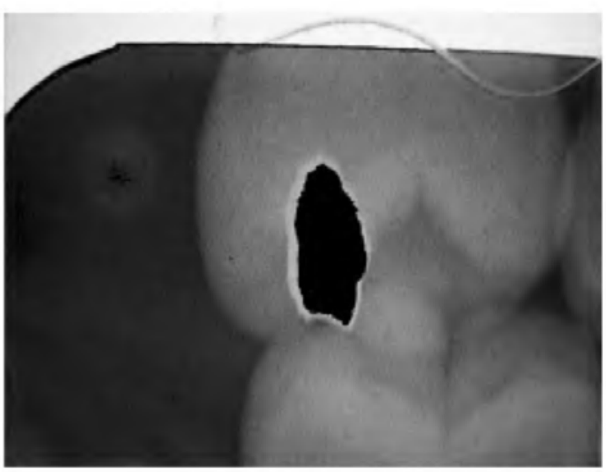


FIGURE 18 The postmortem filling (black) is superimposed onto the white antemortem filling in the background. *Photo courtesy of the family of Nichole Hendrix.*

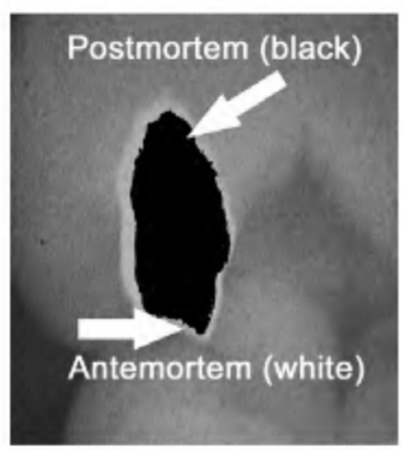


FIGURE 19 The perimeter detail of the two fillings is significantly similar. *Photo courtesy of the family of Nichole Hendrix.*

Results

Based on the comparison of the restoration on tooth #3 and the physical characteristics of the human remains (gender and the estimated age and height of the victim) and other corroborating circumstances of the investigation, it was concluded that the before- and after-death dental features were from the same individual.

Case Two

The recovered unknown human remains were fragmented due to trauma from a high-energy aviation accident. The lower right human jaw fragment contained only two molar teeth (FDI #46 and 47; Universal numbering system: #30 and #31). Tooth #30 had separate occlusal and buccal restorations (silver amalgam). Tooth #31 had an occlusal amalgam restoration. Police investigators provided one set of 10-year-old antemortem records for evaluation. These known antemortem records consisted of a written treatment record and four bitewing radiographs. The antemortem radiographs showed tooth #30 with a buccal (or lingual) metallic restoration. The dental restorations were not a definitive identification because additional restored surfaces were seen in the postmortem remains.

X-rays of the dental remains were made at varying angulations. One x-ray was similar to the tooth angulation seen in the antemortem dental record. Figure 20 shows antemortem and postmortem images that were selected for comparison based on their physical similarity.

Once digitized, both images were opened in the imaging program, adjusted to identical resolutions (300 dpi), and placed side-by-side on the computer monitor. The cemento-enamel junction (CEJ) of tooth #31 was chosen as the orienting horizontal plane for both pictures. Figure 21 shows this comparison.

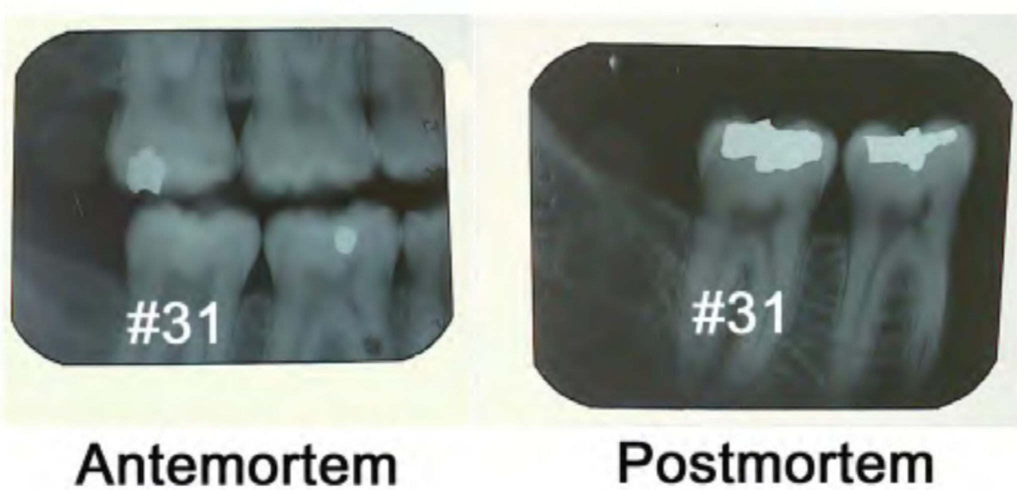


FIGURE 20 Each image was separately rotated to create an identical horizontal orientation for the antemortem and postmortem evidence (also see Figure 21).

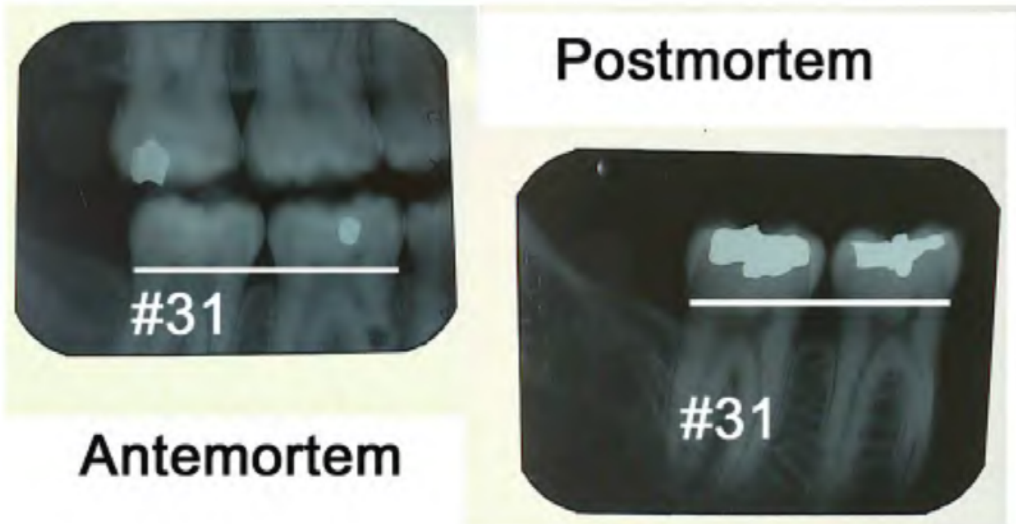


FIGURE 21 Postrotation images with the CEJ of tooth #31 defining the *x*-axis.

Results

The computerized comparison analysis revealed significant differences of tooth features in this case. The root shapes differed by 12.8° and the root heights differed by 32%. Based on these factors, it was concluded that the antemortem dental records and postmortem dental evidence did *not* come from the same individual.

Case Three

The decomposed body of an elderly male was found floating in the ocean outside a harbor. No personal identification was in the clothing, and the body was transported to the Ventura County medical examiner's office for examination. The autopsy disclosed advanced decomposition, with bloating and multiple areas of postmortem marine animal depredation. Postmortem loss of tissue from the right wrist revealed a stainless steel orthopedic fixation device on his radius. The dentition was severely carious, with many teeth missing and no evidence of dental restorations. Fair-quality fingerprints were obtained, but no matching prints were found in fingerprint databases. None of the local law enforcement agencies had records of missing persons matching the general characteristics of the decedent during the prior month.

The medical examiner released the general information about the decedent to the local press, along with a description of his clothing and the orthopedic device. An adult daughter of the decedent called the medical examiner after reading the news release and provided a description of her father, who had been missing for three weeks. The physical description was consistent, and the daughter recognized some of the clothing. She also recalled that her father had broken his wrist several years prior. Calls to several hospitals led to finding a radiograph of the decedent's right wrist that was taken after placement of an orthopedic device for stabilizing a fracture seven years prior to his death. Postmortem radiographs of the forearm produced images of the

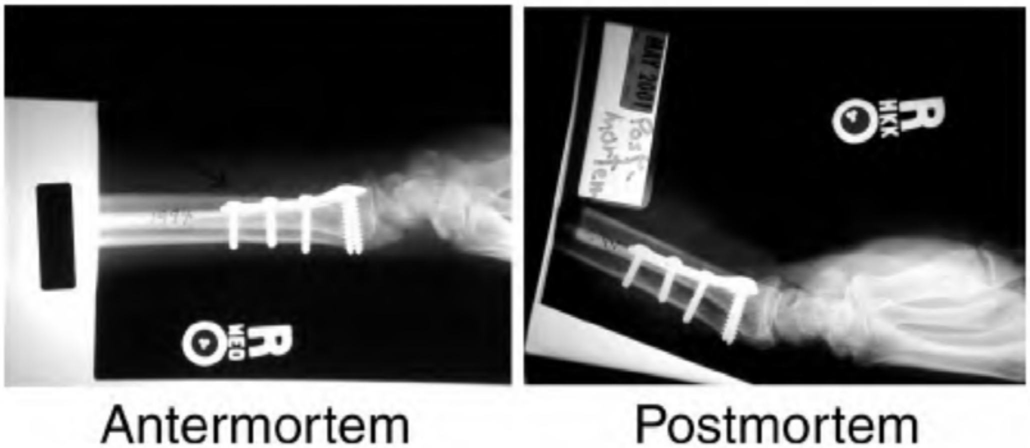


FIGURE 22 Images consisted of the antemortem forearm radiograph (labeled 1994) and the postmortem forearm radiograph (labeled 2001).

orthopedic device that were very similar to the antemortem films. This was believed sufficient to establish the identification. The original image objects analyzed are shown in Figure 22.

Checking the Reference Shapes for Angular Photographic Distortion

Radioopaque labels were contained within each of the two radiographs for the purpose of orientation, identification, and size verification. Each of these reference labels consists of the letter "R" above a three-letter sequence. A circular reference shape lies below the identification letters. This circle has an outside dimension of 1 5 cm. Angular distortion occurs when the object being photographed or radiographed is not perpendicular to the film or x-ray beam. This distortion is revealed when the object within the resultant image is not its real-life size and/or shape.

The reference objects in both the antemortem and postmortem images are circular, thereby indicating no photographic distortion in these images. This was confirmed by superimposing a digitally created perfect circle over the reference shape. This procedure was carried out for both the antemortem (1994) and the postmortem (2001) images. Figure 23 illustrates this technique. The image size for the antemortem and postmortem radiographs was then corrected to life-sized (1:1).

FIGURE 23 The black circle was digitally created to assess the symmetry of the x-ray reference object.

Digital Superimposition of the Antemortem and Postmortem Devices

The postmortem device was then digitally colored black (see Figure 27) and placed on top of the antemortem device (Figure 24). Digital analysis affords an option, which is to assume that the antemortem image of the device is correct and to use those dimensions to resize the unknown (postmortem) image. A comparison of the two images based on this reference would then allow the investigator to analyze other similarities and discrepancies between the two samples. Specifically, the outline contours, relative dimensions, angular relationship of the device components, and individual contours of the components can be compared. This method was chosen for this case. The relative position of device components (angular and dimensional relationships of screws, etc.) and specific outline characteristics can now be compared.

Visual Comparison

The general size and shape of the postmortem device shows a high degree of concordance with the antemortem device. There was good agreement when more specific features (individual screw threads) were compared. Photoshop® can correct for the majority of photographic distortion, but there can still be minor angular differences remaining after the rectification process. This is especially true when comparing images with large amounts of angular discrepancies and/or three-dimensional curved surfaces. This case falls into both of these categories. In order to accurately compare the screw thread outlines, slight alignment adjustments must be made when different areas are analyzed. It is unrealistic to expect the entire image to exactly superimpose in this type of analysis due to subtle differences in the radiographic samples. Sectional analysis is advised in this circumstance (Figure 25).

FIGURE 24 The postmortem device is colored black to contrast with the antemortem x-ray.

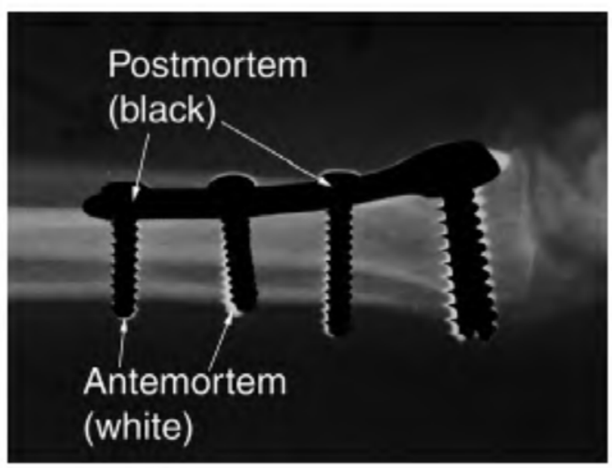


FIGURE 25 This initial superimposition revealed noticeable linear and angular differences between the antemortem and postmortem device images. This was caused by differing positions of the forearm on the film cassette between the two radiographic sessions (1994 and 2001). This is called Type II distortion.

Determining Identity

One of the major advantages of digital image analysis is the ability to quantify concordant and/or dissimilar features. Although visual comparisons as described above can be extremely helpful, the addition of quantitative analyses can provide a more objective result. The task is to first find the area (in pixels) of the antemortem device image. The same is done for the rectified postmortem image. Following superimposition, the degree of commonality can be quantified by the percentage of pixels the two samples share. Figure 26 shows superimposed images of the two devices. The table in Figure 27 shows the results of the comparison between the antemortem and postmortem orthopedic devices and quantifies the differing pixel values for each image.

Case Four

A woman had been murdered outside her trailer at a remote desert location in California in 1994. She died from severe head trauma from being struck with a

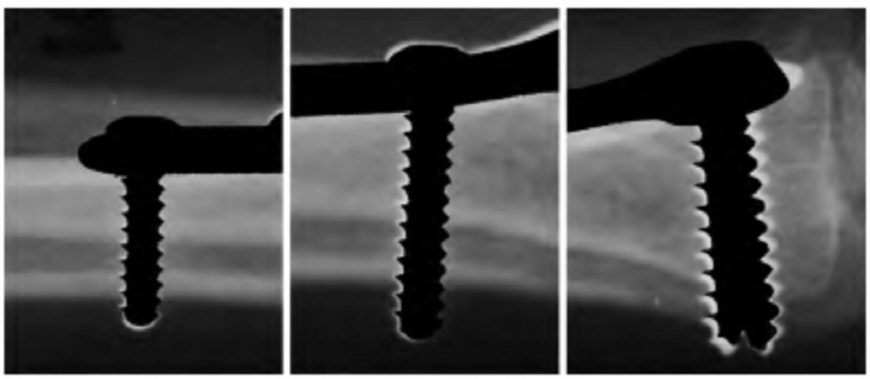
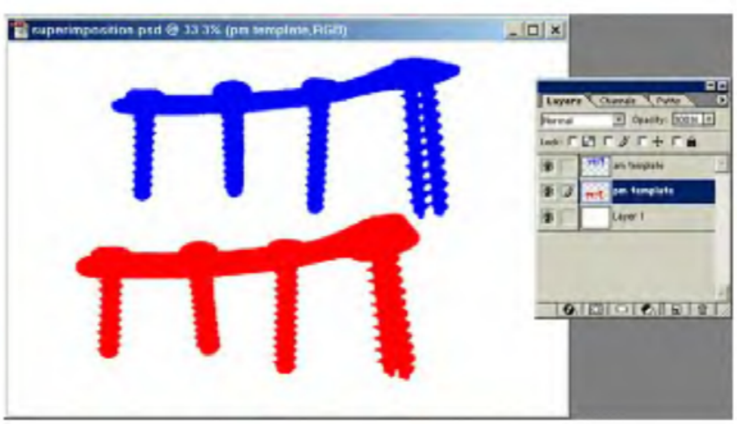


FIGURE 26 Three sections of the comparison are viewed after digital adjustments are made to correct for slight dimension differences between the two x-rays.



	# of pixels	% common pixels
Antemortem template (blue)	177,975	92
Postmortem template (red)	197,559	83
Common pixels (purple)	164,136	

FIGURE 27 The number of pixels in each color image are counted and then compared for concordant values. The use of digital comparison methods helps the investigator control dimension variables during the comparison of physical objects. In this case, the identification was confirmed by other means, with this portion of the investigation being supportive of the final decision.

concrete block. The murder weapon was covered in blood and recovered from the scene. The victim's husband, who had called 911 from the crime scene, was soon arrested for the crime. The husband stated he had arrived home late at night and found his wife dead outside the trailer. His light blue flannel shirt showed extensive blood transfer from contact with the victim. He stated that he had cradled his wife's body. This shirt was seized by the authorities and sent to the sheriff's crime lab for later analysis. The victim's body was left unprotected at the crime scene until its removal the next day. Photography of all of the woman's injuries was performed during the autopsy. Photographs included her hands. Her fingertips were later removed and sent to the sheriff's crime lab in order to preserve possible evidence for analysis.

The husband was charged with murder and faced four trials before being convicted. Compelling evidence of his guilt was provided by a sheriff's CSI, who stated that when he recovered fingernail scrapings, small strands of light blue fiber where found and removed from one fingertip. He opined that the fiber was from the husband's shirt and had been forced under the wife's fingernail during the attack that ended in her death. A videotape taken during this discovery in the lab was shown to the jury. He also stated that some of the blood transfer (spatter and wipes) on the husband's clothing was in a shape that indicated forceful contact between the husband and the victim.

The husband was granted another new trial after 15 years in jail. This trial allowed for a new review of forensic evidence that had been presented by the state at the previous trial. The original testimony about the fiber evidence was of particular interest. A certified crime scene analyst obtained access to the original color slides taken of the victim's hands at the autopsy. The crime lab video of the recovery of the fibers in the sheriff's lab was provided, and "screen shots" from the video were chosen for inspection. All of the images were digitally compared. The autopsy fingertip was digitally selected from the original color slide and enlarged. The close-up of the fingertip indicated no light blue fiber along its surface (Figures 28 and 29).

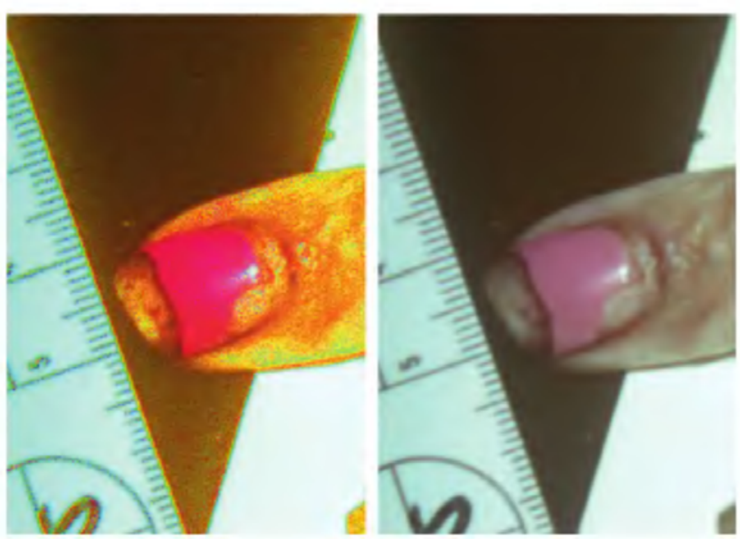


FIGURE 28 This shows the autopsy fingertip in normal color (right) and as a high-saturation test (left). The saturation test brings out the basic colors present in the image. There is an absence of light blue in either picture along the fingertip area of the nail.

FIGURE 29 The black circle focuses on the area of interest for the investigator.

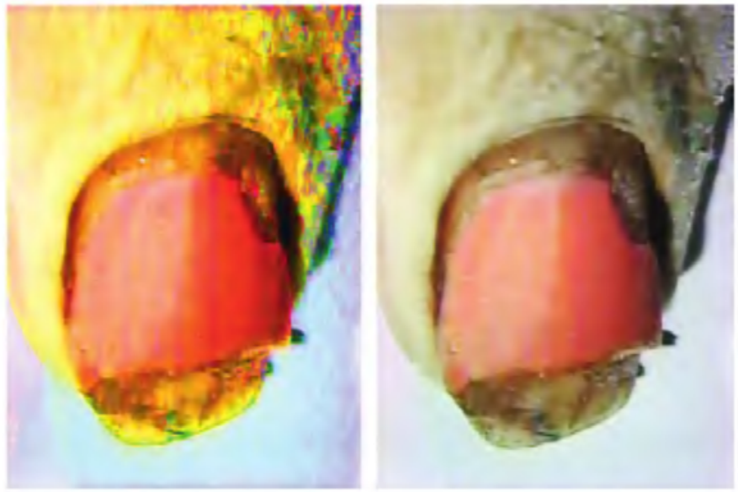


FIGURE 30 The crime lab video clip image indicating the original image (right) and the saturation test (left). The fingertip shows the irregular blue line that contains the light blue fiber.

FIGURE 31 Close-up image of the crime lab fingertip. The fiber may be seen embedded in the nail.

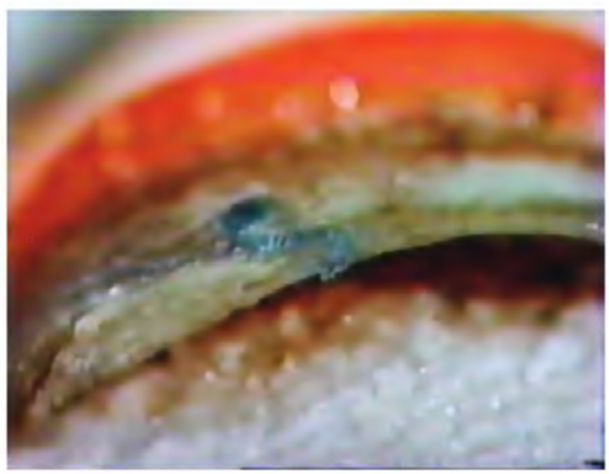


FIGURE 32 Close-up of the blue fiber from the nail edge.

Figures 30, 31, and 32 show the condition of the same fingertip during the crime lab investigation. The blue fibers can be seen clearly.

The judicial effect of these two digital images was in favor of the husband. The judge who was presiding over the new pretrial proceedings (2008) declared that the fiber evidence had been tainted by unknown means and that the evidence would be excluded from future use. The husband was found innocent of murder, and the conviction was reversed, in part, on this digital analysis. The murder weapon was found to have a combination of the victim's blood and an unknown male's blood. The blood spatter opinion was rejected by the judge. Dentists' opinions at the fourth trial (1999) regarding a hand injury on the victim being a bitemark were recanted by both experts. The possibility of the husband having bitten the victim was also recanted. The husband, at this date of publication (2010), is still in jail awaiting release due to the county district attorney exercising his appellate privileges regarding this current judge's opinion.

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