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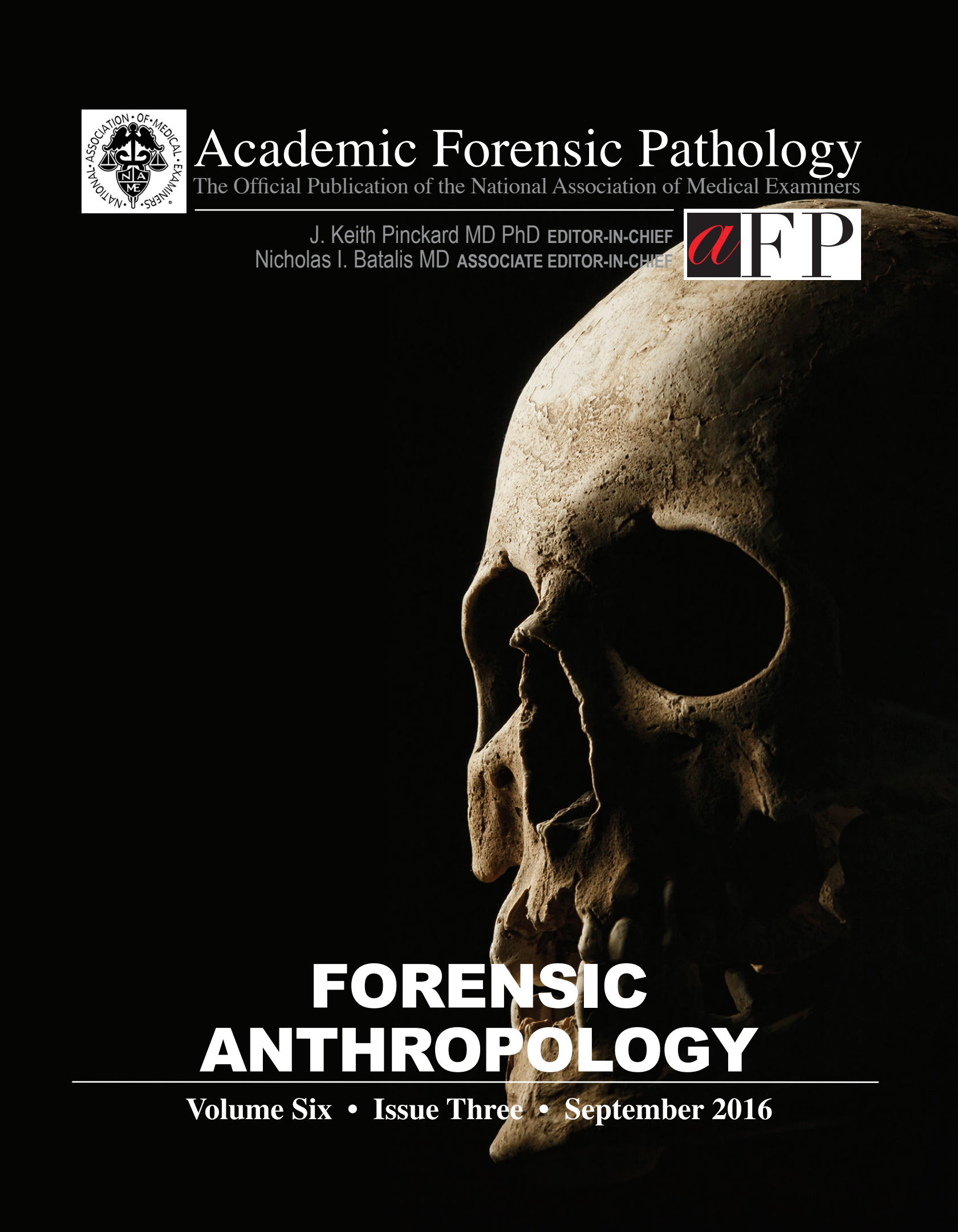

FORENSIC ANTHROPOLOGY

Volume Six • Issue Three • September 2016

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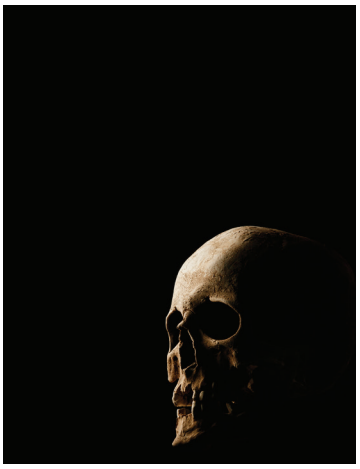

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Letter From the Editor-In-Chief

J. Keith Pinckard MD PhD
Editor-In-Chief

The theme of the third issue of 2016 is "Forensic Anthropology" and the Special Guest Editor is Dr. Jason Wiersema. Occasionally we like to feature related disciplines that work closely with forensic pathology. Our goal was to assemble a collection of articles covering the aspects of forensic anthropology that are most important and applicable to forensic pathology practice, all in one place, with updates on the latest philosophies regarding anthropology practice, such as establishing the biological profile.

We begin with a discussion of accreditation for forensic anthropology laboratories, followed by an introductory paper on the utility of forensic anthropology within medical examiner/coroner offices. Much of forensic anthropology centers on identification, and we feature papers on the biological profile, metric and nonmetric methods of identification, and on the identification efforts of two large offices. We continue with papers on forensic anthropologists' use of NamUs and their work in identifying decedents in the American Southwest. Other topics include taphonomy, the use of forensic anthropology in mass fatality incidents, and three papers dealing with the anthropological assessment of trauma. Finally, we have a paper discussing the use of advanced imaging modalities as an adjunct to forensic anthropology. We also feature several original articles on various topics in forensic pathology.

The final issue of 2016 will be released on December 1; the theme will be "Child Abuse" and the Special Guest Editor will be Dr. Kathryn Pinneri. But remember, only about half of each issue is devoted to the specific theme. It's really just a way to promote submission of articles on a particular topic. Manuscripts about any topic can (and should) be submitted at any time! As always, I will continue to encourage the readership to submit articles to the Journal. We depend on submissions from the readership—NAME members like you—to sustain our excellent content.

Letter From the NAME President

David R. Fowler MD
NAME President 2016

The practice of death investigation calls for many skills and a very broad knowledge of medicine and science. As a death investigator, the forensic pathologist must be knowledgeable of every natural disease process known to medical science. Superimposed on that are all of the non-natural processes that can cause a sudden and unexpected death. Can we do it all alone or should we even try?

Death investigation has become super-skilled, and forensic anthropologists are one of the critical "ologists" we turn to on a regular basis.

If one looks in the NAME accreditation checklist, there is a list of consultant services that an office must have access to avoid a deficiency. These consultants are there to ensure that the office will be able to draw on the appropriate expertise at the right time.

These, and the many other checklist items, such as caseload, are in place to create an environment where the forensic pathologist has the tools to produce high quality results from their investigation.

If administrators looked at the number of investigations an office completes each year and translated that into a public impact picture, they would be very surprised. Approximately 20-25% of all deaths in a jurisdiction are reported to the medical examiner or coroner's office. In Maryland, we are on track to have over 14 000 cases reported to the Office of the Chief Medical Examiner for a population of six million residents. For those of you who have additional reporting requirements by local statutes (such as cremation and hospice deaths), then this number is far larger. Regardless, over a single election cycle, that is about 60 000 families in Maryland. How many voters are

there in each of the families that needed the services of the OCME? What is the political cost if any office collapses? They do time after time, so it seems there may be little or no consequence. However, we do see these agencies resuscitated so is it there?

So without looking at impacts on public health and safety, there is a very real personal impact at the individual household level that we all know too well. We need to communicate this to our respective administrations. In reality, we rarely get thanked for doing our investigations properly. However, if a family is unhappy, we certainly hear about it. As the shortage of forensic pathologists worsens, there will be pressure to use nonforensic pathologists and other para-medically trained individuals to the detriment of the quality of the outcome.

So having all of the tools we need is a challenge. So I am looking forward to receiving this issue. This Journal always has focused on high-quality content. Continued updating of our personal knowledge base is critical. Reading *AFP* is an excellent way to do this. Having the wisdom to know when you need assistance and getting a consultation can only be done if you know what you do not know. Add this to our annual meeting and we will have a very educational month.

Regards to all.

Letter From the Guest Editor

Jason M. Wiersema PhD D-ABFA D-ABMDI
Guest Editor

Forensic anthropology has expanded its presence in the medical examiner/coroner's office setting exponentially in the past few decades. Historically, most forensic anthropologists were university faculty members who worked as consultants to local medicolegal or law enforcement agencies. There is now a considerable number of anthropologists embedded directly in medical examiner/coroner operations, and the caseload of the typical university-based anthropologist has increased significantly. There has been a concomitant expansion in the variety of questions asked of the forensic anthropologist. Historically, the primary role of the forensic anthropologist was in the development of a biological profile from unidentified skeletonized remains. In recent decades, their role has widened to include a variety of services including search and recovery of remains, trauma analysis, and radiographic identification. In fact, trauma analysis has become the primary contribution of the forensic anthropologist in some large medical examiners' offices. This issue is intended to update the understanding that forensic pathologists have of the array of contributions that the forensic anthropologist can make to medicolegal investigations via a series of articles that address specific anthropological methods.

Forensic anthropologists are prolific researchers, and novel publications describing experimental evaluation of skeletal trauma and new methods for establishing the biological profile are regularly published in a variety of journals and texts. There is also significant recent research focused on assuring the validation of existing forensic anthropological methods and reporting. Beyond the forensic anthropological literature, there is also a wealth of skeletal biology literature that identifies and addresses the effects of temporal change and population level variation on the analysis of individual remains. Many of these publications are relevant to and have influenced forensic anthropological methods significantly. The Scientific Working Group for Forensic Anthropology (SWGANTH) was formed in 2008 to draw from all of this research a set of best practices for use by forensic anthropologists. The group developed and made publicly available a

significant number of documents pertaining to the appropriate application of anthropological methods for recovery of remains, sex, ancestry, age and stature estimation, and skeletal trauma analysis. These documents are now under review by the Forensic Anthropology Subcommittee of the Organization of Scientific Area Committees. Most active forensic anthropologists have embraced the guidance developed by these organizations, and if employed correctly, the practices they describe are both methodologically and scientifically sound.

However, there remains significant variation in training among forensic anthropologists. Unlike forensic pathology, there is no single curriculum through which forensic anthropologists must matriculate, nor are there enforceable restrictions on who can refer to themselves as a forensic anthropologist. There are a small number of universities from which the majority of forensic anthropologists have graduated, though the list has expanded considerably in recent years. The introductory courses available at these programs resemble each other generally, but the more specialized courses vary based on the interests of the particular faculties. There are often opportunities for students to gain response experience at these universities, but again there is no standard minimum level or variety of experience that typifies the forensic anthropologist. There is a greater number of postgraduate level training opportunities than in the past that include fellowship and/or visiting scientist programs at several medicolegal offices around the United States, though these types of programs remain few in number.

In spite of the variation in education and experience among forensic anthropologists, most have broad training in cultural anthropology, skeletal biology, archaeology, anatomy, physiology, human evolution, bone biology, paleopathology, functional morphology, histology, and biomechanics. As a result, the typical forensic anthropologist maintains 1) a population-based perspective on interpretation of skeletal variation as it pertains to sex, ancestry, and other demographic characteristics, 2) a bone biology based perspective on bone development, degradation, and response to traumatic insult, and 3) a detailed knowledge of archaeological methods for scene recovery.

In addition, there is a certifying body for forensic anthropology that requires a degree of standardization in training and certification among those who carry their certification. The American Board of Forensic Anthropology (ABFA) is a nonprofit organization, incorporated in 1977, that provides a program for certification of doctoral level forensic anthropologists. In addition to a PhD, ABFA certification requires three years of postgraduate casework experience, passage of a certifying exam, and maintenance of certification requiring an ongoing record of forensic anthropological casework activities and proficiency. The recommendation of the ABFA is that board-certified forensic anthropologists are the most appropriately qualified for consultation with forensic pathologists because 1) certification represents the highest level of achievement in the field rather than a minimum measure of competence, 2) certification requires rigorous examination and continued competency, and 3) the ABFA requires adherence to high standards of ethics, conduct, and professional practice. There are currently approximately 80 active ABFA-certified forensic anthropologists in 29 states.

Readers of this issue will find articles that address the theoretical underpinnings of forensic anthropology, as well as operational reviews of forensic anthropological methods for site recovery, sex, age and ancestry estimation, and the application of these methods in the medicolegal and mass fatality contexts. My hope is that this issue will serve as an introduction to the value of the forensic anthropologist to those who are unfamiliar and a reference for those who have experience working with an anthropologist.

I would like to thank Dr. Keith Pinckard for the invitation to guest edit this issue and more broadly for providing this conduit to communicate the role of the anthropologist directly to the *AFP* readership. I would also like to extend my gratitude to the various anthropologists who took the time to contribute to this important issue. Each was selected carefully, and each is a preeminent expert in the particular part of forensic anthropology about which they authored articles for this issue.

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Volume Six Issue Three September 2016

Progress in the Accreditation of Anthropology Laboratories

Michal L. Pierce, Jason M. Wiersema, Christian M. Crowder

ABSTRACT

While crime laboratories are commonly accredited under programs utilizing international standards, options for forensic anthropologists to do the same were limited, until recently. The American National Standards Institute-American Society for Quality (ANSI-ASQ) National Accreditation Board (ANAB) and the American Association for Laboratory Accreditation (A2LA) both offer accreditation programs for forensic anthropology services using either the International Organization for Standardization/International Electrotechnical Commission (ISO/IEC) 17025 or ISO/IEC 17020 standard. The significant efforts made to specifically include forensic anthropology, and also forensic pathology, in these national programs demonstrate the importance for all practitioners in the field of forensic science to develop and maintain quality assurance programs consistent with international standards. Among the requirements for quality assurance is validation of methods, a practice that was previously identified as needing improvement within the forensic anthropology community. *Acad Forensic Pathol. 2016 6(3): 344-348*

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KEYWORDS

Forensic pathology, Accreditation, Method validation, Forensic anthropology, International organization for standardization standards

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INTRODUCTION

Following the publication of the 2009 National Academy of Sciences (NAS) Report: *Strengthening Forensic Science in the United States: A Path Forward* (1), establishing quality assurance programs and achieving accreditation became a priority for forensic anthropology practitioners. In light of the focused response within the field, Syracuse University hosted a conference in 2011 entitled "Beyond the NAS Report," during which the current and future impacts of the report were examined. One aspect discussed was the need for accreditation of anthropology laboratories. While it has been several years since the NAS recommended mandatory accreditation for laboratories performing forensic analyses, and decades since many crime laboratories had already achieved accreditation, very few forensic anthropology laboratories have accomplished this objective. The topic, however, remains relevant today for multiple reasons: 1) good scientific practice requires accuracy and repeatability, neither of which is possible without transparency, and accreditation invites the kind of transparency that facilitates accuracy and repeatability via detailed communication of procedures, error rates, etc.; 2) the public expects unimpeachable service from forensic science laboratories and practitioners; and 3) delivery of a deficient service or lack of transparency can result in poor public perception, fair or not. The latter occurrence will further result in loss of either customer base (for privately-owned agencies) or funding (for government-owned agencies). Therefore, it is imperative that agencies allocate resources to ensure solid scientific practice to protect their public image and maintain the public's trust. These resources should ultimately support a quality management system. By adhering to established standards for quality service, a forensic anthropology laboratory can demonstrate its credibility to the community it serves. This process will become more urgent as the federal government, and all of the public and private practitioners it has engaged, gains momentum in its efforts to advance the forensic sciences through entities like the Organization of Scientific Area Committees (OSAC) and the National Commission on Forensic Sciences (NCFS).

DISCUSSION

Forensic anthropology laboratories face several obstacles that complicate the pursuit of accreditation. Lack of meaningful precedents and guidance, insufficient human resources, tight funding, unsupportive management, and feelings of disconnect from the rest of the forensic domain are among the reasons anthropologists have cited for not pursuing accreditation (2). One of the main reasons cited is that existing accreditation programs are unsuitable or an improper fit for forensic anthropology. Until recently, no program named anthropology under the disciplines it accredited. Whereas the National Association of Medical Examiners (NAME) accredits forensic pathology offices, none of the professional anthropology organizations accredit forensic anthropology laboratories.

There has been considerable progress on at least some of these fronts. The Organization of Scientific Area Committees was developed in 2014, and is tasked with the development and maintenance of standards and best practice guidelines for many of the forensic disciplines, including anthropology. The Anthropology Subcommittee of the OSAC has leveraged the work completed by the preexisting Scientific Working Group for Forensic Anthropology (SWGANTH) to develop best practice recommendations for forensic anthropology regarding practitioner certification, methodology, and reporting of analytical results. As far as precedent, until recently the Defense POW/MIA Accounting Agency (DPAA), formally known as the Joint POW/MIA Accounting Command Central Identification Laboratory (JPAC-CIL), was the only forensic anthropology laboratory with any type of accreditation. The DPAA developed a quality assurance program that facilitated the laboratory's accreditation by the American Society of Crime Laboratory Directors/Laboratory Accreditation Board (ASCLD/LAB) in 2003. The laboratory was re-accredited under the ASCLD/LAB-International Program in Crime Scene and Trace Evidence in 2008. At the time, accreditation of anthropology laboratories was only available under a trace laboratory rubric.

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Standards and Accreditation Bodies

The International Organization for Standardization (ISO) is an independent organization headquartered in Geneva, Switzerland that develops and publishes international standards. These international standards are used to ensure that products and services being sold are safe, efficient, and of high quality. From agriculture to engineering, from automotive to healthcare, standards exist for every type of industry. These highly regarded standards translate across continents because experts from around the world develop them. In addition to subject matter experts, opinions from consumer associations, academics, and government officials are taken into consideration when creating these standards.

The original purpose for establishing industry standards was to facilitate international trade. It brought opportunities for developing countries to conduct business in markets previously unattainable to them. Not only have ISO standards promoted fair trade, but they have also led to great economic expansion during the past 70 years. Currently, there are over 21 000 international standards being utilized across 162 countries (3). While some ISO standards have been incorporated into legislation to ensure businesses are mindful of public health and safety, other ISO standards have been added to voluntary accreditation programs for testing, inspection, and certification bodies.

In 2013, Forensic Quality Services (FQS), now known as the American National Standards Institute-American Society for Quality (ANSI-ASQ) National Accreditation Board (ANAB), added anthropology as a recognized field in its accreditation program for forensic agencies. The ANAB is a U.S. entity that provides accreditation to certification bodies and inspection bodies. The ANAB accreditation programs geared towards forensic agencies incorporate ISO standards, along with field-specific supplemental criteria. The American Association for Laboratory Accreditation (A2LA) is another accreditation body in the United States that offers accreditation for laboratory-related services, also using ISO standards. A2LA's Forensic Identification Accreditation Program is now open to disciplines involved in recovering and identifying human remains, including forensic anthropology, forensic biology, forensic odontology, and fingerprint collection and analysis.

There are currently two ISO standards being used by accreditation bodies to accredit forensic science agencies: ISO/IEC 17025 (general requirements for the competence of testing and calibration laboratories), and ISO/IEC 17020 (conformity assessment - requirements for the operation of various types of bodies performing inspection). ISO/IEC 17025 has a long history of broad utilization in the accreditation of crime laboratories and is more appropriate for laboratories whose experts report results based on data generated by analytical equipment. ISO/IEC 17020 has more recently gained popularity with crime scene investigation units and is more appropriate for anthropology laboratory accreditation because it is focused instead on analyses that require an expert's professional judgment.

ISO/IEC 17025 contains requirements that testing and calibration laboratories must meet in order to demonstrate that they operate an organized management system, are technically competent, and are able to generate technically valid results. ISO/IEC 17020 is a set of standards with many of the same quality management principles but focus technically on "inspection activities," which is another term for conducting an investigation or examination. This can be applied to a crime scene unit, a latent print unit, a digital media laboratory, and a forensic anthropology laboratory. The main difference between ISO 17025 and ISO 17020 is that the former applies more to analytical testing, while the latter pertains to functional examination.

In August 2015, the Harris County Institute of Forensic Sciences (HCIFS) Forensic Anthropology Division became the first forensic anthropology laboratory to be accredited under ANAB's ISO/IEC 17020 inspection body program. The accreditation required collaboration by management, anthropology staff, and quality assurance staff. Among the areas assessed under this program are an agency's personnel, facilities, administration, examination methods, procedures, records, and management system. Therefore, agencies accredited under this program have objective proof of a quality operation, as they must continuously meet or

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exceed the international standards for quality examinations. As of yet, no other anthropology laboratory is accredited through this program; however, the program is still new to the anthropology community and preparation for accreditation can take several years.

Validation of Methods

Accreditation requires compliance with several hundred criteria, the most important of which are the use of validated methods and written procedures for performing said validations. This is an area that is particularly difficult for seasoned practitioners to embrace because, more than likely, they already use methods that have been widely accepted within the community. Once qualified to work independently, anthropologists usually adopt the same methods and equipment used by their mentors and/or absorb methods from the peer-reviewed literature. Thus, analysts often believe the validation is already completed or find it not applicable if a method has been well-examined in the literature. It is only through understanding of the quality assurance process that one realizes adopting and implementing a popular method is not enough.

Compliance with method validation requirements can be subdivided into three components: validation, verification, and performance monitoring. Although these terms may be used interchangeably, or with different meanings in other disciplines, they serve distinct purposes for assessing the validity of a method used by a forensic examiner. Validation, occasionally referred to as a developmental or primary validation, provides objective evidence to confirm that requirements for the method's specific intended use or analytical application have been fulfilled (4). By conducting and analyzing data from a set of studies, the efficacy and reliability of a technique or procedure can be established. Validation differs from verification in that verification provides objective evidence to confirm that specified requirements set forth by the primary validation have been fulfilled (5). Also known as an internal validation or secondary validation, a laboratory may conduct a verification to demonstrate it is capable of reliably and precisely performing a method for its intended use as seen in the literature or at another laboratory. This is not to be confused with performance monitoring, which is a quality check of a procedure or instrument to ensure it performs as expected. Quality control samples or reference standards are often used to check the performance of an existing procedure or piece of equipment that underwent validation and verification.

In order to meet the accreditation requirements encompassing validation, practitioners should decide which methods would be subject to each of the above-mentioned measures. A method previously validated by an outside party does not necessarily need to be revalidated by the lab seeking accreditation. As long as the procedure for the method validation can be located, the laboratory is only required to verify the analytical method can be used correctly within its own setting. The procedure and equipment used for that method must then be subject to intermittent performance checks for quality assurance purposes. Performance checks ensure that a random change affecting the method does not go unnoticed.

As previously mentioned, anthropology practitioners are likely already employing validated methods; however, in-house verification is warranted for guaranteeing the appropriateness of their use for fulfilling the service needs of the laboratory. Not only will this practice contribute to the reliability of examination results, but it will also bring forensic laboratories one step closer to complying with accreditation standards.

A newly developed method, on the other hand, must be validated in-house if it has not been validated elsewhere. Documented validation studies should include, where applicable, precision and accuracy, sensitivity and stability, reproducibility, and population data. The validation must produce data that demonstrates the method is capable of successfully performing at the level of its intended use and to identify its limitations under normal operating conditions (6). Previously validated methods must also undergo a new validation when changes are made to the procedure or its application. Although not as extensive as the developmental validation, the new validation must be sufficient to demonstrate that the method continues to produce reliable results despite the modification. Procedural mod-

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ifications requiring additional validation are typically changes made to either improve the method or extend its use beyond that for which it was originally validated. Examples include changes in materials or equipment used or the introduction of an automated step.

Software programs are also subject to validation, verification, and performance checks if casework depends on their data output. The need for in-house programs and templates to be properly tested before use is unquestionable, considering the specialized software used for statistical calculations and new efforts to render documentation of laboratory functions paperless. Therefore, known sets of data should be generated to adequately test these software programs and the procedures utilized by staff that runs them. Analytical programs that involve a significant user interface, allow manipulation of data, and make decisions determining the direction of the analysis require more complex validation procedures. Forensic laboratories that fail to validate or verify their software programs, automated report templates, and macroinstructions risk introducing errors into their analyses. An accredited laboratory should have a formal procedure for validating and implementing programming changes. The strategy used by the HCIFS to meet this requirement was presented at the National Institute of Science and Technology (NIST) International Symposium on Forensic Science Error Management in July 2015 (7). Given the rate of technological advances, programming validation will continue to be an important component of laboratory quality assurance.

CONCLUSION

The examination and reporting process of forensic anthropologists are more similar in nature to that of forensic pathologists than crime laboratory analysts. They rely less on data from automatic instrumentation and more on findings and interpretations from direct observation. Due to the often subjective and experienced-based nature of analyses in forensic pathology and anthropology, it is easy to see how practitioners may not feel the necessity to adopt all quality assurance standards recommended for a laboratory. However, quality systems are adaptable and should be developed to address the specific needs of each discipline. Method validation, for example, is an area that warrants discipline-specific instruction. The forensic anthropology community will benefit from publication of the detailed guidance being generated by the Anthropology Subcommittee of the OSAC.

In May of 2016, ANAB announced its coalition with the National Association of Medical Examiners, effectively adding the ISO 17020 standards to the NAME accreditation program. It was determined that the ANAB ISO 17020 program applies to forensic pathologists just as it applies to forensic anthropologists; both types of experts use their training and experience to examine remains and formulate conclusions based on their observations. While these changes to the NAME accreditation program may seem intimidating, the intention is to advance, along with other forensic disciplines, towards uniformity and higher quality. All forensic practitioners have the responsibility to ensure their opinions and testimonies are based on sound science, ethical practices, and transparent operations. The ISO standards have always fostered these objectives, and now avenues exist for forensic practitioners in the medicolegal setting to become accredited to those standards.

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The Utility of Forensic Anthropology in the Medical Examiner's Office

Christian M. Crowder, Jason M. Wiersema, Bradley J. Adams, Dana E. Austin, Jennifer C. Love

ABSTRACT

Over the past few decades, the field of forensic anthropology has seen major advancements and experienced a considerable growth of professionals in medical examiner/coroner offices. Despite this expansion, misconceptions regarding the role and utility of the anthropologist in the medicolegal setting still exist. This article brings together practitioners employed full-time in four medical examiner's offices, with each practitioner providing a unique perspective and emphasis regarding their role as an anthropologist. Discussed is the history of the anthropology division in each office as well as the types of casework and ancillary duties completed by the anthropologists. Consistently, the anthropologists are involved in the search and recovery of human remains, managing long-term unidentified cases, facilitating disposition of unclaimed decedents, and developing mass disaster protocols for their respective agency. Also consistent across the four offices is the fact that the anthropologists receive far more consult requests for trauma evaluation of nonskeletonized cases than any other type of case. *Acad Forensic Pathol. 2016 6(3): 349-360*

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INTRODUCTION

The evolution of the field of forensic anthropology is signified by the broadening of the discipline's scope of work and the growing presence of anthropologists in medical examiner/coroner offices. These two aspects are interrelated considering that the increasing representation of anthropologists in the medicolegal context correlates with the burgeoning breadth of forensic anthropological applications. In medicolegal death investigation, the utility of anthropology has grown beyond traditional skeletal analysis involving the construction of the biological profile (age, sex, ancestry, and stature). More common roles today include skeletal trauma analysis and decedent identification. Despite advancements of training and research in forensic anthropology, the misconception appears to persist that the utility of the forensic anthropologist is limited to the analysis of unidentified skeletal remains or simply the application of physical anthropology methods and theory to medicolegal skeletal casework. Therefore, the perceived need for anthropology staff in medical examiner and coroner offices may often be gauged by how many unidentified skeletal cases are received annually.

Medical examiners and coroners (ME/C) typically consult a forensic anthropologist who is on staff at their facility or employed by a local university or museum. Further, the Federal Bureau of Investigation (FBI) Laboratory and The University of North Texas Health Science Center - Center for Human Identification are federally funded agencies that provide anthropology services to ME/C upon request through law enforcement. There are numerous advantages to having a full-time anthropologist working at ME/C offices. These include rapid response for scene or autopsy consultations, prompt completion of case reports, and continuity with chain of custody within the same agency. In addition, full-time forensic anthropologists often assume additional roles in the ME/C office. Currently, anthropologists employed by ME/C offices are responsible for daily tasks such as supervising other divisions within the office, managing long-term unidentified decedent cases, facilitating final disposition for unclaimed decedents, submitting and tracking DNA submissions for decedent identifications, and coordinating tissue procurement agencies. Staff anthropologists in many offices have handled larger projects such as the development or enhancement of existing mass disaster response protocols along with contributions toward training and implementation. Contributions to training and research programs have allowed for creation of postdoctoral fellowship programs and enhancements to pathology fellow learning opportunities.

Currently, there are fewer than 15 forensic anthropologists certified by the American Board of Forensic Anthropology (ABFA) who hold full-time positions in a ME/C office. The number of nonboard-certified anthropologists with full-time positions in ME/C offices is not well documented. There are several offices that employ an anthropologist primarily in another role, such as death investigator or autopsy technician, who are consulted for skeletal cases when needed. In these instances, the anthropologists are typically not ABFA board-certified and may have a master's degree rather than a PhD. The largest employer of forensic anthropologists is the Department of Defense POW/MIA Accounting Agency. Other federal agencies that employ full-time forensic anthropologists include the FBI and the Armed Forces Medical Examiner System.

This article brings together anthropologists employed full-time by four large medical examiner's offices, either as sole practitioners or within multi-staffed divisions, to review the breadth and variation of their contributions. Each practitioner provides a perspective of their roles based on the context and region in which they work. The following information is provided by each practitioner regarding their office: 1) the history and structure of the anthropology position, 2) the roles of the anthropologist(s), 3) a summary of casework activity and statistics, and 4) non-casework activities (database management, research, teaching, and training). The goal of this paper is to demonstrate the utility of the anthropologist in the medicolegal setting.

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DISCUSSION

Harris County Institute of Forensic Sciences–Houston, Texas

The Harris County Institute of Forensic Sciences (HCIFS) serves primarily Harris County, a population of four million, and provides limited services to several surrounding counties. The HCIFS is organized into the Crime Laboratory Service and the Medical Examiner Service, which consists of five divisions: Forensic Pathology, Forensic Investigations and Emergency Management, Morgue Services, Forensic Imaging, and Anthropology. The Medical Examiner Service is accredited by the National Association of Medical Examiners and the Texas Medical Association Continuing Medical Education program, and offers a Forensic Pathology Fellowship accredited by the Accreditation Council for Graduate Medical Education. In addition to these accreditations, the HCIFS holds three other accreditations within its crime laboratory: American Society of Crime Laboratory Directors/Laboratory Accreditation Board - International (ASCLD/LAB-International), the Texas Forensic Science Commission, and the American Board of Forensic Toxicology. In 2015, the Forensic Anthropology Laboratory was the first medical examiner's office in the United States to achieve accreditation under the American National Standards Institute – American Society for Quality (ANSI-ASQ) National Accreditation Board (ANAB) ISO/IEC 17020 Forensic Inspection Agency Accreditation program.

In 2006, three PhD-level anthropologists were hired at the HCIFS, resulting in the establishment of the Forensic Anthropology Division (FAD). The mission of the FAD is to provide anthropological consultation to the medical examiner for active cases, 24-hour scene response capability to assist with scene investigations, and to assist with the decedent identification. The FAD also maintains leadership of the Identification and Disposition Committee, which was developed to resolve identification issues in current cases, submit and track DNA samples, review and maintain long-term unidentified decedent case files, and assist with decedent referrals to county burial. Currently, the FAD consists of four doctoral-level forensic anthropologists, three of which are board-certified. Three of these positions have additional responsibilities outside of the FAD. One member manages tissue procurement activities and county burial referrals for unknown or unclaimed decedents, another directs the forensic investigations and emergency management division, and the third is a training coordinator for the Quality Division.

In 2015, the FAD received over 300 requests for anthropologic analysis, representing a 35% increase from its first full year of service in 2007. These requests include consultation resulting in verbal and written reports, scene recoveries, trials, and pretrial consultations. **Figures 1 and 2** demonstrate the breadth of anthropological casework at the HCIFS. The bulk of FAD caseload (69% in 2015) is trauma analysis, which has steadily increased from 53% in 2007. It should be noted that the majority of the trauma analyses involve fleshed and/or moderately decomposed remains. Interestingly, the number of skeletonized cases varies significantly on an annual basis, from a low of six in 2007 to a high of 34 in 2012. While these cases tend to require more in-depth analysis and time for examination, they constitute a small percentage of the overall caseload.

The anthropologists at the HCIFS are highly active in research and publication. They regularly present research findings at scientific meetings such as the American Academy of Forensic Sciences, International Association of Identification, and National Association of Medical Examiners. The division conducts original research and has post-doctorate and summer internship training programs. The anthropologists are also active as members of scientific working groups in forensic anthropology. The FAD has a robust training program for Anthropology staff and fellows at the HCIFS and has obtained grant funding for forensic anthropology fellowships and research positions.

At the HCIFS, the FAD is also involved in the training of various forensic practitioners and students. The FAD provides lectures for the rotating medical residents and students, law enforcement, legal personnel, new HCIFS employees, interns, and some members

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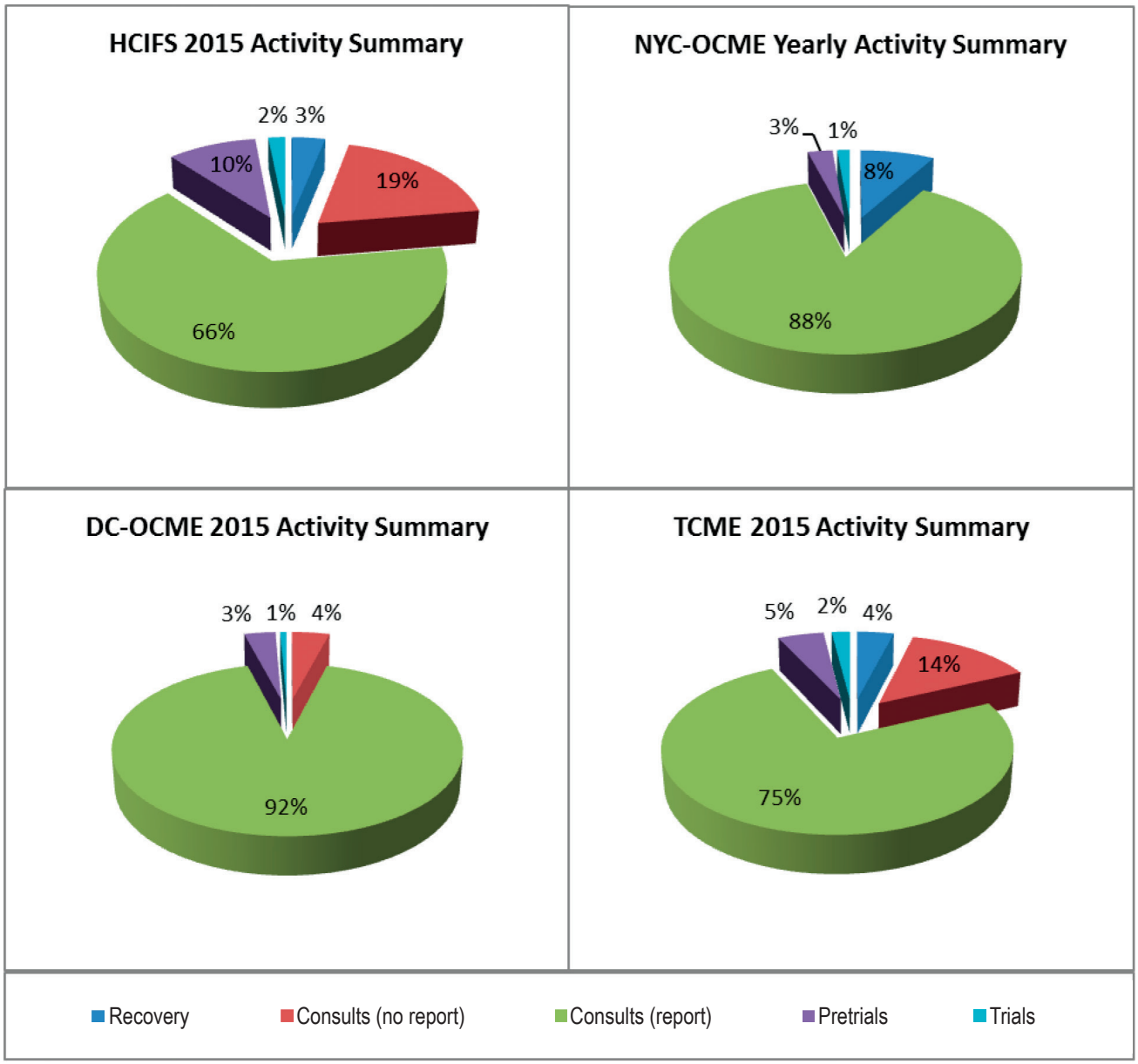

Figure 1: Breakdown (in percent) of typical anthropological activity in 2015 for Harris County Institute of Forensic Sciences (HCIFS), District of Columbia Office of the Chief Medical Examiner (DC-OCME), and the Tarrant County Office of the Chief Medical Examiner and Forensic Laboratories (TCME), while New York City Office of Chief Medical Examiner (NYC-OCME) shows the average activity over multiple years. The percentages do not reflect the volume of casework, but rather the distribution of workload. The activity categories are considered mutually exclusive even though a single case depicted in the percentage may be counted in more than one category (e.g., field recovery, consult-report, and pretrial). These activities represent significantly different interactions with casework.

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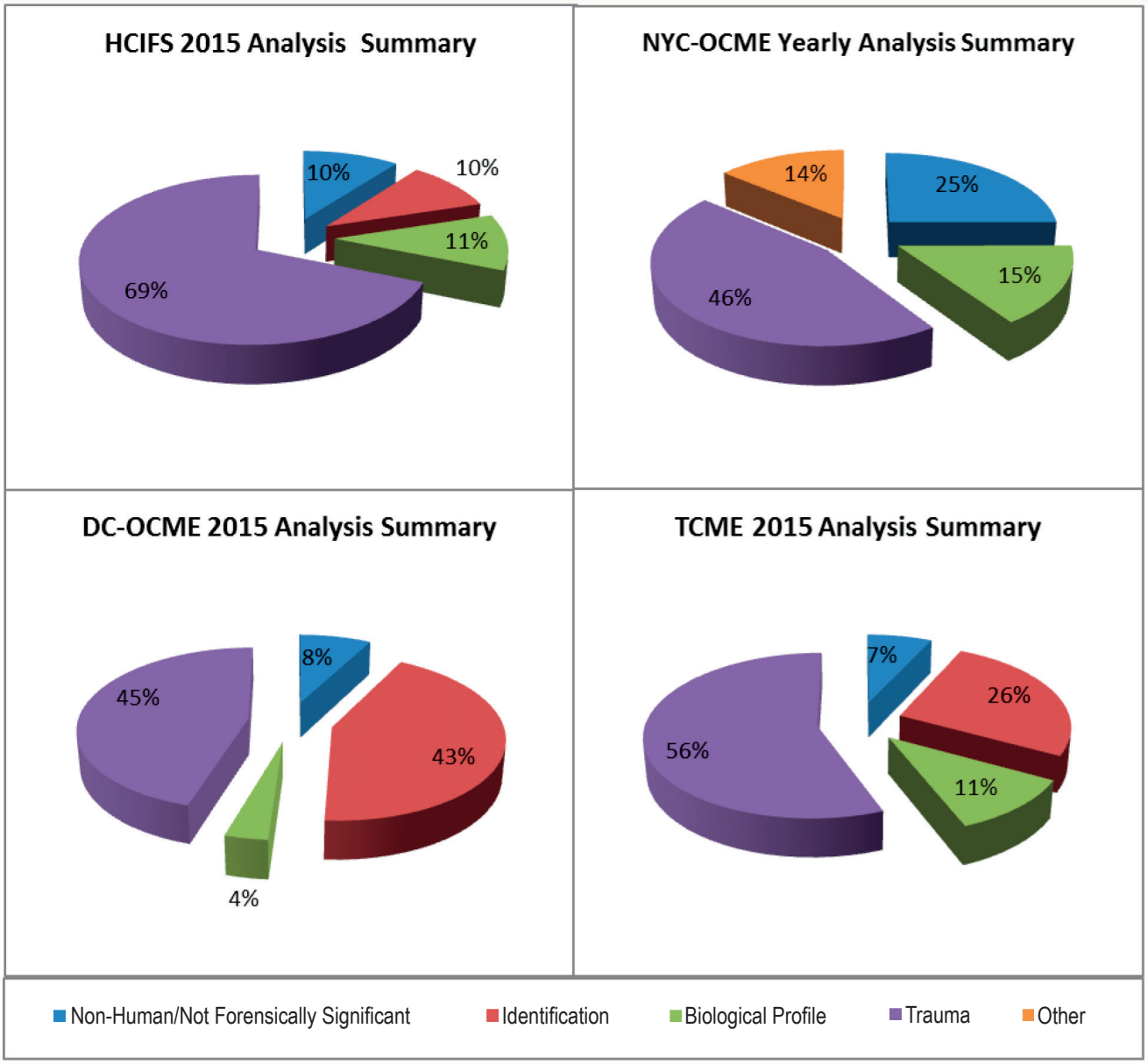

Figure 2: Breakdown (in percent) of anthropological analysis requested in 2015 for Harris County Institute of Forensic Sciences (HCIFS), District of Columbia Office of the Chief Medical Examiner (DC-OCME), and the Tarrant County Office of the Chief Medical Examiner and Forensic Laboratories (TCME), while New York City Office of Chief Medical Examiner (NYC-OCME) shows the average over multiple years. In order to provide continuity between the offices depicted, the analyses performed were distilled into five categories, with four representing specific types of analyses requested. The identification category includes cases in which the anthropologist performed antemortem and postmortem comparisons. The "Other" category for NYC-OCME represents analyses such as reassociation of fragmentary remains and evaluation of exhumation cases from City Burial. The data are presented in percentages considering that the categories are not mutually exclusive, meaning that a case submitted for analysis may involve multiple categories.

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of the general public. The forensic pathology fellows are provided hands-on training in anthropological techniques. Each year, the FAD mentors one anthropology intern, typically a graduate student, who observes the anthropologists during their daily casework and is mentored in a research project that they present at the end of their internship. When grant funding is available, the FAD offers a Forensic Anthropology Postdoctoral Fellowship with the purpose of training individuals to be practitioners. The FAD personnel conduct other training courses and hands-on workshops for specialized law enforcement groups, such as FBI Evidence Response Teams, and participate in the annual Topics in Forensic Science Conference hosted by the HCIFS.

In addition to internal and external training the FAD is involved in community outreach projects. One example of this was the development of "Missing in Harris County Day." The program was designed to raise awareness of missing persons in the Harris County area and provide members of the community, who have missing loved ones, a place to file a missing persons report with law enforcement officers, have the missing person's information entered into the National Missing and Unidentified Persons System (NamUs) database, and voluntarily provide familial DNA samples for identification purposes. More information on this initiative and similar programs can be found in the article authored by Derrick and Figura within this issue (1).

In order to improve mass fatality preparedness and streamline daily operations, emergency management, forensic investigations, and forensic anthropology have integrated roles at the HCIFS. Emergency management in the medicolegal setting is, at least in part, synonymous with mass fatality response. The methods employed in the mass fatality context are simply modifications of the same methods employed to manage daily cases by the operational areas (Pathology, Anthropology, Investigations and Morgue). In order to best prepare the HCIFS to accommodate a surge in cases associated with a mass fatality incident, the agency has elected to incorporate techniques for the management of large numbers of remains into the daily operations of the Investigations Division. The primary changes made to accommodate this integration were 1) to completely integrate the Forensic Investigations and Emergency Management into a single division, which is directed by a staff anthropologist, and 2) to modify the agency's identification procedures to reflect the daily adoption of emergency management concepts. As part of this process, the identification policies for the office were integrated into a single multidisciplinary strategy that operates under the administrative supervision of the Director of Forensic Anthropology and the operational direction of the Identification Manager, a newly created ancillary position also filled by a staff anthropologist. This arrangement benefits the efficiency of the identification of daily cases, and by extension, better positions the HCIFS to manage its operations in the emergency context.

New York City Office of Chief Medical Examiner

Originally established in 1918, the New York City Office of Chief Medical Examiner (NYC-OCME) currently employs approximately 30 medical examiners and performs an average of 5500 autopsies each year. The agency also offers the country's largest forensic pathology fellowship program, having produced 100 board-certified forensic pathologists since 1990. Headquartered in Manhattan, the NYC-OCME has operations in all five boroughs of New York. In addition to standard medical examiner services, the NYC-OCME is home to the largest public DNA crime laboratory in North America, a toxicology laboratory, a histology laboratory, a forensic anthropology laboratory, and the nation's only public molecular genetics laboratory. The NYC-OCME also maintains a division of specially trained experts to respond to any mass fatality event.

In 1999, the NYC-OCME hired its first full-time forensic anthropologist. Since that time, the role of forensic anthropology within the agency has expanded. This expansion is largely due to New York City's high volume of cases, as well as the complex investigations associated with the 9/11/2001 World Trade Center (WTC) disaster. Since 1999, the core staffing level of full-time forensic anthropologists has fluctuated between one and eight people; however, this does not

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account for the large number of anthropologists who have been temporarily hired to work on WTC related projects. Currently, the Forensic Anthropology Unit (FAU) consists of five full-time anthropologists (three assigned exclusively to the FAU and two who have additional responsibilities). Four of the anthropologists have PhD degrees and one has an MS degree. Two of these anthropologists are board-certified by the American Board of Forensic Anthropology.

Although headquartered in Manhattan, the FAU is responsible for coverage of all five boroughs in New York City (Brooklyn, the Bronx, Manhattan, Queens, and Staten Island), with a population of over eight million. The FAU is available to assist the medical examiners with gross and radiographic analysis of bone and cartilage. Generally, the FAU performs analyses and writes reports at the request of the staff medical examiners. Cases that may warrant anthropological consultation include decomposed or skeletonized remains, remains of questioned human or nonhuman origin or forensic significance, unidentified individuals, skeletal trauma (including blunt force, sharp force, gunshot, dismemberment, and thermal alteration), and skeletal pathologies and anomalies. The FAU is also available on-call 24 hours a day to assist medicolegal investigators with scene search and recovery. Depending on the circumstances, the FAU will respond to certain types of death scenes (e.g., buried bodies, surface scatters, and mass fatality incidents). **Figures 1 and 2** demonstrate the breadth of anthropological casework at the NYC-OCME.

Between 2005 and 2015, the FAU analyzed over 1400 cases. The annual caseload has fluctuated from a low of 72 cases to a high of 189 cases and an average of 127 cases (note: in general, a "case" signifies that a formal report was generated; informal consultations with medical examiners or medicolegal investigators that did not result in the generation of an anthropology report are not routinely tracked by the FAU). Approximately 75% of the total cases involve trauma and/or biological profile analysis and the remaining 25% of the cases involve remains that are not forensically significant (e.g., nonhuman remains or historic cemetery remains). Approximately 15% of the cases submitted to the FAU also involve a scene visit by FAU staff. The FAU is also a critical component of NYC-OCME's disaster response team. The FAU fills several roles within the disaster response team, which can be divided into three operational areas: Field, Morgue, and the Family Assistance Center. FAU members are trained for various types of mass fatality events, including both routine and hazmat scenarios, through periodic large-scale, multi-agency drills that allow personnel to practice in a realistic context.

The FAU continues to play a lead role in the NYC-OCME's ongoing WTC operations. The various roles of the anthropologists involved with the WTC operations include forensic oversight of renewed search and recovery efforts (primarily conducted from 2006 to 2013), serving as custodians for the retention and release of over 11 000 WTC remains currently housed within the 9/11 Repository, being the primary point of contact for WTC victims' families, conducting DNA sampling, and completing an anthropological review of DNA results.

Members of the FAU are also involved in research and routinely present and publish research results. They are also active with various forensic organizations and have served as or currently serve as members on the Scientific Working Group of Forensic Anthropology, the Scientific Working Group on Disaster Victim Identification, the American Academy of Forensic Sciences, the American Board of Forensic Anthropology, the editorial board of the *Journal of Forensic Sciences*, and the Organization of Scientific Area Committees.

At the NYC-OCME, the FAU is very involved with both internal and external training for various forensic practitioners and students. The FAU provides training on basic forensic anthropology for the rotating medical residents and students as part of the NYC-OCME monthly lecture series. The FAU also works closely with the forensic pathology fellows each year, taking the opportunity to show young forensic pathologists how anthropologists can assist them with various aspects of their casework. Graduating fellows and pathologists who are slated to take the forensic pathology board examination are offered training in an-

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thropological techniques. FAU personnel conduct other training courses, lectures, and hands-on workshops for groups such as the New York City Police Department (NYPD) Homicide Detectives, NYPD Crime Scene Unit, and the Fire Department of the City of New York Fire Marshalls. In addition, the FAU developed a Visiting Scientist Program that allows advanced graduate students and professionals with a forensic anthropology focus to gain professional development through immersion with the unit for one month. The Visiting Scientist Program was initiated in 2008 and as of the completion of the 2015/2016 program, 65 people have participated. Finally, the FAU mentors several interns per year. Most student interns are selected from the Human Skeletal Biology Masters Program in the Anthropology Department at New York University (of which several members of the FAU are affiliated faculty).

District of Columbia Office of the Chief Medical Examiner

The District of Columbia Office of the Chief Medical Examiner (DC-OCME) was established in 1971 and serves a population of approximately 650 000 residents. DC-OCME received full accreditation from the National Association of Medical Examiners in 2016. The office provides medical examiner and toxicology services to the District. The medical examiner services consist of five units: Anthropology, Identification, Investigation, Mass Fatality Preparation, and Pathology. In 2015, approximately 3000 deaths were reported to the office and DC-OCME accepted jurisdiction of 1085 cases. Of these, 714 cases were autopsied.

During a two-year interval (2002-2004) the office employed a master's-level anthropologist as the mortuary supervisor. In addition to managing the mortuary operations and staff, the anthropologist implemented methods to collect fingerprints from decomposed decedents thus greatly increasing the number of scientific identifications on these difficult cases. The anthropologist also processed all unclaimed decedents for final disposition and organized and reviewed long-term unidentified skeletal cases by compiling case data into a central database.

In 2014, a full-time forensic anthropology position and forensic anthropology laboratory were established in the office. Prior to 2014, traditional skeletal analyses and radiograph comparisons to establish identification were outsourced to forensic anthropologists at the National Museum of Natural History Department of Anthropology. With the hiring of a doctoral-level, American Board of Forensic Anthropology-certified forensic anthropologist, anthropological analyses came in-house and expanded from traditional skeletal cases to consultations of skeletal and fleshed decedents. The staff anthropologist responds to the autopsy suite to consult on skeletal findings and remove skeletal elements and cartilage, when necessary, for analysis. For example, the anthropologist is available to perform pediatric skeletal examinations (2) in cases suspicious for nonaccidental injury as well as fracture pattern analyses in cases of questionable fall versus assault. The on-site services reduced the anthropological analysis turnaround time from greater than a month to an average of 14 days. Furthermore, the anthropologist responds to death scenes that involve burned, skeletal, buried, or dismembered decedents to ensure thorough scene processing and decedent recovery. In 2015, the first full year of in-house anthropology services at the DC-OCME, the anthropologist received nearly 150 cases (**Figures 1 and 2**).

In addition to anthropology casework, the forensic anthropologist supervises the Identification Unit (ID Unit) and facilitates final disposition of unclaimed decedents. The ID Unit is a staff of six individuals who are responsible for facilitating visual identifications at the DC-OCME and fingerprint submissions to law enforcement. Also, the staff process death certificates through the electronic death reporting system, receive and process cremation requests, facilitate the release of decedents, and triage incoming telephone calls. In 2015, the anthropologist and ID Unit facilitated the final disposition of 98 unclaimed decedents. The average length of time between the date DC-OCME received the decedent and date of disposition was 56 days. The anthropologist, with the support of the ID Unit, reviews and processes unidentified decedent cold cases. Fingerprints are resubmitted to various agencies including the FBI and the Department of

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Homeland Security. Decedent descriptions are entered into NamUs. DNA samples are submitted to the University of North Texas, Health Science Center for profile development and upload to CODIS, the Combined DNA Index System. To date, six unidentified decedent cold cases have been identified.

Finally, the forensic anthropologist played a large role in developing the office's mass fatality response plan; specifically, writing the mass fatality victim identification concept of operations (ConOp) and contributing to the scene response plan (SRP). The ConOp delineates acceptable identification methods under various circumstances, details antemortem and postmortem data collection protocols, defines the mechanism for systematic comparison of antemortem and postmortem data, and describes the case tracking and data management system. Relying on training in archaeological methods and techniques, the anthropologist made significant contributions to the SRP addressing fragmented decedents and decedent recovery from large structure collapses. The contributions included developing the search, documentation, and recovery of human remains protocol as well as a defining a numbering system for fragmented remains to be employed on scene.

Tarrant County Office of the Chief Medical Examiner and Forensic Laboratories–Fort Worth, Texas

The Tarrant County Office of the Chief Medical Examiner and Forensic Laboratories (TCME) in Fort Worth, Texas, provides autopsy, death investigation, and crime laboratory services for Tarrant, Parker, Denton, and Johnson Counties in North Texas. The office also provides autopsy services for multiple Justice of the Peace jurisdictions in surrounding counties and crime laboratory services for over 150 law enforcement agencies. The larger cities of Fort Worth, Arlington, Denton, and Weatherford are included in the region. A portion of the Dallas-Fort Worth International Airport, Texas Motor Speedway, multiple rail lines, U.S. Interstates, and multiple lakes fall within the jurisdiction.

The TCME divisions include Forensic Pathology, Forensic Death Investigation, Human Identification, Toxicology and Chemistry, Crime Laboratory, Morgue Services, Histology, Evidence, and Administration. The Crime Laboratories consist of Forensic Biology, Trace Analysis, Firearm and Toolmark Examination, Latent Fingerprints, and Forensic Photography. Forensic Anthropology falls under the Human identification division. The TCME is accredited by the Accreditation Council for Graduate Medical Education, The American Society of Crime Laboratory Directors/Laboratory Accreditation Board, and the National Association of Medical Examiners. In 2015, there were 11 013 reported deaths with 3567 Jurisdiction accepted cases. Over 3600 bodies were brought to the facility with 1494 receiving an external examination, 362 receiving a partial autopsy, and 1711 receiving a complete autopsy.

The Forensic Anthropologist position at TCME initially began as a Trace Evidence Analyst position. In 1993, a newly hired trace analyst with a master's degree in forensic anthropology replaced a consulting academic-based forensic anthropologist. This hiring practice continued as another master's-level anthropologist with duties in trace analysis and anthropology replaced the first trace analyst/anthropologist. In 1996, the current anthropologist was hired with a doctorate in anthropology, specialized training in forensic anthropology, and many years of graduate level casework experience that included morgue consultation with forensic pathologists. It should be noted that the anthropologist had a bachelor's of science in biochemistry that fulfilled the trace position minimum requirement of 30 hours of chemistry. The position remained a dual role within the trace analysis laboratory until 2003. Trace duties for the anthropologist primarily included collection of trace evidence from decedents, clothing, vehicles, and other items of evidence; hair and fiber identification and comparison; and fracture pattern matching. In 2003, the increased demand for anthropology services led to a single role position focused entirely on managing the anthropology laboratory. In 2006, the anthropologist was moved out of the Crime Laboratory administratively and placed within the newly constructed Human Identification Laboratory. The new unit consisted of a forensic odontology director, fingerprint specialists, and the forensic anthropologist.

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The TCME Anthropology Laboratory is responsible for multiple tasks within the office. In 2015, the Anthropology Laboratory received nearly 90 cases (**Figure 1**). The evaluation of human remains originates with a request for assistance in the case by the assigned pathologist. The bulk of the anthropology laboratory casework is skeletal trauma analysis of decomposed, skeletal, burned, and fresh human remains (**Figure 2**). The climate in North Texas leads to a high number of decomposed remains that are examined at TCME. In fresh bodies, common trauma analyses for adult decedents include fracture documentation in the hyoid bone and neck cartilages in suspected strangulation cases, evaluation of gunshot wounds, blunt force trauma, and sharp force injury. Pediatric trauma cases are evaluated by analyzing skeletal segments of the body after removal and cleaning. In these cases, the pathologist and anthropologist determine which injuries to examine histologically and remove those sections prior to skeletal processing. Analysis combining histological cellular data with gross bone evidence is discussed jointly with the pathologists.

Traditional skeletal analysis to create a biological profile comprises about 10% of the casework (**Figure 2**). Metric data from the skeleton are collected with a digitizer and calipers and are analyzed with software to estimate sex, ancestry, and stature. Procedures including digital radiography, stereomicroscopy, and visual examination are used to evaluate the skeleton for antemortem conditions, perimortem trauma, and taphonomic indicators.

Positive identification by comparison of antemortem radiographic images with postmortem images is a common request, although the majority of the unidentified cases at TCME are resolved through fingerprint comparison (87% in 2015). In addition, the anthropologist maintains the database containing information on long-standing unresolved identity cases (3). This database includes the pertinent information on the circumstances of the case, the biological profile of the individual, and the results of comparisons with missing persons. This database was created in 2005 in response to the launch of the CODIS database for missing persons and unidentified bodies and a national impetus to resolve cold identity cases. The Anthropologist obtained all available fingerprint and DNA samples on the older cases and submitted them for processing and inclusion in various databases. Multiple identifications immediately resulted with additional identifications facilitated by the inclusion in CODIS.

Nonhuman bone identification and scene response are regularly requested services. Digital photography allows analysis of images of suspected nonhuman bones sent via telephone text message or email. This is a valuable service to any law enforcement agency that could potentially expend valuable resources on a case of no consequence. In cases of known human remains at a scene or suspected burials, the TCME anthropologist responds within the jurisdiction. The forensic anthropology field team at TCME is comprised of volunteer scientific staff who are given permission by their supervisors to respond to scenes at the request of the anthropologist. The occurrence of buried body and surface scatter recoveries ranges from two to seven annually. The extent of the recovery varies with each scene and time expenditure in the past has ranged from two hours to five days. Assistance to law enforcement agencies outside of the jurisdiction is offered remotely and involves the analysis of crime scene photographs and recommendations for best practices for an individual scene.

Additional duties for the forensic anthropologist include training of forensic pathology fellows and visiting scientists. The anthropologist also presents skeletal analysis findings to the pathologists when the case is reviewed. Court testimony, primarily limited to homicide trials, is required one to two times per year with an equal number of trial preparations for cases that end in plea agreements.

Summary

Examining the roles of the anthropologists in multiple medical examiner offices shows that the contribution of forensic anthropology far exceeds the role of simply examining skeletonized remains. Over several decades, there has been a paradigm shift in the conceptual framework by which the forensic anthropol-

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ogist operates, with specific reference to the analysis of trauma and taphonomy, as well as the use of the anthropologist for recovery and death scene reconstruction (4). Furthermore, anthropologists assume supervisory positions beyond anthropology casework and are actively involved in other aspects of agency operations such as decedent identification, body disposition, and disaster preparedness. This shift has increased the need for anthropologists in the medical examiner's setting and has greatly expanded the role of forensic anthropology.

The authors have uniformly experienced that the anthropology caseload builds as medical examiners learn to appreciate the full range of assistance that forensic anthropologists can provide. In fact, as shown in **Figure 2**, skeletal trauma analysis is the most requested service, ranging from 45-69% of the total caseload received by the four forensic anthropology laboratories examined in this paper. Human identification for three of the offices comprised 10-43% of the annual caseload (**Figure 2**). The development of the biological profile was found to comprise 4-15% of the total case load and scene response occupied less than 10% of the total case load in all laboratories, with the majority below 5% (**Figures 1 and 2**). These percentages will vary somewhat from year to year, but the emphasis on assisting the pathologist with skeletal trauma analysis and identification of remains consistently comprises the bulk of the caseload.

As noted by Austin and Fulginiti (3) and exemplified in this paper, anthropologists within the medicolegal system frequently perform diverse roles in addition to laboratory analyses. These roles span into several operational areas; however, the areas that most frequently involve the anthropologist are mass fatality preparedness, management of long-term unidentified decedent cases, and research and training programs.

Regarding mass fatality incident (MFI) response, the anthropologist's skill set is typically employed in multiple operational areas including Field Operations, Morgue Operations, and the Family Assistance Center (FAC). During field operations, the anthropologist's training in archaeological methods is essential to ensure proper recovery and documentation of a scene, especially in complex instances involving body fragmentation. Regarding disaster morgue operations, the anthropologist assists in triage to evaluate remains and resolve any commingling of remains prior to examination by the forensic pathologist. The anthropologist also provides consultation for the pathologist during the examination of remains as described previously. Finally, anthropologists have been used in the FAC to assist with disaster victim identification, ensuring that the necessary antemortem records are collected. In addition to performing key roles during an incident, forensic anthropologists are frequently involved in the development of the agency's mass fatality response plan.

Long-term unidentified decedent database creation and maintenance is primarily undertaken by the anthropology laboratory in all of the offices discussed in this paper. The review of potential matches is assisted by fingerprint specialists, forensic odontologists, and forensic biologists, with the anthropologist guiding the process and tracking the results of the comparisons, as well as coordinating with law enforcement regarding these cases. The tracking of long-term unidentified decedent cases (i.e., cold cases) became a major consideration after 2005 when the National Institute of Justice supported medical examiner offices with grant opportunities to allow backlog reduction of these types of cases. Forensic anthropologists participate in national training and coordinate with state missing person clearinghouses to move these cases forward by entering accurate data into national databases, including NCIC (National Crime Information Center) and NamUs, as well as submitting DNA samples to CODIS. Anthropologists have proven to be well-qualified to review the case information, specifically the biological profile, and coordinate the efforts for the ME/C offices.

Knowledge in forensic practice is advanced through training and research. Furthermore, continuing education is essential for maintaining certification/licensure and facilitating professional development. The academic training of a forensic anthropologist emphasizes research and teaching, thus qualifying them to

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contribute significantly in the education and training programs offered by the medical examiner's office. The training opportunities are an excellent way for various groups to understand the diverse roles of a forensic anthropologist. These may range from working with law enforcement on recovery scene protocols to introducing forensic pathology fellows to various types of laboratory analyses. The goal of this educational outreach is generally not to train personnel to become forensic anthropologists but rather for the participants to fully appreciate how forensic anthropologists can assist them in various aspects of their medicolegal death investigations.

CONCLUSION

As shown through the National Association of Medical Examiners accreditation checklist, utilization of forensic anthropology is an important component of medicolegal death investigation. More importantly, the contributions of forensic anthropology to a ME/C office far exceed consultation on unidentified skeletal remains. These contributions include, but are not limited to, scene response, skeletal trauma analysis, decedent identification, mass disaster response planning, long-term unidentified decedent case management, and other morgue operational tasks. The intent of this article is to showcase the various roles forensic anthropologists can play in a ME/C office. Perhaps with a better understanding of these roles by ME/C agencies, it will become more commonplace for ME/C offices to employ full-time forensic anthropologists.

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Evolution of Forensic Anthropological Methods of Identification

Jason M. Wiersema

ABSTRACT

Forensic identification of human remains has long been a core contribution of forensic anthropologists to death investigations. The array and scientific robusticity of the identification methods employed by the anthropologist has evolved in the last several decades, and as with other nonidentification methods, anthropologists have embraced the progression toward the use of validated and statistically defensible methods for identification. This article presents an overview of the role that the forensic anthropologist plays in the identification of human remains and the evolution of anthropological methods of identification. *Acad Forensic Pathol. 2016 6(3): 361-369*

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INTRODUCTION

Forensic identification of the deceased is of primary importance in the medicolegal investigation of death. This is true in the daily investigation of individual unexpected deaths and in investigations of mass fatality incidents involving large numbers of human remains and/or fragments of human remains. Since Krogman's 1939 article in the Federal Bureau of Investigation Newsletter entitled "*A Guide to the Identification of Human Skeletal Material,*" the anthropologist has maintained a significant and expanding role in identification (1). Much has changed since the days of anecdotal comparison of skeletal features for identification with advancements in the development of standard and validated methods for identification in the wake of the *Daubert v. Merrell Dow* ruling (2) and the more recent National Academy of Sciences (NAS) report (3). The NAS report called on the forensic sciences to validate existing methods and to develop new methods that can be validated via assurance of repeatability, reliability, and accuracy. Recognition by forensic anthropologists of the need for standardized, validated methods for identification predates the NAS report (4-6), as does much of the research aimed at validation of anthropological methods of identification. Anthropologists have continued to contribute to this discussion since the NAS report was published (7-11).

DISCUSSION

Anthropological Methods for Identification

The contribution of the forensic anthropologist to the identification process varies by jurisdiction, in large part due to whether or not the anthropologist is a full-time employee of the medicolegal jurisdiction rather than a contractor. Those who are embedded in a medical examiner/coroner operation are typically involved in a greater variety of components of the identification process than those who consult, including both the application of anthropological methods and administrative contributions (12). This article focuses on the core contribution of the forensic anthropologist to identification: the direct comparison of antemortem radiographs attributable to suspected deceased persons to postmortem radiographic images collected from the deceasent by the medicolegal agency. The anthropologist also impacts the identification process via the extraction of biological indicators of age, sex, ancestry, and stature from unidentified human remains that allow for the development of a biological profile that limits the number of people to whom a decedent bears resemblance (13). Facial approximation and superimposition are methods employed by some anthropologists that are generally useful as tools for eliminating identification candidates or for narrowing candidate pools rather than for identification. These methods are thus not discussed in any detail in this article.

Forensic anthropologists leverage their detailed familiarity with the skeleton and its variability to assess the likelihood that the similarity between two images of the same skeletal feature constitutes identification. This comparison involves consideration of overall bone morphology and contour, trabecular bone patterns, sinus morphology, and the presence and morphology of orthopedic or surgical devices. In general, the greater the morphological complexity, the higher the likelihood that a particular bony feature will have discriminatory value. Thus, most of the bones of the body have the potential to contribute to identification, but certain elements of the skeleton (e.g., frontal sinuses, petrous temporal bone, dentition) are preferable because of their morphological complexity. Some elements that have complex morphology have compromised utility because of their location in the body and their appearance on antemortem imaging. The vertebral column, for example, has very complex morphology, particularly in aged individuals with degenerative changes, but is often viewed by the anthropologist in anterior-posterior chest radiographs and is thus viewed through the anterior ribs, sternum, and thoraco-abdominal organs. Another consideration is the prevalence of imaging in the antemortem record. For example, chest radiographs, though difficult to use for identification for the above stated reason, are commonly used for identification because of their high level of availability. In the author's experience, there also seem to be distinctions between the lay population and the deceased medicolegal population (e.g., higher incidence of interaction with the health-

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care system and/or criminal justice system) in terms of antemortem record prevalence, which can benefit the anthropologist seeking antemortem records.

The first account of comparison of radiographs for the purpose of forensic identification of the deceased was described in the third decade of the last century (14). The authors used the morphology of the nasal accessory sinuses and the mastoid processes to confirm the identity of a heavily decomposed person. The subsequent literature, particularly between 1995 and 2008, is replete with published attempts to find means of extracting diagnostic information directly from skeletal remains via comparison of ante- and postmortem radiographs. Numerous publications describe individual identifications made using radiographic imaging of various parts of the postcranial skeleton including the leg and foot (15), chest (11, 16), clavicles (17, 18), pelvis (19, 20), vertebral column (9, 21), and the hand and wrist (6, 22), as well as features of the cranium, including the mastoid sinuses (23), nasal sinuses (14), cranial suture patterns (24), frontal sinuses (25-34), and orthopedic/surgical devices from various parts of the body (35, 36).

The frontal sinuses have received considerable attention as a highly variable and individualistic character of the human skull (25-31), and provide a synopsis of the progression of the identification literature from anecdotal accounts of comparisons to the development of methods for comparison of images complete with statistical measures of likelihood. An exhaustive review of the literature pertaining to identification methods based on every part of the skeleton is beyond the scope of this article. The following paragraph uses the frontal sinus as an example of the development of, problems with, and considerations associated with radiograph identification methods.

Articles discussing the radiographic evaluation of the frontal sinuses in personal identification have been published on several occasions (25, 27, 28, 37, 38). However, the majority of the early publications are case reports and do not present techniques for future application, nor do they satisfy the requirements of the Daubert guidelines or address the limitations identified in the NAS report. For example, Quatrehomme and Fronty suggests simple superimposition of ante- and postmortem conventional radiograph images as a viable technique for personal identification from the frontal sinus (39). The authors acknowledge the considerable difficulty associated with the correct orientation of the skull for postmortem imaging, but do not address the subjectivity associated with the method. Quatrehomme and Fronty's method is typical of these articles, which present a case, or series of cases, in which "identifications" were made based on matches perceived by the observer (25, 28, 38). Kirk et al. published the results of a survey of 39 cases in which identifications were made in Ontario, Canada, based on nonmetric comparison of frontal sinus configuration (40). Only three of the 39 cases were considered unidentifiable using the frontal sinus because of poor film quality and the remaining 36 produced "*conclusive postmortem to antemortem pattern matches*" (40). The identifications were made based on uniqueness, as perceived by the viewer, between superimposed ante- and postmortem anteroposterior radiographs of the skull. They also refer to the "quantitative" association of 16 cases. This quantification involved measurement of the maximum vertical and horizontal dimensions of the sinuses. "*Any discrepancy between antemortem and postmortem values greater than 5 mm was classified as a metric nonmatch*" (40). Although less subjective than the identifications made solely on the basis of simple superimposition of ante- and postmortem imaging, this technique does not provide either a statistical measure of the strength of the associations or error rates associated with its use. More comprehensive systems for classifying and/or identifying crania according to variability of the frontal sinuses have been presented by Yoshino et al. (29), Yoshino et al. (41), Schuller (26), Reichs (31), and Reichs and Dorion (30). Yoshino et al. developed a potentially repeatable methodology for personal identification from conventional radiographs of the frontal sinuses (29). The method involved the development of a code number from the classification of six independent characteristics of the frontal sinuses. The code was a series of numbers that was statistically unlikely to be derived from more than a single individual by virtue of its length and the number of possible

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combinations represented by all of its possible variations. Yoshino used the skulls of 35 Japanese adults (21 males and 14 females) to develop the technique. They tested the technique on a single forensic case and concluded that the technique is of "*considerable value in cases in which dental remains are not available*" (29). Reichs and Dorion (30) and Reichs (31) modified this technique for use with axial computed tomography (CT) scans of the skull. Their argument is essentially that future use of CT imaging will far outweigh the use of fronto-occipital radiographs, and that identification techniques based on radiographs will someday become obsolete. Thus instead of conventional radiography, they developed a method similar to that of Yoshino et al. using axial CT imaging (29). They evaluated a slightly different series of characteristics than Yoshino et al. that were more effectively imaged on CT scans, including bilateral dimension, bilateral asymmetry, superiority of side, distribution of partial bony septations, number of partial bony septations, distribution of complete bony cells, and number of complete bony cells (29). They suggested that scoring these attributes on several consecutive CT slices added to the length of the code derived, and therefore, to its statistical uniqueness.

Development of Quantitative Methods for Identification

There has been a surge in publications regarding the validation of all aspects of forensic anthropological analysis in the last ten years, particularly since the publication of the NAS report. For many of the analyses conducted by forensic anthropologists, including sex and age estimation, this involves the statistical validation of existing anthropological methods like pubic symphysis or sternal rib end aging. On the other hand, identification of decedents via radiograph comparison has been historically subjective. The discriminatory value of subjective comparison of skeletal radiographs is valuable and these methods are likely to persist as an identification tool for use by the forensic anthropologist. This is true in part because the anthropologist cannot validate radiograph identification methods for every bone in the body, nor can we anticipate what bone(s) may be available for comparison in a given case. However, the importance of the development of validated identification methods is well recognized. "*Because forensic anthropologists are trained first and foremost as physical anthropologists, they emphasize estimation problems at the expense of evidentiary problems*" (42). Steadman and colleagues outline the application of Bayesian statistics, in particular likelihood ratios, in the validation of anthropological methods of identification. They explain the conceptual and practical differences between appropriate reference samples and the population at large. The authors identify several databases that can be used as references for population at large estimates, as well as novel data that can be used to calculate the frequency of specific identifiers within the population at large.

The primary problem with historical usage of radiograph comparison is the real or perceived lack of repeatability of the comparisons. Repeatability is dependent on the objectivity of the methodology employed, and objectivity is difficult to establish when using methods dependent on the investigator's individual assessment of subjective characteristics, such as a particular shape, level of symmetry, or side dominance. For example, the features of the frontal sinuses evaluated in the publications by both Yoshino et al. (29) and Reichs and Dorion (30) are arbitrary. There is a need for more easily reproducible character evaluations. Some authors have tried to increase the objectivity of radiographic methods by various means. As mentioned above, Kirk et al. attempted to add quantitative robusticity to the radiographic analysis of frontal sinuses by recording the maximum width and length of the sinuses in a sample of 39 crania, in addition to the more subjective variables used in other investigations (40). Reipert et al. completed an investigation that aimed to "*improve the objectivity of X-ray comparison for the identification of unknown individuals*" by using a computer program named FoXSIS to reduce subjectivity in the analysis of the frontal sinuses (43). Computed tomography data were collected for 30 skulls, and were converted to virtual X-ray representations of the skulls. According to the authors, the primary advantage of the program was that its use of digital measurements of

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the features of the skull allowed for a quantification of the "probability of identity" without reliance on the more subjective, and less repeatable measures of identity such as side dominance, shape, and symmetry levels.

There is also a problem with techniques that are based on the assumption that it is statistically improbable for two individuals to have the same or similar codes just because there are a large number of possible combinations. This is problematic (at least with the techniques outlined above) because no effort is made to weigh the various characters relative to one another. For example, it is much more likely for an individual to have a single or very few septations of the frontal sinus than for them to have six or seven, thereby increasing dramatically the statistical probability that two individuals may indeed have the same code for that particular trait. This is a problem with many of the characteristics considered by both Reichs (31) and Yoshino et al. (29). Christensen published the most objective and statistically robust analysis of the frontal sinuses to date (32). She used elliptical Fourier analysis (EFA), a geometric morphometric technique that imposes a set of coordinate data points to a closed curve, to quantify the superior border of the frontal sinuses. The coordinate data were then used to quantify the outlines by generating a set of coefficients that represent a numerical reproduction of the curve. She traced the superior border of the frontal sinuses of 808 individuals and closed the curve inferiorly by connecting the inferior-most extensions of the left and right sides of the curve with a straight horizontal line. The Euclidean distances between the EFA-generated outlines were compared as a means to test the accuracy with which they could be used to associate the correct images. The Euclidean distances between repeat images from the same individual were significantly smaller than the distances between individuals. She used typicality statistics to evaluate the statistical strength of the associations with good results. The probability of making an incorrect association between two outlines using her method is very small, and she concludes that "*there is a quantifiable and significant difference between the shapes of individual frontal sinus outlines*" (32).

Wiersema developed a method for comparison of ante- and postmortem axial CT images of the petrous portion of the temporal bone (44). The data used in the study were collected from repeat axial head CT images of 115 individuals, and the Euclidean distance comparisons were made between images of the same individual and images from different individuals. Two-dimensional coordinate data from 36 landmarks on each of the CT images were calculated and the distances between each of the coordinate points were captured to generate the data used in the statistical analyses. Measurement subsets were developed based on two separate models, the first of which used anatomical criteria identified by the study author and the second used principal components factor analysis to identify the subset with the most statistical significance (**Images 1-3**).

The measurement sets of both models were then compared to one another using nearest neighbor analysis, to test their relative efficiency in matching replicate images to one another. The results of both models were highly accurate. Three incorrect nearest neighbor matches resulted from the biological model and five from the principal components factor analysis model. The errors appear to have been the result of variation in the axial plane between the first and second scans. The results of the nearest neighbor comparisons were then considered within the context of Bayes' Theorem by calculating likelihood ratios and posterior probabilities. The likelihood ratios and posterior probabilities were very high for both models, indicating that 1) there is significant individual variability in the measurements of the petrous portion used in this research and 2) this variation represents a high level of potential accuracy in the application of this method in the identification of forensic remains.

Derrick et al. describe an automated method for comparison of lateral images of the cervical spine that was mathematically validated for use by medical examiner's/coroner's offices (9). The software quantifies the likelihood that any two of the radiographs in an array of cervical spine images (**Image 4**) contain matching vertebral body morphology. Six validations were conducted to evaluate the repeatability, reliability, and sensitivity of the method. The authors report

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a 92-100% success rate in matching the test image to the correct image in the array. The success rate for cervical vertebrae is particularly high, less so for lumbar vertebral bodies (which tend to be less morphologically distinctive and often partially obstructed by intermediate objects).

The limitation of this particular method is the limited availability of antemortem lateral cervical spine radiographs. The utility of the method would be greatly enhanced if antemortem lateral CT scout images of the head and neck were deemed appropriate for comparison.

Forensic Anthropological Identification in the Mass Fatality Context

The role of the anthropologist in the mass fatality context is discussed at length elsewhere (45). However, that article does not address the methodological issues associated with the identification of fragmentary remains, or of common, unidentifiable tissue that is

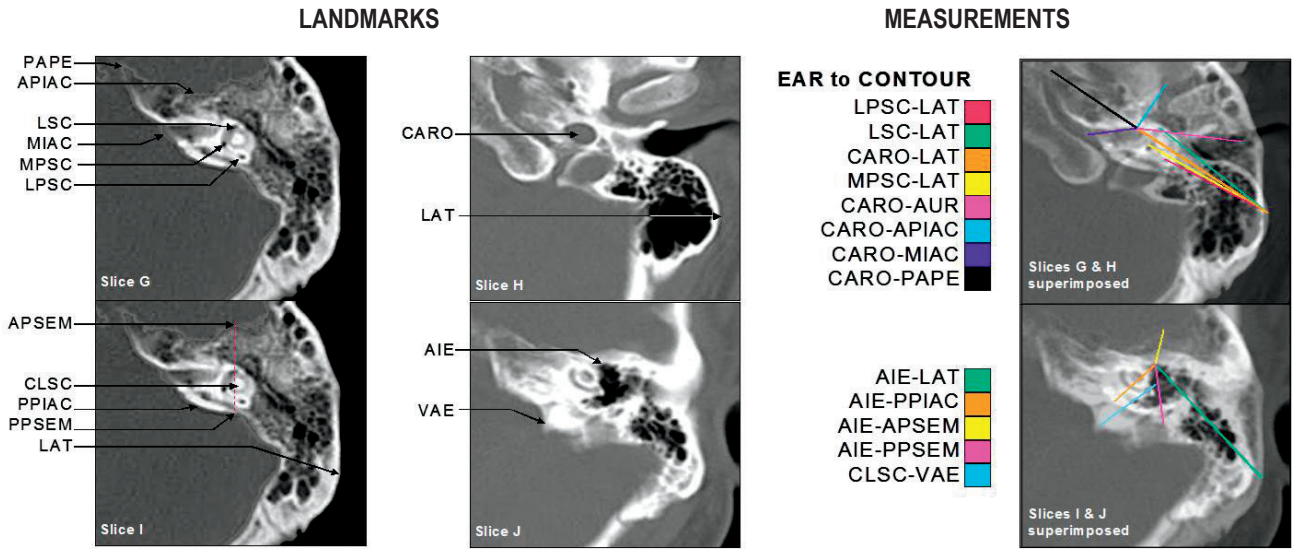

Image 1: The first two columns illustrate the landmark locations in the inner and middle ear segments of the petrous part of the temporal bone used in this research. The third column illustrates the measurements between the landmarks in the inner and middle ear segments. The measurements are color-coded according to the legend located between columns 2 and 3.

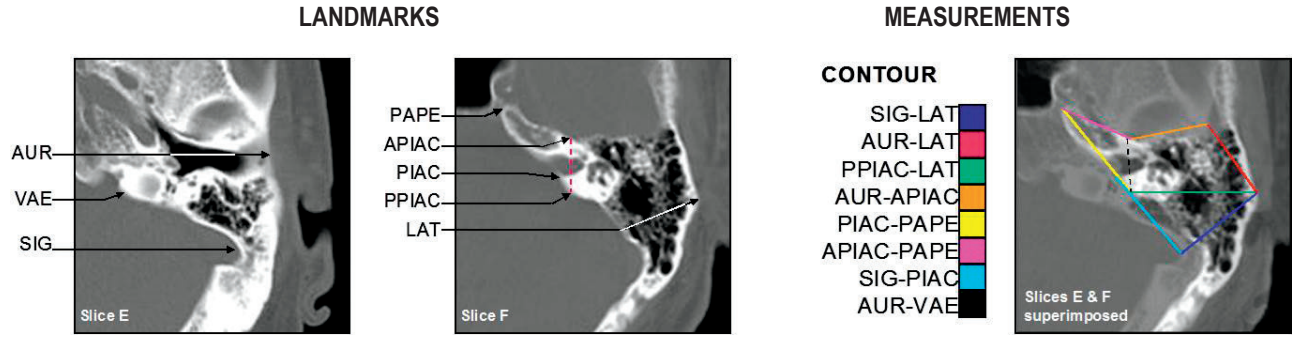

Image 2: The first two images (labeled slices E&F) illustrate the locations of the landmarks around the contour of the petrous part of the temporal bone. The third image illustrates the measurements between the landmarks around the contour of the petrous part of the temporal bone. The measurements are color-coded according to the legend located between the second and third images.

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sometimes present following a mass fatality incident. Many of the radiographic techniques employed for daily cases are not useful for postdisaster fragmentary remains. Some of the more diagnostic portions of the skeleton, including the frontal sinus, are at considerable risk of destruction. Focus of current/future methods for use in the mass fatality context should involve segments of the skeleton that resist taphonomic destruction, including the petrous portion of the temporal bone. It may also be difficult to employ radiographic techniques due to availability of antemortem radiographs, as the victims of mass fatality incidents are often more similar to the lay population rather than the deceased medicolegal population.

CONCLUSION

The forensic sciences have undergone a considerable transformation in recent decades toward a more robust network of services that are based on validated methods and accredited laboratories. Anthropological methods have evolved concomitantly from the anecdotal to the statistically validated, accurate, and repeatable methods that are being developed today. The need for more subjective anthropological evaluation of radiographs will continue to have a place in forensic anthropology for identification, but validation of these methods is as important as it is for other anthropological methods (sex, age and ancestry estimation).

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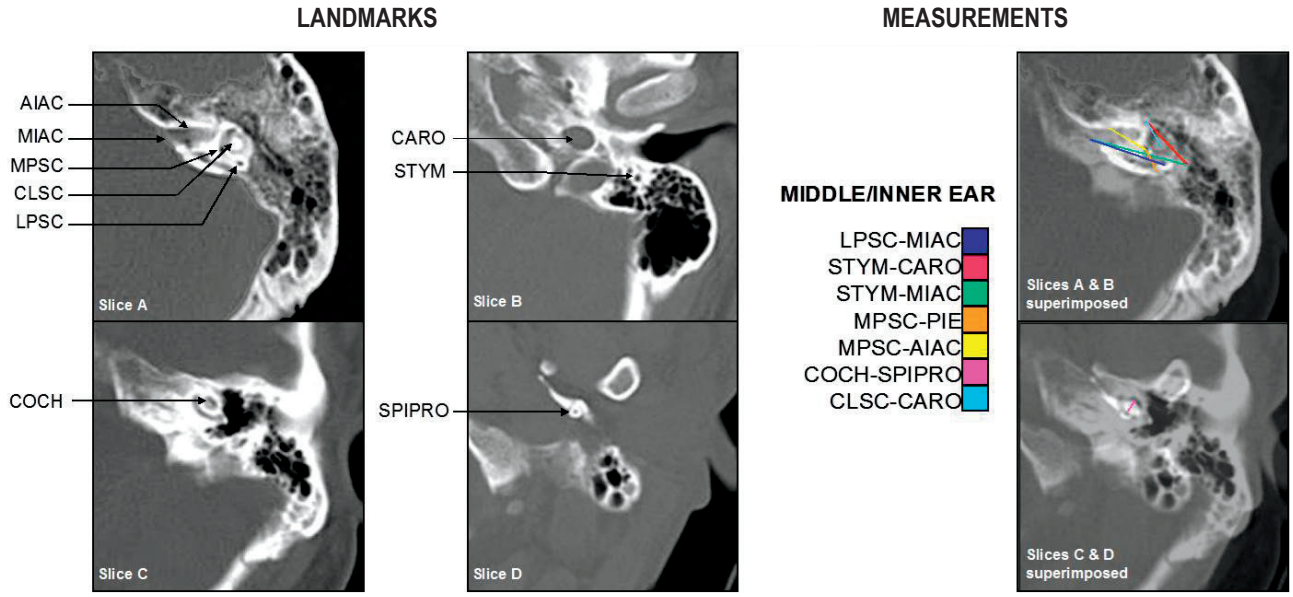

Image 3: The first two columns illustrate the remaining landmark locations in both the inner and middle ear, and the contour segments of the petrous part of the temporal bone. The third column illustrates the measurements between the measurements that extend between the landmarks of the inner and middle ear, and the contour of the petrous part of the temporal bone. The measurements are color coded according to the legend located between columns 2 and 3.

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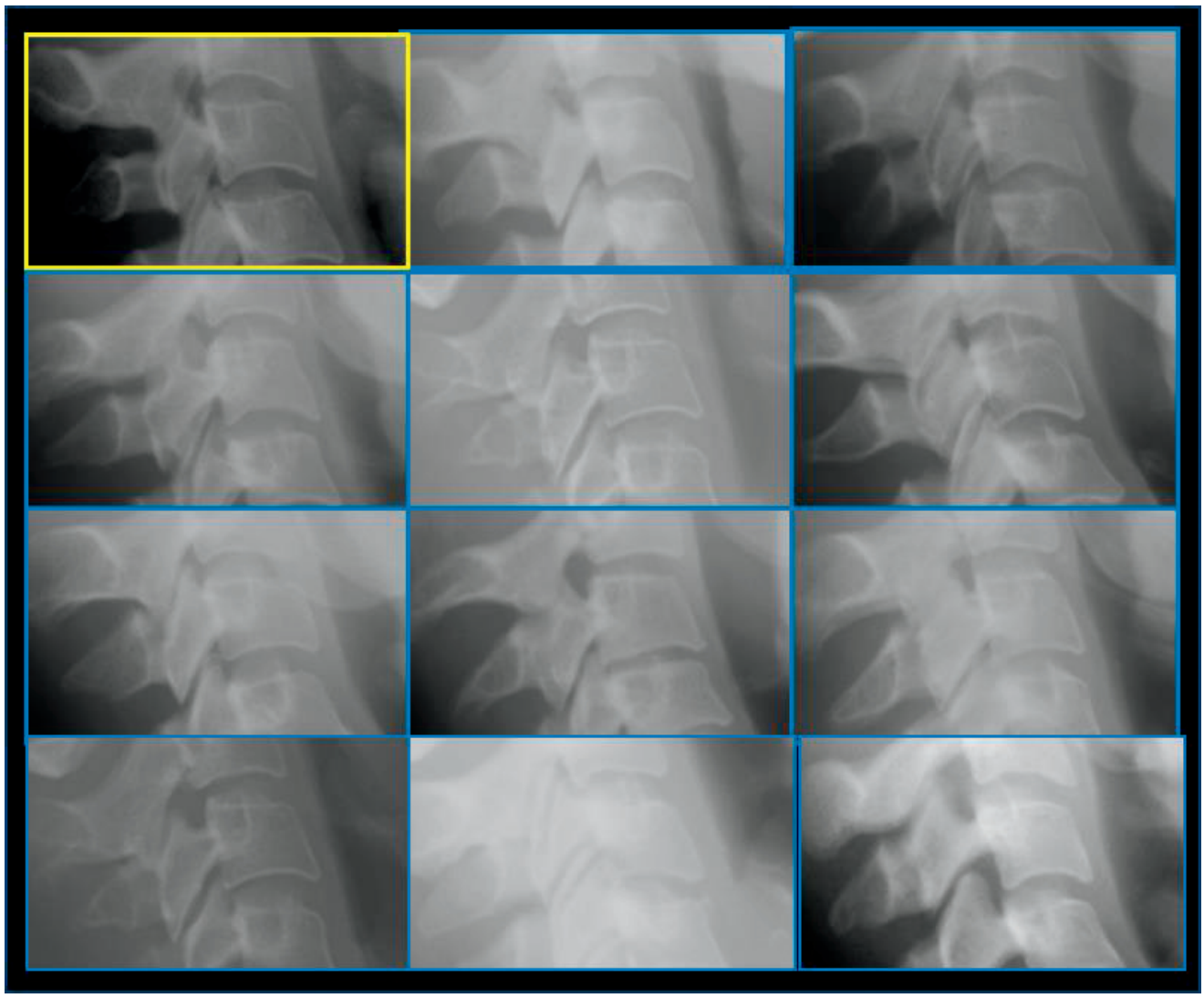

Image 4: Sample test array.

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The Biological Profile of Unidentified Human Remains in a Forensic Context

Dana Austin, Rebecca E. King

ABSTRACT

Estimation of the biological profile of unidentified human remains is a critical component of an anthropologic evaluation of unidentified human remains. The profile is used to search for missing persons that may match the decedent. The individual components of sex, ancestry, stature, and age at death require reliable methods to ensure accurate recording of these biological markers. This article showcases an unidentified skeleton that was misclassified as a female when the original evaluation was done in 1963. The revaluation in 2004 quickly led to resolution of the identity. Methods used today to evaluate the components of the biological profile are reviewed along with a limited review of the historic literature. *Acad Forensic Pathol. 2016 6(3): 370-390*

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As per Journal Policies, ethical approval was not required for this manuscript

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No identifiable personal data were presented in this manuscsript

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KEYWORDS

Forensic pathology, Biological profile, Demography, Sexual dimorphism, Sex, Age, Ancestry, Race, Stature, Forensic anthropology

INFORMATION

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INTRODUCTION

Unidentified human remains with a tentative identification are a common occurrence at most medical examiner's offices. Decomposition or other conditions may render a body unrecognizable. Modern forensic identification is accomplished by the comparison of antemortem records including fingerprints, radiographs, and DNA profiles with postmortem findings. Less common is an unidentified person with no tentative identification. In these circumstances, a biological profile is needed to lead the medicolegal investigation to a list of tentative persons. The biological profile includes the decedent's age at death, sex, ancestry, stature, and any individualizing traits that would be known to family and friends, such as the presence of braces on the teeth, healed or healing fractures, amputations, skeletal deformities, and other medical and anomalous conditions of the bones and teeth. An accurate biological profile provided by a trained forensic anthropologist is paramount for the investigation to reach an identification.

DISCUSSION

Most forensic anthropologists are likely to have worked cases that have gone cold for various reasons. The anthropology lab at the Tarrant County Medical Examiner's Office (TCME) has investigated many past cases where the skeletal remains were initially examined by a nonanthropologist and a biological profile was generated at the time of examination. In 2004, the first author received a skeleton that had been housed in the Fort Worth Police Department Crime Laboratory Evidence Locker since 1963, along with a copy of the analyst's case file. At the time of discovery of the decomposed, mostly skeletal remains, the Tarrant County Medical Examiner's Office was not yet established. The duty of the examination of the remains fell to the Crime Laboratory Director of the Fort Worth Police Department. The Director, being a good scientist, turned to the literature and found the sentinel publication by Wilton Marion Krogman, "*A Guide to the Identification of Human Skeletal Material,*" published in the Federal Bureau of Investigation Law Enforcement Bulletin in 1939 (1). In 1963, this would have been the most comprehensive of a handful of published references (2-6) on the subject of human biological profile creation from skeletal remains. A review of the case file along with the remains showed that the Director collected some of the data outlined in Krogman's guide (1). The maximum diameters of the humeral and femoral heads were measured correctly and unambiguously fell into the male range. The femur, tibia, and humerus were measured in inches and used to estimate the stature. When the measurements and observations were repeated, it was found that each one had been correctly recorded. Krogman's guide (1) clearly placed the skeleton on the male side of the male/female continuum; however, for unknown reasons, the remains were labeled as female. In the bulletin published by the Fort Worth Police Department Crime Laboratory the narrative of the remains includes a description of a "*green lady's jacket with gold lining and dark blue teen-age type socks*." Furthermore, the pelvis was complete; thus, the indicators of sex from the pelvis could have been evaluated visually as recorded in Krogman (1). There is no notation in the file that these indicators were examined.

It is unknown why the results of metric analysis of a few traits in the skeleton were not taken into account. It could have been due to unfamiliarity with Krogman's methods and that the estimate of sex was based largely on the observations of the clothing. Contained within the case file is a copy of the Fort Worth Press from February 3, 1964, showing a facial approximation drawing of the decedent (**Image 1**). The chin has male characteristics and the overall appearance is of a male with a female hairstyle. Also contained in the file is correspondence between the Crime Laboratory Director and law enforcement agencies with missing females. Multiple comparisons with dental records of missing females are documented.

In 2004, following the anthropology analysis which included the male sex assessment, TCME commissioned a clay facial reconstruction and submitted the results to the news media. Within hours, the office received multiple calls regarding the case. All of the calls were about a possible match to the missing person, Kenneth Glaze. Mr. Glaze was a 35-year-old

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male from Hillsboro, TX who lived in Fort Worth and was reported missing in August 1963. The facial reconstruction looked remarkably similar to Mr. Glaze (**Image 2**). In 1963 Hillsboro, TX was a small town that was served by a single dentist and we attempted to locate archived dental records to no avail. Fortunately, a maternal first cousin was located and was able to provide a sample for DNA analysis. The mitochondrial DNA confirmed the maternal relationship and the medical examiner classified the positive identification.

As the example above dramatically demonstrates, the standard components of the biological profile are critical to the successful resolution of many unidentified remains cases. The modern forensic anthropology lab-

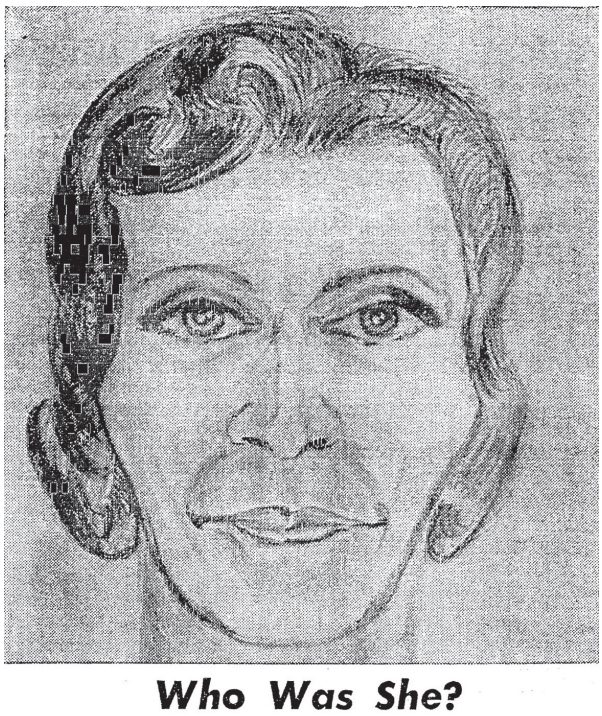

Image 1: Facial approximation of the decedent, February 1964.

Image 2: Clay facial reconstruction by Dr. Suzanne Baldon showing dentition compared to known photograph of decedent, 2005.

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oratory uses macroscopic, microscopic, metric, and radiologic information to estimate the age at death, biological sex, ancestry, and stature of an individual from the skeleton. Modern methods are based on scientific research that provides quantified error and accuracy rates and meets the guidelines for admissibility of scientific evidence (7). Additionally, the continued development of the Forensic Anthropology Data Bank (FDB) (8) has provided forensic anthropology with a wider variety of comparative skeletal data from the contemporary period, thus allowing more meaningful studies to be conducted on temporally relevant data for the development of methods used in forensic contexts.

This paper will explore the processes by which the biological profile is estimated by the modern forensic anthropologist. There is a tremendous amount of published material that addresses different components of the biological profile. This paper will address the most salient methodology used today with a brief description of the most pertinent historic references.

Sex/Ancestry Metric Evaluation

Similar metric methods are used to evaluate sex and ancestry and thus they are discussed together in this segment. Both sex and ancestry assessment rely on cranial and postcranial measurement data, Fordisc software, and multivariate discriminant function analysis (DFA). Morphological features are observed by the forensic anthropologist to form an initial opinion of the sex/ancestry for any skeleton, yet we rely on metric confirmation of our visual assessment. There has been a continual collection of measurement data for the past 30 years that is available for comparison to an unknown skeleton. Forensic anthropologists record spatial coordinates of anatomical landmarks on the cranium and measurement data of the mandible and postcranial skeleton. These data represent the size and shape of individual bones that allows for an estimation of sex and ancestry of unknown human remains. Forensic case data along with data from skeletal collections representing various genetic ancestries have been gathered by anthropologists into the FDB to build a database of groups commonly encountered in modern forensic casework. Sex and ancestry classifications are most commonly determined by using a computer program, Fordisc 3.0 (latest version: 3.1.307), that statistically compares measurements taken from unidentified cranial and postcranial remains to measurements from individuals of known sex and ancestry (9). Although this process appears to be uncomplicated, it is imperative to have an understanding of discriminant function analysis, the capabilities and limitations of the Fordisc software, and potential sources of error when applying these methods.

Current FDB cranial group sample sizes include adequate numbers of American whites (518 males/340 females) and blacks (156 males/96 females) and Hispanics of Mexican origin (227 males/62 females). The Chinese (n=79), Vietnamese (n=51), and Guatemalan (n=83) samples contain only males, and as with the Japanese (84 males/58 females), do not include many individuals who are American-born. Most individuals in the database are positively identified to sex and ancestry from antemortem information. All have 20th century birth years except the historical American Indian group (59 males/32 females). In this group, 15 males and five females were derived from forensic cases; however, the remainder have birth years from the mid to late 19th century (9, 10).

Recent technological tools, such as a digitizer, enable Cartesian coordinate (x, y, z) data point collection of cranial and postcranial anatomical landmarks that are used in sex and ancestry estimation. Software is available that converts the digitized coordinates into the cranial measurements used in Fordisc. The digitizer minimizes error as each landmark is recorded one time, as opposed to caliper measurements that necessitate the accurate location of many landmarks (e.g., basion) multiple times. The measurement is recorded by the instrument, reducing data entry errors. Measurement definitions are described by several authors (11-14) and proper understanding and application of measurement performance is essential to an accurate ancestry estimate. Because differences of a few millimeters may misclassify a cranium, and these missteps are common, measurement error should always be evaluated (9).

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To use Fordisc, the operator inputs measurement data and selects sex/ancestry groups for the comparison. Multiple analytical, reporting, and graphing options are available. Recommended operational guidelines can be found in the "help" file (9, 10). It is important to realize that some of the populations included in Fordisc are underrepresented and that may cause classification errors. For example, Hispanic males frequently misclassify as female in Fordisc due to low sample sizes of Hispanic individuals (15). Thus, interpretation of the results is critical to a positive outcome. The lack of large sample sizes of varied populations is a considerable limitation; however, the numbers continue to grow with time (9).

Fordisc uses DFA to compare inputted cranial and postcranial metric data from an unidentified forensic case to a database of known populations within the FDB. Discriminant function analysis has been used for many years to estimate sex and ancestry from human skeletal remains using the skull (16-20) and the postcranial skeleton (15, 21-37). Most of the early studies were developed using the Terry and Hamann-Todd collections and American military war dead, and thus represent black and white males almost exclusively. More recently, DFA based studies for estimating sex have been expanded to include males and females of populations considered to be Hispanic (15, 35, 37, 38) and modern American blacks and whites (36). Other metric methods have been developed for use in the postcranial skeleton, including those using measurements of the femur (39-42). Within Fordisc, the discriminant score of an unknown individual is compared to the mean discriminant function score for each reference group. When multivariate analyses are run, the results are organized by Mahalanobis distance (d^2) from the centroids of each group in the comparison (43, 44). Posterior probabilities and F, R, and Chi typicalities are reported for each test (**Image 3**). Higher probability and typicalities are more indicative of an assessment being correct. Low typicalities result from individual crania that are atypical of a group, don't belong to the group, or error, and should be considered with caution.

The estimation of sex from complete or nearly complete skeletal remains is straightforward in most cases when evaluated by a forensic anthropologist. Although it is commonly published that the reliability of sex assessment is best in the pelvis, second best in the cranium, and less accurate in the postcranial skeleton, recent research has shown that the latter two should be reversed in this statement. Recent studies looking at postcranial measurement data clearly shows that it outperforms the cranial measurement data for sex as-

FDB | Howells | Postcranial | Results | Graph | 3DGraph | Options

Basic | Extended | Log | Notes | Copy | Save | Print

Total Correct: 649 out of 1158 (56.0 %) *** CROSS-VALIDATED ***

Multigroup Classification of Current Case

Group	Classified into	Distance from	Probabilities Posterior	Typ F	Typ Chi	Typ R	
WM	**WM**	10.1	0.833	0.762	0.753	0.751	(122/485)
BM		14.9	0.076	0.406	0.385	0.442	(68/120)
HM		15.9	0.046	0.337	0.319	0.356	(146/225)
CHM		16.9	0.028	0.285	0.260	0.186	(58/70)
JM		19.3	0.009	0.174	0.155	0.094	(78/85)
AM		20.2	0.005	0.145	0.123	0.309	(39/55)
GTM		22.5	0.002	0.083	0.070	0.065	(73/77)
VM		23.7	0.001	0.063	**0.050**	**0.041**	**(48/49)**

Current Case is closest to WMs

Image 3: Fordisc 3.0 statistical output.

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sessment (36). Recent statistical models using ordinal observation data are cited as having 83-90% correct sex classification for the cranium, compared to correct classification rates at 90% or higher for postcranial metric classifications of long bones (36).

Recently, Hispanic skeletal collections have received a large amount of attention and new DFA of the population has shown promise in assessing sex and ancestry. In a recent study by Spradley, DFA, similar to that used in the Fordisc software, resulted in high accuracy rates for estimating Hispanic ancestry from the cranium (85% correct for Guatemalans and 76% for Mexicans) (38). Postcranial measurements of Hispanic individuals developed on U.S.-Mexico border crossing decedents from an Arizona medical examiner combined with measurement data on Hispanic individuals from the FDB were used to create DFA formulae with a reported classification rate greater than 80% for sex estimation (15) and 70% for ancestry estimation (45). For sex estimation, single bone section points were reported for fragmentary or partially recovered remains, and the most accurate of these ranged from 85-87%, with the radius, humerus, and clavicle displaying the highest cross-validated classification rates. When compared to the data from American blacks and whites (36), population-specific differences in sexual dimorphism were apparent (15). The most accurate bones for Hispanic sex discrimination were the radius and humerus; for American whites, the humerus and ulna; and for American blacks, the humerus and clavicle. Univariate statistics compared among groups reported the top three bone measurements for correct classification between these populations (15). For ancestry estimation, DFA formulae for postcranial measurements were most accurate in American blacks (85%) and American whites (80%) and a bit less accurate in Hispanics (72%) (45). The lower accuracy rates for Hispanic populations are likely due to unavailability of large sample sizes of Hispanic remains with known provenience, but anthropologists hope to improve metric ancestry estimates of Hispanic individuals in the near future (45).

In addition to analysis performed using Fordisc software, many anthropologists are using geometric morphometrics analysis (GM), a metric method that constructs a three-dimensional (3D) digital model of the bone in question by using Generalized Procrustes Analysis (GPA) to record digitized Cartesian coordinates of defined landmarks. The three-dimensional nature of GM data in its original state allows for the study of shape without size influences, which can incorporate sophisticated statistics into the formation of biological profiles. While GM can be used to test a variety of hypotheses (46, 47), several methods have been developed in recent years to estimate sex and ancestry from cranial, dental, and postcranial information with varying degrees of success (38, 48-59). The most holistic of these methods is 3D-ID, a computer program that acts in much the same way as Fordisc to produce sex and ancestry estimates of an unknown cranium (54). Another study used GM to assist in distinguishing between Hispanics and American blacks and whites, an ancestry estimation that has previously been difficult to perform accurately with traditional craniometrics (38). Geometric morphometric analysis has not yet been shown to be more accurate than traditional linear measurement methods, but these types of methods are still being refined (59, 60).

Nonmetric Assessment of Sex

Skeletal variation attributed to sexual dimorphism can be visually evaluated and used to estimate the biological sex of the individual. Overall size and muscular development are good indicators of sexual dimorphism in adults because they are influenced by extrinsic mechanisms such as biomechanical load bearing and intrinsic mechanisms including sex hormone levels (61). Skeletal robusticity is assessed by bone diameter and length, while bone rugosity is judged by the extent of development of markers of muscular and connective tissue interface with the bone (62). Populations vary in the expression of sexual dimorphism and it is therefore important to use comparative data from an appropriate population when applying these techniques to forensic cases.

Although there is a great deal of interest in bioarchaeology and forensic contexts to assess sex of immature skeletal remains, it has been shown by multiple stud-

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ies that there is insufficient discrimination to allow accurate estimations from unknown fetal, infant, or subadult material (63-67). Sex differences have been noted during fetal development in the ilium and pubis (68, 69), and postnatally in the os coxa (64, 65) and the mandible (70, 71). These explorations to separate the sexes of immature remains have shown that sexual dimorphism is not sufficiently developed in subadults and methods to estimate sex in subadult skeletons have low predictive value and high interobserver error.

In the forensic arena, the amelogenin locus as a biological sex marker is available in the forensic DNA short tandem repeat (STR) kit and is the most reliable method for confirming sex of immature remains. The commercial STR multiplex kits most commonly use a primer set that produces fragments of X and Y chromosomes. Amplification failure of the Y chromosome in male samples can cause misidentification of sex as female in these tests (72).

Sexual dimorphism in the adult human skeleton has been observed in the pelvis, skull, and postcranial skeletal elements. Nonmetric analysis of pelvic morphology (**Image 4**), along with metric methods, is reported to be the most reliable estimator of sex for adult skeletons (36, 73). Within the pelvis, the morphology of the pubic region is regarded by forensic anthropologists to contain the most reliable indicators for sex estimation. The presence or absence of the ventral arc (**Image 5**) and the subpubic concavity, and the morphology of the medial surface of the ischiopubic ramus were identified by Phenice as an accurate method for sex estimation (73). Recently, the three traits described by Phenice have been further explored by assigning five classifications to each trait (74). These revisions provide posterior probabilities and low estimated error rates in black and white males and females. The Klales method can be readily explored via a website with pictures and phase descriptions (http://nonmetricpelvissexing.weebly.com/) (74).

In addition to the features of the pubic region, the general robustness of the os coxa, particularly the diameter of the acetabulum, is a good indicator of sexual dimorphism. Studies reporting descriptions of morphology with scoring mechanism for sex estimation are available for the greater sciatic notch (63, 75), the auricular surface of the ilium (76), and pre- and postauricular sulci (63, 76). This anatomical area contains the thicker bone of the ilium that is likely to survive long-term burial and other destructive taphonomic processes more readily than the pubis.

Within the skull, nonmetric sex assessment relies mostly upon gradations in the robusticity and rugos-

Image 4: Comparison of female (left) and male (right) pelves.

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ity of the muscle attachment sites. Scoring methods for observations on the mental eminence, superior orbital margin, glabellar projection, nuchal crest development, and mastoid process volume are commonly used by the forensic anthropologist (63, 77). Recent evaluation has provided data on intra- and interobserver error and accuracy (77).

Nonmetric methods describing sexual dimorphism in other areas of the postcranial skeleton have been published recently on the morphology of the distal humerus (78, 79), rhomboid fossa of the clavicle (80), and bridging of the sacroiliac joint (81). Advanced valgus angulation of the female elbow is readily visible and is about 20-25° compared to 10-15° in males. Attempts to recognize the variation in morphology in the bony distal humerus have resulted in mildly accurate nonmetric techniques to distinguish sexual dimorphism (78, 79). Observations of the bony marker of the syndesmosis of the costoclavicular ligament found that a fossa on the clavicle was a strong indication of male sex and more likely to be a young male 20-30 years of age (80). Bony bridging and ankylosis of the sacroiliac joint has been found to have dimorphic presentation; males more commonly manifest extra-articular bridging, defined as bony bridging from the ilium to the sacrum with a dome-like appearance over the superior portion of the sacroiliac joint, while females demonstrate intra-articular bridging defined as smooth, continuous fusion that can lead to ankylosis of the joint (81).

Nonmetric Ancestry Assessment and Considerations

Morphoscopic ancestry estimation methods require visual assessment of skeletal traits that show popu-

Image 5: Female pubic bone. Ventral arc indicated by red arrows.

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lation variation according to broad ancestral groups such as African, Asian, and European. Studies have examined the frequency of trait expression in skeletal samples of known ancestry and evaluated these traits in unidentified remains to estimate ancestry. Recent methods assign numerical values to the expression of a trait, allowing for the calculation of accuracy and error rates (82). This quantification has statistically proven that nonmetric methods perform equally well in ancestry estimation as metric methods such as Fordisc (44, 83).

The majority of nonmetric traits analyzed for ancestry estimations are found on the skull. Observed traits include: shape of the nasal aperture, root, spine, bridge, and sill (42, 62, 83-87); shape of the orbit and interorbital breadth (83, 85, 86); angle of the midfacial profile and zygomatics (42); shape of the zygomaticomaxillary suture (83, 85, 86); presence or absence of zygomatic tubercles, inion hook, wormian bones, postbregmatic depression, and canine fossa (42, 62, 83, 86); shape of the cranial vault and presence and complexity of its sutures (42, 86); palate shape and complexity of its sutures (83, 85, 86); and shape of the mandible border, rami, and gonial angles (86, 88). Dental traits can also be indicative of ancestry, including the presence or absence of Carabelli's cusp, crenulated molars, and shoveled incisors (86, 89, 90). Many of these nonmetric traits are expressions of evolutionary adaptations to differing climates, making it possible to categorize expressions into broad geographically-based ancestry groups. Traits are also examined in the postcranial skeleton with varying degrees of accuracy, including the rugosity of the gluteal ridge and tuberosities (91) and bifid spinous process expression of cervical vertebrae (92).

Recent statistical analysis has found that, in distinguishing between American blacks and whites, six cranial nonmetric traits are most accurate: anterior nasal spine, inferior nasal aperture, interorbital breadth, nasal aperture width, nasal bone structure, and postbregmatic depression (82). The analysis of these six traits together has been shown to be nearly 90% accurate in estimates of black and white ancestry (82). The development of ancestry estimations for populations other than black and white has been delayed due to low representation of these groups in the Bass, Grant, Terry, and Hamann-Todd collections, the most readily available collections with known antemortem provenience. The most holistic collection currently available for study in the United States is the Forensic Anthropology Data Bank, developed at the University of Tennessee, which is based on traditional metric analysis of donated and forensically sourced remains from across the world (14, 43). The FDB includes Asian and Hispanic populations with limited sample sizes, thus representing less variation than may exist in the living populations. No Hispanic individuals in the FDB originate from the Caribbean, effectively eliminating the possibility of studying a large subset of the American Hispanic population (9, 49). While studies strive to establish methods for estimating Hispanic ancestry (38, 93-96), many in the field argue that borrowing the cultural definition of Hispanic as any persons hailing from Spanish-speaking countries is representative of far too much variation to be grouped into one biological ancestry (44, 49, 93, 96). Though Cuban and Mexican people would be considered Hispanic socially, those of Cuban ancestry have been found to display African morphology when evaluated geomorphometrically, while Mexican crania were found to appear more similar to Native Americans (49).

Stature Estimation

Stature estimation methods use bone length measurement data and regression analysis to predict a stature range that are compared against antemortem reported height included in routine medical checkups and listed on government-issued identification and military records. Regression formulae have been developed for all long bones (97-102). Because limb length ratios vary between ancestry groups and are affected by sexual dimorphism, a population-specific set of equations should be used for each sex/ancestry group; in the most commonly used software, Fordisc, the available equations encompass male and female black and white Americans and male Hispanic Americans (43, 99). Fordisc also gives an option to use a combined "Any" sex/ancestry group, but the stature range produced is much larger to account for the increased error

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when using these nonspecific equations and the use of this approach is suggested only when no population information is available (9). Based on original regression equations that estimated stature within a range of 3 cm (97-99), Fordisc calculates stature estimates for each long bone present as well as all possible combinations of bones and presents the stature range and error associated with each equation (9, 43). Final stature estimates are performed by choosing the equation with the lowest standard error and smallest range (9). Regression equations have also been developed using long bone measurements in non-American populations, including Eastern Europeans (103) and Guatemalans (104).

The most accurate adult stature calculations incorporate each bone that contributes to standing height and are deemed the "anatomical method." In this method, measurements of the cranium, vertebrae, sacrum, talus and calcaneus, and bones of the lower limb are combined with given values representing soft tissues to form an estimate of complete stature within a range of approximately 4.5 cm (105, 106). While this method can be used regardless of the individual's sex and ancestry, it does require all necessary bones to be present and complete, which can be difficult to achieve in the face of many taphonomic processes (105-107).

Total long bone length may be calculated from fragmentary long bones using linear regression that requires measurement data between anatomical landmarks (104, 108, 109). These equations are also sex- and population-specific and are currently available for American blacks and whites (108), Native Americans (109), and Guatemalans (104). Once calculated, the total long bone length may be used in stature estimation equations as substitutions for the actual measurements, but this method should be used with caution in a forensic setting as statistical error rates have not been established (104, 108, 109).

Just as in adults, subadult stature is estimated using long bone length equations that incorporate sex and ancestry (110-112). These age-specific regression equations are based on diaphyseal lengths taken from antemortem radiographic images (110, 111). Due to heavy influences on children's growth from a variety of environmental and nutritional differences, stature estimates in subadults are much more complex than those of adults and may be heavily influenced by socioeconomic status (110).

Age

Age at death estimations of unidentified remains are dependent on growth and developmental indicators for immature remains and degenerative indicators for adult skeletons. Knowledge of skeletal and dental development is critical to identify processes that provide age-specific data. Endochondral and intramembranous bone formation, ossification center appearance and growth, epiphyseal ossification and fusion, dental formation and eruption patterns, and histomorphological changes in diaphyseal cortices from birth onward are processes that provide usable data when predicting age at death. A visual scan of the skeleton readily distinguishes adult and subadult individuals. "Subadult," a broad term meaning "not yet adult," is commonly used interchangeably in the literature with more narrowly defined age terms such as fetal, neonate, infant, child, juvenile, and young adult. A multivariate approach is more accurate than a single age method approach (113, 114) thus the more completely recovered skeleton has more data available to accurately estimate the age at death.

Gestational age has forensic significance in a variety of circumstances including maternal/stillborn death, illegal abortion investigations, unattended fetal demise cases, and infanticide. Crown-rump and crown-heel lengths are commonly used to estimate the age of fetal and neonate remains. Regression formulae for predicting crown-heel length (115) and age in weeks directly (67, 116) have been developed using radiographic measurements of long bone diaphyses. Regression formulae are available for dry bone measurement of most bones of the cranial and postcranial skeleton except for vertebral elements (69).

Histomorphometric methods of subadult bone analysis use a phase system to evaluate the amount and location of primary lamellar bone, the absence or pres-

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ence and form of remodeling, the location of woven bone, and the thickness and composition of the cutaneous and pleural cortices in histological sections of subadult ribs (117).

Tooth development and eruption data are useful for estimating age until the early third decade (**Image 6**). Tooth mineralization has been found to correlate better with gestational age than skeletal development (67). Mineralization and cusp coalescence, crown formation, and root formation data for some deciduous and permanent teeth of males and females are available from radiological data (118, 119). Tooth formation/eruption charts are commonly used (63, 120); however, they combine sex data and present a wide age interval when the standard deviations of the mean are expanded to an appropriate range. Standards appropriate to the population and sex of the unidentified person should be applied when available. The London Atlas addresses tooth development and eruption for both sexes from 28 weeks *in utero* to 23 years. It can be downloaded and used free of charge (121, 122). The data in the atlas were compiled from cemetery populations and odontology collections and include English whites and Bangladeshi. Differences between dental and chronological ages have been evaluated and found to be minimal (123).

Early childhood age estimation is accomplished by comparison of skeletal development with radiographic atlases (124-126) and complimented by dental formation and eruption data. In the teenage and early adult years epiphyseal union together with permanent molar formation and eruption data (127-130), is most useful. Epiphyseal union data have been collected from various populations using dry bone evaluation (131-136) (**Images 7 and 8**) and medical imaging (137-141). Many of these studies document clinical norms of skeletal development for a particular chronological age. Forensic anthropologists work in reverse and estimate an age range corresponding to the physical expression of bone and tooth development.

Adult age estimates are generally much broader than those for immature remains due to the varied environmental and nutritional stresses experienced during the lifespan and the discrepancy between biological and chronological age in many individuals. When fleshed unidentified individuals are evaluated, it is common for the anthropologist to pull bone samples for analysis to predict the age at death. The skeletal elements most commonly examined are the pubic symphysis (**Image 9**) and the sternal end of the right fourth rib that have shown predictable morphological change with age. Data sets comprised of hundreds of individuals of known age, sex, and ancestry have been examined to develop techniques for predicting an age range for an unknown individual (131, 142-148) and comparative testing between methods has been conducted (149).

Additional skeletal elements are used to supplement age estimation data obtained from the pubic sym-

Image 6: Maxillary dental arcade: neonate (top photo)/five-year-old (bottom photo).

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Image 7: Medial clavicle epiphyses in the process of fusing.

Image 8: Humeral and radial epiphyses demonstrating fused elbow and ununited shoulder and wrist.

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Image 9: Pubic symphysis morphology comparison: young adult (top photo)/middle years (middle photo)/ late years (bottom photo).

physis and rib. These methods are applied as needed and often depend upon the availability of skeletal elements for analysis. The auricular articular surface of the ilium undergoes a morphological change with age (150, 151). The first rib costal surface geometric shape and the texture of the rib's tubercle have been shown to undergo predictable changes with age. The study combines the expression of each of these traits in a component analysis that provides an age interval estimate (152). Cranial sutures of the vault (153, 154) and palate (155) provide broad age estimations and are often used when only a cranium is recovered. Remodeling of the occipital condyles due to osteoarthritis may help narrow this range to younger adult versus older adult. Tooth root translucency and periodontal regression (156, 157) may also provide information to narrow an age range when only a cranium is recovered.

Overall degenerative changes in the skeleton are often considered (**Image 10**), especially by a more experienced forensic anthropologist. A few scoring techniques exist to quantify age-related changes in joint surface morphology including the development of vertebral osteophytosis (39, 131, 158, 159). Marginal osteophytes develop at the site of the insertion of the anterior longitudinal ligament (**Image 11**) (160). In extreme cases, the marginal osteophytes of articulating vertebrae many exhibit bony union or form a joint-like space at the point where they meet (160). Studies have shown that, in general, regression analysis does not find a strong predictive value of age using the scoring methods on osteophyte and osteoarthritis development within the vertebral column (159). However, osteophyte development is often used to narrow an age at death estimate established by methods in other parts of the body. General guidelines indicate that individuals aged 45 and older always show some development of lipping of the vertebral bodies, although this will be dependent upon the population or subpopulation and the physical activity level (158, 160).

Histomorphometric methods may compliment an age profile generated by other methods such as those discussed above; however, these data may also replace morphological methods in cases that consist entirely

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Image 10: Degenerative changes in the shoulder.

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Image 11: Osteophytosis of the vertebral column.

of bone fragments or isolated long bones and ribs. An unstained bone section reveals a lifetime of bone turnover (161). Bone remodeling is responsible for mineral homeostasis, maintenance of gross structure within the stresses of biomechanics, and repair of damage caused by a multitude of insults. The aging process leads to an abundance of fragmentary osteons that result from creation of secondary osteons during bone remodeling. The quantification and ratio of these structures are the major predicting variables in most histological age estimation methods along with the amount of unremodeled bone (in subadults) and mean osteon size (161). The first published method observed and quantified complete and fragmentary osteons to develop regression formulae for the lower extremities (162). Modifications have included methods using less destructive, smaller bone samples and upper limb bones (163, 164). Rib and clavicle methods count complete and fragmentary osteons over the entire cortical surface of a section to estimate the osteon population density that is used in the regression formula to predict age (165, 166). The variability of these methods across various populations has also been explored (167).

In constructing a final age interval, the forensic anthropologist will assess the developmental and degenerative changes mentioned above that are most appropriate to the anticipated age of the individual. An age interval is constructed based on the data gathered from the assessment with appropriate caveats noted. The final age estimate is a matter of expert judgment after synthesis of all available information.

Statistical methods applied to age estimation are evolving in forensic anthropology. Many methods presented in this article use a phase system to evaluate morphological traits. Multiple observed traits are grouped together with the assumption that the bony morphology of all traits is related and based on age (168). In the phase system, an analyst must make a decision to value one variable over another in assigning the phase at times when an individual specimen does not completely match the description (168, 169). The sample size, mean age, standard deviation, and 95% range of age within a phase, referred to as a percen-

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tile method, is not an optimal statistical strategy for comparison of an unknown sample. The 95% range is equivalent to listing the 2.5 and 97.5 percentiles of age. Percentile methods should include standard errors on the percentile because when the sample is subdivided into phases/stages, a single phase may only have a few cases to represent it and that stage may have substantial sampling variance (170).

An alternative approach that is gaining favor is to incorporate a component system that evaluates each trait independently and allows for that trait to have an individual course over the span of a lifetime (168). Component-based systems have been statistically evaluated using transition analysis, a parametric method for modeling the passage of individuals from a given developmental state to the next higher stage in an ordered sequence (170, 171). Transition analysis of component scores provides statistically robust age ranges that are less sensitive to problems resulting from developmental outliers and sample size constraints seen in the percentile method. A maximum likelihood estimate for the average age at which an individual is likely to transition from one phase to another is the result (136).

The recently released updated data collection protocols of the Forensic Data Bank reflects a movement from phase system aging methods to component-based systems evaluated with transition analysis (8). As described in the Data Collection Procedures manual, the pubic symphysis, iliac portion of the sacroiliac joint, and cranial sutures are examined. Defined components that undergo age-related morphological change are evaluated. Each component is scored by selecting one of the characteristic phase options presented with the system for each bone (8). Over time, the collection of these types of data will allow forensic anthropologists to test their accuracy and precision for estimating the age of adult skeletal remains.

CONCLUSION

The case study presented in this article demonstrates how inaccurate assessment of any component within the biological profile may impede the successful resolution of an unidentified remains investigation. Proper application and interpretation of anthropological methods produced an accurate biological profile 41 years later that resulted in a positive identification.

The biological profile comprised of sex, ancestry, stature, and age at death estimations is used to compare the data from unidentified remains to reported missing persons in order to generate leads in cases that have no tentative identification. The individual components are inputted into national databases such NCIC and NamUs where they can be accessed by law enforcement agencies and private citizens concerned with resolving missing person cases.

This article has distilled a large body of literature consisting of methods for estimating the components of the biological profile in order to inform forensic pathologists of the practices used in modern forensic anthropology laboratories.

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Metric Methods for the Biological Profile in Forensic Anthropology: Sex, Ancestry, and Stature

M. Kate Spradley

ABSTRACT

The biological profile, conducted by a forensic anthropologist, is necessary for severely decomposed or skeletonized remains. The biological profile consists of estimates of sex, age, ancestry, and stature. It is crucial to have a correct estimate of sex, as this designation will narrow down the search through missing persons reports by half (e.g., searching through NamUs). However, sex estimates can be population specific, necessitating accurate ancestry estimation. When estimates of age and stature are added, the search narrows further. If these estimates are incorrect, the unidentified human remains may never be identified. These biological profile components are estimated based on either metric or nonmetric methods (visual observation and recording of categorical data). While age is inherently nonmetric, stature is inherently metric. Estimates of sex and ancestry can take a metric or nonmetric approach. The purpose of this review article is to review metric methods in forensic anthropology (sex, ancestry, and stature), to provide general knowledge of why and how these metric methods work, and to highlight that estimates of sex, ancestry, and stature do not subscribe to a "one size fits all" model.
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INFORMATION

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INTRODUCTION

Metric methods of sex, ancestry, and stature play an important role in building the biological profile for unidentified human remains—the first step toward a positive identification. Because they involve well-defined measurements, metric methods for the biological profile have less potential for inter- and intraobserver error than nonmetric methods. The purpose of this article is to review the current status of metric methods for sex, ancestry, and stature estimation within forensic anthropology.

Sex, ancestry, and stature estimates depend on methods derived from the most appropriate reference data for use in forensic practice. In some cases, sex is more straightforward than ancestry as the outcome is one of two groups (for biological sex) while the outcome for ancestry estimation is one of multiple groups. Stature is an estimate along a continuum. For sex and stature, the best estimates are usually provided by population specific formulae. For example, formulae derived from one population group (e.g., Mexican-Americans) may not work well for another group due to differences in sexual size dimorphism. Moreover, an estimate of sex helps narrow down search parameters by approximately 50% when searching through missing persons reports for an identification hypothesis. An accurate estimation of ancestry and stature can narrow down search parameters even further.

This article contains three sections: sex, ancestry, and stature. Each section contains background information on each topic, describes the most appropriate method and data needed to make an informed estimation, and provides practical considerations on how to make the best estimation possible for each topic. Simple, straightforward conclusions are included at the end of each section to highlight the main points to consider when estimating sex, ancestry, and stature.

DISCUSSION

Sex Estimation

The pelvis provides the best estimate of sex based on differences in sexual size and shape dimorphism between males and females. Because females have the potential for childbirth, their pelves differ not only in size, but also in shape. Although the pelvis is the best estimator of sex, the second best indicators are postcranial bones. While using postcranial bones may seem counter to traditional teachings and older texts, Spradley and Jantz demonstrated, using large samples of individuals who self-reported as American black and white, that the long bones outperform the cranium in sex estimation achieving classification rates between 92-94% (1). Measurements of postcranial bones are often entered into a discriminant function formula (multivariate) or a sectioning point (univariate) that yields a score indicating male or female. As for the skull, it is usually measurements from the cranium (craniometrics) that are used in conjunction with a discriminant function program, Fordisc 3.1 (2), for an estimate of sex and ancestry.

Better results from the cranium can be achieved using three-dimensional (3D) computed tomography (CT) scans, computer automated analyses, automatic landmark detection, and linear discriminant function analysis. Abdel Fatah et al. was able to achieve 97% correct classification for sex from the cranium with 11 variables (3). These 11 variables consist of both standard and nonstandard measurements, meaning some of the variables could only be derived from the use of CT scans. In cases where there is a cranium only, this method is highly useful for sex estimation.

Postcranial bones

Although Spradley and Jantz demonstrated that postcranial bones outperform the skull in sex estimation, the formulae they provided are most applicable to Americans that identify as black or white. Moore et al., following the methodology outlined in Spradley and Jantz (1), developed population specific sex estimation criteria for Columbians (4). In 2013, Albanese developed nonpopulation specific methods for sex estimation using the clavicle, humerus, radius, and ulna and logistic regression (5). As many methods are population specific, sometimes population affiliation may not be accurately estimated if skeletal remains

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are fragmentary. Albanese's method worked well in general, with the exception of small males that were classified as female. Population groups that are nutritionally stressed during growth and development may produce individuals that do not reach their genetic potential for height (6). Spradley et al. found that Hispanic males, particularly migrants that died crossing the U.S./Mexico border, were more often classified as female using formulae derived from other population groups (7). For individuals working with populations that may contain smaller, gracile males, population specific methods will work best.

Gulhan et al. set out test the applicability of population-specific equations in a Turkish population for the purpose of assisting with mass fatalities (8). While not providing specific classification functions for the end user, Gulhan et al. did suggest that population-specific equations for the femur work best on a Turkish population. Frutos developed a univariate method of sex estimation from the superior-inferior femoral neck diameter for rural Guatemalans (9). These particular groups of Guatemalans were victims of genocide during the Civil War in the 1980s. Frutos was also able to develop sex estimation formulae from the clavicle, scapula, and humerus for these rural Guatemalans, with the humerus providing the highest classification accuracy (9-11). Overall, Frutos found that rural Guatemalans tend to be smaller than other North American groups, necessitating population-specific formulae for sex estimation (9).

Pelvic Bones

The pelvis provides a high degree of reliability using macroscopic, nonmetric data in conjunction within a statistical framework. However, several researchers have published metric methods for estimating sex from the pelvis. Mestekova et al. (12) using ten measurements from a French sample, tested a method proposed by Murial et al. (13), and achieved accuracies ranging from 92-97%. Bytheway and Ross utilized 36 landmarks and geometric morphometric methods (GM) and achieved classification rates between 98–100% (14). Measurements of the pelvis are often difficult and ambiguous due to the lack of identifiable and well-defined landmarks. Further, if enough of the pelvis is present to directly measure or collect landmark data, then a visual observation of nonmetric traits using statistical methods could also be employed with high accuracy (e.g., Klales et al. [15]) without the need for collecting measurements or landmark data.

Short, Flat, and Irregular Bones

Although the pelvis and long bones, followed by the cranium, are the most popular bones for sex estimation, in cases of extreme fragmentation or incomplete skeletal recovery, other bones may be informative for sex estimation.

Cranial bones

Focusing on specific bones of the cranium, Saini et al. used the mastoid process to estimate sex in Indian population with 87% accuracy (16). Further, Jung and Woo used the mastoid process and GM analysis in American whites, also with 87% accuracy (17). Saini et al. used measurements that can easily be obtained with calipers, while Jung and Woo used GM analysis, which requires a digitizer and is not easily extrapolated for use in forensic practice. Although both show promise for using the mastoid process in sex estimation, as this portion of the cranium is compact and often found intact in fragmentary crania.

Sternum

Hrytl proposed that the length of the manubrium compared to the sternum provides a ratio of 1:2 in females and 2:1 in males (18). Although Bongiovanni and Spradley found that Hrytl's law holds true, there is too much overlap between males and females for the ratio to prove useful (19). Rather, it is metric analysis in the form of discriminant function analysis that was a more reliable indicator of sex using a recent American sample (19). Franklin et al., using data derived from multislice computed tomography in a Western Australian population, found that sex could be estimated from eight standard sternal measurements with accuracies ranging from 72-85% (20).

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Scapula and Clavicle

Dabbs and Moore-Jansen utilized metric data from the scapula from the Hamann-Todd Collection, with birth years from the late 19th and early 20th century, to develop new criteria for sex estimation from the scapula (21). Dabbs and Moore-Jansen used a training sample that yielded results up to 94%; however, the test sample from a more recent cadaver collection in Kansas yielded classification rates of 83%. The discrepancy between the two classification rates could be that the test sample had more recent birth years that the training sample.

Using data derived from CT images from living people, Torimitsu et al. found that standard measurements of the scapula provided classification rates up to 95% for a Japanese population, although no test sample was utilized (22). Using a contemporary Spanish sample, surface scans, linear measurements and quantification of volume and curves of the clavicle, Mediavilla et al., was able to achieve classification rates of 85-100% for sex (23). Mediavilla et al. further suggest that volume alone provided a 92% correct classification.

In addition to the previously described methods, there are other published sex estimation methods including the use of hand, foot, and other bones (24-29). Use of hand, foot, and other bones such as patella, should only be used when no other highly diagnostic bones are available.

Summary of Sex Estimation

While the pelvis provides the best estimate of sex, the best metric method for sex estimation falls with the long bones, clavicle, and scapula. However, the single best bone for sex estimation will depend on the population at hand. Mulitvariate methods such as discriminant functions are more robust than univariate sectioning points.

Ancestry Estimation

Ancestry estimation, or estimation of geographic origin, is most commonly accomplished through statistical analysis of measurements from the cranium (craniometrics). However, postcranial measurements can also be used for ancestry estimation. Ancestry estimation has been shaped by long-term evolutionary trends and is best explained in terms of population genetic theory. Early humans traveled in small groups and migrated to various geographic areas across the earth. Over several hundred thousand years, evolutionary forces such as natural selection and genetic drift shaped differences in physical appearance of these various human groups (e.g., skin color, hair color, height). While there is more gene flow in recent human history, geographic, language, and cultural barriers (e.g., religion) still shape mating practices in the modern world. Population groups living in close geographic proximity are more similar to one another while populations groups living far apart are more dissimilar, a concept referred to as isolation by distance (IBD) (30).

Because underlying genetics shape human morphology, it is possible to use cranial and postcranial measurements to estimate where in the world someone comes from—based on IBD and assortative mating. Further, in the United States there is a concordance between socially constructed, bureaucratic racial categories (e.g., U.S. Census Bureau categories) and population substructure. Therefore, it is possible to estimate socially constructed racial categories from the human skeleton (31). The estimation of ancestry is an estimation and should always be expressed with a degree of probability. Further, populations are constantly changing due to migration and relaxation of barriers to gene flow. Moreover, ancestry estimation involves statistically classifying one individual into one of many groups. Therefore, when attempting to estimate ancestry, it is important to have appropriate reference groups for comparison purposes.

Reference Data

Obtaining reference data can be difficult. In the early 2000s, the Hispanic population began to increase and by 2014 Hispanics became the second largest population group in the U.S. (32). However, there was little skeletal data available for individuals considered

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Hispanic and little understood about the biological variation of these individuals. Due to the forethought of early anatomists, skeletal collections representing American blacks and whites born during the late 19th and early 20th centuries were readily available for study by forensic anthropologists (33). Several skeletal collections derived from body donation programs have been able to pick up where these anatomical collections have left off, including the William M. Bass Donated Skeletal Collection at the University of Tennessee (https://fac.utk.edu/wm-bass-donated-skeletal-collection/), the University of New Mexico Documented Skeletal Collection (http://www.unm.edu/~osteolab/coll_doc.html) and the Texas State Donated Skeletal Collection (http://www.txstate.edu/about).

Even with the more recent skeletal material, the collections still primarily contain American whites followed by American blacks with very few Hispanic or Asian-American groups. Due to increases in U.S./Mexico border crossing deaths over the past decade, standardized data collection of these deaths, particularly in Arizona and Texas (34), has allowed for a better understanding of the biological variation of individuals from Latin America and how to better estimate sex and ancestry for this diverse group.

Ross et al. found that Cubans, a group that would be considered Hispanic in the U.S., were more similar to American blacks and precontact Cubans (35). Using migrants that died crossing the U.S./Mexico border, thought to be Mexican, Spradley et al. found that this group displays an intermediate position between Native American and American whites (7). Thus Ross et al. and Spradley et al. were able to demonstrate variation among different groups considered Hispanic highlighting the importance of appropriate reference group selection.

Cranial and Postcranial Ancestry Estimation

Osteometric data, measurements that capture the overall size and shape of the skeleton, are the most commonly used data for estimation of ancestry (2, 36, 37). However, craniometric data (measurements from the cranium) are more often used than postcraniometrics. Sex estimation can be performed with single measurements through univariate methods like sectioning points, even though multivariate methods are more robust. Ancestry estimation is a multivariate endeavor and the Scientific Working Group for Forensic Anthropology (SWGANTH) guidelines suggest that the best practice is to use multivariate methods to estimate ancestry (38).

Fordisc 3.1 is a discriminant function program that contains craniometric data from recent population groups and uses standard, well-defined measurements for the estimation of ancestry (2). The program has a user-friendly interface where measurements from an unknown skull are entered into the program and then statistically compared to the reference groups. The program provides statistical output (Mahalanobis d^2 and posterior probabilities) that the user must interpret to ascertain which reference group the unknown is most similar to. Fordisc 3.1 is arguably the most widely used program for ancestry estimation. The authors of the program strive to continually update the program with current reference data. Recently, Spradley and Jantz suggested that nonstandard measurements, measurements calculated from landmark data collected by a 3D digitizer, provide better estimates of ancestry (39). Further, these nonstandard landmarks provide better estimates for Hispanic groups, likely because they capture craniofacial variation that standard, caliper-driven measurement cannot capture (39).

When the cranium is not available, postcranial metrics can provide reliable results. Using long bone lengths, trunk height, and bi-iliac breadth measurements, Holliday and Falsetti achieved good classification rates for ancestry estimation for American whites and blacks (40). However, estimating trunk height and bi-iliac breadth required all vertebrae and both innominants to be present. Using postcranial data from three groups, American blacks and whites and Hispanics, Spradley ran a discriminant function analysis for each postcranial bone, with classification accuracies reaching 75% (41). However, when all postcranial bones were combined, classification rates increased as high as 85%. Liebenberg et al., exploring ancestry estimation among

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three South African groups, also found that a combination of postcranial measurements worked better than using individual bones and achieved classification rates of 85% (42). Further, both Liebenberg et al. and Spradley found that results obtained from postcranial metrics were similar to results obtained using craniometric data from the same groups (41, 42).

Summary of Ancestry Estimation

It is possible to achieve good ancestry estimation with cranial or postcranial metric data, provided that the reference data is appropriate. Unlike sex estimation methods that provide an outcome of male or female, ancestry estimation requires user interpretation of statistical output for classification of an individual into one of many groups. Therefore, the user needs to have a working knowledge of multivariate statistics in order to make a sound estimation.

Stature

There are two main methods of stature estimation: mathematical models and the anatomical method (43). For mathematical models, it is usually long bone lengths regressed on stature that provides a prediction formula for stature estimation. In these cases, a measurement of the femur or measurements from a combination of bones are entered into a formula and a stature estimation is generated along with a confidence interval or prediction interval. Konigsberg et al. gives a discussion of inverse calibration and regression of stature on long bone lengths (44). The anatomical method consists of an estimation of stature based on measurements of various skeletal elements from the cranium to the foot. These skeletal measurements are then summed and a soft tissue and age correction factor may be applied (45).

Mathematical Models

Early mathematical stature formulae, such as Trotter and Gleser's formulae, were derived from measured stature from World War II dead and the Terry collection (46). However, in current practice, the Trotter and Gleser method is no longer applicable for current forensic cases due to secular changes in long bone length in the American population as regression-based stature equations are often population-specific and even period-specific (47). Ousley reviewed the merits of developing stature equations from measured (e.g., Trotter and Gleser) versus forensic stature (e.g., driver's license) (48). Ousley concluded that

> *…forensic stature estimation is less precise than Trotter and Gleser stature estimation but is more accurate for modern forensic cases because a forensic stature is the only stature available for a missing person.*

Further, Trotter and Gleser used standard errors to provide ranges for stature. Ousley recommends using formulae that provide prediction intervals (48).

While most stature formulae are population specific, they are also period-specific. Secular change, short-term generational change in human morphology, has been shown to affect heights (49). Fordisc 3.1, in addition to ancestry estimation, also estimates stature and it does so "on the fly" (50). Fordisc 3.1 will allow a user to enter all available postcranial measurements into the program. Based on the reference data in Fordisc and the measurements selected, the program will provide multiple stature equations and the end user can choose the one with the highest R squared value. When estimating stature in Fordisc 3.1, the user also has the option of selecting from "20th Century Forensic Stature," "Trotter Measured Stature," or "19th Century Cadaver Stature," depending on the need for estimation. Additionally, a prediction interval is provided.

Albanese found that using century specific equations in Fordisc did not provide better results (51). However, the test sample used for the basis of these conclusions had birth years ranging from the late 19th to the early 20th century.

Anatomical Method

The anatomical method is best suited for all population groups as it lacks the temporal sensitivity of

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mathematical stature and accounts for any differences in long bone proportionality among groups. In 1956, Fully developed an anatomical method of stature estimation (52). In 2006, Raxter et al. published a test of the Fully method providing clear definitions for employing the method (45). Further, in 2007, Raxter et al. published a technical note urging anyone using the formula to use an age-specific equation as stature can decline with age (53). Maijanen tested eight different versions of the anatomical method (54) and found that the Raxter et al. (45, 53) modification of the Fully technique had a low error rate and that anatomical models in general work well for individuals with body proportions outside of the normal range of human variation. The revision of the Fully method by Raxter et al. includes measurements of cranial height, vertebral heights, sacral height, long bone lengths, and a measurement from the articulated calcaneus and talus (45, 53). While this is the best method to use, according to SWGANTH, it also requires a complete skeleton, which is not always available.

Summary of Stature Estimation

Mathematical methods provide a good stature estimate for incomplete skeletal remains, although it is important to keep in mind the population group and the time period that was used to develop the method. The anatomical method provides the best estimate of stature and is not population or time period-specific and should be used when the complete skeleton is available.

CONCLUSION

It is important to remember that estimation of sex, ancestry, and stature are estimations, approximations of reality. These approximations may be close to reality if we use the best method, based on the most appropriate reference data with regard to population group and time period. Metric estimations of sex are more robust if multivariate approaches are utilized, such as a classification function derived from a discriminant function analysis. However, if dealing with fragmentary remains, then univariate sectioning points may be the only option.

Ancestry estimation is inherently multivariate and using a single metric is considered unacceptable practice (38). Craniometric data, in conjunction with multivariate statistical models, are highly reliable for ancestry estimation. The ancestry classification is predicated on the assumption that the unknown individual belongs to one of the reference groups (50), therefore it is important to be familiar with the demographic structure of the population at hand and have the ability to interpret statistical output.

The best stature estimation method is the anatomical method (38), in particular the modification of the Fully technique (45, 53). However, this technique requires a nearly complete skeleton. If the Fully method can't be used, postcranial metrics can be entered into Fordisc 3.1. Fordisc 3.1 contains reference data from forensic cases around the country and donated skeletal collections, therefore making it applicable for forensic casework.

No matter what methods are used for sex, ancestry, and stature estimations, they should always be based on the best possible reference data.

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Ancestry Estimation Using Macromorphoscopic Traits

Amber Plemons, Joseph T. Hefner

ABSTRACT

Anthropologists have a lengthy history using cranial nonmetric traits to assess biological distances between populations. These concepts were adopted by forensic anthropologists to estimate ancestry at the individual level using population-based human variation. However, this method of estimation must adhere to the Daubert guidelines to be applied in the modern court system. To that end, a set of cranial macromorphoscopic traits have been proffered to generate a methodological approach to the estimation of ancestry that can be empirically tested and verified. Additionally, various statistical frameworks, parametric and nonparametric, have been employed to calculate error rates and provide probabilistic statements of the strength of these estimations. Recent studies have further advanced the reliability and validity of macromorphoscopic trait analysis through reference datasets, validation studies, and demonstrable exploration of the complex population histories impacting human variation between and within populations worldwide. *Acad Forensic Pathol. 2016 6(3): 400-412*

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KEYWORDS

Forensic pathology, Forensic anthropology, Ancestry estimation, Macromorphoscopic traits, Classification statistics, Daubert

INFORMATION

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INTRODUCTION

Ancestry estimation from human skeletal remains is one of the primary objectives of the forensic anthropologist when establishing a biological profile for unidentified human skeletal remains. Such estimations can be accomplished through various methods, including cranial metrics (1, 2), dental metrics (3, 4), dental morphology (5, 6), and macromorphoscopic traits (7). Cranial metric analysis is generally the most utilized method for ancestry estimation; however, this method is of limited use when skeletal remains are fragmented or poorly preserved (8). Macromorphoscopic traits can be coupled with cranial metrics to strengthen ancestry estimations or they may provide an alternative method to classify ancestry when cranial metric data cannot be collected.

Macromorphoscopic traits are slight variations in cranial form (7), which capture some aspect of cranial morphology through an assessment of 1) a bone's shape (e.g., nasal bone structure), 2) a bony feature morphology (e.g., inferior nasal aperture morphology), 3) a suture's shape (e.g., zygomaticomaxillary suture), 4) the presence or absence of a particular feature (e.g., postbregmatic depression), and 5) a bony prominence or protrusion (e.g., anterior nasal spine) (7). Cranial morphology as a tool to discriminate between groups of humans is not a new approach, but is rooted in the works of 18th and 19th century natural historians and biologists. For example, Linnaeus created a taxonomy of four human subspecies (*Homo sapiens amercianus, africanus, asiaticus,* and *europaeus*) based on morphological variation between crania (9). While others built upon the work of Linnaeus, modern forensic anthropologists rely on procedures developed at least initially by E. A. Hooton (1887-1954) at Harvard University. Hooton focused the majority of his studies on human variation using cranial metrics and cranial nonmetric traits to distinguish between so-called "races" of humans.

Hooton's acceptance of the biological validity of discrete packages of humans led him to believe adaptive traits—those that respond to environmental influences—should be avoided so analyses could focus on variation specific to each biological race (10). Hooton's methodology to racial classification from cranial morphology resulted in a long-standing acceptance of the typological approach to ancestry estimation in forensic anthropology (8). Until very recently, most forensic anthropologists viewed cranial nonmetric traits (i.e., macromorphoscopic traits) as expressions of a character state specific to one ancestral group, a method we now refer to as the "trait list approach" (8, 11).

The trait list approach is the result of the Harvard List, a scoring system for traditional cranial morphological traits initially developed by Hooton (12, 13) to determine biological relatedness between populations via archaeologically derived skeletal samples. Today, the trait list approach centers on line drawings and trait tables outlining so-called expected trait values within groups based on typological models of human variation. As conflicting theories on the existence of race developed within science in general and more specifically in anthropology, many anthropologists switched focus from studies of race to population-based studies intending to understand the complexities of human variation without the use of broadly based geographic races.

Throughout the 20th century, forensic anthropologists continued to use the Harvard List scoring system. Unfortunately, the continued reliance on this subjective method results in an approach to ancestry estimation that relies heavily on the experience of the observer and does not account for the total range in human variation due to the typological nature of trait lists. Moreover, the visual assessment of these traits and subsequent comparison to trait lists is usually followed by *post hoc* trait selection to support a conclusion, an unscientific and unverifiable approach in any science. The trait list approach was unscientific and unverifiable because there was no way to empirically test the method nor could forensic anthropologists calculate an error rate for a final estimation of ancestry (14). Although the trait list approach to the estimation of ancestry has largely fallen out of favor, the method continues to be used in some laboratories today.

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Forensic anthropologists still using the trait list approach frequently cite Rhine's study on nonmetric traits (15) to justify using the method in forensic case reports. Rhine documented 45 cranial traits for American black and white, Hispanic, and Amerindian groups (15). However, as he notes, the results are somewhat uncertain due to limited sample sizes and the high occurrence of unexpected trait values within groups (16). In addition to those shortcomings, the trait list approach does not currently meet the Daubert criteria. To satisfy the Daubert requirements, Hefner developed a standardized and more objective framework for scoring macromorphoscopic traits (7). This new methodology is a more rigorous approach to ancestry estimation and provided a starting point for future work.

DISCUSSION

Macromorphoscopic Trait Analysis

The Daubert guidelines underscored the need to produce a more scientific framework for macromorphoscopic trait analysis. Ousley and Hefner coined the term macromorphoscopic traits by noting the differences between the traditional cranial nonmetric traits used in biodistance analysis for population comparisons and the traits used by forensic anthropologists to estimate ancestry for an individual. They also hinted at the potential for trait analysis on a more robust level using statistical analyses (14). Building on that research, Hefner examined eleven macromorphoscopic traits for African, European, Native American, and Asian populations and indirectly recommended several statistical procedures appropriate for classifying unknown crania into an ancestral group (7). **Table 1** lists a number of macromorphoscopic traits and their standard abbreviations. Hefner provides illustrations (line drawings) and definitions for these traits (7). His research focused on determining trait frequencies within and between groups, intertrait correlations, and suitable statistical procedures for classifications. Hefner reported classification rates between 84% and 93% depending on the statistical method used (i.e., logistic regression, naïve Bayesian, k-nearest neighbor) and the combination of traits incorporated in an analysis (7).

Applied statistical methods are lacking from the earlier work of Hefner and colleagues. Recently, Hefner (17) and Hefner and Ousley (18) reported that using fewer traits may provide more accurate classifications. By narrowing the list of traits used in an analysis, the *post-hoc* nature of trait selection is mitigated. The traits suggested by these researchers were selected based on previous research identifying their utility for classifying unknown ancestry between American black, American white, and Hispanic groups and through stepwise variable selection procedures in multivariate statistical analyses (17). We will focus herein on seven of the more commonly employed traits. A description of each is provided below. **Figures 1-3** provide the general location of each trait on a diagrammatic cranium. Figures corresponding to the descriptions below are available from Hefner (7, 17).

Macromorphoscopic Traits

The anterior nasal spine (ANS) is a protrusion of bone extending forward at the base of the nasal aperture. In some cases the anterior nasal spine is quite small; in others the anterior nasal spine dominates the vertical maxilla. Because of the fragility of the anterior nasal spine and the position of this trait on the face, tapho-

Table 1: Macromorphoscopic Traits and Their Standard Abbreviation

Morphoscopic Trait	Abbreviation
Anterior nasal spine	ANS
Inferior nasal aperture	INA
Interorbital breadth	IOB
Malar tubercle	MT
Nasal aperture width	NAW
Nasal bone contour	NBC
Nasal overgrowth	NO
Palate shape	PS
Postbregmatic depression	PBD
Supranasal suture	SPS
Transverse palatine suture	TPS
Zygomaticomaxillary suture	ZS

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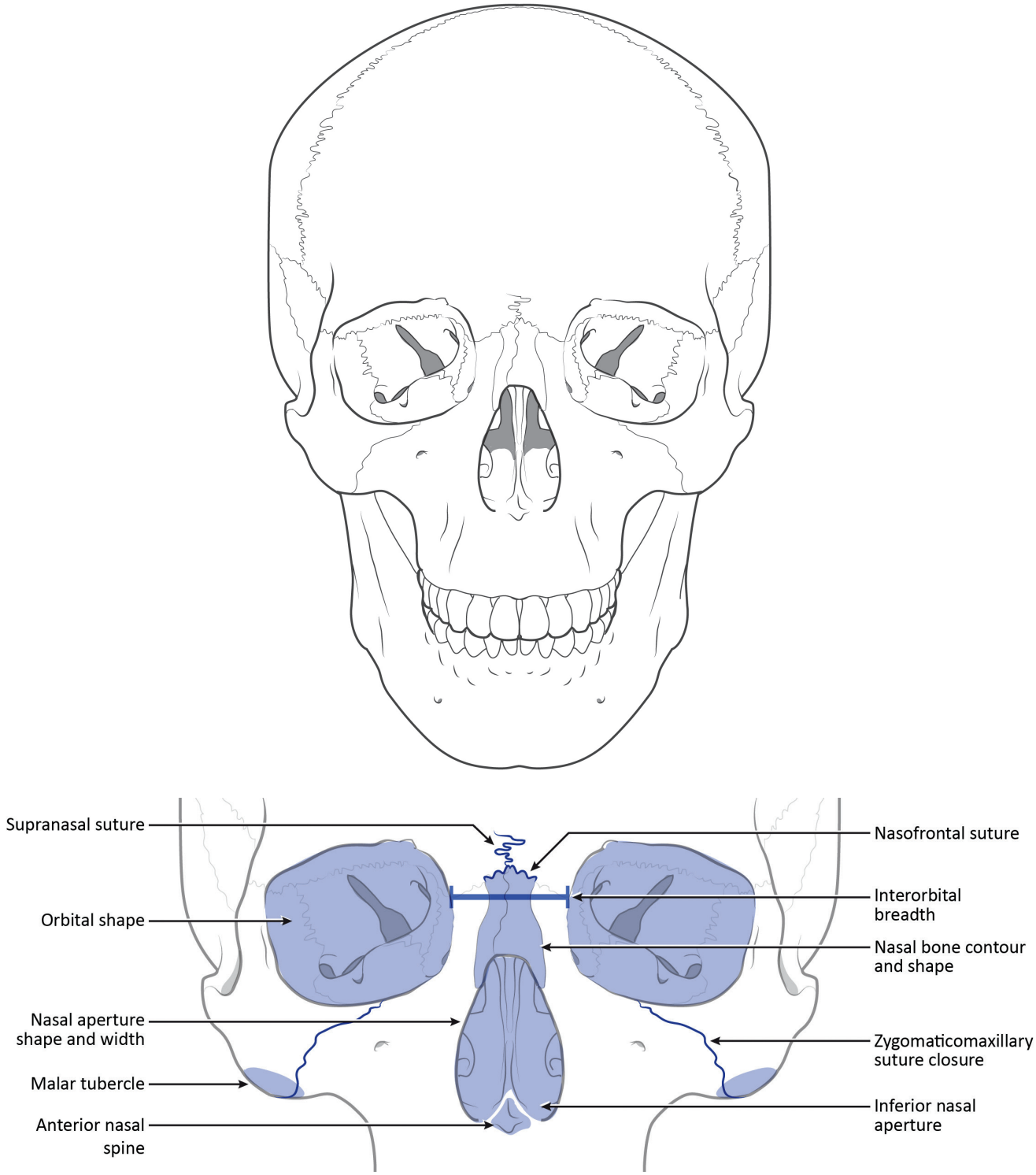

Figure 1: Anterior views of a cranium to demonstrate approximate location of macromorphoscopic traits. Drawn under contract with professional medical illustrator Diana Kryski.

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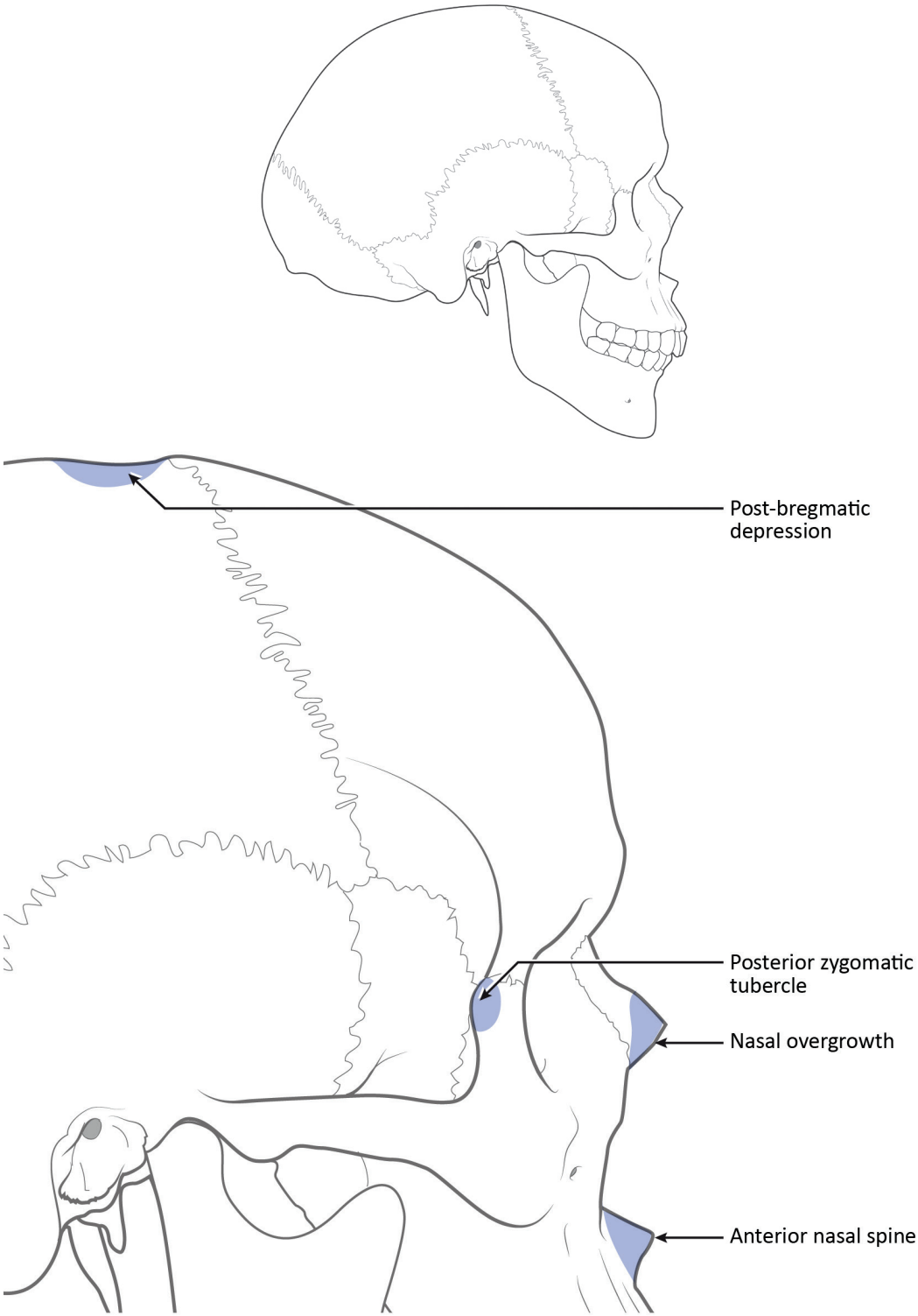

Figure 2: Lateral views of a cranium to demonstrate approximate location of macromorphoscopic traits. Drawn under contract with professional medical illustrator Diana Kryski.

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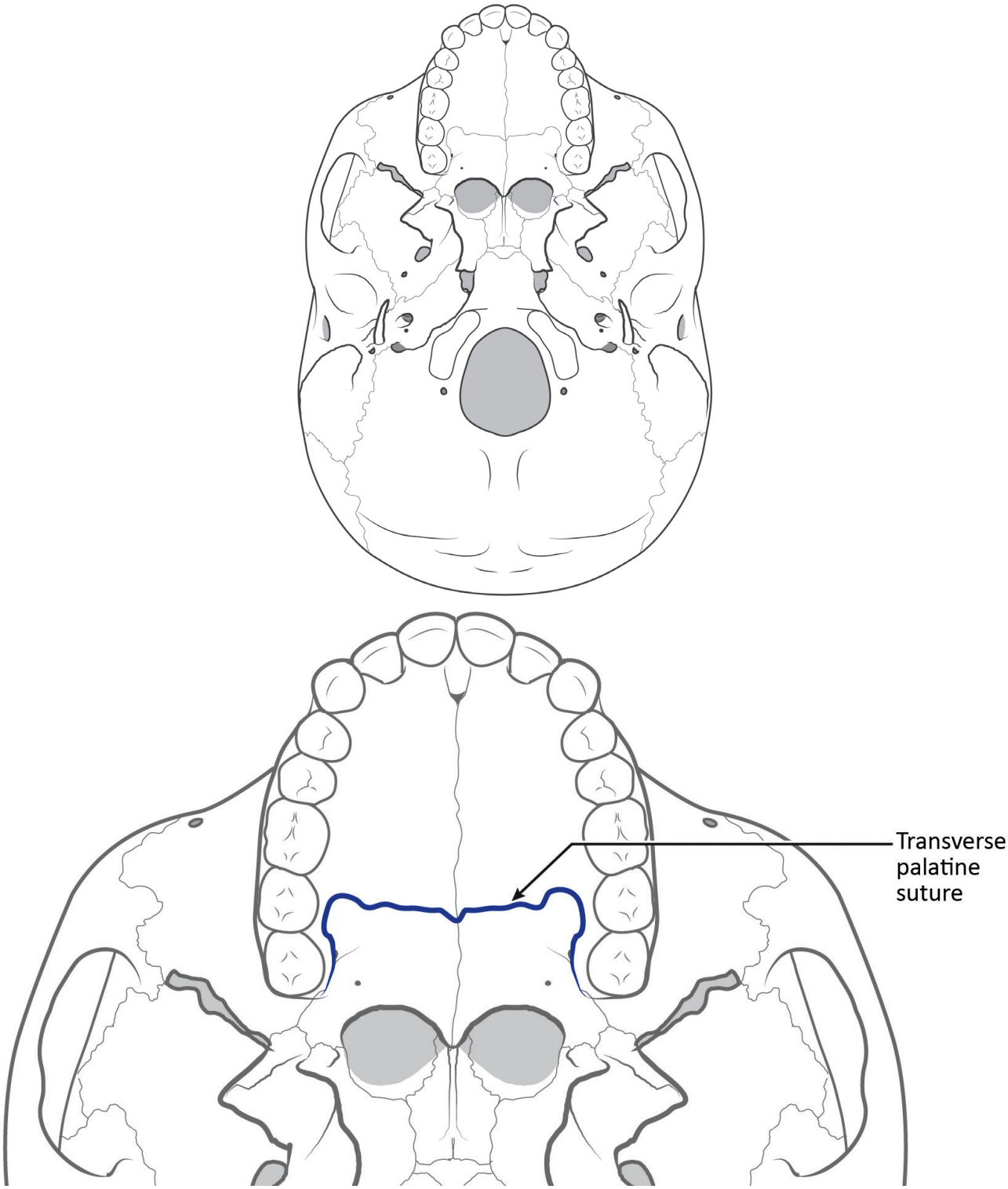

Figure 3: Inferior views of a cranium to demonstrate approximate location of macromorphoscopic traits. Drawn under contract with professional medical illustrator Diana Kryski.

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nomic factors and pathological responses to disease can alter the projection of the spine. Those crania exhibiting trauma, pathology (including alveolar resorption), or postmortem damage to the overall inferior nasal margin should be excluded from the analysis. To score the anterior nasal spine, view the cranium laterally. Anterior nasal spine is scored progressively as slight, intermediate, and marked: 1) *Slight*- minimal to no projection of the anterior nasal spine beyond the inferior nasal aperture; 2) *Intermediate*- a moderate projection of the anterior nasal spine beyond the inferior nasal aperture; 3) *Marked*- a pronounced projection of the anterior nasal spine beyond the inferior nasal aperture.

Inferior nasal morphology (INA) is the most inferior portion of the nasal aperture, which, when combined with the lateral alae, constitutes the transition from the nasal floor to the vertical portion of the maxillae, superior to the anterior dentition. Inferior nasal aperture is an assessment of the shape of the inferior border of the nasal aperture just lateral to the anterior nasal spine. The morphology of INA ranges from an inferior slope with no delineation of the inferior border (guttering), to a sharp and vertical ridge of bone (nasal sill). The five character states of INA should be scored following these guidelines: 1) *Guttering*- a pronounced sloping of the nasal floor beginning within the nasal cavity and terminating on the vertical surface of the maxilla, producing a smooth transition (this morphology is can be differentiated from INA 2) by noting the more posterior origin and greater slope of INA 1; 2) *Partial Guttering*- a moderate sloping of the nasal aperture beginning more anteriorly than in INA 1, and with more angulation at the exit of the nasal opening; 3) *Straight*- a straight transition from nasal floor to the vertical maxilla with no intervening projection of bone, usually angled sharply, although more blunted forms have been observed; 4) *Partial Sill*- any superior projection of the anterior nasal floor, creating a weak (but present) vertical ridge of bone traversing the inferior nasal border (partial sill); 5) *Nasal Sill*- a pronounced ridge (sill) obstructing the nasal floor-to-maxilla transition.

Interorbital breadth (IOB) is the distance between the dacrya. As a macromorphoscopic trait, interorbital breadth is assessed relative to the total breadth of the facial skeleton: 1) *Narrow*, 2) *Intermediate*, and 3) *Wide*.

Nasal aperture width (NAW) is the breadth of the nasal aperture relative to the facial skeleton. The width of the nasal aperture is: 1) *Narrow*, 2) *Medium*, and 3) *Broad*.

Nasal bone contour (NBC) is the contour of the midfacial skeleton in the region where the nasal bones and the frontal process of the maxilla meet. Assess the contour approximately 1 cm below nasion. The following character states are used to assess NBC: 0) low and rounded; 1) an oval contour, with elongated, high, and rounded lateral wall; 2) steep lateral walls with a broad (roughly 7 mm or more) and flat superior surface plateau; 3) steep-sided lateral walls and a narrow superior surface plateau; 4) triangular cross section and no superior surface plateau.

Nasal overgrowth (NO) is the inferior projection of the lateral border of the nasal bones beyond the maxillae in the area of *nasale inferious*. Assessment of nasal overgrowth does not include anterior bulging of the nasal bones. Observations should be made of the left side if it is undamaged. If the left side is damaged, the right side may be substituted. If both nasal bones are missing or fractured (ante-, peri-, or postmortem), the trait is not scored. Running a finger along the borders of the maxilla and nasal bones near *nasale inferious* to determine whether a projection is present may be useful. Nasal overgrowth is scored dichotomously as 0) *absent* or 1) *present*.

Postbregmatic depression (PBD) is a slight to broad depression along the sagittal suture posterior to bregma that is not the result of pathology or trauma. Observed in the lateral profile, the trait is scored as 0) *absent* or 1) *present*.

Analytical Options

There are several tools available for the collection of macromorphoscopic data. The computer program Osteoware (Smithsonian Institution, 2015) includes

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the eleven macromorphoscopic traits originally assessed by Hefner (7) as well as five additional traits (nasal aperture shape, nasal bone shape, naso-frontal suture, orbital shape, and posterior zygomatic tubercle). This software provides descriptions for each trait expression together with images and a back-end data management system using a relational database. Following data collection, trait scores can then be applied to classification models providing the necessary statistical framework for analysis. Another program, based largely on Osteoware, is Macromorphoscopic Traits 1.61 (MMS), a free-standing beta-version designed for data collection. This program is one part of a data collection effort for the Macromorphoscopic Databank (described in more detail below).

There are a number of appropriate classification statistics for analyzing macromorphoscopic data. Hefner suggests k-nearest neighbor, canonical analysis of principal coordinates (CAP), artificial neural networks, and other non- and semi-parametric methods to classify unidentified individuals (8). Hefner and Ousley outline multiple methods of analysis and provide a novel statistic, the Optimized Summed Scored Attributes, or OSSA, for a dichotomous classification between American blacks and American whites (18). This method relies on the bimodal distribution of optimized macromorphoscopic trait scores to provide an estimation of ancestry. More detailed discussions on these statistical methods are available in Hefner (8) and Hefner and Ousley (18). Several case studies presented below will guide the reader through a typical analytical process, demonstrating trait scoring, a relatively simple analytical process, as well as reporting strategies for casework.

More Recent Advances

Macromorphoscopic traits analysis has recently witnessed expansion and improvement. Two primary lines of research include testing the validity and observer error of Hefner's original study (19, 20, 21) and expanding that method to other population groups (22-25). Several important studies are highlighted below.

Klales and Kenyhercz (21) conducted a validation study of Hefner (7). This study adhered to the Daubert guidelines, which require methods to be empirically tested and validated. The authors examined 208 American white and American black individuals from the Hamann-Todd Osteological Collection to determine if classification is successful between the two groups, whether sex impacts classification rates, and assess observer error between experienced and inexperienced observers. Overall, this study supported the findings of Hefner (7) with similar trait expressions between the groups, as well as higher classification rates when pooling male and female samples in the reference collection. The classification accuracies ranged from 73.3% to 86.6% depending on the combination traits used and the statistical procedure applied, with rates falling to 46.7% and 64.3% when sex is included (19). However, the authors found that interobserver error was greater between experienced and inexperienced observers than previously reported by Hefner (7) and L'Abbe et al. (22). Klales and Kenyhercz (21) recommend forensic anthropologists familiarize themselves with macromorphoscopic traits, their various character state expressions, and the trait definitions prior to performing an analysis during casework (19).

The second area of advancement in macromorphoscopic trait research is expansion of these methods to other groups beyond the traditional American populations. Several studies broaden the application of this method to accommodate current populations across the globe. First, the rising Hispanic population in the United States required updated ancestry methods. Recent studies focused on determining which macromorphoscopic traits are most reliable for classifying Hispanic Americans, as well as establishing trait frequencies for reference samples and calculating classification rates for these groups (23, 24). Spradley and Hefner argue that the traditional three-group model (African, European, and Asian or Hispanic or Native American) of ancestry estimation should no longer be used (26). The authors demonstrate it is possible to correctly classify an individual beyond the three-group model when applying Artificial Neural Network statistics (26).

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Additionally, researchers in other parts of the world are adapting these methods to approach ancestry estimation in their region. For example, L'Abbe et al. used 13 macromorphoscopic traits to determine if ancestry is correlated with South African social races (white, black, and "colored") (22). Nine traits from Hefner (7) (NBC, NAW, ANS, INA, NO, MT, IOB, ZS, and TPS) were used in their analysis. Additionally, zygomatic and alveolar projection (27), mandibular torus, and palatine torus (28) were incorporated to correspond to South African forensic case reports using those traits. The authors found significant correlations between all traits, with the exception of the transverse palatine suture shape. Additionally, this study reported seven traits (NO, INA, NAW, ANS, NBC, IOB, and MT) being highly to moderately repeatable in scoring with very little interobserver error, while the remaining six are highly variable and may not be reliable for forensic casework. The six traits with high observer errors are not present in Hefner's suggested seven-trait suite (17).

Rather than focusing on classification of social race using macromorphoscopic traits, Ratliff used trait variation between Pacific Island groups (island Southeast Asia, Melanesia, and Polynesia) and mainland Asia (China and Japan) to document trait variation arising from geographic boundaries and inhibited gene flow (25). She found that the Pacific Island groups were more related morphologically and differentially expressed macromorphoscopic traits compared to mainland Asia. All traits examined were statistically different between these groups with the exception of postbregmatic depression and nasal overgrowth (24). Regional studies such as these are important for identifying the degree of human variation between populations.

Researchers are also combining cranial macromorphoscopic trait data with other ancestry estimation methods, such as genetic markers (i.e., mitochondrial DNA, Y-chromosomes, and single nucleotide polymorphisms) (29) and cranial metric data (30). By combining multiple methods of ancestry estimation, forensic anthropologists have multiple lines of evidence to support their classifications and increase the empirical nature used to establish a biological profile of an unidentified individual.

One final notable advance in macromorphoscopic trait analysis is the introduction of the Macromorphoscopic Databank, or MaMD, a National Institute of Justice funded project (NIJ 2015-DN-BX-K012) designed for the collection and analysis of macromorphoscopic data from around the world. The MaMD will serve two primary purposes: 1) as a repository for macromorphoscopic trait data; and 2) as reference data for an analytical program designed for ancestry estimations using these traits. Currently, MaMD contains data for over 2400 individuals from around the world. Trait scores for all of the aforementioned traits are included along with an additional trait (palate shape) recently added to the Macromorphoscopic Module (MMS). The data collection program and the reference data will be available to researchers following completion of the NIJ project.

CASE STUDIES

The following case studies outline the analysis of macromorphoscopic traits for the estimation of ancestry. These examples are drawn from casework at several laboratories. Although full biological profiles were conducted, only the ancestry estimation is discussed below. Case numbers and other identifying information have been redacted. All analyses were conducted using reference data from MaMD.

Image 1 presents the cranial remains of a previously unidentified middle-aged male. **Table 2** provides the individual macromorphoscopic trait scores. We utilized five potential groups from the MaMD (American black, American Indian, American white, Asian, and Hispanic) and twelve macromorphoscopic traits (ANS, INA, IOB, MT, NAS, NAW, NBC, NBS, NO, PBD, TPS, and PS) in a CAP classification analysis with stepwise variable selection. **Table 3** provides classification statistics for this individual. Overall, the CAP analysis correctly classified 63% of the reference sample using seven traits (ANS, INA, IOB, NAW, NBC, NO, and PBD). Case study 1 is classified as American white (d^2 = 5.4; posterior probability =

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Table 2: Macromorphoscopic Trait Scores for the Two Case Studies

Case Study 1		Case Study 2	
Trait	Score	Trait	Score
ANS	3	ANS	1
INA	4	INA	1
IOB	1	IOB	2
MT	1	MT	1
NAS	1	NAS	3
NAW	1	NAW	2
NBC	4	NBC	1
NBS	3	NBS	—
NO	1	NO	0
PBD	0	PBD	1
TPS	3	TPS	2
PS	3	PS	3

0.477). However, the classification statistics for Hispanic are also very close ($d^2 = 5.5$; posterior probability = 0.451). These results are seemingly ambiguous between American white and Hispanic; for a forensic anthropology report, the ancestry estimation would best be stated as: "Based on seven macromorphoscopic traits and a 6-group CAP analysis, this individual is most likely American white, although Hispanic ancestry cannot be ruled out." Of course, if craniometric data are also available, then the final assessment of ancestry may rely on both methods to further refine the overall statement on ancestry. The individual in case study 1 was later identified as a white male.

The cranial remains of case study 2 are provided in **Image 2**. These remains represent a previously unidentified young adult female. See **Table 2** for the individual macromorphoscopic trait scores. For this analysis, we utilized the five potential groups and eleven macromorphoscopic traits in a CAP classification analysis with stepwise variable selection. **Table 4** provides classification statistics for this individual. Overall, the CAP analysis correctly classified 65% of

Image 1: Two views (anterior and lateral) of the cranium from case study 1.

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Image 2: Two views (anterior and lateral) of the cranium from case study 2.

Table 3: Classification Data for Case Study 1

Group	Classification	d^2	Posterior Probability
American white	AMW	5.4	0.628
Hispanic		5.5	0.615
AmerIndian		9.7	0.056
Asian		12.3	0.015
American black		18.5	0.001

Table 4: Classification Data for Case Study 2

Group	Classification	d^2	Posterior Probability
American black	AMB	5.6	0.783
Asian		9.2	0.127
AmerIndian		10.9	0.055
American white		12.8	0.021
Hispanic		13.6	0.014

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the reference sample using seven traits (ANS, INA, IOB, NAW, NBC, NO, and PBD). Case study 2 is classified as American black ($d^2 = 5.6$; posterior probability = 0.783). The next closest group is Asian ($d^2 = 9.2$; posterior probability = 0.127). For a forensic anthropology report, this ancestry estimation would best be stated as: "Based on seven macromorphoscopic traits and a 5-group CAP analysis, this individual is most likely American black." The inclusion of craniometric data to support this analysis would strengthen the overall statement on ancestry. The individual in case study two was identified as a black female.

CONCLUSION

Ancestry estimation is a critical and complex component in the establishment of biological profiles for unidentified human skeletal remains. While cranial morphology has been used to determine ancestry since the early 20th century, those attempts were based on observer experience and typological trait lists (14). Forensic anthropologists now have available more robust and empirically based approaches to macromorphoscopic trait analysis, all designed and developed in an effort to more strictly observe the Daubert guidelines (7). This statistical framework allows the calculation of error rates (How often am I going to be wrong when I estimate ancestry?), in addition to probabilistic statements of an individual belonging to a particular group (How likely am I to be right for this one estimate?). These advances in cranial macromorphoscopic trait analyses should be combined with or, when those data are not possible to collect because of fragmentation or poor preservation, used alternatively to cranial metric analyses.

Forensic anthropologists are continuously improving reference samples and the understanding of population-based human variation to increase the accuracy of ancestry estimation. Recent studies focus on adapting macromorphoscopic trait analyses to accommodate regional judicial system requirements of identifying unknown human remains, such as trait frequencies of prominent ancestral groups or social races unique to a region (22). Historic approaches, such as the three-group (white, black, other) typological model, are being abandoned due complex population histories. The changing demographic structure of the United States is resulting in much greater levels of admixture within the general population. Currently, there is no way to determine admixture from the cranium using these traits, and, until the genetic component of macromorphoscopic traits is better understood and appropriate reference samples are available, this knowledge gap will remain.

However, as the case studies above demonstrate, the switch to multigroup classifications beyond three-group models is not only possible, but works very well. Methodological improvements to—and further refinement, verification, and validation of—the current approaches to the estimation of ancestry will only improve our ability to correctly assess ancestry from human skeletal remains. More accurate and empirically sound biological profiles of unknown human remains increase both the likelihood of identification by law enforcement and the admissibility of anthropological evidence in courts of law.

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The Role of the Anthropologist in Identification at Two Urban Medical Examiner Offices: New York City and Harris County

Sharon M. Derrick, Benjamin Figura

ABSTRACT

Two urban jurisdiction medical examiner offices, the New York City Office of the Chief Medical Examiner (NYC OCME) and the Harris County Institute of Forensic Sciences (HCIFS), receive large numbers of unidentified decedents each year. In 2015, the NYC OCME received over 400 decedents whose identities were initially reported as unknown. The HCIFS received 226 unknown decedent cases in 2015. These offices have faced similar challenges in the past when pursuing identification of long-term and otherwise complex identification cases. Within the past decade, the NYC OCME and HCIFS have successfully integrated forensic anthropologists into their offices to supervise routine identifications, direct resolution efforts in complex identification cases, manage disaster victim identification efforts, and organize community outreach events focused on identification. Accordingly, the NYC OCME and HCIFS anthropologists have successfully streamlined identification procedures to make them more efficient for all cases, and increased identifications of completely unknown individuals, effectively discharging the statutory responsibility held by the Chief Medical Examiner for decedent identification.

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INTRODUCTION

The incorporation of a formalized Forensic Anthropology department within the organizational structure of the medical examiner office is a relatively new, but expanding phenomenon. As such, forensic anthropologists working daily in the medical examiner setting are charting new territory and have the singular opportunity to develop innovations that effectively support the mission of the office through valuable contributions to medicolegal casework. One example of the innovative value currently provided by anthropologists is a new take on a traditional forensic anthropology role, that of contributing to the identification of unknown deceased persons. Two large urban jurisdiction medical examiner offices, the New York City Office of the Chief Medical Examiner (NYC OCME), which received 7444 cases in 2015, and the Harris County Institute of Forensic Sciences (HCIFS), which received 4644 cases in 2015, have faced similar challenges in the past when pursuing identification in complex cases. Both offices currently rely on organized strategies and formalized procedures developed by their forensic anthropology department personnel to manage and resolve complex identification cases.

DISCUSSION

The Forensic Anthropology Unit, New York City Office of the Chief Medical Examiner

Background

Anthropologists at the NYC OCME have been involved in the investigations of unknown individuals for decades. However, this involvement has historically been limited to cases of individuals with advanced decomposition or skeletonization. The first full-time anthropologist at the NYC OCME was hired in 1999 and their involvement in identification issues increased dramatically in the response to the 2001 World Trade Center (WTC) disaster. When this first anthropologist left the agency in 2004, the position was filled by a doctorate-level anthropologist, with a second masters-level staff member added in 2005. The Forensic Anthropology Unit (FAU) expanded further in 2006 and 2007 in response to renewed WTC-related efforts. By the end of 2007, the FAU consisted of eight anthropologists: three with doctorates, three with master's degrees, and two with bachelor's degrees.

In 2008, the FAU took a more central role in managing long-term unknown cases by providing anthropological analysis on all unknowns regardless of body condition and by managing case entry into the National Missing and Unidentified Persons System (NamUs). NamUs is a web-based reporting and searching system funded by the United States National Institute of Justice and currently managed by the University of North Texas Health Science Center. NamUs provides and maintains integrated unidentified deceased persons and missing persons databases with assigned levels of access. The general public may search these databases with sensitive information redacted and may also contact NamUs to process their missing persons case. Medical examiner office staff, law enforcement entities, and other authorized professionals may upload information to the databases and see the redacted information once they receive approved official access. All uploaded case information is validated by NamUs personnel prior to publication on the website (1).

The FAU shift toward management of long-term unknown cases was based in large part on the unit's experience managing the WTC victim identification operations. In 2009, the FAU's involvement in long-term unidentified cases resulted in an anthropologist being put into the position of Director of Identification to oversee daily identification work in the agency's Identification Unit. The Identification and Forensic Anthropology Units have historically served as part of the agency's Pathology department. The Identification Unit was recently moved to become part of a newly developed Forensic Investigations department.

At the NYC OCME, all medical examiner cases begin as unidentified, with two subcategories of unknown and unverified. Cases are considered as unknowns if there is no tentative identifying information; cases with tentative identifying information are categorized as unverified and are treated separately. If the tentative identity of an unverified case is proven to be incorrect,

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the case will be recategorized as unknown. Conversely, cases are often called into the agency as unknown but tentative identity information is quickly found and the case may change from unknown to unverified. In 2015, the NYC OCME received over 400 cases that were initially reported as unknown. The vast majority of these cases received tentative information and/or were formally identified quickly after the agency took jurisdiction. As of May 2016, only seven cases remain listed as unknown for 2015.

In 2008 the FAU began tracking long-term unknown cases on a day-to-day basis and also began performing a historical accounting of all unknown cases. Long-term unknowns are loosely defined at the NYC OCME as cases that remain unknown after 30 days. The historical review began with the year 2007 and worked backwards through 1990. Case files were requested for any cases with death certificates filed with the name as "Unknown Unknown," "John Doe," "Jane Doe," or any other combination of words that may have been used to indicate an individual had no tentative identity. Each case file was reviewed by an anthropologist and then entered in NamUs. To date, the NYC OCME has reviewed and entered nearly 1300 unknown cases into NamUs dating back to the late 1980s.

During the late 1990s and early 2000s, the NYC OCME averaged around 50 long-term unknown cases annually. This number dropped in the mid-2000s to around 30 cases per year. Since 2008 this number has dropped further to an average below ten cases per year. This significant drop is attributed to a number of factors including more emphasis on the use of fingerprints, increased use of DNA, the advent of the NamUs website, and increased involvement of forensic anthropologists.

Beginning in 2012, members of the FAU took part in a joint effort between the NYC OCME and the New York Police Department Missing Persons Squad to resubmit fingerprints from our unknown decedents for searches in various databases. Technological advances and the inclusion of additional records meant that there was a high potential that resubmission of fingerprints may lead to additional identifications. This effort led to the subsequent identification of over 100 long-term unknown decedents dating back to 1990.

Most recently, the FAU applied grant funding from the National Institute of Justice to the purchase of a three-dimensional (3D) printer. The printer is used to create full-size duplicates of the skulls of unknown individuals whose remains were skeletonized. The FAU provides the printed skulls to a forensic artist to create facial reconstructions without the need to use the physical remains.

Process

In 2015, the NYC OCME created an Identification Investigator (IDI) position, staffed by former death investigators and managed by a forensic anthropologist. The purpose of this position is to provide enhanced investigative capabilities to cases with complex identification issues, including unknowns. Each morning, the IDI reviews the cases for that day and develops a "plan of action" to resolve their identifications.

For unknown individuals, this process includes a thorough review of all case information including scene photos, medicolegal investigator's report, The New York City Police Department (NYPD) reports, and postmortem findings. The NYC OCME has the benefit of NYPD Missing Persons detectives being stationed at each morgue location, permitting the exchange of postmortem information obtained during examination of the body and investigative information obtained through law enforcement efforts.

All cases are fingerprinted during the initial exam using Live Scan capture devices installed on dedicated mobile carts. The captured fingerprints are electronically submitted to the New York State Division of Criminal Justice Services (NYS DCJS) to be searched against their criminal and civil databases. If the mortuary technicians are unable to capture the fingerprints using the Live Scan devices due to decomposition or other factors, they will attempt acquisition using more advanced methods such as ink and paper, powder and lifters, injection, rehydration, or silicone casting material. Multiple reviews of the current science of fingerprinting,

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including discussion of techniques, procedures, and submission policies, are available in the literature (2-6).

The resulting fingerprints are manually or electronically transferred to a standard ten-print fingerprint card template and submitted to the NYS DCJS by way of a certified fingerprint card scanning device. The submission results are then returned electronically into the NYC OCME's Case Management System (CMS). If a match was found, the response will include the individual's civil/criminal history record, including demographic information, prior addresses, social security numbers, and associated aliases. If no matching record is found at the NYS DCJS, the record is automatically passed to the federal level for search in the Federal Bureau of Investigation Next Generation Identification (FBI-NGI) system. Fingerprints are also regularly submitted to the Department of Homeland Security or to neighboring states.

All fingerprint results are reviewed by an IDI prior to submission to the medical examiner for approval. The IDIs compare the demographic information contained in the record to the case in question and attempt to resolve issues with multiple aliases. Any leads are followed up on immediately using Accurint.com, HHS Connect (a database allowing access to records from other city agencies), and other Internet search engines.

If tentative antemortem information is located but is insufficient for formal identification, the case is referred to the Identification Review Committee (IRC). The IRC meets once a month to review cases with complex identification issues and make recommendations for or against identification, or for additional investigative avenues. The IRC is comprised of individuals from the FAU, forensic biology, pathology, and investigations, and is chaired by a forensic anthropologist.

If the identification cannot be resolved, the case will be prepared for burial by the City of New York. A checklist of items is completed to ensure that all information necessary for identification is collected prior to release. This list includes photographs for visual identification (e.g., facial, tattoos, scars, birthmarks or other unique features), dental charting, dental radiographs, full-body radiographs, fingerprints, and a DNA sample. DNA samples from unknowns are processed at the NYC OCME's Forensic Biology laboratory for both short tandem repeat (STR) nuclear DNA and mitochondrial DNA (mtDNA), with resulting profiles uploaded to the Federal Bureau of Investigation (FBI) Combined DNA Index System (CODIS) database.

The final action on the checklist is an anthropological age estimate, at minimum; the policy was put into place in 2008. The anthropological age estimate provides two primary benefits. First, it provides age information based on reliable and reproducible scientific techniques. In our experience, age assessments based on subjective judgment of the physical appearance of a body have been off by as much as 20 years. Secondly, using age estimation methods with defined confidence intervals provides scientifically justified limits for searches of potential missing persons. Age estimates are performed regardless of the condition of the body and are accomplished by removing the medial ends of the clavicles, the sternal ends of the fourth ribs, and the pubic symphysis. Assessment of ancestry, race, or stature may also be completed depending on the condition of the body. Fully skeletonized cases are investigated directly by the FAU and undergo a full analysis with the creation of a biological profile and description of any antemortem trauma, pathological conditions, or other notable features.

The NYC OCME is a heavy user of the NamUs website, having entered over 1200 cases since 2008. The FAU manages the entry of the case to the site. Case entry occurs around the 30-day mark, though it may be completed earlier depending on the context of the case. Complete details of the case are entered, including the anthropological age estimate and identification photographs, when appropriate. Any resulting matches or inquiries are handled by the FAU.

The work that began in 2008 was supported in part by multiple grants through the National Institute of Justice's "*Using DNA Technology to Identify the Missing*" program. The grant submissions were joint projects between the FAU and the Missing Persons unit in the

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NYC OCME's Forensic Biology Department. The first grant provided funding to facilitate the historical review of cases and made the NYC OCME's anthropological services available to other jurisdictions in New York State. The second grant made it possible for FAU to disinter nearly 50 unidentified individuals from the late 1990's and early 2000's to obtain DNA samples and perform anthropological examinations if warranted.

The Forensic Anthropology Division of the Harris County Institute of Forensic Sciences

Background

In February 2006, a specialized full-time equivalent position (FTE) was created within the Investigations Division of the Harris County Medical Examiner's Office (renamed the HCIFS in 2009). The Agency Coordinator/ID Unit Supervisor was assigned to spend 50% of the FTE as the primary liaison with organ and tissue donation agencies contracting with the office and the other 50% as the supervisor of the ID Unit. At the time the position was created, the ID Unit consisted of a group of four forensic investigators and two administrative assistants who maintained a large file cabinet of long-term unidentified case files, fielded phone calls related to unidentified cases, and managed the flow of unidentified or unclaimed decedents to the Harris County disposition assistance program. When directed by the medical examiner, one of the investigators was responsible for packaging skeletal remains and shipping them to a contract forensic anthropologist. The ID Unit duties related to long-term unidentified cases were discharged when time permitted because daily casework had to be prioritized. Therefore, progress on long-term unidentified cases was basically at a standstill in 2006.

The Agency Coordinator/ID Unit Supervisor position was filled by a doctorate-level physical anthropologist. A staff liaison with the organ and tissue procurement agencies was a necessary position for the office but the hire of a physical anthropologist provided a means to segue decedent identification from the previous ID Unit design into a component of a full-fledged Forensic Anthropology Division (FAD). By late fall of 2006, the Forensic Anthropology Division was firmly in place, managed by an experienced Forensic Anthropology Director and staffed by two doctorate level anthropologists and an administrative level Identification Specialist.

In addition to setting up a functional forensic anthropology laboratory and conducting routine casework, the initial time-sensitive responsibility of the newly formed FAD was the examination of approximately 100 decedents awaiting identification under refrigeration in the HCIFS morgue. The storage of these bodies dated back to the early 1970s, when the office was located in the basement of a county hospital. The remains were subsequently moved with the medical examiner's office to the current building in 1985 in the hope that these unknown individuals might be identified due to expected future improvements in forensic identification methods.

Each of the three anthropologists performed full anthropological analyses of the stored bodies, including creation of a biological profile and description of any antemortem trauma, pathological conditions, or other notable features. Detailed photographs were taken and the images were electronically archived. DNA samples were collected from each body and submitted to the University of North Texas Center for Human Identification in Fort Worth, Texas (UNTCHI) for analysis and upload to the missing persons component of CODIS. Detailed examination results and appropriate images were entered into NamUs. The National Crime Information Center (NCIC) unidentified decedent entries were either updated or created through submission to the Texas Department of Public Safety (TXDPS). Following the collection of all pertinent evidence, the decedents were released for burial in the county-maintained cemetery.

As a part of FAD examination of the stored bodies, long-term unidentified decedent hard copy files retained in the large file cabinet at the HCIFS were also reviewed. Many of the files represented the stored bodies but some of the files represented previously buried unidentified individuals and some of the stored decedents were not associated with a file on-site. Cop-

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ies of missing and incomplete files were ordered from the Harris County Archives, a well-maintained document repository. During review and organization of the files, the FAD located over 400 paper files corresponding to long-term unidentified decedents that dated as far back as 1957, the year the Harris County Medical Examiner's Office was formally established. The majority of these case files contained inked fingerprints, which were resubmitted to law enforcement.

In 2010 and again in 2013, the FAD received an award through the National Institute of Justice "*Using DNA Technology to Identify the Missing*" grant program to exhume some of the long-term unidentified decedents that were buried prior to standardized DNA sample collection for identification. The grant funds were used to defray exhumation costs and to hire a full-time project forensic anthropologist to oversee disinterment and reinterment of 45 unidentified decedents whose files had been archived. The project anthropologist performed a complete skeletal analysis on the exhumed decedents, provided full reports, updated the information in NamUs and other databases, and collected and submitted DNA samples to UNTCHI for each case. Additionally, the project anthropologist reviewed archived case files and resubmitted fingerprints. The two NIJ funded projects resulted in 46 identifications, bringing the total number of identified cases from the archived case files to 70. Most of these identifications were obtained through fingerprint resubmission or DNA profile comparisons.

In terms of recent unidentified cases, 226 decedents were completely unknown at arrival to HCFIS in 2015. Only six 2015 cases remain unidentified at this writing. The majority of the 220 identified cases were quickly resolved through fingerprints. The other identifications were made through DNA, radiograph comparison by the FAD, and an occasional consultation with a contract forensic odontologist. Including the six unidentified 2015 cases, 28 unknown decedents have been added to the long-term unidentified files since 2006, accruing an average of only three long-term unresolved cases per year. The FAD regularly compares the unidentified case files against missing persons entries in NamUs, and queries from law enforcement or the public regarding missing persons. Available fingerprints are resubmitted for each case on a two year rotating schedule.

In 2014, one of the forensic anthropologists was named Director of Forensic Investigations, where he oversees the Forensic Investigators and Victims Assistance Specialists. He also continues to develop and provide input into revision of identification procedures. The FAD Director reports to the Deputy Chief Medical Examiner and oversees the FAD Identification Manager (ID Manager) and two other doctoral level forensic anthropologists. The FAD and Investigations are housed under the HCIFS Medical Examiner Service.

Process

Identification at HCIFS follows a procedural path outlined in a comprehensive standard operating procedure document (SOP) developed by representatives from the FAD, Investigations, and the Quality Division with input from the medical examiners. The SOP, modeled on principles of mass fatality preparedness plans (2, 7-10), delineates HCIFS departmental responsibilities in the identification process, and defines the membership and role of the Identification and Disposition Committee (IDC). The IDC is similar to the IRC at NYC OCME, and is managed by the FAD and chaired by the ID Manager. IDC core membership includes representatives from the FAD, Investigations, Pathology, the Forensic Genetics Laboratory (FGL), the Quality Division, and Morgue. The comprehensive SOP is supported by several procedural SOPs that detail the technical steps to follow for specific aspects of the identification process.

The first attempts at identification occur at the death scene where the forensic investigator assigns one of three identification statuses based on information gathered from law enforcement or individuals well-acquainted with the decedent. Decedents are not assigned a positive identification status prior to transport to HCIFS. Positive identification is based on a thorough evaluation of available information and analytical processes and is assigned by a medical examiner post-examination. The identification statuses

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that may be assigned at the scene are presumptive, tentative, or unknown. Presumptive status is assigned by the investigator at the scene based on available preliminary information that forms a reasonable basis to support positive identification. The presumptive status indicates strong support for positive identification but the medical examiner performs an evaluation of the evidence prior to assigning the positive status. Tentative status is assigned based on preliminary information available at the scene that provides a lead for identification. Tentative status requires that further information is sought prior to attempting positive identification. The unknown status is assigned if there is no available information regarding identification at the scene, and/or if the condition of the body renders the individual visually unrecognizable.

Once the decedent is checked in to the HCIFS morgue, forensic investigators facilitate electronic fingerprinting and transmission of fingerprints to law enforcement or other agencies using a fingerprint scanning device (Live Scan). All fresh decedents are electronically fingerprinted without respect to identification status at check in. Submission results for the electronically submitted fingerprints are received rapidly and viewed by the investigators on a transaction monitor, often providing evidence for positive identification prior to autopsy. Possible aliases or other identification discrepancies related to presumptive identification status may also be caught with the scanned fingerprint results. In cases of decedents whose condition requires advanced techniques to capture fingerprint features, morgue staff specially trained in complex fingerprinting methods attempt fingerprints post-examination. When the resulting fingerprints are not of sufficient detail for automated comparison, a scan of the inked prints is sent to a qualified law enforcement latent examiner for analysis.

To track progress of tentative or unknown cases when initial fingerprint identification is unsuccessful, Investigations opens a tracking page in the medical examiner software package used at HCIFS to monitor case progress and disposition. The investigators then follow up on information gathered at the scene or provided by law enforcement that contains leads for locating possible family members and potential documentary evidence, such as medical or dental records that include radiographic imaging. When antemortem radiographs are located, the FAD is consulted to perform radiographic comparison for identification. Dental comparisons that are determined to be beyond the expertise of the FAD are referred to a contract forensic odontologist. The imaging comparison results are submitted to the medical examiner along with recommendations regarding positive identification. If the identification is not resolved through these modalities, the case is referred to the IDC. Based on review of the case, the IDC suggests further actions, either returning the case to Investigations or transferring the case to the FAD for anthropological examination.

Fleshed cases transferred to the FAD may receive an examination for age only or for age and sex depending on the condition of the body. Those decedents with moderate bone exposure as well as fully skeletonized decedents receive a complete anthropological analysis that includes development of a biological profile, assessment of skeletal trauma and pathological conditions, and collection and submission of DNA samples.

The biological profile is used to target identification efforts by exclusion of missing persons who are not consistent with the profile. The FAD follows a similar procedure to the NY OCME FAU regarding dissemination of information for each unidentified case. Detailed anthropological examination results and appropriate images are entered into NamUs. National Crime Information Center unidentified decedent entries are submitted to the TXDPS for upload. If warranted by the estimated age of the decedent, the information is also submitted to the National Center for Missing and Exploited Children (NCMEC) intake line and the Internet version of Critical Reach within ten days of decedent check-in. An Unidentified Decedent Flyer (UDF), which is a single page summary of the physical description of the decedent and the events surrounding the decedent's death and/or discovery is created and uploaded to the Missing Persons page of the HCIFS public website. The UDF includes the law enforcement agency and case number, the demographic profile of the remains, clothing and personal

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items found on or near the body, location, date and time the body was found, and events surrounding the death or discovery. Photographs of the decedent and personal items are incorporated into the UDF when possible. The FAD follows up on any leads generated by the local and national dissemination of the unidentified decedent information.

DNA samples collected during the examination are sent to one of two laboratories. The on-site internationally accredited FGL provides STR analysis and profile comparison with family reference samples (FRS). The samples obtained from decedents with a tentative status and known family members may be submitted to the FGL. In these cases, the FAD collects the FRS from the family members or facilitates collection if they are not local. In cases of completely unknown status, the decedent samples are submitted to the UNTCHI for mtDNA and STR analysis and upload to CODIS.

The files of unresolved identification cases remain open and are worked indefinitely until the decedent is finally identified. However, the remains must be transported for burial once all pertinent evidence is collected from the body itself and there are no open leads. The ID Manager maintains a list of all unidentified cases and monitors the progress of the investigation, referring decedents for burial in the Harris County-maintained cemetery to await further identification leads.

Missing Persons Day Initiatives at the NYC OCME and HCIFS

The anthropology units at the NYC OCME and HCIFS have played lead roles in the development of successful "missing persons days" in their jurisdictions. These events that are designed to support families of the missing while providing new leads to resolve long-term unidentified cases have become more frequent nationally in recent years. Missing persons days are primarily held at the state level, but the NYC OCME and HCIFS jurisdictions are large enough in population density and geographical spread to warrant their own events.

NYC OCME has held two New York City Missing Persons Days (MPDs) in 2014 and 2016, the second of which was partially funded through NIJ grant awards. The idea to develop a missing persons day event specifically for New York City grew out of previous experiences with a similar event occurring at the state level. While the NYC OCME works closely with the NYPD Missing Persons Squad, not all individuals who are missing are formally reported to law enforcement. Given the numerous state and local jurisdictions and the large numbers of undocumented individuals from various regions around the world in the greater New York City metropolitan area, the NYC MPD was developed as a barrier-free event for families of the missing to receive assistance, make an inquiry of the NYC OCME, and submit DNA reference samples for upload to CODIS. The NYC MPD was specifically developed to minimize law enforcement involvement in order to provide a neutral atmosphere where individuals would feel more comfortable to provide information.

The MPDs provide opportunities for families with missing loved ones to visit the NYC OCME, participate in an antemortem interview to collect information about the missing person, submit DNA reference samples to be searched against the NYC OCME's database, and ultimately be uploaded to the FBI's CODIS database. Representatives from other city services and from NamUs and NCMEC were also present. The first MPD was in November of 2014 and assisted nearly 100 individuals on-site, with 250 other people providing information by phone, resulting in seven identifications of unidentified remains in NYC and surrounding areas. The second MPD took place in 2016 and assisted 50 families in person with 90 inquiries made via telephone. A total of 62 DNA kits were collected or mailed out. As of this writing, at least three cases have been resolved.

Two Missing in Harris County Days (MHCD) have also been held recently, one in April 2015 and one in May 2016 (**Image 1**). The strategy of MHCD is to provide one location for families to 1) report a missing person to law enforcement without concerns of being arrested or being questioned about their immigration

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status, 2) have the missing person's information entered into NamUs, and 3) voluntarily submit cheek swabs for entry into CODIS. Those individuals not wishing to do any of the above at the event are given the information necessary to negotiate the processes on their own. Additionally, educational programming for the public regarding missing persons issues was provided in the form of panel discussions and community service tables at each of the two events. MHCD has not offered telephone assistance as provided by the NY OCME MPDs but this option may be explored in the future. Based on early identification successes and local response, this community service event will likely become an annual or biannual offering to the South East Texas region.

The idea for the first MHCD grew from the 2014 identification of a long-term unidentified decedent who arrived at HCIFS in 1980. The identification is a testament to the value of NamUs and improvements in dissemination of information, as well as the efforts of the public who use online databases to associate possible identities to medical examiner cases. This young woman in her mid-twenties was a "failure to stop and render aid" pedestrian fatality. She had no identification on her person at recovery, although her face was clearly recognizable. She was from Michigan and her large family had been searching for her off and on for decades. She had been traveling in 1980 but was not known to be in Texas. In 2014, her online missing persons profile and her NamUs unidentified decedent profile were compared by a member of the public who submitted the possible match to the HCIFS FAD. An investigation ensued that led to a positive identification. During multiple conversations with the FAD ID Manager and the person who submitted the comparison, the sisters of the missing woman extolled the successes of the well-established Missing in Michigan

Image 1: Missing in Harris County Day, May 14, 2016. Photograph courtesy of Desmond Bostick, HCIFS Forensic Imaging Division.

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Day. Following these conversations, plans to have a MHCD were developed with the assistance of local law enforcement and community service agencies.

The April 2015 MHCD was funded entirely by donations from community service agencies and local businesses. It was held at a large church building whose pastor and congregation offered their hospitality and "day of" support without charge. Student volunteers from several universities and staff volunteers from HCIFS managed the flow of attendees, preparing and serving a donated lunch and setting up the panel discussions. Three panel discussions made up of local experts discussed missing persons issues for children, migrants and trafficked people, the homeless, and the mentally/emotionally challenged. The event was attended by 146 adults, and 46 persons submitted cheek swabs. As of this writing, eight long-term unidentified cases have been resolved as a direct result of the April 2015 event.

The May 2016 version of MHCD was expanded to include Galveston County. Once again the event was funded by donations. MHCD 2016 was held in a university atrium with use of an adjacent classroom hall designated as a private area for families to report missing persons. The atrium was the setting for refreshments, community service tables, and two panel discussions. The panel discussions at the 2016 event included effective participation from families of missing persons identified as a result of the 2015 MHCD. A severe thunderstorm with associated flash flooding may have limited public access but the event was still attended by 162 adults, and 28 persons submitted cheek swabs.

CONCLUSION

Anthropological training in general stresses the idea of holism, which drives an appreciation of the individual as part of a species that has developed physically and culturally across chronologic, geographic, and social dimensions. Forensic anthropologists carry this idea into their work by understanding an unidentified person, and the subsequent approach to identification, from many different aspects. A well-trained forensic anthropologist will not only understand osteology, but also dentition, DNA, radiography, and fingerprints and how they are applied towards identification. No other forensic discipline holds this concept of the corporeal unidentified human as a foundational principal for the majority of their work. Forensic anthropologists are ideal candidates to bring specialized insight into the medicolegal identification process.

Forensic anthropologists have traditionally acted as expert consultants for medical examiners and coroners in cases of advanced decomposition or fragmentation of unidentified individuals (7, 9-11). Although assessment of any suspected acute trauma is a given, the majority of the anthropological examination is focused on development of a biological profile and description of pathological conditions or remote trauma that may be helpful for identification. In the last 15 years or so, some larger medical examiner offices have embraced the benefit of on-site staff anthropologists whose skills may be utilized quickly for decedent recovery and for daily case consultations regardless of body condition. Trauma evaluations of fleshed elements and fresh cartilaginous tissues during autopsy and post-autopsy have become relatively routine at some offices. However, much of forensic anthropology casework within the medical examiner setting is still centered on supporting identification (11), whether working with completely skeletonized remains or, as noted previously, pursuing identification through radiographic comparison or removing skeletal age indicators from unidentified fleshed decedents to provide a more accurate age.

Despite the value forensic anthropologists bring to daily casework in the medical examiner office, hiring anthropologists for trauma consultations, archaeologically-based recoveries, and analysis of the sporadically received set of skeletal remains may be viewed by some as a luxury that cannot be justified or sustained under the typical medical examiner budget. In fact, the breadth of advanced anthropological training may be applied to medical examiner office functions that are considered by all to be essential. Consequently, and due to their background in identification, anthropologists are ideal candidates to lead or

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coordinate forensic investigation of unidentified cases. The NYC OCME and HCIFS have successfully integrated forensic anthropologists into their offices. Despite the geographical distance between New York City and Houston and constraints built into the different structures of governmental oversight (city or county), the two large, urban offices have constructed anthropological approaches that are very similar. This similarity may be related to the fact that the field of forensic anthropology is relatively intimate, as is that of forensic pathology, and the utilization of forensic anthropologists at the NY OCME and HCIFS did not occur in a vacuum. Certain routine procedural aspects may be handled differently, such as the use of "unknown," "unverified," or "verified" identification statuses at the NY OCME versus "unknown," "tentative," "presumptive," or "positive" statuses at HCIFS, but the basic mission and organizational principals are much alike.

Both offices have placed forensic anthropologists in management positions where they supervise routine identifications, direct resolution efforts in complex identification cases, manage disaster victim identification efforts, and organize community outreach events (MPDs) focused on identification. Accordingly, the NYC OCME and HCIFS anthropologists have successfully streamlined identification procedures to make them more efficient for all cases, and increased identifications of completely unknown individuals, effectively discharging the statutory responsibility held by the Chief Medical Examiner for decedent identification.

The NYC OCME and HCIFS have formally incorporated existing full-time forensic anthropology staff to lead forensic identification investigations. The NYC OCME Identification Unit is supervised by a doctoral level forensic anthropologist as the Director of Identification. At HCIFS, three doctoral level forensic anthropologists are integrally involved in supervision of identification efforts, the FAD Director, the FAD ID Manager, and the Director of Investigations. These two large, urban-based medical examiner offices have faced challenges in the past with a backlog of long-term unidentified cases. Forensic anthropologists working on-site at the offices have reduced the number of long-term unidentified cases from previous decades and have developed innovative procedures and instituted formal SOP documents that have reduced the number of current unidentified cases that become long-term. This is highly responsive to the statutory requirement of medical examiners to securely identify medicolegal case decedents. The resolution of these cases is of great value to medical examiner offices but is invaluable to the families of the missing persons who receive an answer as to their whereabouts.

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The Role of the Anthropologist in the Application of NamUs

Emily Craig

ABSTRACT

The National Missing and Unidentified Person System (NamUs) provides a web-based platform where forensic scientists, law enforcement investigators, and the public can share information related to missing person and unidentified decedent cases across the United States. Through this secure online database, forensic anthropologists, along with medical examiners, coroners, law enforcement officers, family members of missing persons, and concerned citizens, can access varying levels of information on a common platform to assist in the resolution of these cases. Conventional wisdom and experience allows that an individual who is known within the community and has been dead a very short time is more likely to be identified than someone who is badly decomposed and/or skeletal. For others, even when there has been an extended postmortem interval, circumstances, associated evidence, and location of the remains are just some of the elements that direct the investigation and help establish the identity of the decedent. When the remains are degraded by factors such as extended postmortem interval, mechanical disruption, scattering, or burning, however, the identification becomes much more difficult. In the first week of May 2016, there were 10 767 open cases of unidentified remains in NamUs. Of these, 7257 were classified as unrecognizable by a variety of aforementioned factors. By the very nature of their work, anthropologists can develop key pieces of information from decomposed and/or skeletal elements and NamUs can provide the technology to consolidate and share their findings as well as those of all subject matter experts involved with the investigation. *Acad Forensic Pathol. 2016 6(3): 424-431*

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Roles: Data acquisition, analysis and/or interpretation, manuscript creation and/or revision, approved final version for publication, accountable for all aspects of the work.

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STATEMENT OF INFORMED CONSENT

No identifiable personal data were presented in this manuscsript

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Forensic pathology, NamUs, Forensic anthropology, Unidentified remains, Missing persons

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INTRODUCTION

As outlined on the National Missing and Unidentified Person System (NamUs) website, NamUs was created in response to an overwhelming need for a centralized reporting system and resource center for unidentified human remains cases, and to aid in the resolution of missing person cases (1). Over the years, numerous individuals as well as civilian and government organizations had teamed together and compared lessons learned while attempting to consolidate and search information on the unidentified and missing.

The pilot Unidentified Decedent Reporting System (UDRS) was launched in 2005. The unidentified person section of NamUs was an outgrowth of this public service project by the Data Committee of the National Association of Medical Examiners (NAME), in conjunction with Occupational Research and Assessment, Inc. (ORAINC) and the International Association of Coroners and Medical Examiners (IACME) (2). Openly sharing identifying information on the deceased was a huge step forward in resolving many difficult cases, but having a central repository filled with detailed information on missing persons was equally important. Building on the success of the DoeNetwork (http://doenetwork.org), Operation Passageway was populated by volunteers in 2007 and this functioned as the prototype and initial data source for the current missing person component of NamUs.

Together, these would establish case matching between unidentified decedents and missing persons, and in 2007, the National Institute of Justice (NIJ) began its work to coordinate, develop, and implement NamUs within a multidisciplinary community of criminal justice stakeholders whose work continues to evolve today. NamUs is wholly owned by the Department of Justice, and is the first nationally centralized online repository, technical assistance service provider, and resource center for missing persons and unidentified human remains cases that is available to both criminal justice providers and the public. NamUs harnesses technology and employs a talented team of professionals who provide support and resources for unidentified persons cases, missing persons cases, and unclaimed persons cases. NamUs is both searchable and accessible by the general public, law enforcement community, medical examiners and coroners (ME/C), victim advocates, allied forensic professionals, and others. It is a powerful tool with which subject matter experts can assist the criminal justice community to cross-jurisdictional boundaries by simplifying the sharing of information between law enforcement agencies, medical examiners' and coroners' offices, as well as the general public. New cases can be added by law enforcement, medical examiners or coroners' offices, or the general public; be verified by case managers; and become visible and searchable across the country in a very short time. By breaking down barriers to communication among these key groups, the potential for solving missing persons' cases is enhanced and investigative workload is reduced. NamUs also provides data management and forensic resources for missing and unidentified cases at no cost to investigating agencies or searching family members.

Most decedents are identified quickly by conventional means. Following the identification, the next of kin is/are notified and the remains undergo customary funerary procedures. In some instances, however, the identity of the individual is not immediately established and medical investigators may turn to available missing person databases to try and find appropriate matches. This is not a simple task. That National Institute of Justice reports that on any given day the list of missing persons in the U.S. is approximately 100 000 (2). The odds of finding a match between a missing person on this list and an unidentified decedent during a random search is almost infinitesimal. The problem is further complicated by the fact that not everyone with knowledge about a missing person is using the same list, or even the same method of sharing their information.

Since some decedents remain unidentified for an extended period of time and for a variety of reasons, it will eventually become necessary for medical examiners/coroners/justices of the peace, and other medicolegal investigators to initiate action that reaches out to persons unknown. The objective at this point is to publicly circulate information on the deceased

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in an attempt to reach someone who has information on a person who is considered unaccounted for or missing.

These attempts usually start with a local focus. Unidentified bodies are almost always newsworthy, and local professional media outlets (as well as social media resources) are eager to circulate any and all information that investigators are willing to share. Sometimes these efforts are immediately successful. Occasionally, they are not. When the case goes "cold" and the medicolegal authority feels it is necessary to circulate information to an even larger audience, NamUs is available as a free resource to aid in this effort. In the past, ME/C officials did not have a common platform or an integrated technology-based system by which they could openly and easily exchange information about the unidentified decedents in their care.

DISCUSSION

How it Works

NamUs is a powerful tool to help share information on missing persons and unidentified remains, but it must be emphasized that NamUs is not a substitute for an official investigative case file or an official report related to missing and unidentified persons. NamUs is only a repository for information entered by users from across the country, and a NamUs record may or may not contain complete information about any particular case. User provided information is crucial to resolving many cases entered into NamUs, as each piece of information has the potential to provide the crucial link between a missing person and an unidentified decedent (3).

From the perspective of a medical examiner or coroner entering a case into NamUs, this is not the same as sharing a complete autopsy report. NamUs is a tool whose primary goal is to circulate information that can be used for identification of that individual. ME/Cs and criminal justice agencies may choose what information they share with the public, but they can also choose to share law enforcement sensitive information exclusively with other medical professionals and/or criminal justice agencies by entering that information into areas of the system that are restricted from public view. Full details of the policies and procedures for case management can be seen in the online policy manual (4).

Before a case can be entered into the database for unidentified remains, the entering party must register as a user. Users may register in several different categories and users can be granted different levels of access. By virtue of their medicolegal authority, medical examiners, coroners, and justices of the peace are allowed to enter cases as soon as they register in the system. The anthropologist, even though they are oftentimes the primary investigator, must first obtain permission from one of the aforementioned individuals. Full-time employees of a ME/C office, professional consultants, even third-party resources can use the system, but to have the ability to enter and edit cases, the jurisdictional authority simply grants written permission for them to act on their behalf. This is just one of the ways NamUs provides a common forum on which subject matter experts involved with all aspects of the investigation can share information on a common platform even before the case is published.

"Published" in the context of NamUs means that the case can be seen by anyone with access to the Internet and who accesses the database. Therefore it is important to understand that cases are not just directly published on the site as they are entered as might happen on a private website or on a social media page. When a case is entered, it falls into a queue that allows the case to only be visible to the case creator, the NamUs Regional System Administrator, and any other specific person who has been given access to that case though their professional role or through written permission by the jurisdictional medical examiner/coroner. This common confidential platform allows the involved parties to decide what information is to be shared only with other professional individuals who have full-view access and what information is to be shared with the public. After the case is entered, it remains invisible to other investigators and the general public until all involved parties are satisfied that the

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entered information is complete and accurate. Once the involved parties are satisfied regarding the accuracy and integrity of the report, they may elect to publish the case for others to see or choose to keep the report unpublished. There are various reasons why they may choose to keep the report from public view, but the choice to do so remains strictly with the case administrators.

One possible reason for a case to remain unpublished is that investigators have already established a presumptive identification of the victim, but there is no way for them to confirm the identity without further forensic testing. It is necessary for a case to be entered into NamUs in order for associated analysis such as DNA to be conducted by the University of North Texas DNA Lab (1). The case does not need to be published, but it does need to be entered into NamUs and have a NamUs number assigned to it. If the investigating agency needs to take advantage of the various other services such as anthropology, odontology, or fingerprint analysis offered by NamUs, the case needs to be entered into the system, but again, it does not need to be published. This way, various direct comparisons can be made to establish positive identification where there was previously only a presumptive identification.

It is also important to note that when the status of a case changes, the case owners and/or managers have the ability to alter that case status online. If a previously published unidentified case becomes identified, it can be archived. This removes the case from all published components of the NamUs but the entering party retains the ability to access the information.

Role of the Anthropologist

Due to the scripted television dramas and information posted on the Internet, there is an unrealistic expectation that all the features associated with dead bodies can be immediately and easily analyzed and categorized. This may be true when the person has been dead for a short time and there has been no disruption or degradation of the remains by mechanical or thermal means. However, developing a precise biological profile during any stage of the postmortem interval can be problematic. This becomes increasingly difficult when the rather subjective soft tissue criteria often used to produce a complete biological profile are obliterated or not recovered at all. This is where the specialized training and skills of a forensic anthropologist can prove invaluable.

During the first week of May 2016, there were 10 783 open cases of unidentified persons in NamUs. Of these, over 67% were considered unidentifiable because of the body conditions. (**Table 1**).

Networking

Many aspects of the dilemma regarding unidentifiable remains are discussed by other anthropologists contributing to this themed issue of *Academic Forensic Pathology*, and won't be covered in this article. Suffice it to say that anthropology-based materials and methods can become especially important when developing a thorough biological profile, and even more important when that profile is entered into a system such as NamUs. Understanding and interpreting the anthropological findings is also critical when searches between missing and unidentified persons are conducted.

When preparing a case for entry into NamUs, agencies are strongly encouraged to rely on established relationships and professional agreements already in

Table 1: Cases in Which the Body Conditions were Entered as "Not Recognizable"*

Partial remains, skeletal parts only	2820
Putrefaction	2292
Near complete or complete skeleton	1235
Charred/burned	326
Mummified	269
Trauma	267
Insect activity	48

*Readers should realize that there are constant changes in the number of unresolved cases entered into the system and there can be changes pertaining to individual cases.

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place between ME/C and forensic anthropologists. The secure and tiered access levels inherent in NamUs allow for such collaborations.

For instance, in those jurisdictions where cases of unidentified remains are routinely handled by a forensic anthropologist, the medical examiners work through the NamUs Regional System Administrator to grant full-view, full-edit permission to the anthropologist. This access is in addition to, not in lieu of, the ME/C who is still legally responsible for the remains and the identification. This proactive addition of an anthropologist allows all involved parties to enter details of the case they are investigating and allow online consults during the "life" of the case. Because of the flexibility of the system and user-friendly options, these consultations can be conducted online even before the case is published. Individuals involved with the case can always go back and edit or enhance a case both during and after publication.

NamUs also provides the opportunity for agencies without anthropology resources to access the professional services of forensic anthropologists. In Denton, Texas, the Laboratory of Forensic Anthropology has provided anthropological analyses of skeletal remains to investigative agencies since 1988. The laboratory is under the direction of a board-certified forensic anthropologist and employs three full-time forensic anthropologists dedicated to active casework. As part of the University of North Texas Center for Human Identification, the laboratory provides services to investigative agencies, medical examiners, and other medicolegal entities at no cost (4).

During the postmortem examination, the pathologist is likely to have the majority of information regarding an unidentified deceased person. When consulted, anthropologists often find, interpret, and analyze key pieces of information, odontologists and fingerprint specialists may be able to assist with others, and crime scene investigators may even be able to produce more, such as maps, photos of the scene and associated evidence. The resources of NamUs are there for everyone to use, and it provides a common forum in which subject matter experts of many disciplines involved with all aspects of the investigation can share information on a common platform even before the case is published.

Cold Case Review

Starting with UDRS, which was initiated by the National Association of Medical Examiners, volunteers began entering unidentified persons cases into the first iteration of the NamUs Unidentified Person Database in 2007. Since that time, the number of cases entered into the system has been steadily rising, with nearly 13 000 cases entered into the system at the time this article was submitted. Many of the entered cases have been resolved, but as of May 11, 2016 there are still 10 783 active, published cases in the system, with some cases dating back over a century.

Even as new active cases are being entered on a regular basis, agencies are going through the process of cold case review. Sometimes investigators discover a box of bones in a storage facility or the back of a closet, or perhaps an entire skeleton has been carefully curated in a medical examiner or coroner's office for years. It is entirely possible that only the case file and a stack of photos are all that remain after the body was unceremoniously cremated before the collection of critical biological evidence according to protocols that likely wouldn't be allowed today.

As experts review these old cold cases, it is possible that the investigation will uncover the existence of additional identifiers. Maybe a tattoo was mentioned or even described in the narrative, or perhaps even a photograph of it exists somewhere. This information can be entered directly into the NamUs case file. Once the remains are reexamined, there is a chance to enhance or even change the original assessment of the remains: age, race, sex, stature, etc. If the skull and mandible are available, perhaps a facial reconstruction can be undertaken in order to bring new visual attention to the case. With NamUs, the case manager (or anyone attached as a subject matter expert for that case) can log-in, edit, and add anything they feel would appropriately enhance the case.

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There are also opportunities for additional subject matter experts to consult with the entering party. Cases can be vetted and shared between any number of medicolegal investigators. Through NamUs, several parties that may have been working independently in the past can now become a cohesive team that can then use this system to consolidate information from numerous sources and to put all available pieces together.

Exhumations

Sometimes, during the process of cold case review, there may be a need to conduct an exhumation. This is not uncommon. Over the years, some information may have been lost due to changes in case ownership and disasters such as fires and floods also occasionally destroy case files. Sometimes details of a case may be only anecdotal and the only hard evidence available for forensic analysis is in the grave. Being buried without identification was not rare, and in many cases the investigation was hampered by the limited technology available at the time the remains were discovered. In many places across the United States, it was common practice to place remains in pauper cemetery shortly after death if identification was not immediately elicited and more often than not, key biological identifiers were not collected before interment.

Exhumations for obtaining DNA are becoming more and more common. Sometimes, the prospect of an exhumation is considered primarily to obtain bone samples that can be processed to establish a DNA profile, but an exhumation should always be considered an opportunity to get a second look at the remains. Anthropologists should also be considered to be key participants when an exhumation is undertaken. There may be a temptation to only collect a limited number of skeletal elements for DNA processing, leaving the majority of remains in the ground. This should be discouraged if many or all of the bones and teeth are present. These can be removed in order to allow a complete anthropological or dental workup that may not have been conceivable at the time because of limited resources. Even if the original workup was considered adequate at the time, this is an excellent opportunity to obtain a second look and opinion from other professionals including anthropologists, odontologists, and fingerprint experts, as well as those collecting evidence that may yield a complete DNA profile.

As the case is revisited, any newly gathered information can be added or original entries can even be revised to enhance the total information contained in a NamUs case. This might include an updated biological profile, the addition or reanalysis of a dental chart or radiographs, photos of clothing, or other personal affects that may have been buried with the remains. If soft tissue has been preserved, fingerprints or new photos of tattoos might be used to supplement the original written description or interpretation. As in any cold case, if the skull and mandible are available, a facial reconstruction should be considered to bring new visual attention to the case and perhaps create a lead that can be further investigated.

Sometimes, an exhumation produces a large amount of information that can be reanalyzed and shared, and it is possible that the result can be less than anticipated. Much depends on the postmortem interval, method of interment, and the amount of material collected during the initial investigation. Each and every exhumation should be approached as an opportunity to shed light on a cold case involving an unidentified deceased person.

Investigators may also want to include journalists in this process, and by being proactive in this respect they can help guide the media exposure and make certain that the information available to the community is accurate and timely. If the initial event focus is primarily on the process of exhumation, and not the remains themselves, there will be additional opportunity to bring attention to the case when it is updated and circulated through a universal medium such a NamUs.

Entering the Information

The biological profile and estimated postmortem interval must be as accurate as possible when a case is entered into NamUs, but NamUs was designed to take into account the fact that when dealing with an unidentified person, many of the biological profile

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particulars need to be expressed as an *estimate* and not an *absolute*. In NamUs, the age of the individual can be entered as an estimate with categories as broad as "adult" or "adolescent." There is a separate place to enter the age estimate as both minimum and maximum numbers. Height and weight can be entered as measured or estimated values, but there is also a consideration for when these features cannot be calculated at all. The year of death can be categorized into a "probable" range of years and the postmortem interval can also be entered as an estimate.

This is not a final process, as cases can be edited after initial entry. NamUs staff, as well as online resources, are always available to help with case entry and modification.

Searching for Matches

When a new missing person or unidentified decedent case is entered into NamUs, the system automatically performs cross-matching comparisons between the databases, searching for matches or similarities between cases (5). This list of suggested matches is available and viewable by all registered users of NamUs, and the parameters of the automatic searches can be changed to include additional states or altered information (e.g., larger or smaller range of age or height). Vetted professional users of the system can see and review many additional details that can allow them to assess these proposed matches, and compare entered information such as dental charts and radiographs, as well as fingerprints and medical identifiers that are not circulated to the public for privacy reasons. These users with enhanced access can also see case notes and investigative details that may help with identification or at least guide further investigation.

Since investigators routinely narrow their searches to try and find matches based on the biological profile of the unidentified deceased, anthropologists who are familiar with skeletal features are an excellent resource to help search through thousands of files where the missing person reports can contain ambiguities or even subtle hints of skeletal anomalies that can lead to an identification.

With skeletal findings, in particular, an anthropologist can help guide the query of data fields, as well as reassess prior searches for possible matches. Anthropology specialists may also be able to advise other users within and among different agencies. Words that are common and almost universal among the medical community may have a different level of use and meaning among the public. Searching for the key word "spine" in NamUs missing persons (MP) may prove to be less fruitful than searching for the word "back." It is important to remember that the descriptors on the MP side are often entered by the family and it is incumbent on the forensic experts to interpret these entries. Searches can be conducted by anyone, but searches by an anthropologist can clarify that a missing person described as having "bone lumps near each eyebrow" or a "bone lump on center of rear of head", may simply be describing the fact that this missing person demonstrates exaggerated but not atypical male characteristics associated with supraorbital ridges and/or an occipital protuberance. A missing person with "suffers from polio" listed as a descriptor may be a match to a skeleton that was found to have unique atrophy of skeletal elements whose description or analysis may not have been linked to this the specific disease of polio. A missing person's described "goose egg" on the head could mean many different things to many different people.

It is especially important for investigators to be willing to search each parameter with words that are likely to be used by the general population and be willing to adapt and alter the search accordingly. For example, when conducting a search of the open-text field under "skeletal findings" the unidentified person (UP) section had 69 cases wherein the key word "mandible" was entered. In the missing person section, there were only five cases where the word "mandible" was entered but the word "jaw" was entered 27 times. Similarly in UP the word "femur" appeared 69 times, and MP the word "femur" appeared 13 times. The word vertebrae appeared 109 times in UP. The same word only appeared six times in NamUs MP.

Anthropologists are also aware of ambiguities developed in the process of assessing the biological profile,

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and experienced NamUs users from any subject matter discipline know to avoid exclusions or a possible match because of a slight deviation from the height estimation or age estimation. They also know that exclusions should never be made on subjective criteria such as race, eye color, hair color, or even postmortem interval estimations. Some exclusions, however, can be based on skeletal criteria alone. The most obvious example would be the confirmed presence of an antemortem limb amputation. A scientifically sound exclusion can be considered if those same skeletal elements are present in the remains.

CONCLUSION

The role of the anthropologist in the application of NamUs is varied but crucial. By the very nature of their work, anthropologists can develop key pieces of information from decomposed and/or skeletal elements and NamUs can provide the technology to consolidate and share their findings along with those of all subject matter experts involved with the investigation.

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The Role of the Anthropologist in the Identification of Migrant Remains in the American Southwest

Bruce E. Anderson, M. Kate Spradley

ABSTRACT

This article focuses on the role of the forensic anthropologist in the identification of migrant remains in the American Southwest. These migrant cases present a unique set of circumstances that necessitate a regional approach to identification. The Pima County Office of the Medical Examiner (PCOME), located in Tucson, Arizona has developed best practices that facilitate high identification rates of migrant deaths. These best practices have provided a foundation for other agencies that are faced with similar issues; namely, developing specific protocols for migrant deaths, working with nongovernmental humanitarian organizations, and sharing information have maximized identification efforts. In 2012, Texas surpassed Arizona in the number of migrant deaths. The Forensic Anthropology Center at Texas State (FACTS) began identification efforts for migrant remains found in Brooks County, Texas in 2013. Informed by best practices from the PCOME, FACTS has made successful identifications. Descriptions of the processes at both the PCOME and FACTS are described in detail. *Acad Forensic Pathol. 2016 6(3): 432-438*

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KEYWORDS

Forensic pathology, Forensic anthropology, Migrant deaths, Foreign nationals, Personal identification, Skeletal variability

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INTRODUCTION

The purpose of this article is to provide information on the role of the anthropologist in the identification of migrant remains in the American Southwest. The harsh climates and remote spaces of much of the borderlands in southern Arizona and Texas, combined with rampant undocumented border crossing by foreign nationals, have resulted in thousands of deaths of these would-be migrants and the need for additional postmortem examination beyond the autopsy. Forensic anthropologists are well suited to perform these additional examinations and can extract essential information from the decomposed, mummified, and skeletonized remains that are a result of high temperatures and remote places. In the past 15 years, the U.S. forensic anthropology community has vastly increased its knowledge of the skeletal variability of groups from Mexico and Central America because of these forensic anthropological examinations in Arizona and Texas. The dissemination of this knowledge is important because it is believed that most migrants make it to their destination and thus may become medicolegal cases in jurisdictions far from the borderlands.

This issue of undocumented migration through Mexico into the U.S. is decades old, with the medicolegal agencies in Texas and Arizona, along with California, being responsible for the bulk of the death investigations—to include personal identification—on these foreign nationals. Because of the clandestine nature of these crossings and the resultant deaths the families of the missing are often unsure of the location of crossing, thus leading to the need for a regional approach to mitigate the identification issue. Sharing of data, both descriptions of the dead and descriptions of the missing, among medicolegal jurisdictions within the borderlands is essential to more fully understand the scope of migrant deaths and in helping the families of the dead. The Pima County Office of the Medical Examiner (PCOME) and the Forensic Anthropology Center at Texas State University (FACTS) have taken this first step by partnering with the humanitarian organizations Argentine Forensic Anthropology Team, South Texas Human Rights Center, and the Colibrí Center for Human Rights with the goal of sharing antemortem and postmortem information in an effort to maximize the number of personal identifications.

DISCUSSION

Arizona: Forensic Anthropology at the Pima County Office of the Medical Examiner

Forensic anthropology has been utilized in medicolegal death investigation in southern Arizona for over 50 years, beginning in 1965 when the late Dr. Walter H. Birkby consulted with the local sheriff's office after the discovery of the skeleton of a young woman in the foothills north of Tucson. By 1978, when the state of Arizona created a county-based medical examiner system, the Pima County Office of the Medical Examiner was established and Dr. Birkby had already consulted on over 100 medicolegal cases, mostly from the counties of Pima and Cochise. The late Dr. Richard C. Froede became the first Chief Medical Examiner for both counties and saw in Dr. Birkby a forensic science colleague who could contribute mightily to medicolegal case resolution given the oft-times harsh and remote conditions of the Sonoran Desert. By the year 2000, the PCOME had already utilized the services of a forensic anthropologist (chiefly Dr. Birkby) on more than 1700 such cases (by the end of 2015, nearly 4000 forensic anthropology examinations on medicolegal cases have been performed by PCOME forensic anthropologists). Thus, there is a long history of utilizing forensic anthropology in medicolegal death investigation in southern Arizona and in doing so, a systematic approach to the examinations has been utilized to hone a very efficient process.

While very few of the first 1700 forensic anthropology consultations were known or believed to be undocumented border crossers (UBCs) from Mexico and Central America, by the summer of 2000 this would dramatically change due to changes in Immigration and Naturalization Service migration policy that made it more difficult for these undocumented migrants to gain access into the U.S. through Texas and California. In essence, the flow of undocumented migrants into the U.S. had been redirected through Arizona.

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Because of the long-standing use of forensic anthropology at the PCOME, the staff there was up to the task of investigating the dozens then hundreds more such cases per year.

This substantial increase in the medicolegal death investigations on known or presumed foreign nationals did, however, require the PCOME forensic anthropologists to develop some innovative methods: 1) create the cultural profile, 2) take missing person reports from the families of foreign nationals, 3) share data with other agencies (e.g., consulates and United States Border Patrol [USBP]), 4) collect skeletal data in a systematic manner, 5) share geolocation information by creating accurate maps, 6) use a cultural anthropologist in seeking missing person information and in making comparisons to descriptions of the dead, 7) explain all aspects of the identifications directly to family members or their representatives, 8) develop an Unidentified Release Protocol (URP), 9) immediately utilize the National Missing and Unidentified Person System (NamUs), and 10) help create a Spanish-language version of NamUs to make it possible for non-English speaking family members to use this new publically viewable website.

Texas: Forensic Anthropology at the Forensic Anthropology Center at Texas State

The Forensic Anthropology Center at Texas State is comprised of the Forensic Anthropology Research Facility (FARF), the Osteolological Research and Processing Laboratory, and the Grady Early Forensic Anthropology Laboratory. The FARF is a 26-acre decomposition facility that receives approximately 60 donations per year for decomposition studies. The Osteolological Research and Processing Laboratory is large skeletal processing laboratory and has separate classrooms for workshops and training. The Grady Early Forensic Anthropology Laboratory houses the Texas State Donated Skeletal Collection and equipment for forensic skeletal analysis and research (e.g., computed tomography machine, white light scanner, histology, osteometric equipment). The FACTS mission is to advance forensic anthropology through world-class education, research, and outreach. In 2013, shortly after Texas surpassed Arizona in migrant deaths, FACTS began assisting with UBC analyses and identifications.

Unlike Arizona, in Texas there is not one centralized medical examiner's office that receives UBC deaths. Texas has 254 counties, 11 of which have medical examiner's offices. For counties with no medical examiner, the Justice of the Peace has jurisdiction to order death inquests and has ultimate jurisdiction over unidentified human remains. Unlike Arizona, Texas has specific laws regarding unidentified decedents requiring an inquest that includes an autopsy and/or forensic anthropological analyses and DNA sample submission to the University of North Texas (UNT). However, some counties have followed this law while others have not. It remains unclear if the counties in question did not know of the law or did not have the resources necessary to follow the law or whether it was (and continues to be) a combination of both.

The two medical examiner's offices and the two private practice forensic pathology offices along the border in Texas have no anthropologists on staff; therefore, any skeletal cases must be outsourced. Many of the skeletal cases are sent to the UNT while others are or have been sent to universities, including Texas State University, Baylor University, and Sam Houston State.

With the rise in undocumented migrant deaths in 2012, much attention was brought upon Brooks County in particular. Brooks County is located in the Rio Grande Valley and contains a USBP checkpoint. In efforts to bypass the checkpoint, many UBCs attempt to go around the checkpoint and many die during this process. In 2012 and prior, all the deaths found in Brooks County were sent to a funeral home for identification efforts. Autopsies were not performed consistently, skeletal remains were not sent for anthropological analysis, and DNA samples were not taken or submitted for Combined DNA Index System (CODIS) entry. If no identification was made by the funeral home, the unidentified individual was buried in a local cemetery (1). In 2013, grass roots efforts by nongovernmental organizations (NGOs) raised awareness of these ongo-

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ing practices in Brooks County and ultimately, funds were provided by the state for the county to send remains to a medical examiner's office, compliant with Texas State law.

However, unidentified bodies remained buried in Brooks County. In 2013 and 2014, Drs. Lori Baker and Krista Latham performed voluntary exhumations in Brooks County, exhuming approximately 85 burials. A total of 63 remains (from exhumations and a funeral home in Brooks County), mostly individuals in varying states of decomposition, were brought to FACTS for processing, analysis, DNA submission, and identification efforts – an effort named *Operation Identification*. The second author, MKS, was fortunate to spend time as a researcher at the PCOME at various times throughout a six-year period and therefore had a general familiarity with operating procedures at the PCOME. While efforts by the PCOME could not be exactly duplicated at FACTS, the processes at the PCOME informed practice at FACTS, including 1) the use of the cultural profile as it is never assumed that an exhumed body from Brooks County is a UBC, 2) collaboration with NGOs that collect missing persons reports, 3) collection of systematic skeletal data, 4) working with NGOs to provide families a comprehensive identification report, 5) working with collaborative forensic partners, and 6) the use of NamUs as a tool to facilitate identifications.

Additional challenges faced for UBC identification include that FACTS is not affiliated with a medicolegal agency, analyzes cases for multiple jurisdictions, and for the first three years of operation, all efforts were 100% voluntary.

PCOME: Innovative Methods of Identification for Undocumented Border Crossers

In an effort to define the total number of migrant deaths in southern Arizona, a system of profiling all unidentified remains as being more likely foreign nationals or more likely American citizens was implemented. This profiling was based upon a series of criteria that would come to include location of recovery of remains, personal effects, body features, skeletal features, and DNA profiles. The abbreviation UBC was coined for those individuals believed to have crossed the U.S. border in an undocumented, clandestine manner.

Because local law enforcement agencies (LEAs) did not make a practice of taking missing persons reports (MPRs) on foreign nationals known or presumed to be missing in southern Arizona, the PCOME developed a systematic approach in taking these MPRs from family members, friends, and others who were reluctant to report the missing to LEAs or to governmental consulates.

In an effort to understand the magnitude of the number of missing migrants who might be deceased in Southern Arizona, the PCOME shared data on the dead and the missing. This sharing of information was essential in adjusting USBP's reporting of the total number of dead migrants and in finding duplicate MPRs that had been taken by the Mexican Consulate.

The PCOME first contacted Dr. Richard Jantz at the University of Tennessee to discuss how to better capture craniometric data from the skeletons of presumed migrants so that Fordisc could become a better tool to use on individuals from this growing group whose skeletal variability was under-represented in the database. In addition to this collection of cranial data, measurements from throughout the infracranial skeleton were also compiled to address the increasingly common finding of small-bodied adults. The analyses of these infracranial data led to a refining of sexual dimorphic sectioning points (1, 2). Two special symposia on migrant deaths have been organized in the past ten years within the Physical Anthropology section of American Academy of Forensic Sciences' annual meeting with the goal of disseminating this skeletal variability to all members of the medicolegal community.

The PCOME partnered with local humanitarian group, Humane Borders, to exchange information on death location and to produce accurate maps of these deaths. This partnership was created by anthropologists at the PCOME and in the Department of Anthropology at the University of Arizona.

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Forensic anthropology at the PCOME was expanded to include a cultural anthropologist who would take the lead in examining selected personal effects and in taking UBC MPRs. This latter innovation has served to create the possibility of producing many identifications. Although initially performed under the PCOME, and dubbed the Pima County Missing Migrant Project, this facet of missing person data collection now is accomplished by the Colibri Center for Human Rights. By including the taking of UBC MPRs in their mission statement, The Colibri Center (cofounded by cultural anthropologist Dr. Robin Reineke) essentially serves as the UBC family assistance center for the PCOME.

The PCOME implemented a policy of engaging the families, or their designated representatives, in the identification process. For many families of identified migrants, high-tech tools such as geographic information system or GIS mapping and DNA profiles do not offer the same confidence as more traditional means of identification. Thus, there can exist an opposite to the so-called "CSI Effect" in which some families need a fuller, more tangible explanation for the personal identification of their loved one. While the PCOME may base an identification, in part, on the results of a DNA comparison, an individual family may find more power in the recognition of personal effects through photographs or in a small scar on the decedent's hand. Forensic anthropologists at the PCOME have aided families by explaining all aspects of the identifications, well beyond those associated with the forensic sciences.

An Unidentified Release Protocol (URP) was developed as a way to ensure that all necessary documentation of postmortem information was compiled and that a biological sample from the decedent was obtained prior to releasing to a mortuary for burial or cremation. This documentation includes a PCOME case number, LEA case number, location of recovery, physical description of the decedent, forensic anthropology examination, description of any personal effects (PE), photographs of decedent and PE, radiographs of decedent, and DNA profile information. Arizona state statutes allow for the indefinite retention of this information on unidentified decedents.

NamUs became a welcomed and logical repository for PCOME URP data and currently houses over 1200 PCOME cases, with likely 1000 of these cases relating to UBCs. The PCOME maintains all original case file data and views NamUs as the appropriate tool to publicize these decedent descriptions to those families looking for a specific missing person. Because photographic images can be a powerful way to connect a missing person to a decedent, PCOME forensic anthropologists have produced many such photos, some after laundering clothing, and published these in NamUs. Many identifications have been made following next of kin contacting the PCOME after viewing information on NamUs or other Internet websites that obtained these descriptions from NamUs.

The PCOME's cultural anthropologist worked with the Occupational Research Associates, the developer of NamUs, to create an accurate Spanish-language version (accessed through a link on the English version website). It was hoped that for some families, including those who never filed a MPR, having a Spanish language version would make it easier to navigate through the pages of NamUs unidentified persons.

FACTS: Undocumented Border Crossers Identification Methods at an Academic Institution

It is not assumed that any exhumations or remains brought to FACTS from South Texas are UBCs. During the anthropological analysis the biological profile, the clothing, personal effects are all given consideration when using this designation (3), similar to the PCOME.

FACTS works with nongovernmental organizations including the South Texas Human Rights Center (STHRC), Colibrí Center for Human Rights, and the Argentine Forensic Anthropology Team (EAAF). All NGOs collect MPRs for individuals that go missing along the border. The STHRC mostly collects MPRs for Texas; Colibrí, for Arizona, and EAAF collects MPRs across the border. However, sometimes MPRs overlap or are taken out of jurisdiction. Therefore, these NGOs work together to cross-reference MPRs and reconcile cases.

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Unlike the PCOME, *Operation Identification* is housed within FACTS, a departmental center within Texas State University. The FACTS mission is to advance forensic science and anthropology through world-class education, research, and service. Thus, in addition to providing anthropological analyses and identification services, standard data are collected on each case and used for research endeavors that focus on understanding the biological variation and growth and development of UBCs as well as the development of new methods and techniques that will benefit the UBC population group. Further, instead of releasing unidentified remains for burial or cremation, all skeletal remains are retained by FACTS pending identification. The retention of remains allows for continued research and development.

Following the lead of PCOME, FACTS works with NGOs not only for comparison with MPR reports but also for DNA comparisons. While FACTS enters all information into NamUs and submits DNA samples to UNT for CODIS inclusion, the problem remains that many families in Latin America are unable to provide a family reference sample (FRS) that fulfills the Federal Bureau of Investigation's CODIS requirements. Therefore, even though DNA samples from unidentified human remains are submitted for CODIS inclusion, the FRS will likely not reside in CODIS. The EAAF collects family reference samples from Latin America. On several occasions, FACTS has submitted additional samples of DNA from unidentified human remains to a private lab for comparison with FRS collected by the EAAF with successful identifications. Further, because foreign genetic databanks cannot be cross-referenced with CODIS due to federal restrictions, short tandem repeat (STR) profiles are requested by the law enforcement agency with jurisdictions over the remains. These STR profiles are then sent to the EAAF and a keyboard search is conducted against the foreign genetic databanks. Successful identifications have also been facilitated using this method.

A collaborative partnership was developed between FACTS and the University of Indianapolis Archeology and Forensics Laboratory to help advance casework, which in turn advances identification. Faculty, Dr. Krista Latham, and graduate students from the University of Indianapolis helped exhume the remains from Brooks County and spend one week each year at FACTS analyzing cases and writing reports with FACTS faculty and graduate students. This collaboration provides professional development and much needed hands-on training for the next generation of forensic anthropologists.

All case information is entered into NamUs. Additionally, Texas State students volunteer to wash, catalog, and photograph all personal effects. These photos are then uploaded to NamUs for public viewing. Personal effects aided in the identification of one individual early on in our endeavors. After remains are processed and analyzed, they are curated pending identification.

FACTS is not affiliated with a medicolegal agency and as such has no jurisdictional authority over the unidentified human remains. Therefore, additional steps must be taken during the identification process through working with the Justices of the Peace. FACTS is not affiliated with one specific jurisdiction and provides forensic anthropological services for multiple jurisdictions along the Texas border and elsewhere in Texas. As Texas has 254 counties, keeping track of jurisdictional authority for each county is a priority.

During the first three years of *Operation Identification*, all efforts were 100% voluntary. Working within FACTS, a laboratory infrastructure was available; however, all labor was voluntary including maceration of human remains, forensic anthropology case reports, washing clothes, photographing cloths, NamUs entry, DNA sample submission, curation of remains, and identification efforts (cross-referencing MPRs with anthropological reports to form identification hypotheses). Because FACTS is a departmental center within a university, many undergraduate and graduate students volunteer. At any given time, there are between 15-20 undergraduate volunteers that clean and process the human remains, wash and photograph clothing, and assist with any additional laboratory duties. Further, graduate students within the anthropology department volunteer their time to assist with

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anthropological analysis of remains. All efforts are supervised by the second author, who also volunteers her time to run this project. Because efforts are voluntary, they are not full-time. However, our efforts have always remained steady. In 2015, funds were obtained through a private foundation and from the Texas Governor's Office to hire a 40-hour per week postdoctoral research associate to focus on processing and casework and to hire a 20-hour per week graduate research associate. Since funds were obtained, progress has greatly increased.

CONCLUSION

The PCOME is located in close geographic proximity to the Mexico border, employs two full-time forensic anthropologists, and the majority of cases recovered near the border are brought to the PCOME. This makes the PCOME a centralized location for undocumented migrant deaths while allowing for pathologists and anthropologists to collaborate on identifications. This inadvertent centralization, collaboration, and the lack of specific laws pertaining to unidentified decedents in addition to innovative methods developed by the PCOME—as contrasted to Texas—undoubtedly helps in the successful identification of undocumented migrants. Additionally, the innovative and best-practice methods developed at the PCOME and the shared knowledge of these methods provides a foundation for other agencies, including FACTS, to more efficiently work towards identifications of UBCs.

Although FACTS is located about four hours north of the border and housed within an academic institution, the collaborations with STHRC and local jurisdictional authorities at the local level and Colibrí and EAAF at the regional and international level allow for successful identifications. Further, these collaborations extend across jurisdictions making them both flexible and sustainable. Colibrí, STHRC, EAAF, and FACTS in addition to the Migrant Rights Collective have come together to form the Forensic Border Coalition (FBC). The mission of the FBC is to support families of missing migrants searching for their loved ones and to address problems related to the identification of human remains found near the U.S./Mexico border.

Through the sharing of information and by creating a regional approach to the medicolegal death investigation—including personal identification—of these borderlands cases and by including both governmental, universities, and NGOs, a more complete understanding of the scope of migrant deaths can be achieved.

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Forensic Archaeology and Forensic Taphonomy: Basic Considerations on How to Properly Process and Interpret the Outdoor Forensic Scene

Dennis C. Dirkmaat, Luis L. Cabo

ABSTRACT

Medicolegal death investigation requires a multidisciplinary approach to the collection of data from the crime scene to the autopsy table. Law enforcement processing of the indoor crime scene works extremely well for documenting evidence and producing reconstructions of past events. However, outdoor crime scenes require a new set of scene processing protocols — a need primarily derived from the wider array of natural agents, such as plants, animals, soil chemicals, or environmental conditions that will affect the evidence after burial or deposition outdoors. Forensic archaeology provides the principles, practices, and protocols for documenting and analyzing this type of evidence at a variety of outdoor and other complex crime scenes, including large-scale scene searches, surface-scattered remains, buried body features, fatal fires, and mass disaster scenes. Scene recovery protocols require 1) documentation of the context of the scene, including specific location, local flora and fauna, and geological, geographic, and environmental factors and conditions and 2) detailed notation of the spatial distribution of the evidence in order to establish association of evidence to other evidence and to a particular incident. The discipline of forensic taphonomy provides the techniques and conceptual framework to combine these scene-derived data with laboratory analysis of the biological tissues in order to build and test scientific hypotheses regarding the events surrounding death and deposition. The primary assessments resulting from a forensic taphonomic interpretation include scientific estimates of postmortem interval; whether and how remains have been moved, removed, or altered; and ultimately, whether there is an indication of human intervention. *Acad Forensic Pathol. 2016 6(3): 439-454*

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Forensic pathology, Forensic taphonomy, Forensic archaeology, Context and association

INFORMATION

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INTRODUCTION

Medicolegal death investigation is a complex multidisciplinary endeavor involving law enforcement, coroners and medical examiners, and a variety of forensic scientists including, but not limited to forensic pathologists. The information required to clarify the death event is obtained from a wide array of evidentiary materials and contextual observations gathered from the body, crime scene, and police inquiries on the circumstances surrounding victims, witnesses and suspects. Similarly, the analyses and inferences of each forensic expert taking part in the investigation are informed not only by the isolated evidence or pieces of information derived from their own work and type of evidence, but also require the collection and transfer of other types of information from the remaining experts.

DISCUSSION

The Outdoor Scene

Medicolegal death investigation of the indoor scene is generally conducted with detailed protocols based on clear standards and objectives proven to render best results in determining forensic significance, establishing chain of custody, and collecting all necessary information at and about the scene. However, if the body is discovered at an outdoor setting, the classic protocols and procedures for the collection of evidence from outdoor scenes are often neither comparably robust nor often as comprehensive (1-3). Further, these scenes may be associated with lower expectations of significant outcomes, compared to what is expected from indoor scenes (**Image 1**). This raises several concerns. Are the standard questions asked at the indoor scene still relevant at the outdoor crime scene? Is there still information to be gathered? What new/different factors affect the evidence that has been exposed to the elements? How do we gather/preserve outdoor information and evidence?

Upon reflection, the primary questions asked at the outdoor scene are nearly the same as those that are asked at the indoor scene. Who is the individual? How did he/she get here? How long has he/she been here? What are the specifics of the events surrounding the death (and in particular, the role that other humans

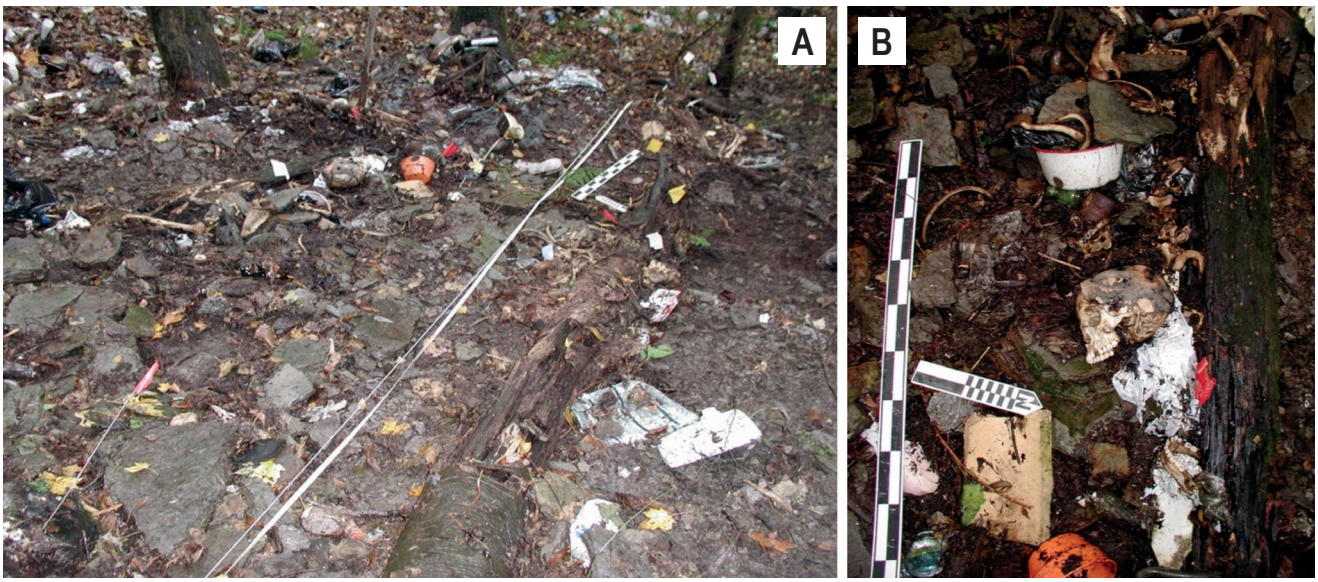

Image 1: A) General view of outdoor forensic scene following denuding. The image illustrates the complex nature of the outdoor scene in which forensic significance needs to be determined, careful mapping procedures are required, and random and nonsystematic collection of evidence would not provide useful information. **B)** Close-up of scene showing mixture of garbage and forensically significant human remains.

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may have played in the victim's demise and placement at that location)? Other than determining identity, however, how these questions are addressed and what evidence is used in the formulation of answers must necessarily be a bit different.

The primary difference between indoor and outdoor scenes is indeed that evidence at an outdoor scene has been potentially disturbed/modified by more agents and processes that are not commonly encountered at indoor scenes: plants, animals, insects, environment, water, gravity, and a whole range of environmental, climatic, and biotic factors. However, that does not mean that all evidence has been destroyed and the amount of information decreased; but rather, it suggests that the quantity and array of information will be different, and in many cases, actually greater, resulting in a scene more complex than the indoor scene. This added information requires a different approach and different datasets for the reconstruction of past events (1, 4). Since so many natural factors impact the evidence after the death event, reconstructing events that have transpired at the outdoor scene also requires a wider array of factors and variables to be considered and recorded (e.g., temperature, humidity, plants, animals, insects, sunlight, snow, rain, water, soil), placing a much more intense focus on post-depositional/postmortem alteration than at typical indoor scenes.

The approach to processing outdoor scenes, therefore, must address a new set of questions. Have the remains been moved, removed or altered from their original depositional positions? If so, what are the agents responsible for those alterations (e.g., plants, animals, water, gravity, humans)? How long ago have the remains been deposited at this location, taking into account the combined effects of those natural factors?

Forensic Taphonomy

The answer to many of the questions asked of the outdoor scene, lies in the discipline and approach of forensic taphonomy. Forensic taphonomy has been defined simply as the study of what happens to a human body after death (5, 6). Since most of what happens to the body (and evidence) at an outdoor setting is the result of alteration or modification by natural agents such as plants, animals, soils, environment, gravity, and many others, the recognition and documentation of the specific role played by each of these natural agents is critical to understanding and explaining why evidence ends up where it ends up, or why it looks as it looks at present. This allows us to focus on unusual patterns of dispersal or removal of evidence and remains that can provide indications of human intervention (e.g., moving/removing remains to hide evidence). Providing hypotheses of the role that humans play in altering a scene or evidence after the death event therefore represents one of two major assessments provided by a forensic taphonomic investigation. The other primary assessment is that of postmortem interval (PMI), and how long the body has been at the location.

Even though the scene, body, and evidence have been disturbed to some degree at all outdoor scenes, it must be emphasized that much information remains and we will be able to present a evidence-based scenario of what transpired at the scene based on proper documentation and collection of that information. The forensic taphonomic approach to the processing and understanding of the outdoor scene thus represents an important paradigm shift from the old-school thinking that the outdoor scene is almost totally devoid of usable forensic information (especially with respect to reconstructing past events) to the active scientific pursuit of uncovering the fine details of past events hidden in the seemingly complex outdoor scene (4, 7).

As mentioned above, the pieces of information required for these reconstructions of outdoor scenes include new types of evidence (e.g., details of decomposition of biological tissues, or of marks on tissues resulting from animal, plant, and insect interactions) and new factors to consider (no walls to the scene and no easily definable boundaries). Therefore, new documentation and recovery protocols are required as compared to what is employed at the indoor scene. Forensic taphonomy focuses on the identification, documentation and interpretation of a wide variety of potential taphonomomic agents, including how and to what extent they have altered the remains and evidence at the outdoor scene. It includes large amounts

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of information drawn from both the scene and laboratory examinations. As with indoor scenes, it is vital to place the focus firmly on maximizing evidence location and collection, including comprehensive documentation of context and association of scene and evidence. Indoor scene processing protocols do not cover all natural taphonomic agents and are generally ineffective and incomplete for dealing with the outdoor scene. Thus, we must turn to other disciplines, and in fact one is ready-made: forensic archaeology, by which standard archaeological principles, practices and methods (with some minor modifications, see below), is employed to systematically and comprehensively locate, document and interpret evidence at the outdoor forensic scene (8).

General Considerations of Forensic Taphonomy and Forensic Archaeology

The discipline of forensic archaeology arose in the 1980s just after the debut of forensic anthropology in the 1970s. It was quickly realized by all parties in the forensic investigation that scene processing protocols for outdoor scenes may not have been as rigorous as those employed at indoor scenes, and the quality and density of informations gathered diminished. Possibly, this can be attributed to common mistaken assumptions that since the scene and associated evidence was exposed to the elements and animals, it likely was lost entirely or altered to such a degree that it was no longer of much value. Common questions asked of the indoor scene could thus not be addressed at the outdoor scene, as the evidence for the construction of the scientific hypotheses had not been collected. The most effective tool for evidence collection of the outdoor scene was clearly archaeology (1, 4, 7-9). This was evident simply by comparing the coincidental primary goals of both disciplines: reconstruction of the past based on evidence found in highly altered contexts. In the 1970s and 1980s, discussion of the role of archaeology in forensics focused on the recovery of clandestine graves (10, 11). Since that time, common archaeological methods and practices began to be employed on other forensic scenes, including searches, burials, surface scatters, and eventually, fatal fire and mass disaster scenes. These methods and practices, modified to meet forensic standards, were incorporated into a new discipline appropriately named forensic archaeology (8).

With the consideration that the discipline of archaeology provided the appropriate methods, principles and practices to uncover, document, and collect evidence, as well as to understand patterns of evidence distribution through consideration of stratigraphy, context, and association at the outdoor scene, came the realization that a more general framework was required in order to put together the additional field and laboratory information considered in forensic contexts as compared to archaeological sites and in a manner that permitted the interpretation of outdoor crime scenes much in the same way that indoor scenes were analyzed and interpreted. The discipline of taphonomy, originally defined by Ivan Efremov (1940), and considered as a branch of paleontology, would come to bridge this gap (12). Taphonomy studies all the modifications and alterations that a biological organism suffers since its death to the moment we recover its fossil remains and study them. This includes how the animal (or plant) died (necrology), how it ended up in its current location (biostratinomy), and how it was altered after burial by different physical and biological agents and processes (diagenesis and bone modification), including by the manner in which its remains were located, excavated and handled. It is immediately clear that there are distinct parallels between these goals and those of a forensic investigation, with the advantage that taphonomists had already been studying these issues for half a century. They have constructed the best methods for determining issues such as whether a particular fracture occurred antemortem or could instead be better attributed to natural postmortem damage or decay; whether the remains had been originally deposited at that location, or had been transported there after death by different physical and biological processes; or how and how fast they had been interred. With the introduction and quick adoption of taphonomy into anthropology and archaeology in the 1970s and 1980s (13-15), taphonomic methods and inference came to incorporate past human behavior, including how to distinguish alterations caused by

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humans from similar ones caused by natural agents, if a deposit could represent an intentional burial or natural interment post deposition, or how to identify the tool or process that fossil humans employed to break or cut a bone. These are almost exactly the same questions posed by forensic scientists regarding forensic significance or manner of death, considering exactly the same natural processes playing a role at outdoor crime scenes and addressed by many of the same types of materials (human and animal remains).

Producing Testable Hypotheses

Perhaps it is best to consider that forensic taphonomy focuses on the creation of testable hypotheses that attempt to provide key answers related to the death event, including 1) the condition, location, position and orientation of the body when deposited at the scene originally; 2) what has happened to the body between the time of deposition and the time or recovery and how long it took (PMI), and importantly, whether humans were involved; and 3) whether we can provide information of events leading up to the body getting to the site. Important answers that can now be provided scientifically include how the individual got to the site,whether they were alone, whether they were alive when they arrived at the scene, how long ago the event transpired, the taphonomic agents responsible for moving and removing remains out of anatomical position, whether animals scavenged or altered the remains and when this occurred, whether humans came back to the scene and attempted to hide evidence, and the assessment of broken and damaged bones.

How are These Questions Addressed at the Outdoor Scene?

The answers to these questions always begin with the proper location, documentation, and collection of evidence at the scene. Similar to the indoor scene, the processing protocols focus on noting context and association attributes of the evidence. Following scene processing, the detailed analysis of the biological tissues (e.g., soft tissue decomposition characteristics, bone surface modification, skeletal trauma analysis) in the laboratory permits better assessment of a wide variety of forensic taphonomic interpretations: PMI (16-18), effects of various taphonomic agents (19), the identification of perimortem vs. postmortem trauma (20), and scientific reconstructions of past events.

Forensic Archaeology Practices at the Outdoor Scene

The following is a general schematic of how an outdoor scene is approached and processed utilizing forensic archaeological principles, methods, and practices. One significant difference from an indoor scene is that a search of a large outdoor area may be required in order just to find the outdoor site. When a forensic scene is located, similar to an indoor scene, the processing requires the detailed notation of context and association. This information in turn is linked with the results of the analysis of materials in the lab so that an evidence-based scenario of what happened in the past can be presented.

Forensic Searches for Unlocated Scenes

Unlocated remains or scenes will require a systematic search of the suspected area or areas. To be both efficient and effective, search protocols require: 1) a visual assessment of 100% of the surface within the target search area and 2) a detailed notation of the specific area that has been covered at each step by exacting search methods (preferably on maps or aerial photographs). Drawing from both forensic research and what has been learned in regular archaeology, the most effective search methodology is based on straight-line pedestrian searches, with searchers lining up shoulder-to-shoulder and scanning the surface thoroughly and rapidly (8). Properly trained cadaver dogs are often useful in the early stages of the search for relatively fresh (i.e., actively decomposing) remains and can expedite the finding of the body (21). If the remains are lying on the surface anywhere within the searched area, these methods produce nearly 100% success rates in locating the body. However, the probability of locating the body drops dramatically if the remains have been buried. Specialized equipment able to detect subaerial anomalies potentially indicative of a burial, such as ground penetrating radar or fluxgate

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magnetometers, can be helpful in searches under the appropriate conditions such as open fields, relatively small search areas, and areas with certain soils or soil conditions, although their efficacy may decrease at less ideal scenarios such as extensive searches in forested areas (22).

Associated with all searches is the necessity that determinations must be made whether a particular item of evidence is forensically significant or not. Ultimately this determination depends on whether it relates to the forensic incident and will be based on whether there is an indication that an item was generated, moved, or altered during the event (and in what state and where it was before the incident). Everything may be potentially altered, and the nature of that alteration must therefore be documented and incorporated into the reconstruction of the death event. If the alteration is determined to have occurred during the death event, it would immediately become 1) forensically significant, 2) evidence, and 3) associated with that particular event. Thus, the documentation and eventual analysis of the *in situ* position, location, and orientation of the evidence is vitally important and plays the most significant role in the death event reconstruction. Importantly, this documentation process also establishes the first link of the chain of custody (2).

Thus, it is particularly important to have a trained individual available during the search who can quickly and accurately assess forensic significance of found remains, especially suspected osteological materials. These professionals can make real-time evaluations of human vs. animal, even in cases in which the remains are isolated, fragmented, or heavily modified rather significantly by animal gnawing or burning (23). With smart cell phones available to law enforcement, evaluations of forensic significance can be conducted through email or text messaging exchanges in near real time.

Processing of Outdoor Scene Through Forensic Archaeological Methods

After evidence is located and potential significance has been established, the processing of the scene involves properly documenting context and association of that evidence. In the field of archaeology, hypotheses of association are used to indicate that artifacts found in proximity actually entered the scene at the same time and are related to a particular depositional event (9, 24, 25). This depositional event could be hours, days, weeks, or even months in duration. In forensics, the depositional event is usually of very short duration (on the scale of minutes or hours). It must be kept in mind that although pieces of evidence may be found in the same place/same room, they may not have been deposited at the same time. The focus of the recovery is on the acquisition of locational information and will include 1) general and specific descriptions of the scene, including geographical location (geographical coordinates, street address) and 2) the notation of the precise location, position, and orientation of the unaltered, as-found evidence within the scene (defined, in archaeological parlance, as its *provenience*) (24). This documentation of the spatial distribution of evidence leads to hypotheses regarding the association of evidence to a particular depositional event (thus establishing association).

The best way to properly collect all these data is through forensic archaeological principles, methods, and protocols, which share the same basic goals as indoor forensic protocols but with an added component largely derived from classic archaeology. However, due to a few major differences in perspective, requirements, and in general, the types of information and evidence targeted at outdoor scenes, forensic archaeological protocols incorporate new, additional techniques, data types, and objectives not considered at either indoor scenes or archaeological sites (1, 8, 9).

The primary difference between indoor and outdoor scene protocols is that the latter must focus on the post-depositional factors affecting the remains, requiring a complete inventory of the taphonomic agents moving, removing, and altering the evidence and remains. As important as listing these factors is assessing the degree and scale of their impact (e.g., rodent chewing on the ends of a few bones, as compared to a black bear scattering remains 30 meters from the main concentration of the body). As always, the pri-

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mary goal of this taphonomic agent inventory and impact documentation is sorting out natural factors from forensically significant human activity.

The types of evidence encountered, considered, and documented in the reconstruction of events at the outdoor scene are quite different from those at the indoor scene, and nearly always related to potential taphonomic agents interacting with the evidence (8). They will include environmental evidence, including trees, grass cover, and leaf litter; soil chemistry; animal interactions (e.g., scavenging, bone gnawing activities); insect interactions (especially anthropophagic insects); past weather and temperature conditions; humidity and flowing water factors; and gravity effects on remains located on sloping terrain, among many others.

Thus, it must be kept always in mind that the goal of the recovery of the outdoor scene is not just making sure that all remains are found and recovered, but recording and understanding the variety of taphonomic agents that affected the remains, as well as how they did so. We seek explanations of why things are moved or removed, determination of where the body was originally located, and even suggestions for the original position and orientation of the body since the time of deposition on the scene.

In the following section, we describe general forensic archaeological recovery procedures employed during the processing of the outdoor forensic scene.

Step 1: Careful Documentation of the Condition/ Context of the Scene at the Time of Discovery

Descriptions of the forensic scene begin with the notation of location. Identifying the location of the outdoor scene requires more precision than the street address commonly available for the indoor scene. Currently, global positioning system (GPS) coordinates obtained through the use of higher quality GPS units work best, especially considering that this information is critical for eventual incorporation into geographic information systems (GIS) analysis.

The immediate vicinity of the scene is described thoroughly via written notes and photography. Notation will include descriptions of factors such as tree and ground cover, slope, general soil types, proximity to water, roads and trails, and a myriad of other scene attributes that may be of potential relevance to reconstructing past events (e.g., how the individual got to the scene, impact on decompositional sequence and rates, the particular scavenging animals residing in the area). Photographic documentation begins from afar, capturing the general setting of the scene and then progresses inward toward the scene.

Step 2: Clearing Debris From Atop the Evidence

Following initial documentation of the scene, efforts to expose the remains from beneath vegetative covering can be started without disturbing or altering the position and location of the remains themselves. This denuding effort progresses from outside to inside the scene and serves to locate and expose the evidence as well as the underlying microtopography of the ground surface or substrate that the remains are resting upon, which permits further understanding of effects of taphonomic influences such as slope wash and gravity (**Image 2**). However, it should be noted that the process of searching and clearing the scene must not be conducted hastily and indiscriminately to serve the sole purpose of locating the underlying evidence. The presence and condition of biotic evidence and other evidence beyond the body might be key to addressing issues of missing or out-of-place remains or PMI estimation. For example, in the northeastern U.S., the stratification of deciduous leaf litter relative to the human remains provides a useful indicator of depositional timing of the body on the scene.

During this stage of scene processing, the ability to evaluate forensic significance of biological tissues (i.e., bone from non-bone, human vs. animal, fragment and altered bones) remains a crucial skill. If the scene is recent, it is important to search for recently overturned dirt, footwear impressions, and damaged vegetation indicative of recent human activity. In addition, evaluation of forensic significance extends to determining whether other natural items found at the

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scene may be directly associated with the death event. Has the log, or branches, or leaf litter been moved over the remains or the burial in order to conceal them? If they have, they provide a piece of the forensic taphonomic interpretation of past events and must be noted as evidence.

Step 3: Notation of the Spatial Distribution of the Evidence

Following removal and notation of the overlying vegetation, the next step in scene processing requires the careful notation of the precise location, position, and orientation of all the evidence via cartographic means. This could involve hand-drawn maps created through rather standard coordinate system mapping procedures as well as through electronic total stations, survey-grade GPS, or even three-dimensional (3D) scanners. The best practice combines multiple mapping procedures through several of these methods. A map of the immediate scene, including all the evidence associated with the death, body, or deposition event will allow the analysis of the spatial distribution of evidence as well as the assessment of forensic taphonomic factors (e.g., remains scattered in a pattern common to coyote or bear activity and behaviors). The map should include indications of scene contour (slope) and microtopography. This is best acquired through electronic total station mapping procedures. Notation of GPS points provides the location of the site at the global scale and permits incorporation into already existing maps and geographical resources and subsequent analysis in GIS software.

Extensive photographic and written notation of the evidence continues. This is particularly important not only for chain of custody purposes, but also for the analysis and interpretation of human skeletal trauma patterns. Detailed notation of the condition of the bones at the scene will provide evidence related to the relative timing of the trauma to bone, primarily, but not limited to, the distinction between perimortem trauma (at and around the time of death) and potential trauma induced during collection, transport, or laboratory examination.

Step 4: Collection and Transport

After completing all mapping procedures, proper collection and removal procedures can be started. Prior to placement in appropriate collection receptacles, each item of evidence receives a unique label matching that

Image 2: A) General view of human remains partially covered by leaf litter, obscuring appendages and other evidence. **B)** Plan-view hand-drawn map of remains following denuding with all associated evidence visible.

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in the plan-view and topographic maps, which is of prime benefit to subsequent analysis of the spatial distribution of the evidence and to retain chain of custody. The collection and transport process is then completed with protocols aimed at preventing any further alteration of the evidence from the time of recovery to the time of analysis in the laboratory or of postmortem examination.

Step 5: Laboratory Analysis

Either at the autopsy or at the forensic anthropological laboratory, key assessments are made of the condition of the biological tissues, especially relative to the state of decomposition, location, condition of the clothing and apparel on the body, and any other information that could potentially have an impact on forensic taphonomic interpretations. Next, soft tissues are removed from the bones in order that all surfaces of the bones can be examined. In addition to standard assessments of biological profile (chronological age, sex, stature, and ancestry), evidence is sought to explain unusual stains on the bones (20), fracture and traumatic impact patterns (26), and other bone modification patterns, such as animal gnathic marks, or burning and heat alteration of the bones (20). Analysis of other evidence found at the scene, including soil chemistry, weapons analysis, clothing specifics, potential fingerprints, and many others, can be completed by forensic specialists.

Step 6: Forensic Taphonomic Interpretation

The final step in the interpretation of the outdoor forensic scene is to put together the multidisciplinary recovery and analytical efforts into a coherent, scientifically defendable hypothesis of past events that have occurred at the forensic scene under investigation. This requires that the outdoor forensic scene must be processed with the idea that much critical information still resides there and exacting, well-thought out recovery procedures can retrieve it. It is no longer acceptable to use random, rapid, non-systematic collection procedures to find and recover evidence and remains at the outdoor scene. Taking a few pictures of the outdoor scene, randomly searching and collecting what can be seen without clearing the scene, and placing the body into body bags for rapid transport to the morgue or lab will always result in losses of evidence, context, and association information, and ultimately will prevent scientific reconstructions of key events transpiring at the scene. Just as this would not be acceptable at an indoor scene, this haphazard approach and destruction of evidence is not tolerable at the outdoor scene.

The common goal when processing all of these outdoor scenes is collecting the appropriate information to produce and test hypotheses regarding what happened there. The key first step requires the employment of the now common forensic archaeological methods and protocols described above, which have been shown to provide optimal results at outdoor forensic scenes time and again (9). These approach and protocols maximize the detection of evidence while minimizing the potential disturbance and loss of relevant forensic information and evidence.

Large-scale searches for unlocated scenes and remains that employ proper search protocols result in efficient and effective searches of large areas. These approaches maximize the finding of evidence while minimizing the potential disturbance and loss of information.

The recovery of surface-scattered remains focuses on the notation of the spatial distribution of the evidence through precise mapping procedures in order to understand how the remains were scattered and which taphonomic agents (e.g., gravity, slope wash, animals, humans) were most responsible for the moving, removing, and alteration of the evidence (1). By combining all the information recorded at the scene related to environmental factors and conditions, physical processes and indications of activity of potential natural agents that could have altered the remains, with laboratory analysis of the observed bone modifications (20), it will be possible to identify the specific agents most likely responsible for post-depositional modification. The analysis of this scene information takes into considerations factors such as animal behavior, botanical influences, and decompositional sequences and patterns, as well as considering the effects of environmental parameters affecting all the above, such

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as humidity, temperature, and water transport. Once these natural agents are identified, the focus turns to determining unusual or suspicious patterns that might not be explained by them and thus could provide evidence of human intervention. Attempts will be made at every scene to determine the location of the body when originally deposited at the scene, based on factors such as where are most of the remains congregated, location and spatial distribution of articulated remains or body decomposition fluids, as well as attempts to determine the position and orientation of the body at the time of deposition (e.g., face up or face down, feet upslope, head downslope). The forensic case example below provides a case study that will serve to better illustrate these points.

The recovery procedures for buried bodies in clandestine graves (27) will draw upon methods and practices of regular archaeology for the excavation of bodies and evidence in a burial feature, although with a few differences: 1) unlike the excavation of a prehistoric burial, much attention will be focused on the evidence of digging activities outside of the burial pit (e.g., footwear impressions, trampled vegetation, moved branches and logs); 2) the back-dirt pile will be carefully documented and excavated; 3) the configuration of the grave feature (e.g., size, shape, depth, presence of vertical walls) will be used to indicate haste or preplanning; 4) tool mark impressions on the edges of the grave will prove important as an indicator on the digging instrument employed, and may even point out a specific tool (27); 5) the position and orientation of the body in the feature will be compared to witness descriptions of the burial event; and 6) evidence may be found within the grave that might provide useful PMI estimates, such as the state of decomposition of plant material inadvertently added to the grave (1, 4, 8).

Fatal Fire Victim Scenes

Fatal fire scenes also benefit from a forensic archaeological approach to the collection of evidence. Scene processing at most fatal fire scenes traditionally involved little more than photographing the scene and the victims as found—a practice that, unfortunately, is still common today. Typically, no search for evidence is conducted through the fire-altered rubble. Following cursory notations, the body is then placed in a soft-sided body bag and taken back to the morgue for identification. A first problem with this approach is that following exposure to heat and fire all materials within a fire scene take on a similar appearance, making it difficult to detect and distinguish severely altered biological tissues from their surroundings, which may result in remains being left behind (28-30). A second problem is that skeletal tissues, following exposure to fire, become brittle, shrink, warp, and tend to fracture easily due to the losses in moisture and organic (collagen) components (31) and tend to break easily during recovery. Placing the remains in a soft-sided body bag exposes them to adverse conditions during transport, such that when the remains arrive on the morgue table they are commingled and significantly altered. Forensic archaeological protocols once again address and correct all these issues (28, 29). The context of the body relative to the scene is addressed diligently and with attention to detail, such as notating in which room of the house and on what floor the individual was located (based on the stratigraphy of debris covering and beneath the body) at the time of the fire, and whether there is evidence (e.g., guns, shell cases, knives) associated with the body. The documentation and recovery of the fatal fire scene calls for 1) a detailed search conducted at a distance from the body in order to locate associated evidence *in situ*; 2) careful hand-screening of burned debris in the vicinity of the body; 3) careful documentation of body position, location, and orientation via written, photographic and cartographic notation; and 4) detailed examination and documentation of the condition of the unmoved body *in situ*, specifically focused on initial descriptions of trauma, including specific location of defects (e.g., tool or cut marks).

Heat/fire alteration of bodies often leads to disassociation of parts such as distal appendages, cranial fragments, and dental remains. Careful recovery methods and attempts to associate all elements to a particular individual while excavating, even in commingled scenarios, lead to fewer disassociated remains to be sorted in the morgue and through DNA analysis.

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Processing at Mass Disaster Scenes

The crash of a plane, especially a large commercial airliner, results in a large, typically widely scattered scene in which large numbers of fragments of the crashed vehicle, human remains, and personal effects are commingled and altered, often including burning. Efficient and effective search, documentation and recovery methods to deal with the huge volume of material in a large area are even more crucial at these scenes. Forensic archaeology fits the bill best at these scenes, because of well-conceived search methods and the application of technology to the documentation process, including the inclusion of electronic total stations and survey-grade GPS units, bar-code scanning technology, high-quality digital photography, and even 3D scanning. Recently, research conducted on mock scenes have validated high throughput protocols for processing disaster scenes, and have resulted in national standards in the form of the Weldon Spring Protocols (32, 33) applicable to widely dispersed scenes, such as those encountered during the recovery of USAir Flight 427 (Pittsburgh, in 1994) and United Flight 93 (Shanksville, PA, in 2001), and the Clarence Center Protocols (34) for processing more condensed scenes, such as that found at the crash of Colgan Air 3407 (Buffalo, NY, in 2009).

Forensic Case Example: Surface-Scattered Remains in Deep Woods

A couple taking an early September walk on a wooded trail in central Pennsylvania discovered what looked to be a human skull (**Image 3A**). They decided the best course of action was to not disturb the skull and instead call the local authorities, the Pennsylvania State Police (PSP). A text message exchange between the county coroner and the first author confirmed the humanity of the specimen. The county coroner and PSP requested assistance from Mercyhurst University's Forensic Scene Recovery Team (M-FSRT) to process the scene. The next day, a preliminary review of the scene (following a search by the PSP the previous day) revealed the presence of many other human remains scattered a distance away and upslope from the skull (**Image 3B**). Prior to proceding directly into scene processing activities, consideration was given to addressing the standard questions asked of these outdoor scenes from a forensic taphonomic standpoint. It was suggested to the recovery crew that during the processing effort they were to think about how to answer and address each of the following questions (in essence, creating and then testing forensic taphonomic hypotheses, in real time at the scene). What evidence can be used to assess PMI? Why are the remains scattered? What taphonomic agents played an active role in moving/removing the remains? Is there evidence that humans interacted with the remains after initial deposition? What was the original location and position of the remains prior to dispersal? Each member of the recovery team was to be involved in hypothesis building and testing, such that they would have to make a case for a particular hypothesis and provide the evidence to back it up. They would be attempting to analyze the patterns of evidence distribution, and trying to explain unusual patterns. In this way, discussion on-site would attempt to answer many of the questions prior to the team departing the scene.

The first step of the recovery required a systematic search of the scene and vicinity for the purpose of attempting to find all of the remains of the victim, as well as any associated physical evidence. A straight-line pedestrian search ensued (**Image 3C**) and it was noted early on that the remains were situated stratigraphically on top of the leaf litter from the previous fall (**Image 3D**). This fact made the search more successful and less time consuming since a hands-and-knees search was not required to search beneath the leaf litter, especially given that the remains were widely scattered (approximately in a 30 m x 20 m dispersal area). This observation also provided evidence of one important aspect of the PMI hypothesis: the individual was deposited on the site sometime between the date of recovery (early September), and mid to late fall (October-November) of the previous year (Hypothesis 1).

After multiple pedestrian search transects were completed and the found evidence (human bones, clothing, belt, and watch) flagged, one area on the site exhibited a concentration of remains that included a collection of ribs and vertebrae, most still articulated, as well as

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a still-articulated right leg, including the pelvis and foot in boot (**Image 3E**). This pattern of a large portion of the skeleton in a concentrated area, with many elements still-articulated, suggested that the body was originally placed (deposited) in this particular location of the scene (Hypothesis 2).

A more detailed hands-and-knees search and vegetation denuding of the main concentration of human remains was then conducted, based primarily on expectations of locating a higher density of evidence in this area. The search revealed a number of smaller skeletal elements and associated evidence and provided fur-

Image 3: A) General view of human skull on surface of wooded area, prior to scene processing. **B)** General view of scene showing the scattering of remains (marked with red flags) prior to scene processing. **C)** General view of straight-line pedestrian search. **D)** Close-up of human remains lying on top of previous Fall's leaf litter level, indicating deposition of remains after September or October of the previous year. **E)** General view of main concentration of remains showing articulated pelvis, left leg, left boot and pants.

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ther support to Hypothesis 2. In addition, the leaf litter and soils beneath the remains (especially beneath the ribs and vertebrae) exhibited dark staining indicative of decompositional fluid presence (**Image 4A**), thus providing further indication that the remains were originally located above this layer (Hypothesis 1) and in this position (Hypothesis 2), with most of the decomposition process occurring at this spot.

A hand-drawn map of the main concentration of remains was completed (**Image 4B**). In addition, an electronic total station was used to map the scattered remains and evidence located away from the main concentration (**Image 4C**). The 3D notation of the provenience (exact location) of the evidence was used to create scene topographic contours, showing that the scene was situated on a slope. This provided evidence of a potential taphonomonic agent (i.e., gravity) during the attempt to answer questions related to why the remains were scattered as they were.

The isolated skeletal elements were individually numbered (Field Specimen Number) on the map, and collected in individual bags which were labeled with the appropriate field specimen numbers. Congregated, commingled, and/or articulated elements were documented and collected as a unit and individually numbered on the map and on the collection bag. The numbering system extended to the permanent labeling of the bones in the laboratory, which in turn facilitated the analysis of the spatial distribution of the remains, again, in attempts to attribute a reason for the scattering (e.g., scavenging animals, slopewash, gravity).

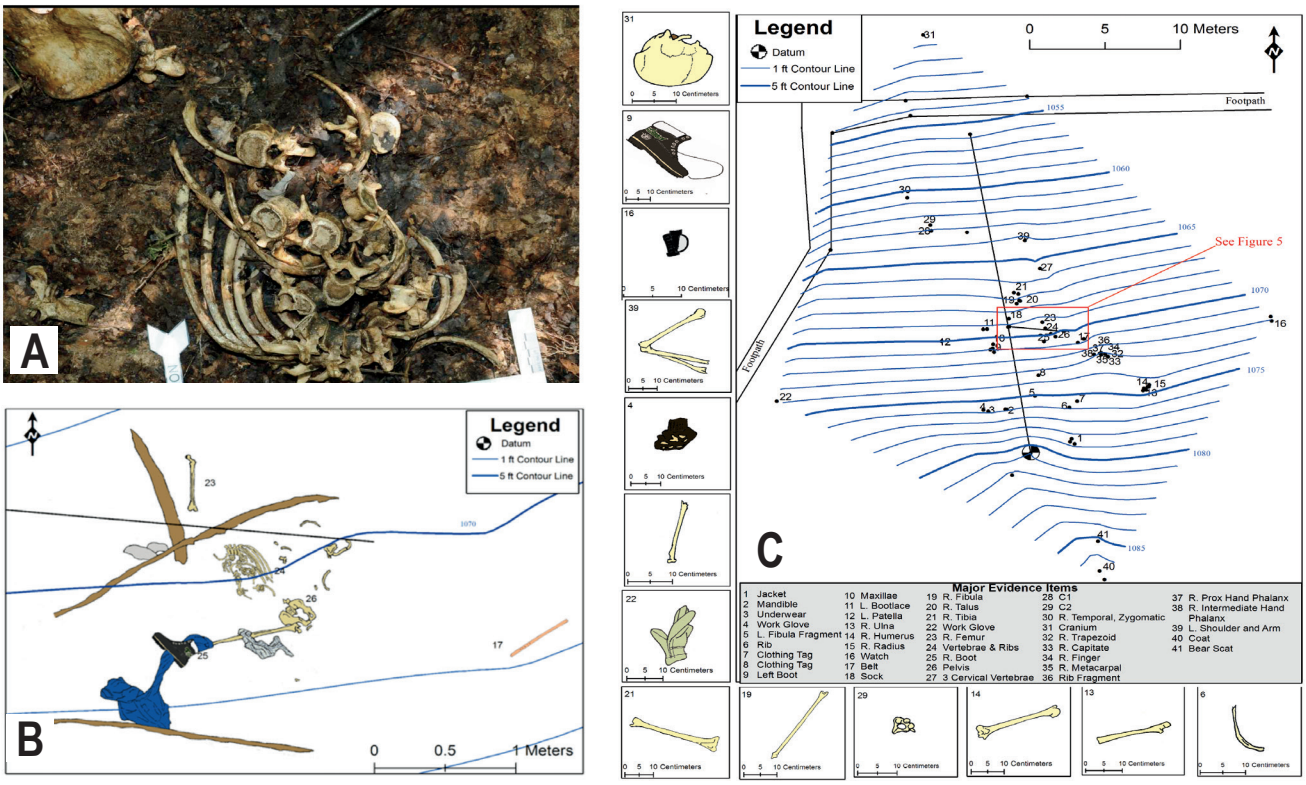

Image 4: A) Close-up of concentration of thoracic elements, also showing dark staining of soil and leaf litter suggesting in-place decomposition. **B)** Close-up hand-drawn plan-view map of main concentration of remains. **C)** Total station-generated map of the scene showing the distribution of evidence. Contour intervals obtained through GIS after collection of GPS points via Trimble R8. Boxes show individual relevant evidence.

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After scene documentation and collection of evidence, and prior to leaving the scene, reflection by the M-FSRT on all aspects of the recovery process and discussion of questions that needed to be addressed in the forensic taphonomic assessment indicated that two rather unusual observations regarding the condition and distribution of the evidence needed to be addressed. One related to the PMI estimates: the leaf litter to human remains stratigraphic profile indicated a PMI of 3-11 months, although the limited amount of soft tissue found on the skeletal remains was usually indicative of a PMI interval of 12-24 months (35). A closer examination of the human bones revealed that much of the articular cartilage remained on many of the long bones (**Image 5**), which corroborated the more recent depositional timeframe.

In addition, the significantly disarticulated and widely scattered pattern of the skeletal elements did not fit the normal pattern of canid scavenging typically found in forensic cases in most parts of Pennsylvania. Reference to another forensic case completed by M-FSRT a few years earlier led to the hypothesis that the body had been deposited in colder conditions and remained relatively fresh until the Spring, when hibernating black bears emerged, hungry, from their dens. Their scavenging behavior of removing most of the soft tissue without total destruction of the long bones, though some tooth marks are noted at the ends of the bones (documented in the laboratory) and scattering the bones widely, fit the pattern well. In addition, bear scat was found within the immediate scene.

In the laboratory, all of the soft tissue associated with the skeletal remains were carefully noted prior to removal. A partially decomposed foot was found still in the boot, further corroborating a PMI of less than 11-12 months. The search and inventory of all bone surfaces noted both definitive animal gnawing activity and somewhat equivocal fractured and fragmented bones. The laboratory analysis then focused on trauma patterns and distinguishing between perimortem (human-induced) from postmortem (animal-induced) damage. After comprehensive examination of the bones both macroscopically and microscopically, the trauma patterns noted in the cranium (**Image 6**) were confirmed to coincide with perimortem blunt force trauma to the face (anteriorly to posteriorly directed) and to the underside of the mandible (inferiorly to superiorly directed) with a heavy instrument that resulted in fracturing of the mandible, much of the maxilla, and many of the teeth. Evidence of sharp force trauma, in the form of a knife defect, was found in the back of the skull behind the ear. Indications of initial impact into the bone were noted, as well two subsequent episodes of altering the path of the blade in order to extract the blade from the bone.

In the final analysis, the forensic taphonomic hypotheses of PMI, perimortem events, original location of the victim, and postmortem events were eventually proven accurate by witness testimony and trial deliberations: murder of the victim in January (four-month PMI, after the previous Fall), deposition during a significant snow storm, use of a shovel handle to inflict blunt force trauma, no subsequent human attempt to alter the evidence, and bears in the area.

CONCLUSION

After proper collection and documentation of the scene, laboratory analysis of human tissue, clothing, decomposition patterns, bone surface modification patterns, analysis of the spatial distribution of the ev-

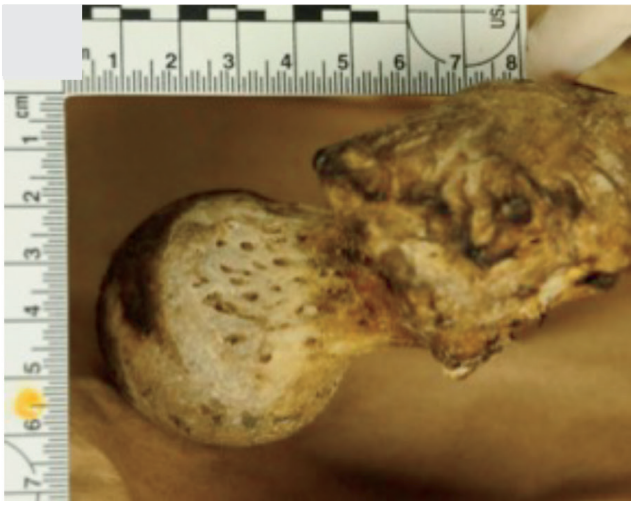

Image 5: Superior view of femur showing significant amounts of articular cartilage indicating relatively short postmortem interval.

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idence is then matched and analyzed with the scene information detailing context and association of the evidence. This matching process permits testing of a variety of forensic taphonomic hypotheses that relate to PMI, the original position and orientation of the body on the scene, and the role played by humans in the subsequent redistribution of body and the evidence. We can now properly address the following questions scientifically: 1) how long has the body has been on the scene (PMI); 2) whether it was moved from elsewhere; 3) why some bones are out of place (anatomically and originally) or even missing; 4) whether the body was originally located at the time of death; 5) whether we can determine how the body was situated in terms of position and orientation at the time of death; and 6) whether the victim was dead or alive at the time of entering the scene?

We can see that, as is certainly true of the indoor forensic scene, the thorough understanding of the context of an outdoor forensic crime scene, derived from exacting and comprehensive documentation and recovery methods, is critical to the successful resolution of the medicolegal death investigation. The multidisciplinary approach to the collection of evidence and information results in defensible reconstructions of what happened in the past at the crime (death) scene. It is clear that with regard to law enforcement methods, practices and principles employed during the processing of the indoor scene are well-defined and extremely effective (3, 36-38). It is also just as clear that law enforcement may not have equally appropriate methods to deal with the outdoor scene. This is where the employment of forensic archaeological methods, principles, and practices can provide the most thorough and comprehensive data collection standards, which in turn provide the best available information for the construction of forensic taphonomic hypotheses of what happened in the past at the scene.

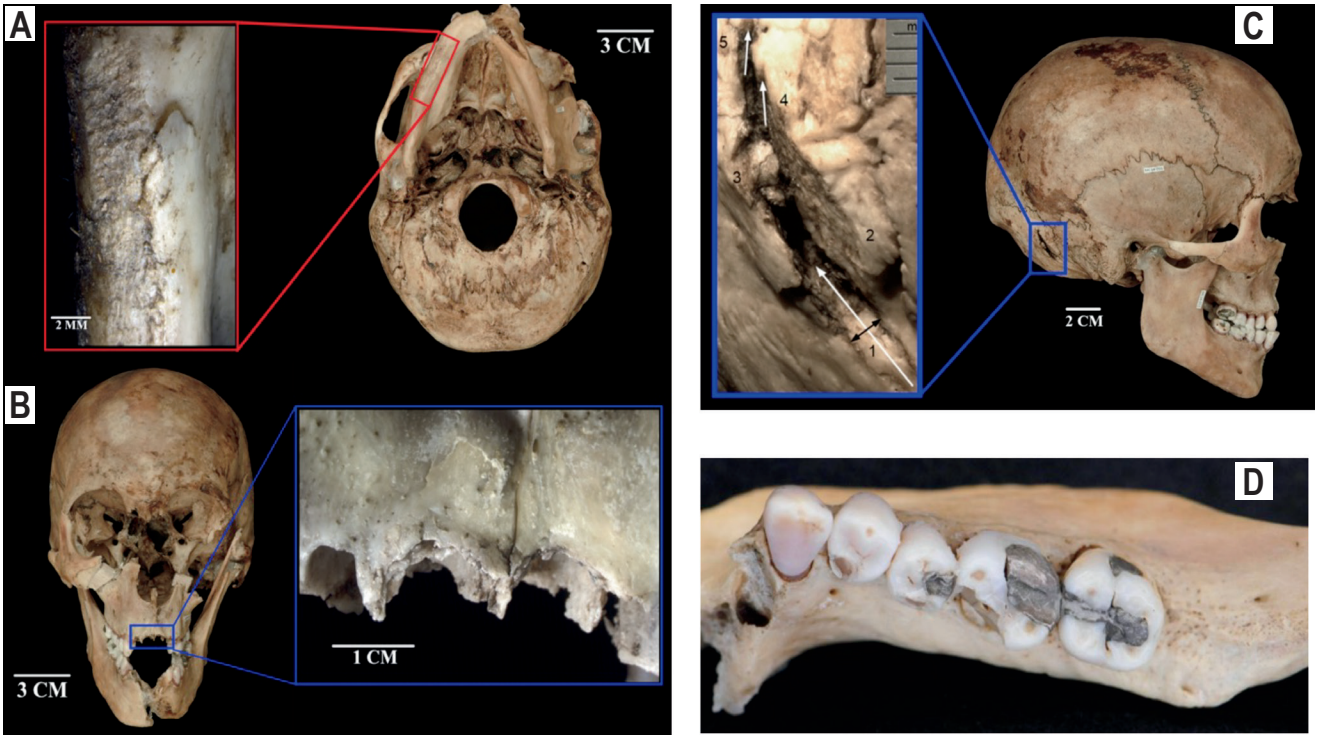

Image 6: A) Inferior view of cranium with close-up of blunt force trauma damage on inferior surface of mandible. **B)** Frontal view of cranium with close-up of fractured alveolar bone. **C)** Right lateral view of cranium with close-up of sharp force trauma defect. **D)** Occlusal view of right portion of mandible showing enamel fracturing of many of the teeth.

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The Forensic Anthropologist in the Mass Fatality Context

Jason M. Wiersema, Allison Woody

ABSTRACT

Mass fatality incidents require a multi-agency, multidisciplinary response to effectively and efficiently manage the recovery and identification of human remains. The forensic anthropologist is uniquely suited for a significant role in the disaster response, demonstrated in the recovery and triage of human remains, interpretation of skeletal trauma, and identification of victims. However, the majority of published literature discusses these response operations in the context of large-scale incidents with significant numbers of highly fragmented and commingled human remains, which does not reflect the operational reality of mass fatality incidents in the United States. This article provides a realistic definition of the term "mass fatality incident" for medicolegal jurisdictions and provides the contributions of the forensic anthropologist for all types of incidents. *Acad Forensic Pathol. 2016 6(3): 455-462*

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INTRODUCTION

Mass fatality preparedness is evolving as a discipline. Significant field, morgue, and laboratory work by a variety of practitioners has occurred in response to incidents around the world in many contexts including human rights investigations, natural and manmade disasters, and terrorist incident investigations during the last two decades. These large-scale incidents have resulted in a significant array of historical and planning guidance-oriented literature including Gursky et al., Saul and Saul, Mundorff, INTERPOL, International Committee of the Red Cross, and National Association of Medical Examiners (1-6). In particular, the discipline of fatality management is evolving to leverage the lessons learned from large-scale responses in order to benefit preparations by local medicolegal jurisdictions to respond to smaller-scale incidents. The primary audience for this article is the medical examiner/coroner jurisdiction whose susceptibility to large-scale catastrophic incidents is real, but far outweighed by its susceptibility to smaller incidents that may also disrupt their operations.

The occurrence of even a small mass fatality incident can present significant challenges to a local medicolegal authority. The fatalities associated with the incident must be managed in excess of daily caseload and often require additional or atypical processing methodologies. For example, there is often a shift in emphasis from determination of cause and manner of death to personal identification. In fact, the identification focus often associated with mass fatality incident response has resulted in development of the term "disaster victim identification" (DVI). The federally-supported activities of the Scientific Working Group on Disaster Victim Identification and the DVI Subcommittee of the Organization of Scientific Area Committees underscores the importance of identification in overall mass fatality incident management. On the other hand, some incident types, particularly mass shootings of the variety that have become commonplace in the United States, necessitate that the emphasis of the medicolegal investigation focus on careful analysis and interpretation of patterns of traumatic injury in addition to identification.

A medicolegal authority's response to a multiple or mass fatality incident will vary based on the circumstances of the incident and the capability of the local medicolegal jurisdiction to manage it. Likewise, the utility of the anthropologist in mass fatality incident response varies considerably depending on the circumstances of a particular incident. The roles of the anthropologist in the mass fatality context have been previously described in detail, including historical accounts of incident responses during which anthropologists made significant contributions (1-3). These publications identify the following as the primary contributions made by the anthropologist during recent mass fatality incident responses: anthropological recovery of remains from the mass fatality site, resolution of commingling, provision of biological profile estimations, interpretation of skeletal trauma, and radiographic identification.

DISCUSSION

Anthropological Recovery of Remains from the Mass Fatality Site

The typical forensic anthropologist has considerable training and experience in the application of archaeological field methods (7). These methods exist to ensure the preservation of contextual information associated with items recovered from archaeological sites, and can be employed in the forensic context to ensure that the location and contextual data recovered meet evidentiary standards. It is important to note two things about the application of archaeological recovery methods in the forensic/mass fatality context. First, the application of archaeological methods can be scaled up or down depending on incident circumstances. For example, detailed total station mapping is not necessary for simple incidents but may be of considerable utility for cases that may benefit from later reconstruction. Secondly, many of the techniques applied by the forensic anthropologist resemble those utilized by law enforcement crime scene technicians. The benefits of their application by an anthropologist is 1) that the anthropologist is operating as a medicolegal (rather than law enforcement) practitioner and 2) that anthropologists combine their knowledge of

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recovery methods with a detailed knowledge of fragmentary skeletal anatomy.

Resolution of Commingling

Most forensic anthropologists have experience in the recovery and identification of isolated or fragmentary remains, and are thus adept at resolving commingling of remains both at the scene and in the morgue. In the morgue, anthropologists will use their detailed knowledge of skeletal anatomy to develop a minimum number of individuals (MNI) based on the inventory of remains present in a particular assemblage. At the mass fatality site, the anthropologist can often circumvent later commingling issues via *in situ* re-approximation of skeletal elements.

Provision of Biological Profile Estimations

Development of the biological profile (estimations regarding a decedent's race, sex, stature, and age using skeletal morphology) is a core capability of the forensic anthropologist (8). Physical anthropologists are typically trained to consider variation in these traits on a population level, but their methods are applicable to individual cases. These methods are appropriate for use during mass fatality incident responses, and are invaluable tools for facilitating identifications by reducing the pool of possible identities for a set of remains. Some portions of the skeleton are more valuable for the development of the biological profile than others, but limited demographic inferences can often be pulled from fragmentary remains making biological profile estimation a valuable tool in the DVI component of a mass fatality incident response.

Interpretation of Skeletal Trauma

The typical forensic anthropologist is adept at recognition and interpretation of skeletal trauma (9), and extensive skeletal trauma is often present on remains following a mass fatality incident. Detailed anthropological interpretation of these injuries is not always of particular utility, for example, in cases when trauma is pervasive and there is no criminal component. There are however, incidents that benefit heavily from anthropological interpretation of skeletal trauma, either because the overlying soft tissue is decomposed or otherwise damaged to the extent that soft tissue trauma cannot be evaluated, or because the particular pattern of trauma lends itself to skeletal reconstruction and interpretation. For example, direction of fire and sequence of injury can be very valuable in the investigation of mass shooting incidents.

Radiographic Identification

Comparison of antemortem and postmortem skeletal radiographs is the mechanism used by the anthropologist to secure identifications of deceased remains (10). The utility of radiograph identification as a means to identify decedents is largely limited by the availability or lack of antemortem records. The frequency of use of radiographic identification by medical examiners/coroners varies considerably, but availability of records should not vary significantly with daily cases at a single office. Mass fatality incidents may represent a significant and abrupt shift in the utility of radiographic comparison, depending on a variety of factors including the degree of fragmentation and the origin of the decedents requiring identification. An office that is accustomed to frequent use of radiographic identification on its daily cases may find that acquiring antemortem records for nonlocal decedents may diminish the utility of radiography as a means to identification.

Evolution of Mass Fatality Preparedness

The existing literature regarding anthropological contribution to mass fatality investigations adequately describes and justifies the inclusion of an anthropologist in large-scale mass fatality response (1-3). However, the focus of each of the above listed publications is on large-scale incidents with large numbers of fatalities and high levels of fragmentation, commingling, and other taphonomic factors. Incidents of this scale typically require significant workflow modification at both the scene and in the morgue. As a result of the focus on large-scale incidents, the current literature implies that mass fatality incidents necessitate an all or nothing response strategy. The reality is that these large incidents are relatively uncommon, but that the

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small incidents that have become commonplace in the United States can present significant obstacles to effective management by a typical medical examiner/coroner operation. The other oft-cited component of mass fatality response that is not of particular utility in and of itself as an indicator of the complexity of a response is the number of fatalities. A large number of intact remains may be considerably easier to manage than a smaller number of fragmented, commingled and thermally damaged remains. Unfortunately, mass fatality variables like fragmentation, commingling, and thermal damage often co-vary, meaning that incidents become complex very quickly with the introduction of certain taphonomic influences. Similarly, a small open population incident where the victims' identities are unknown may be managed using standard operations, but may require additional emphasis on decedent identification and the utility of multiple identification methods (e.g., fingerprints, radiographs, dental, DNA). A measured, incident-specific response rather than a rigid all or nothing response strategy allows for reconciliation of the activation of modified methods with the continued demands of daily casework. For example, a mass shooting with eight victims may simply require an increased number of staff for scene response and pathology examination, incorporating the decedents into the daily case volume, rather than a complete departure from the office's daily operation.

Nevertheless, local medical examiner/coroner jurisdictions often seek guidance for mass fatality planning from federal initiatives that are associated with emergency management grant programs (e.g., Urban Area Security Initiative [UASI], State Homeland Security Program [SHSP], Regional Catastrophic Preparedness Grant Program [RCPGP]) and thus intend to provide preparedness benchmarks for large emergency management jurisdictions located in large urban areas. These programs are typically focused on preparations for catastrophic manmade or natural incidents that involve large numbers of decedents in complicated environments. This guidance is often of minimal utility for medium or small jurisdictions with limited or no mass fatality response capabilities.

Regardless of incident scale, there is currently little in the way of data supported literature examining the importance of forensic scientists (including anthropologists) in mass fatality response; the above listed references are compelling but largely anecdotal. In 2016, Woody et al. developed a database from which a variety of inferences can be made, including the utility of particular expertise in mass fatality incident response (4). The database is intended to generate a realistic definition of the term "mass fatality" for local jurisdictions that are in the process of developing mass fatality incident response plans. The database includes all multiple fatality incidents that occurred in the United States between January 1, 2000 and December 31, 2014 that resulted in four or more fatalities. The data were extracted from federal databases including the National Transportation Safety Board (NTSB), National Oceanographic and Atmospheric Administration (NOAA), the Mine Safety and Health Administration (MHSA), the Bureau of Safety and Environmental Enforcement (BSEE), the National Incident-Based Reporting System, and the Fatality Analysis Reporting System (FARS). Single incidents affecting multiple jurisdictions that resulted in fatalities were split by county/city to avoid over representing the burden of an incident on a single medicolegal jurisdiction.

A total of 2934 incidents met the criteria for inclusion in the database, accounting for more than 19 000 fatalities. The average number of fatalities per incident during the 15-year period included in the sample is seven (**Figure 1**). There is significant variability in the frequency of incidents by location and incident type, but the average number of fatalities is less variable by location (with the exception of the few locations within which very large incidents occurred [New York City and New Orleans]). The median number of fatalities in these areas resembles the median number in other areas.

The database also illustrates an urban distribution of mass fatality incidents (**Figure 2**), with high incident numbers centering around the large population centers (New York, Houston, Chicago, Los Angeles). Homicide incidents also center around population centers. Other trauma-related incidents including motor vehi-

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cle accidents (both mass transit and non-mass transit are more broadly distributed with concentrations in population centers (**Figure 3**). Weather-related incident distribution reflects hurricane and tornado susceptibility with higher concentrations of tornadoes in the central section of the country and hurricanes distributed along the Gulf and Atlantic coastlines (**Figure 4**). In 2016, the database was updated to include the

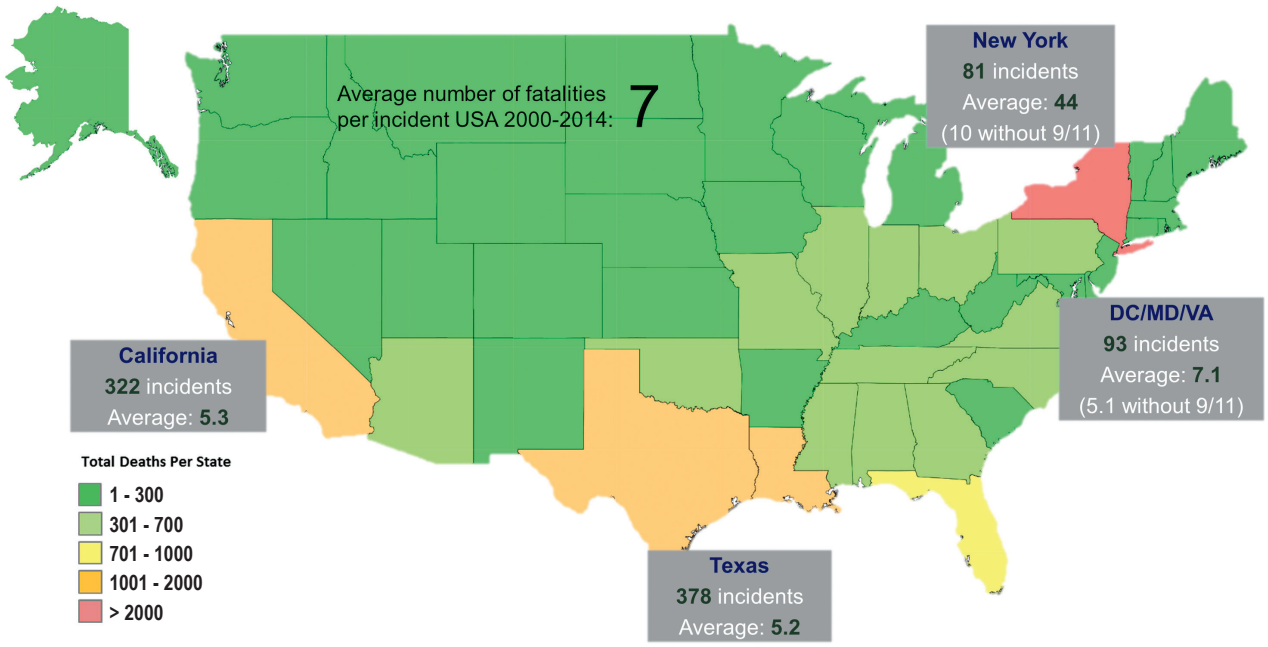

Figure 1: Total deaths resulting from mass fatality incidents 2000-2014 (by State).

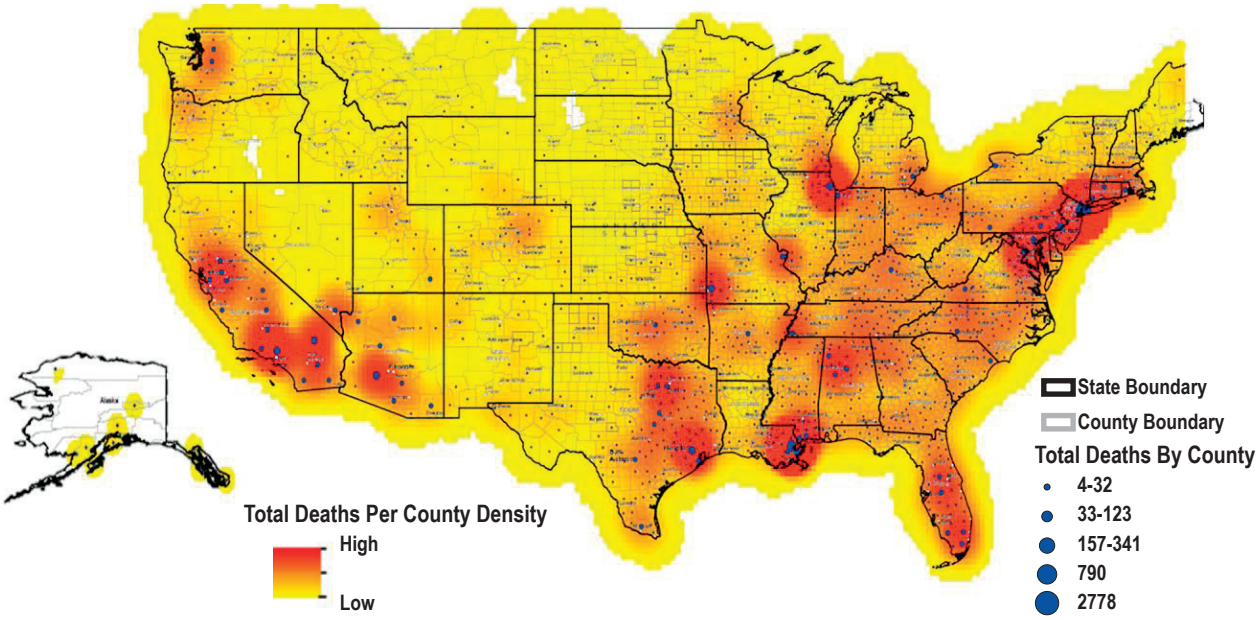

Figure 2: Heat map of mass fatality incident deaths 2000-2014.

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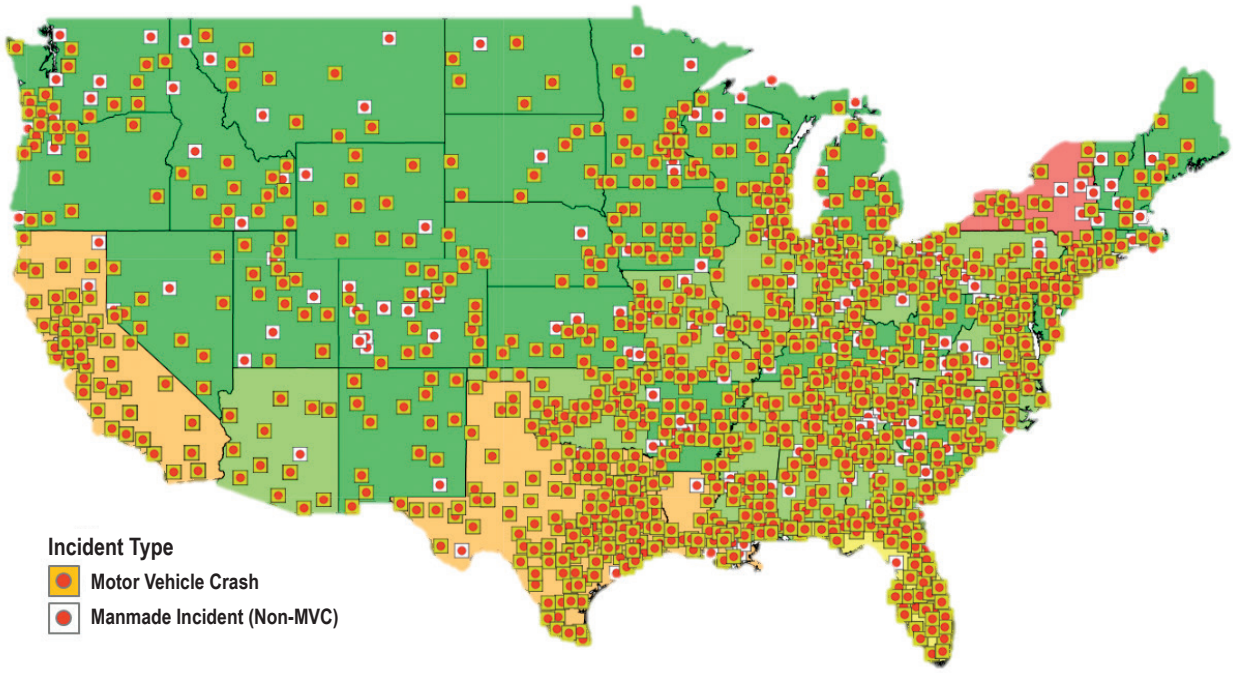

Figure 3: Motor vehicle crashes from 2000-2014.

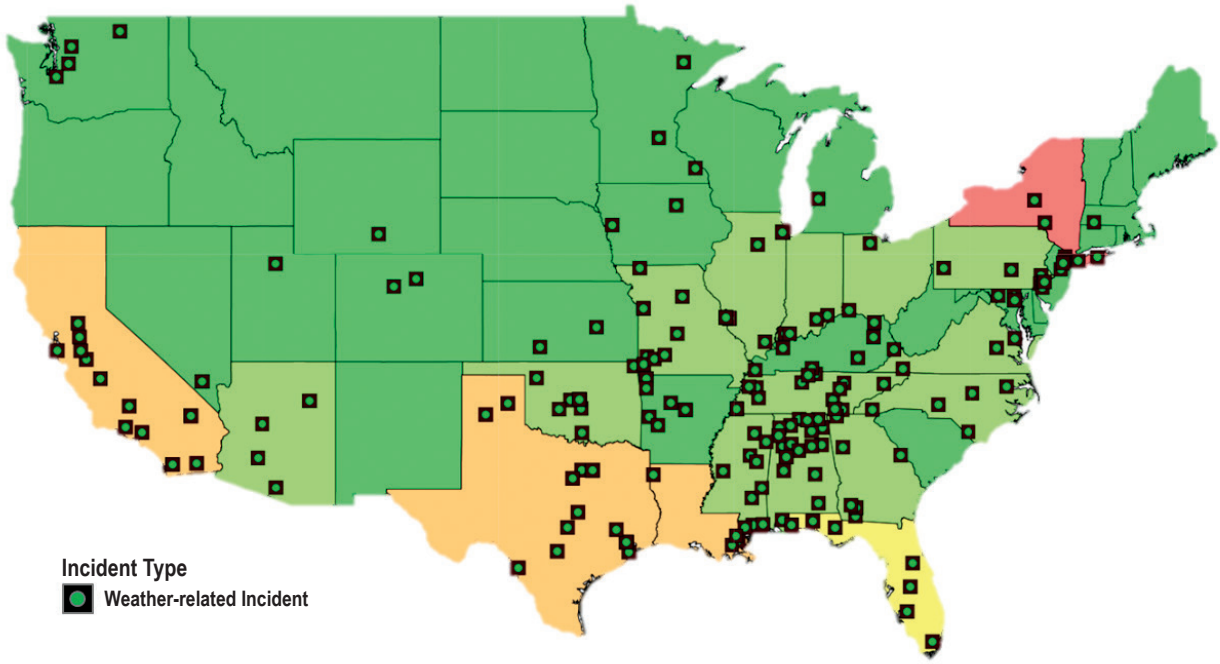

Figure 4: Weather incidents from 2000-2014.

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most recent mass shootings in the United States. The revised mapping demonstrates a high density and frequency of mass shootings in the east, as well as more isolated large-scale incidents in California and Florida (**Figure 5**). These data represent a valuable data supported planning tool for local jurisdictions. Local jurisdictions can use the expertise and techniques described in the available literature to make preparations for the scale and type of incident that they are most susceptible and scale up as needed for larger-scale incidents (1-3, 5, 6, 11).

Operational Implications of Mass Fatality Incident Characteristics

There are some predictable associations between mass fatality response characteristics and incident types (**Table 1**) that can inform planning for and response to a particular incident. **Table 1** compares incident types with the presence or absence of the more complex variant of an array of mass fatality characteristics (e.g., open population incidents are generally more difficult to manage than closed population incidents).

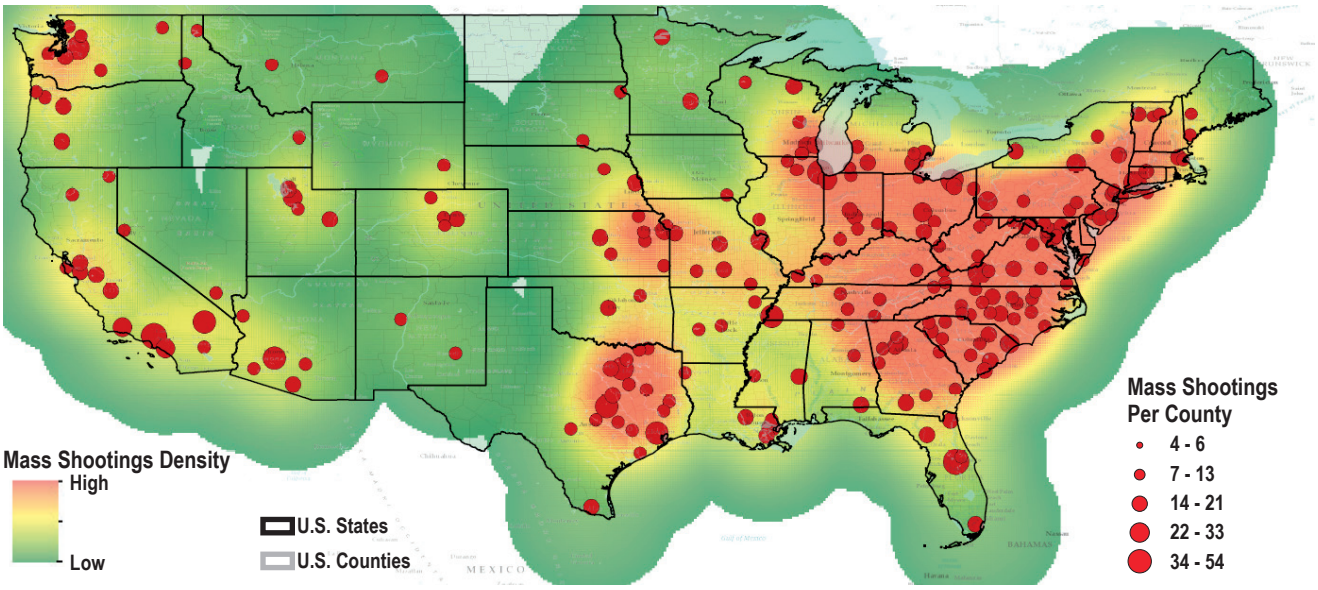

Figure 5: Mass shootings from 2000-June 2016.

Table 1: Complex Variables Associated with Mass Fatality Incidents

	Taphonomic Factors			Incident Factors				
	Fragmentation	Commingling	Thermal	Wide Distribution	Unassociated Personal Effects	Criminal Component	Open Population	Inflicted Trauma
Weather				✓	✓		✓	
Other Natural				✓			✓	
Motor Vehicle Collision / Mass Transit	✓	✓	✓		✓			
Mass Shooting						✓	✓	✓
Accidental Explosion	✓	✓	✓		✓		✓	
Other Terrorism	✓	✓	✓	✓	✓	✓	✓	✓

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Large-scale terrorist incidents like 9/11 are the most complex to manage because they involve a criminal component as well as a variety of taphonomic factors.

The management and response to these complex incident characteristics benefit from the involvement of a forensic anthropologist for the above described functions (e.g., scene processing, resolution of commingling, skeletal trauma analysis, identification). These characteristics also necessitate the development of a flexible and scalable mass fatality management plan that is specific to the hazards, risks, and capabilities of a particular medicolegal jurisdiction. Involving the forensic anthropologist (in addition to numerous other internal and external stakeholders) in this planning process is valuable in developing a strategy for implementation of minor modifications to daily operations versus a complete operational departure from normal procedures. For smaller jurisdictions, it may be more effective to plan regionally or statewide, relying on resources (including personnel) from outside the local jurisdiction to support mass fatality responses. This should include forensic anthropologists employed at medical examiner/coroner offices, colleges and universities, and other institutions. For example, a region or state may choose to work towards the development of a mass fatality incident response team replete with forensic specialists such as pathologists, death investigators, odontologists, and anthropologists.

CONCLUSION

The forensic anthropologist is often uniquely suited to support mass fatality incident operations and preparedness due to their varied expertise in site management, morgue operations, trauma interpretation and identification methods. While the role of the anthropologist has been described in the existing mass fatality literature, primarily within in the context of large-scale mass fatality incidents, there is significant utility for the forensic anthropologist in the smaller mass fatality incidents that occur much more frequently across the United States.

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Skeletal Trauma: An Anthropological Review

Jennifer C. Love, Jason M. Wiersema

ABSTRACT

As anthropologists take on a larger role in medical examiner's offices, the incorporation of bone trauma analysis into the autopsy increases. The purpose of this invited review is to summarize recent anthropological literature that exemplifies the value of forensic anthropology in medicolegal death investigation, concentrating in the area of skeletal trauma analysis. Forensic anthropologists have a strong understanding of bone's response to trauma, gained through research and case studies. With this body of knowledge they are able to examine and interpret skeletal injury resulting from blunt, sharp, firearm, and thermal trauma. For example, toolmark class characteristics are recognized through sharp force injury examination, and fracture pattern analysis provides details of the impacting surface area. Interpretation of skeletal trauma allows for reconstruction of events surrounding death, and may inform the manner of death classification. *Acad Forensic Pathol. 2016 6(3): 463-477*

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INTRODUCTION

The forensic anthropologists' understanding of bone biomechanics position them to thoroughly and accurately evaluate skeletal trauma, which may provide information critical to the medicolegal death investigation. Anthropologists analyzing blunt force trauma fracture patterns can assess the minimum number of impacts, the direction of impacts, and details of the impacting surface. Tool mark analysis can lead to the recognition of class characteristics of a suspect weapon. Assessing thermal changes in bone allows for the conditions of the fire and the relationship of the body to the fire to be estimated. Anthropological consideration of ballistic defects can contribute to interpretation of projectile trajectory. Details obtained from skeletal analysis may have an impact on the manner of death classification, case investigation, and/or case adjudication.

As anthropologists take a larger role in medical examiner's offices, we see increased bone trauma analysis of skeletal as well as nonskeletal cases (1). The information gained through analysis informs not only the individual case but the field of forensic anthropology as well. The purpose of this invited review is to summarize recent anthropological literature that exemplifies the value of forensic anthropology in medicolegal death investigation, concentrating in the area of skeletal trauma analysis. The review is augmented with images taken from the authors' casework that demonstrate concepts discussed in the research.

DISCUSSION

Before reviewing recent anthropological literature in skeletal trauma analysis, a few concepts and terms need to be defined. Bone, like most material, is stronger under compressive rather than tensile stress. The compressive strength of bone is directly proportional to its density (2). The organic component of bone is elastic and capable of absorbing tensile and compressive forces. The load rate and duration dictate how bone will respond to stress. Continual slow loading stress causes elastic deformation (temporary bending of bonds between atoms), followed by plastic deformation (permanent bending of bonds between atoms) and finally failure. Rapid loading stress results in bone failure in absence of elastic and plastic deformation, behaving as a brittle material (2, 3). Slow loading stress is associated with blunt force trauma while rapid loading stress is associated with firearm trauma. Understanding fracture initiation and propagation is important to accurate fracture interpretation. Fracture initiation is the location of initial bone failure and fracture propagation is the course the fracture takes through the bone. Fracture propagation depends on the direction of force as well as bone microstructures and buttressing systems (3). Controlled impacts of bone have shown that fracture initiation and propagation are strongly affected by impact type, magnitude of force, and cortical thickness (2).

Blunt Force Trauma

Skeletal fractures resulting from blunt force trauma reflect the type, amount, and direction of the force causing the injury. Analysis of the fracture characteristics as well as the fracture distribution pattern is often informative to events surrounding death. For example, a rib fracture pattern resulting from a fall onto a broad surface area such as a floor is very different from a rib fracture pattern resulting from a physical assault with multiple strikes in various directions. In some cases, a fracture pattern analysis may assist the pathologist in the manner of death classification.

Bone biomechanical analysis and anthropological case studies have furthered our understanding of fracture mechanics. Both intrinsic and extrinsic factors affect how bone is fractured. Intrinsic factors include bone geometry, bone density, and stress risers (e.g., the buttresses system of the cranium) (2). Extrinsic factors include area of the impacting object, load velocity, and load weight (2, 3).

Cranial fracture patterns provide information on impact location and surface area of the impacting object. Fracture patterns are commonly described as linear, complex, and comminuted (4). Linear fractures have two end points and may be described as linear or curvilinear. Complex fractures have three or more end points; a stellate fracture is a common descriptor of a complex

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fracture. Comminuted fractures are fractures that result in fragmentation of the bone. The different fracture patterns provide varying information regarding the impact.

Case reports illustrate anthropologists' success in linking cranial fracture patterns with suspect weapons. Love describes an anthropologic analysis of a cranial fracture pattern identifying a minimum of seven impact sites, consistent with strikes from an object of relatively small surface area (5). A bloodied hammer was recovered from the scene (**Image 1**). Ta'ala et al. presented ten cranial samples from a Cambodian skeletal collection of Khmer Rouge victims, each with a unique occipital fracture pattern that corresponded to the historical record of a particular execution method (6). The execution method described by several witnesses and an executioner as well as depicted in a prisoner's painting involves the victim kneeling over a large pit with his hands tied behind his back and an executioner striking him in the back of the neck with a blunt object. Further, documents discovered at the Tuol Sleng prison include terms related to kill or destroy that literally translate to "to smash" or "to shatter." The researchers examined 85 skulls held in a memorial at Choeung Ek, a mass grave used by the Khmer Rouge. Ten of the crania demonstrated substantial damage to the occiput that extended from the foramen magnum to the external occipital protuberance. The fracture pattern is consistent with the described execution method of striking a kneeling individual in the back of the neck.

Long bone and rib fractures provide information about the direction of force and type of impact as well and a significant amount of recent research is focused on these bones. For example, Reber and Simmons impacted 255 sheep femora with a pendulum apparatus using an accelerometer to measure the impact force magnitude and a high-speed camera to record the impact site and fracture propagation (7, 8). Evaluating

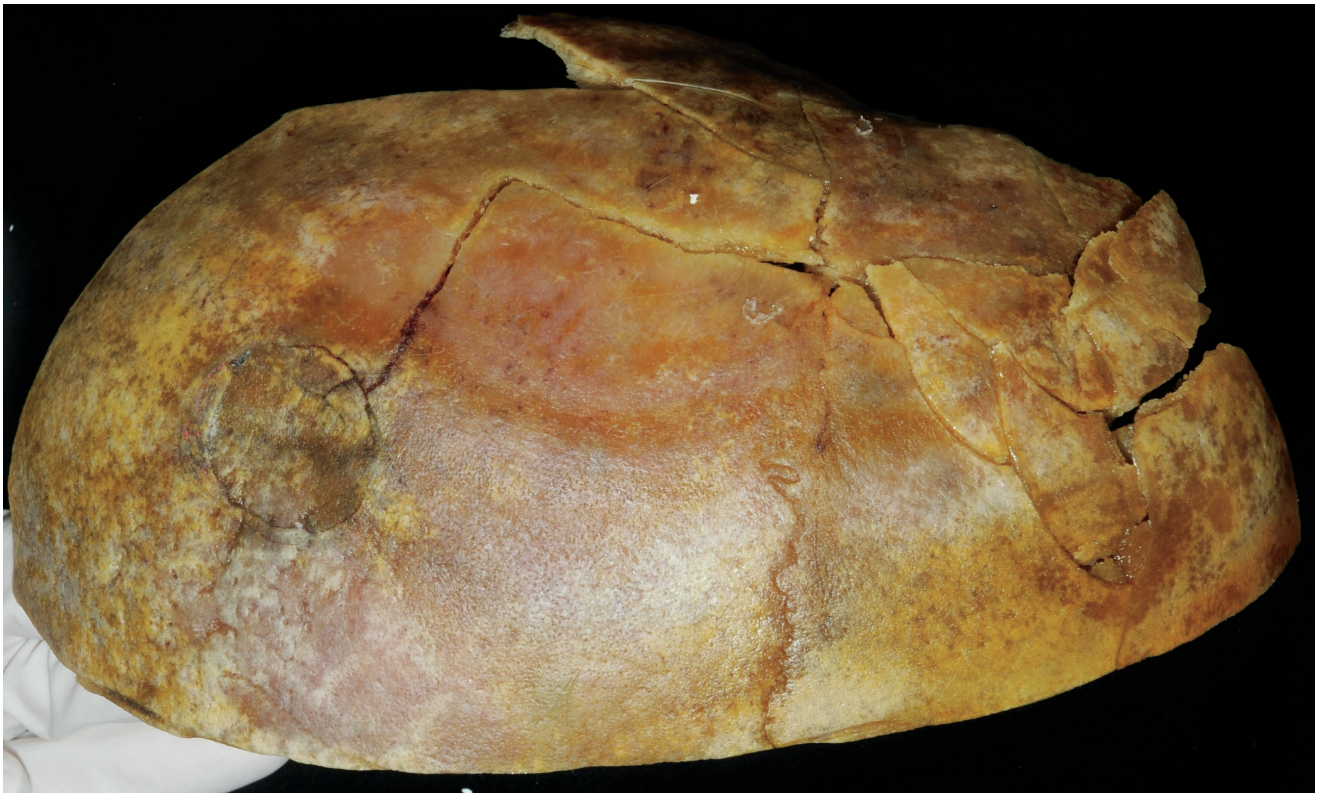

Image 1: Calotte with multiple impact sites consistent with strikes from an object of small surface area. The decedent was reportedly hit in the head with a hammer.

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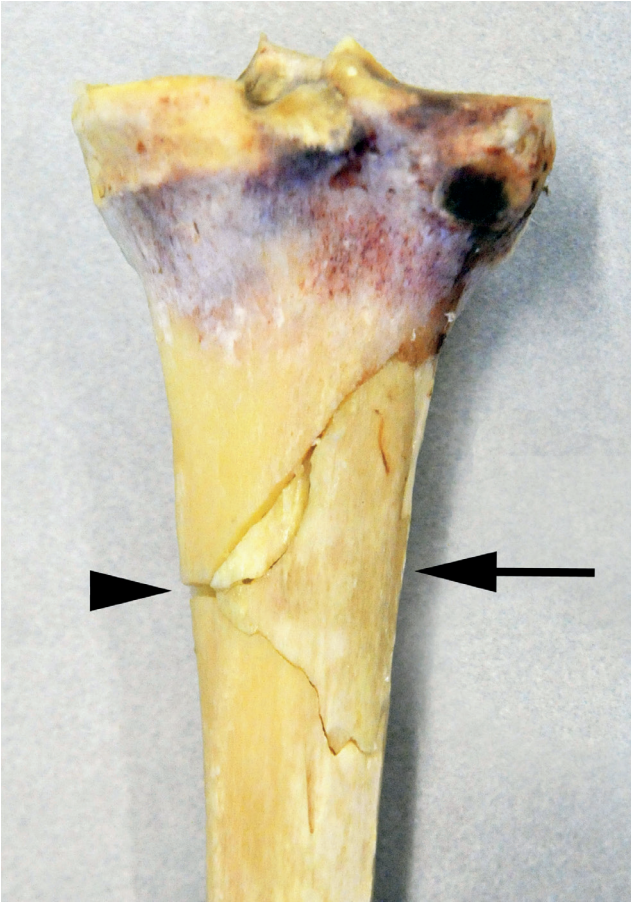

Image 2: Right tibia with a butterfly fracture. The triangle is marking the point of failure in tension and the arrow is indicating the direction of force.

the entire fracture pattern, including complete and incomplete fractures, the authors were able to pinpoint the impact location accurately on 98% of the samples. The authors described eight common fracture patterns. Each fracture pattern consisted of a complete fracture at the point of tension and radiating fractures coursing through the bone at various angles, acute and obtuse. The complete fracture at the point of tension was opposite to the point of impact in the majority of the specimens (**Image 2**). Christensen and Smith evaluated rib fractures resulting from blast trauma (9). The authors exposed 11 pigs to semi-controlled blast events. Tensile failures occurred along the pleural surface of the ribs in all of the pigs. The authors theorized that the blast created an expansive force causing the thorax to expand and the ribs to fail in tension on the pleural surface. The authors stated that blast fracture patterns are distinctive from ballistic and sharp force trauma patterns. Love and Symes examined rib fractures in 43 blunt force trauma cases and found, contrary to current biomechanical understanding, that ribs failed in compression prior to tension in the anterior region, an area of the rib with very thin cortical bone (10). The authors termed the fracture type "buckle fracture" and theorized that the failure was due to structural insufficiency as opposed to material properties. Furthermore, the authors equated these fractures with anterior to posterior forces applied to the anterior chest (**Image 3**).

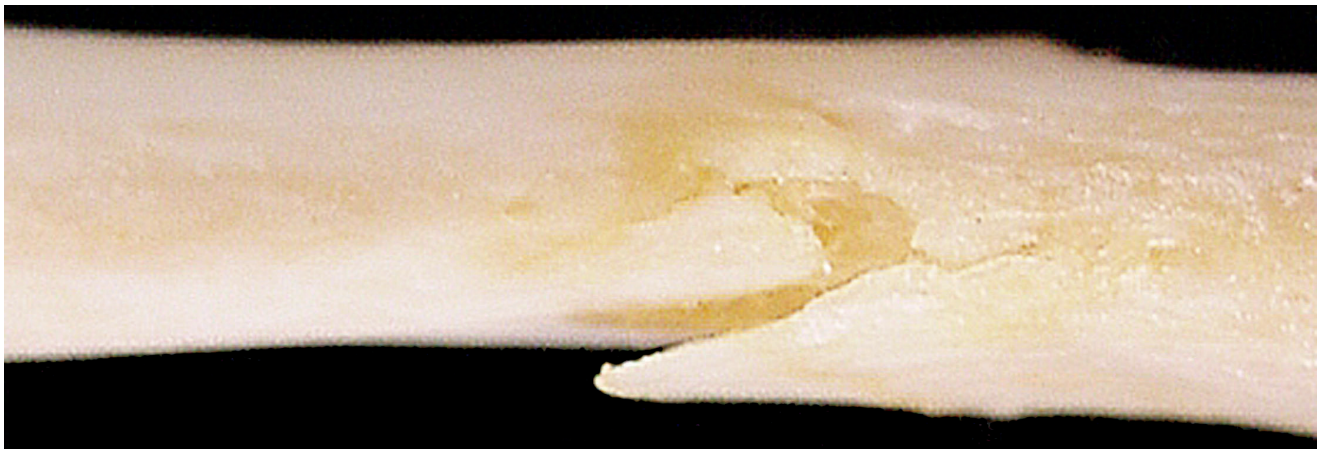

Image 3: Buckle fracture of an anterior rib. Note that the pleural surface (inferior) is folded onto itself, a failure from compressional forces.

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Although a significant amount of anthropological research has enabled practitioners to accurately assess blunt force fracture patterns, other research has continued to raise questions. Most notably is research focused on fracture propagation within the cranium. Gurdjian and colleagues set the foundation for the research by evaluating the propagation of cranial fractures using a "stress coat" technique (11). The researchers coated dry human skulls with a brittle lacquer, dropped the skulls onto a hard surface and evaluated where the lacquer cracked. The team found that on the endocranial surface the cracks initiated at the impact site, regardless of the impact location on the skull. In contrast, the cracks of the ectocranial surface initiated at a location away from the impact site. Based on the lacquer cracking pattern, the researchers concluded that in-bending occurred at the impact site generating tensile forces on the endocranial surfaces and out-bending occurred around the impact site creating tensile forces on the ectocranial surface. Kroman and colleagues tested Gurdjian's theory using unembalmed human heads and a high-speed video camera (12). The researchers placed five human heads in a drop tower structure and struck each on the anterior parietal region with a mass weighing 8.58 kg. The complete skull was exposed except for a small patch of skin at the impact site. Evaluation of high-speed video showed that all fractures radiated out from the point of impact and no out-bending was observed. Baumer and colleagues also investigated fracture propagation using controlled impacts of infant porcine skulls (13). The researchers struck the parietal bone with either a rigid or compliant surface measuring the impact force, impact duration, and fracture length and documenting the location of each fracture. Of the 76 impacted crania, 70 crania were marked with fractures that initiated at the bone-suture boundaries and propagated towards the impact site. This finding is consistent with Gurdjian's theory and inconsistent with Kroman's theory. The use of different methods and human verses animal models limits the conclusions that can be drawn from the research. However, the difference in biomechanical response observed between the human adult and infant pig skulls is a cautionary tale that understandings developed using adult bone studies cannot be applied to pediatric bones without consideration for developmental differences.

Thermal Trauma

Thermal trauma poses unique challenges to decedent identification and recognition of sharp, blunt, or firearm traumata. The role of the forensic anthropologist in cases of thermal trauma often begins at the scene. Forensic anthropologists are trained to distinguish osseous from nonosseous material and human from non-human remains, skills necessary for sorting through fire debris. Furthermore, anthropologists are equipped to thoroughly document the scene, which is critical to maintaining fragment provenience and separating commingled remains. The importance of employing an anthropologist at the scene is best exemplified by the Black Saturday fires that occurred in Victoria, Australia on February 7, 2009 (14). The massive fires resulted in 145 separate scenes spread over 1500 square miles. Initial scene processing did not involve anthropologists. Ultimately, 86 of the scenes were revisited with an anthropologist and 56 additional victims were recovered.

Thermal destruction of bone results in the elimination of water, consumption of the organic components, color change, splitting, shrinkage, and warping (15); yet, significant information can be obtained from burned bone. Warping of bone precludes metric analysis for estimating the biological profile, but morphoscopic methods can be accurately applied (16). Osseous pathologic features are often recognizable in burned bone. For example, remnants of an ossified fracture callus remain adhered to bone despite destruction of soft tissue. Pathologic changes in bone shape (e.g., diffuse idiopathic skeletal hyperostosis) are visible in burned bone despite heat induced warping and shrinking (15). The color of the bone can provide information to the context of the burning and temperature (15, 17). For example green, yellow, pink, or red stains on bone signify that the bone was burned in the presence of metal such as copper, bronze or iron while blackened cortical bone suggest a lower temperature of approximately 300°C and white cortical bone suggests a higher temperature of approximately 800°C (15, 17).

Anthropologists have focused a notable amount of research on recognizing perimortem trauma in burned

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bone. For example, Pope and Smith introduced sharp, blunt, and firearm traumata to forty donated unembalmed cadaver heads prior to thermal damage (18). Following the burning, the cranial bones were reconstructed and examined for signatures of trauma. Internal and external beveling and radiating fractures were observed in the crania subjected to ballistic trauma (**Image 4**). Impact sites and radiating fractures were observed in the crania subjected to blunt force trauma. Linear incisions and chop marks were observed in the crania subjected to sharp force trauma (**Image 5**). Herrmann and Bennett studied fracture patterns resulting from perimortem blunt, firearm, and sharp force traumata as well as thermal damage (19). Using pig femora, the team introduced sharp, blunt, and shotgun traumata prior to burning the remains. The researchers found that signatures of sharp force trauma were easily recognized on the burned bones, but radiopaque scatter was not observed in any of the specimens with shotgun trauma. They found differentiating between heat-induced and blunt force fractures was difficult. Marciniak evaluated saw marks for class characteristics in burned bone (20). The author created saw marks with manually and electrically power saws in pig femora prior to burning. She found that the false starts were well preserved, and diagnostic characteristics were observable in each saw mark after burning.

Sharp Force Trauma

When a knife or saw is used to cut bone or cartilage, signatures of the tool's cutting edge are recorded on the specimen (**Image 6**). A significant amount of research has focused on analyzing tool marks on bone and cartilage. Symes evaluated cut marks in bone made with 26 saws and serrated knives and described numerous features that reflected the class characteristics of the tools (21). The majority of the features reflected the design of the saw, most notably the tooth set and the distance between teeth (**Image 7**). Love et al. furthered Symes's work on saw marks by evaluating the discriminatory value of each characteristic (22). The team made experimental saw cuts in human femora using four saw types. They found that some features such as minimum kerf width, floor shape, and average tooth hop were highly replicable and informative class characteristics. Crowder and colleagues evaluated various class characteristics to assess associated error rates (23). The authors made cut marks in pig cartilage, deer femora, and casting material using serrated, partially serrated, and nonserrated knives.

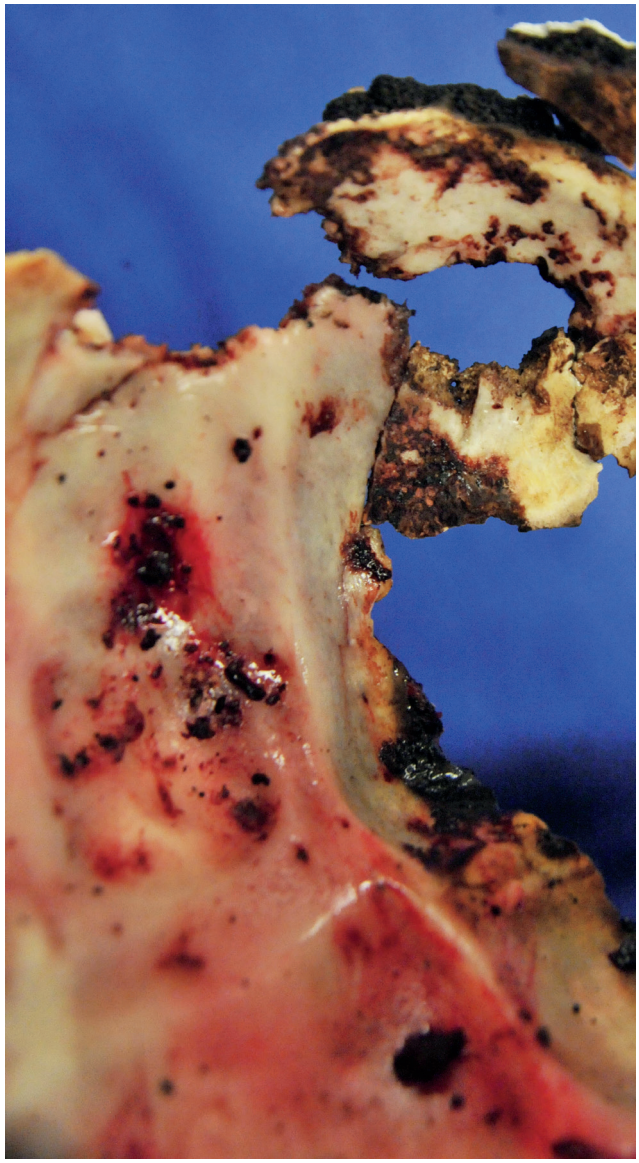

Image 4: Internal surface of a reconstructed occiput with an entrance gunshot wound (GSW). The decedent was burned in a car fire. The majority of the neurocranium was highly fragmented and required reconstruction to identify the GSW. Note the internal beveling of the wound margins.

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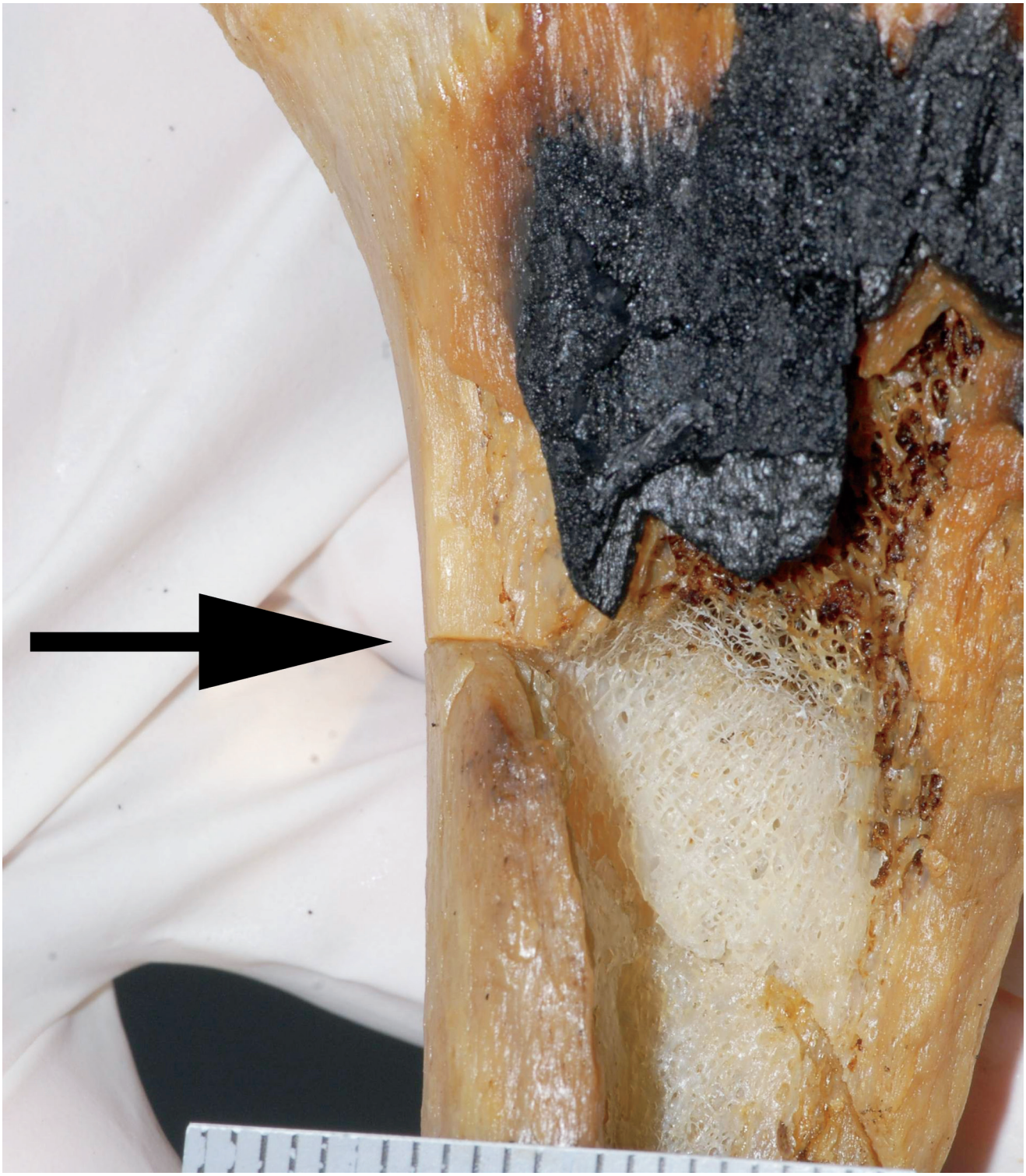

Image 5: Sharp force injury in a burned proximal femoral shaft. Note the straight margins of the cut mark (arrow).

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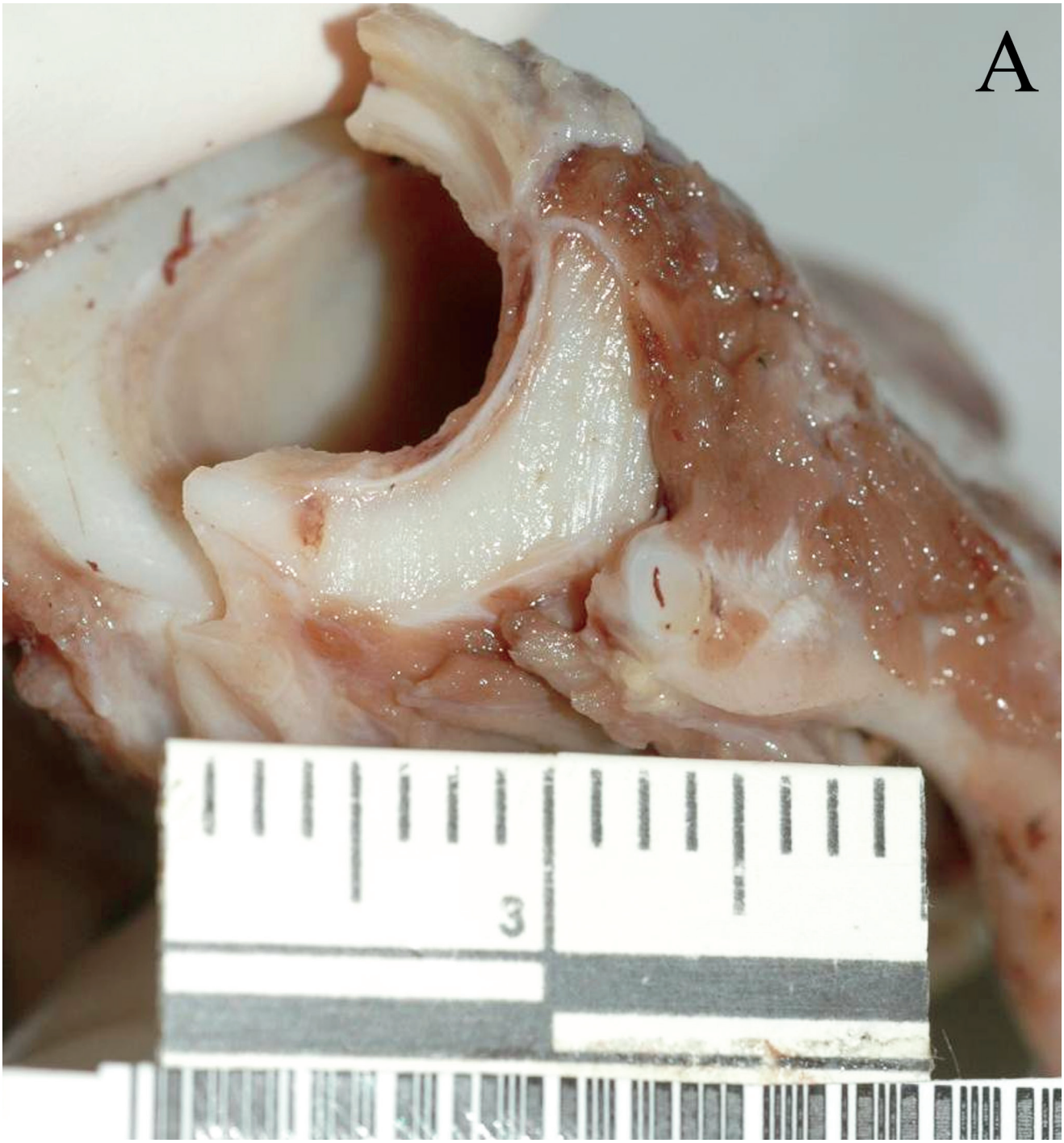

Image 6: A) Cut mark through the trachea.

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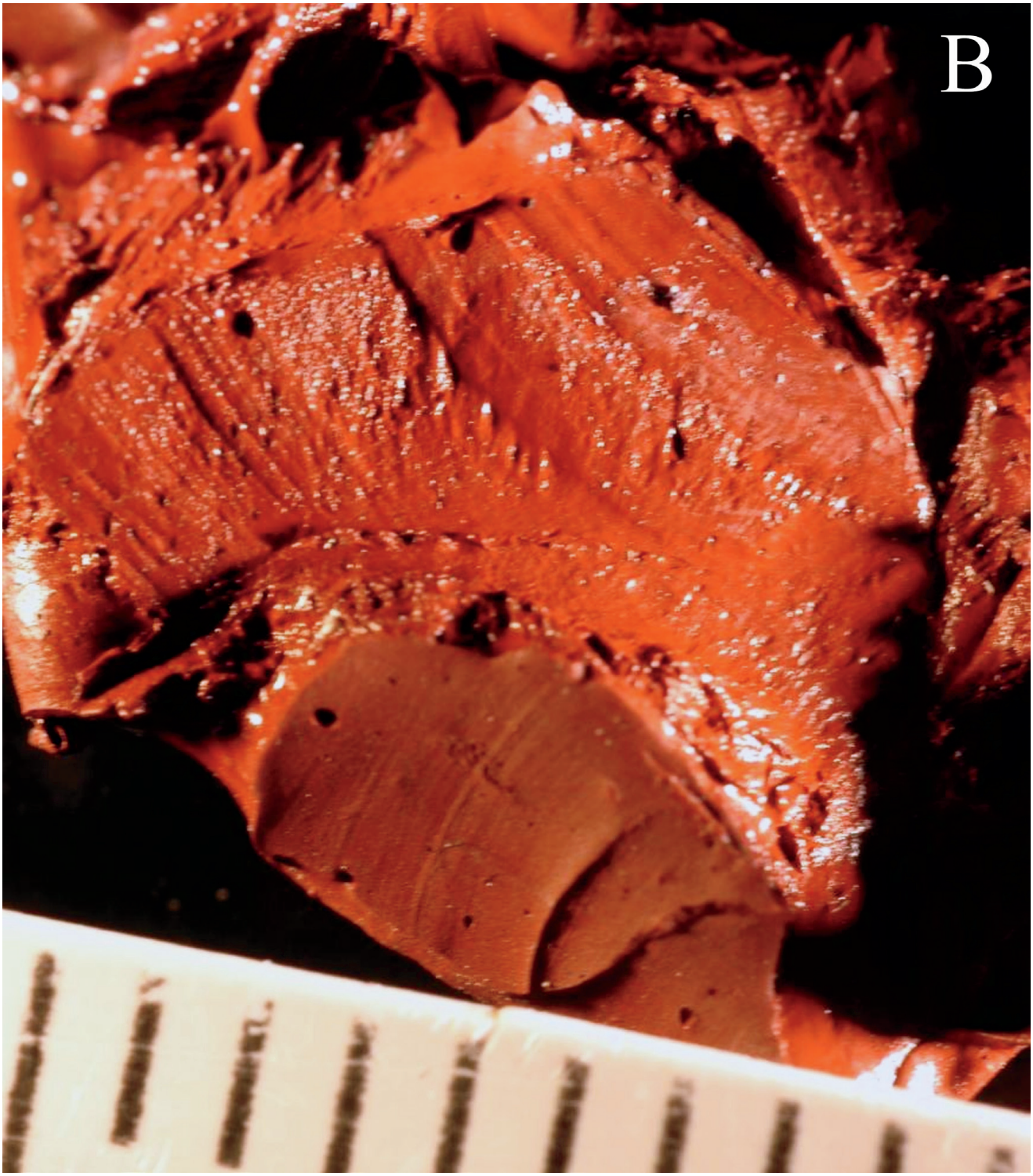

Image 6: B) Cast of the cut mark through the trachea. Note the striation pattern indicating a tool with a major and minor serration pattern along the cutting edge.

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After combining serrated and partially serrated knives into a single group, the researchers found a 98% accuracy rate in recognizing the blade type from the cut mark.

Several sharp force trauma case studies illustrating tool mark analysis from bone and cartilage are published and tool mark analysis has been found admissible in court. For example, Reichs published six saw

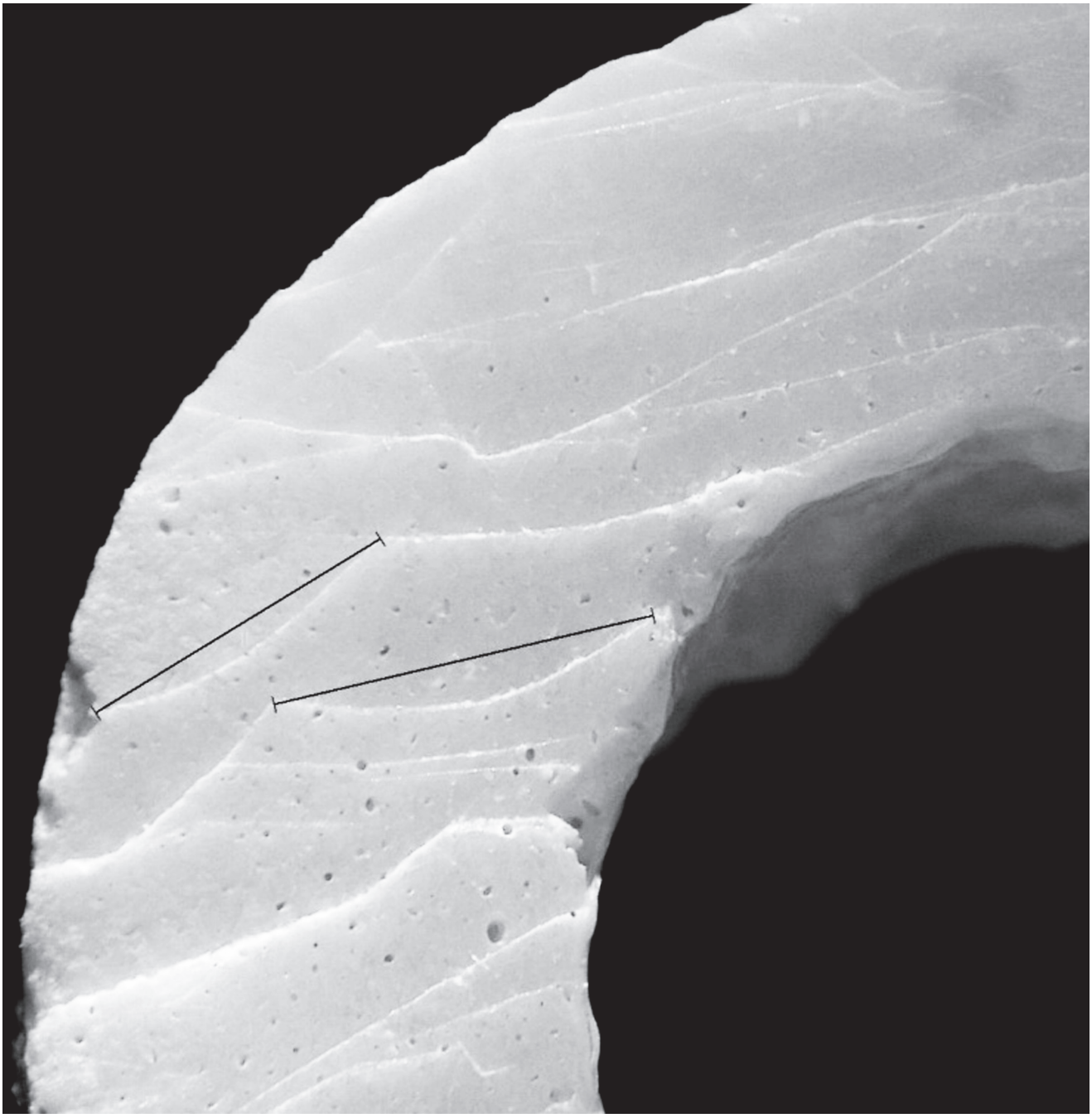

Image 7: Saw mark made with an eight teeth per inch alternating saw. The lines are marking the tooth hop. The peak to peak distance reflects the teeth per inch setting.

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mark cases in her text *Forensic Osteology: Advances in the Identification of Human Remains* (24). In each case, she was able to identify class characteristic in the saw mark. In *Shepherd v. The State of Texas*, the anthropologist provided testimony regarding a tool mark analysis she performed on burned bone (25). During the trial, the defendant admitted to dismembering the victim with an electric jigsaw. The defendant was convicted and sentenced to 99 years of confinement. The defendant appealed the conviction on the grounds that the court erroneously admitted the tool mark testimony based on qualifications of the anthropologist and the reliability and relevance of the testimony. The appellate court found the anthropologist qualified to testify on the tool mark analysis and the testimony to be reliable and relevant under Texas Rule of Evidence 705.

Firearm Trauma

Forensic anthropologists are regularly asked to render their opinion on firearm injuries involving the skeleton. The specific questions asked typically involve projectile trajectory and number of separate impacts. The literature pertaining to the interpretation of ballistic wounds is fraught with problems (26), and has resulted in an oversimplified focus on projectile velocity as the primary factor influencing the characteristics of firearm injuries. For example, the terms "low velocity" and "high velocity" are commonly used to categorize penetrating firearm wounds. These are gradient terms and the thresholds used to demarcate them vary considerably. Ballistic definitions for low velocity vary from less than 400 feet per second to somewhere between 2000 and 3000 feet per second (26). By this definition, most handguns are considered low velocity, and many rifles are considered high velocity, but there is considerable overlap. In addition, velocity alone does not adequately account for variation in ballistic wounds. As with blunt trauma, the manifestation of ballistic injury is influenced by both intrinsic (e.g., bone density, geometry) and extrinsic factors (e.g., size, shape and velocity of impacting object) (2, 3, 26). This is true whether the impact material is soft tissue or bone. Bone exhibits considerable focal variability in its resistance to fracture based on morphology and structure. According to Young's Modulus, the capacity of a material (including bone) to resist fracture is dependent primarily on the rate at which a force is applied (2). In general, firearm projectiles impose rapid loads relative to blunt force impacts, and bone tends to respond to ballistic (rapid) loading as a brittle material. Regardless of the ballistic category of a particular weapon, there is no known biomechanical failure threshold that applies to all bones; but, the harder the tissue, the greater the amount of resistance it presents to an impacting projectile and the more destruction it will undergo upon failure (27). Bone is subject to reduced plastic deformation under higher velocity loads. Because of the relative lack of plastic deformation, the bone fragments resulting from ballistic impact are often numerous, but are more easily re-approximated to facilitate interpretation. Further, the lack of plastic deformation is suggestive of ballistic trauma in cases of incomplete reconstruction due to the extent of destruction or incomplete recovery of bone fragments.

The anthropological contribution to the interpretation of ballistic trauma is often through an anatomically informed reconstruction of bone fragments and subsequent interpretation of projectile trajectory. There is generally less tissue loss in bone than soft tissue, and with careful reconstruction, bones often present a detailed record of ballistic wound characteristics. Trabecular bone, as present in the ends of long bones and the bodies of flat bones like the innominate, and fragile cortical bone, as present in the ribs, the body of the scapula, and the midface, can provide an indication of projectile trajectory when carefully reconstructed. For example, anthropological reconstruction of the fragile bones of the midface can clarify the location and number of ballistic wounds.

Both gunshot and shotgun projectiles leave diagnostic defects in bone. Analysis of these defects enables projectile trajectory reconstruction (28-32). Kieser et al. examined experimental gunshot wounds in pig ribs and identified several consistent entrance and exit characteristics (32). The projectile created a cone within the rib with a smaller defect on the side of entry and a larger defect on the side of exit. Also, the exit

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surface was beveled and radiating fractures extended outward from the wound (**Image 8**). However, experimental evaluation of gunshot wound size shows that caution should be exercised when using defect size to make inferences of projectile caliber (27, 34).

Anthropological interpretation of firearm trauma is dependent on recognizing diagnostic features that may be present on highly fragmented bone. Careful recovery of skeletal elements, some of which may appear too small to be of value, is important to wound reconstruction and subsequent interpretation of skeletal injury. Thus, the contribution of the anthropologist in cases of firearm injury may extend to the scene as well as collecting bone fragments in soft tissue during the autopsy.

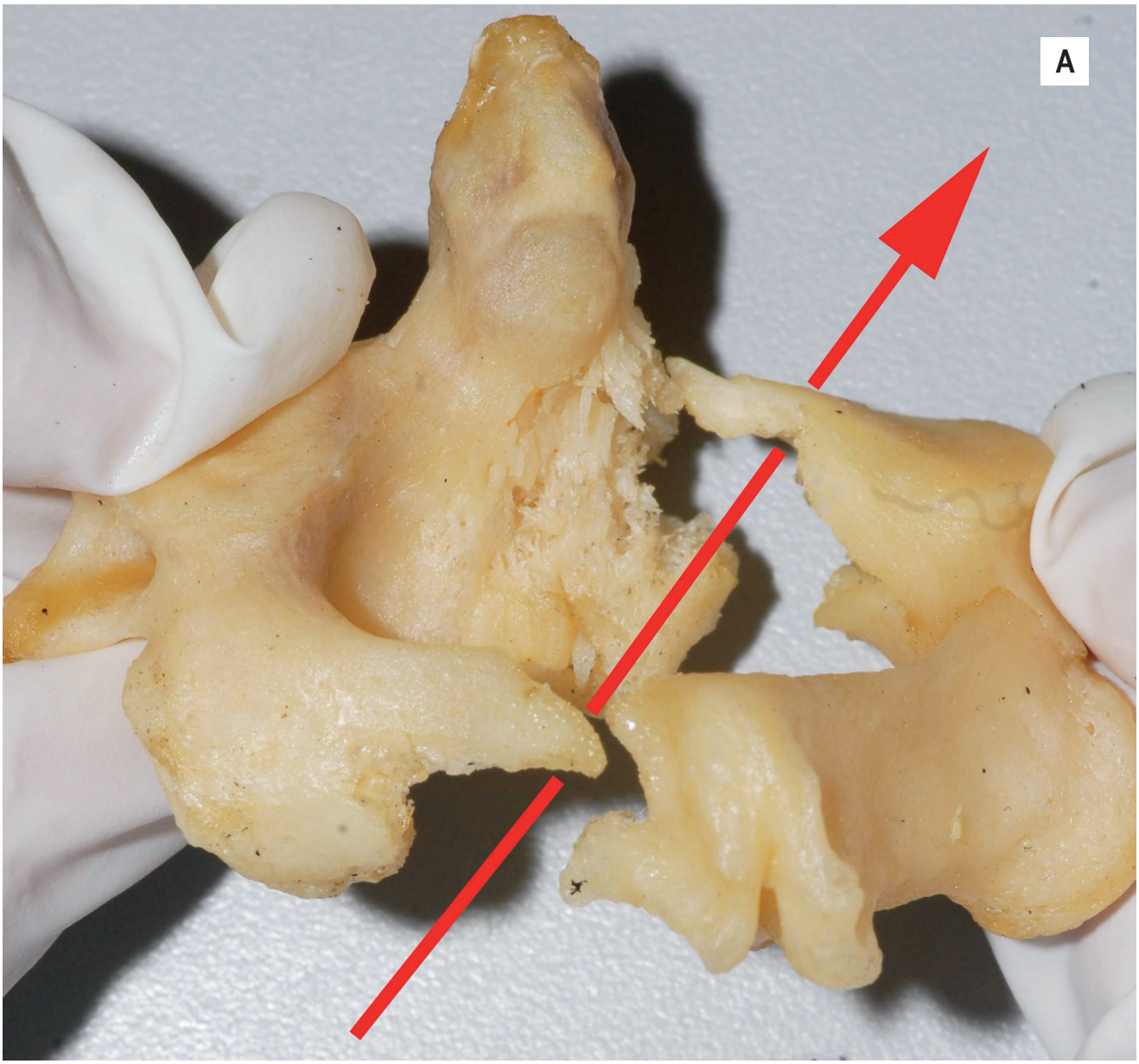

Image 8: A) Gunshot wound trajectory through a 2nd cervical vertebra.

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CONCLUSION

Forensic anthropologists are well-trained to understand bone's response to trauma. Through careful reconstruction of fragmented bone and examination of fracture patterns and wound characteristics, anthropologists can interpret the type of force and minimum number of impacts as well as identify features of the tool. This information may allow for the events surrounding death to be reconstructed and may inform the manner of death classification, case investigation, and/or case adjudication.

Image 8: B) Gunshot wound trajectory through a 2nd cervical vertebra.

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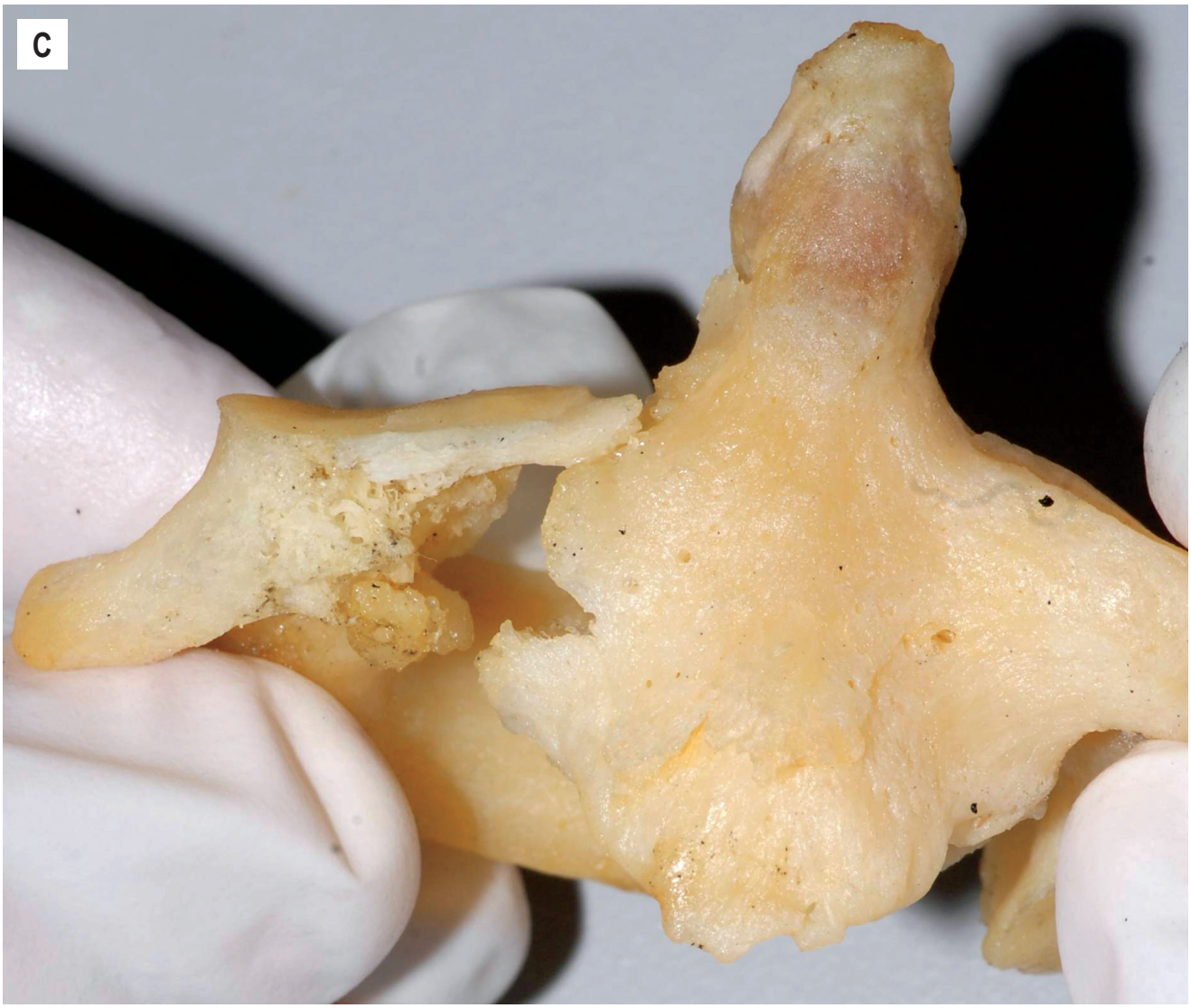

Image 8: C) Gunshot wound trajectory through a 2nd cervical vertebra. Note the external beveling along the wound margins.

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The Value of Anthropology in Medicolegal Death Investigation of Pediatric Nonaccidental Injury

Jennifer C. Love

ABSTRACT

Forensic anthropologists have made remarkable contributions to the medicolegal investigation of nonaccidental injury in pediatric cases. They have created standard nomenclature for fracture descriptions. Anthropologists have developed novel techniques that increase the sensitivity of the pediatric autopsy. They have performed biomechanical research that enables reconstruction of events surrounding death. Also, anthropology practitioners have developed several reference guides on the subject of nonaccidental injury that are of value to forensic pathologists. These advancements assist forensic pathologists in the accurate classification of cause and manner of death in pediatric cases. *Acad Forensic Pathol. 2016 6(3): 478-485*

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INTRODUCTION

Forensic anthropologists have made remarkable contributions to the medicolegal investigation of nonaccidental injury in pediatric cases. Anthropologists have developed autopsy techniques that increase the opportunity to recognize skeletal injury and provide less invasive access to dorsal root ganglia as well as standard nomenclature to enable interoffice data collection. Also, they have conducted biomechanical fracture pattern research that enables accurate interpretation of skeletal injury and provides insight into the incidences surrounding the injuries. These advancements have assisted pathologists in thorough documentation of injury in pediatric homicides and created avenues for multisite collaborative research.

DISCUSSION

Autopsy Techniques

Anthropologists have developed alternative autopsy techniques that are often employed in cases of pediatric nonaccidental trauma. These methods provide greater access to skeletal injury and less destructive access to the doral root ganglia. Utilization of these methods has shown to increase the sensitivity of the autopsy.

The Pediatric Skeletal Examination (PSE) is a technique developed by the staff anthropologists of Harris County Institute of Forensic Sciences (HCIFS) to expose a greater portion of the skeleton *in situ* (1). To employ the technique, skeletal muscle and the periostea are reflected from the long bones, clavicles, and scapulae. The pleurae, musculature, and periostea are reflected from the internal surface of the ribs. Reflecting the musculature and periostea enables the recognition of subperiosteal new bone formation (SPNBF) and occult fractures such as metaphyseal fractures (2). The technique does not require additional cuts to the body when a posterior flay of the skin is performed.

Reflecting soft tissue to expose the bone is not novel to the PSE; often pathologists expose and recover a fractured bone during autopsy. The novel component of the PSE is the exposing and close inspection of long bones, clavicles, ribs, and scapulae when there is no indication prior or during the autopsy that a bone is fractured. A PSE is conducted as a blind search for skeletal trauma. The PSE is a time intensive technique. If the decision is made to remove and process injured bones for gross or histological analysis, the technique can become highly invasive and destructive. With this in mind, Love and colleagues evaluated the value of the PSE (3). The researchers compared the number of skeletal injuries documented during autopsies employing the PSE (experimental group) to the number of skeletal injuries documented during autopsies that did not employ the PSE (control group). Eighty pediatric autopsy cases were included in the study—40 cases per group. The cause and manner of death for all decedents were blunt force trauma and homicide, respectively. The researchers found that skeletal injures were identified in 34 (72%) of the experimental group and 30 (64%) of the control group. Of note, the total number of fractures identified in the experimental group was 512 compared to 198 fractures in the control group. The statistically significant difference in the number of skeletal injuries identified in the experimental group demonstrates the increased sensitivity of an autopsy when the PSE is utilized.

Furthermore, anthropologists working with neuropathologists have developed a method for removing the spinal cord with the ganglia attached without removing the surrounding bony tissue (4). This novel method builds on a method developed by Downs and Alexandra (5) and used by Matshes et al. (6). The original method requires the cervical vertebral column to be removed, decalcified and thin-sectioned. The method is destructive, removing the supportive structures of the neck, and time consuming, requiring an extended period of time for decalcification. The novel method involves removing the posterior and lateral columns of the cervical vertebrae, exposing the spinal cord and ganglia *in situ*. Then, these structures are removed, leaving the anterior column of the vertebrae intact. The neurologic tissue is fixed in 10% formalin; then, is sectioned and stained following standard methods. The technique maintains the structure of the neck, does not require long fixation/decalcification periods,

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and allows examination of the spinal cord with attached ganglia at all spinal levels, not just the cervical region. Also, the tissue is better preserved for special studies, such as immunohistochemistry, because decalcification is unnecessary (4).

There are disadvantages to the posterior laminectomy approach; most notably, the surrounding soft tissues are not recovered. Further, manipulating the structures as they are removed may cause artifacts. However, the advantage of recovering the ganglia of the complete spinal cord with minimal destruction to the body cannot be overstated. Using the posterior laminectomy approach, Beynon et al. conducted a prospective study and removed spinal cords with the ganglia attached from all infants autopsied over a nine-month period (7). During the study period, 59 infants were autopsied, 48 (83%) infants died from nontraumatic causes and ten (17%) infants died from traumatic causes. One infant was excluded from the study because the cause of retinal and nerve root hemorrhage could not be directly attributed to trauma. Hemorrhage in the nerve roots and dorsal root ganglia were scored on a scale of 0-2 (0 = no hemorrhage, 1 = scant hemorrhage, 2 = prominent hemorrhage). Nerve root and dorsal root ganglion hemorrhage was identified in 100% (10/10) of the traumatic death and 42% (20/48) of the nontraumatic deaths. Of the nontrauma cases, only 15% (3/20) showed prominent hemorrhage; the hemorrhage of the remaining 85% (17/20) was scored as scant.

In order to determine the predictive value of nerve root and dorsal root ganglion hemorrhage in a statistically appropriate manner, a large number of spinal cords from traumatic and nontraumatic deaths must be examined. Further, the study population must include traumatic and nontraumatic death and must be free of selective bias. Beynon et al. included all decedents that met an age criterion, regardless of circumstances surrounding death, protecting against selective bias (7). The posterior laminectomy approach enabled the prospective study to occur, as the method reduced the destruction of the body and examination of the spinal cord was incorporated into the autopsy protocol.

Skeletal Trauma Recognition and Evaluation

Thorough documentation of injury is paramount in pediatric cases suspicious of nonaccidental trauma and anthropologists employing the PSE are in a strong position to recognize skeletal injury. Equally as important as identifying skeletal injury is interpreting the cause of the trauma in terms of biomechanical forces. The most common history given by a caregiver for an injury is a low-level fall (8). Through fracture pattern analysis, an anthropologist can provide a defensible opinion as to the consistency between the injury and the injury history.

Metaphyseal, skull, and rib fractures have received considerable biomechanical research. Metaphyseal fractures are commonly found during a PSE and are most likely the easiest facture missed when a PSE is not performed. Difficulties in recognizing metaphyseal fractures stem from the limited osseous disruption. The fracture occurs through the primary spongioso of the metaphysis and a thin disk of cortical bone attached to the cartilage is lifted off the bone (2). Radiologically, the fracture presents as a thin radiopaque disk hovering over the end of a long bone. Typically, collimated radiographs of limb joints at various angles are needed to recognize the fracture (2). Furthermore, the pliable periosteum is loosely attached to the bone at the physeal region, allowing the bone to fail but the periosteum to remain intact. Kleinman theorizes that a metaphyseal fracture results from the application of shear forces to the extremity such as when a limb is whipped back and forth and recognizes it as a fracture highly suspicious for nonaccidental injury (2, 9). Recently, this theory was supported by the experimental studies of Thompson et al., who created metaphyseal fractures in porcine models through the application of varus and valgus forces to the knee (10).

Anthropologists at the Michigan State University working with biomechanical engineers and funded by the National Institute of Justice have investigated skull fracture patterns resulting from blunt force impacts. In a series of papers, the researchers have described fracture patterns resulting from impacts with rigid and compliant surfaces, at low- and high-level

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impact forces as well as fracture characteristics of entrapped and free falling impacts (11-13). The researchers used infant porcine skulls in controlled impact environments with measured force and duration. Fracture locations and lengths were recorded. In general, the researchers found that the energy required to initiate a skull fracture increased with age of the individual (11). They found that a high-energy impact with a rigid interface produced more fractures than an impact of equal energy with a compliant interface. The researchers found that high energy impacts to the parietal bone resulted in fractures of the parietal and occipital bones (12). Also, they found that an impact to a head supported by a plate (entrapped) resulted in a more extensive fracture pattern than a free fall impact. Free fall impacts to the parietal resulted in fractures of the parietal bone that often crossed into the frontal bone. Entrapped head conditions of equal impact force resulted in multiple fractures of the parietal, occipital and frontal bones (13). Perhaps most importantly, the researchers found that a single focal impact often created fractures that did not initiate at the fracture site and created multiple fractures that did not communicate and at times were on separate bones. These findings caution against interpreting each individual cranial fracture as a separate impact site.

One limitation recognized by researchers studying pediatric cranial fractures is inconsistency of language across studies that precludes cross study analyses. In response, Wiersema et al. developed a standardized method to describe pediatric skull fractures using a three-pronged system of increased complexity (14). The first prong, Fracture Category, identified three categories applicable to all fractures: simple, complex, or comminuted. The second prong, Fracture Pattern, allowed for more detailed but common terms to be added to the fracture description, such as curvilinear or diastatic. The third prong, Fracture Descriptors, allowed for idiosyncratic details to be included in the fracture description. In their study, the authors had four individuals describe 44 pediatric cranial fractures. Among the participants, there was 100% agreement in the Fracture Category assigned to each fracture, and 79% agreement of the Fracture Pattern. The value of the fracture description schema is that it provides a common foundation for all fracture descriptions, but does not constrict a practitioner from describing a fracture in his or her own terms.

Kleinman and Schlesinger's study of mechanical factors associated with posterior rib fractures may be the best known research in the area (15). Using cadavers, animal models, and case studies, the authors identified the cause of posterior rib fractures as excess levering of the posterior rib at the costotransverse articulation process (15). Building on this understanding, anthropologists have examined rib fracture locations and types. Love and colleagues developed a novel classification system designed to systematically describe the fracture locations and types recognized in infants (16). The authors identified four fracture locations: posterior, posterolateral, anterolateral, and anterior. Also, they identified four fracture types: sternal end, buckle, transverse, and oblique. The team recognized that the fractures occurring within the rib head were variable in location and extent and performed a follow-up study focused on this area (17). They developed a classification system that broke the rib head into two subregions and recognized three landmarks. For both studies, the authors did not correlate the fractures to biomechanical forces, but set the stage for consistent reporting and future biomechanical research.

To date, anthropologists are unable to establish the predictive value of specific cranial fracture patterns or rib fracture locations, types, and/or distribution patterns for nonaccidental injury because too few nonaccidental injury cases are included in the studies. For example, Love et al. studied 85 infant decedents and identified 158 rib fractures (16). However, only six (7%) of the infant deaths were classified as nonaccidental injury. Although fractures occurring in the posterolateral region appear highly correlated with nonaccidental injury, too few nonaccidental injury cases were included in the study to state these findings in a statistically responsible manner. The goal of the standardized nomenclature is to allow for interagency collaboration increasing the number of nonaccidental injury cases included in the analysis enabling statistically sound results. The ultimate goal of the research is to delineate between fracture patterns resulting

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from nonaccidental injury and fracture patterns resulting from accidental injury and therapeutic intervention and to define the potential error rate associated with the classification.

Forensic anthropologists primarily examine bones grossly as opposed to histologically. Gross bone analysis provides details of a fracture that is lost during histological analysis. For example, the fracture type (butterfly, transverse, and spiral) can indicate the direction of force and the impact velocity, important information for reconstructing events surrounding the injury (18, 19). Further, incomplete metaphyseal fractures are less likely to be missed when the complete surface is examined (**Image 1**). From gross inspection, anthropologists can assess the healing stage of the fracture and correlate it to radiologically identified healing rates. **Image 2** shows a rib fracture in the soft callus stage of healing as described by O'Connor and Cohen (20). During this stage of healing, the fracture is bridged with disorganized woven bone, yet the fracture line is often visible. Radiologically, the soft callus formation stage of healing has been observed in children as early as 10-14 days post-injury with a peak period of 14-21 days post-injury (20). Full analysis of the healing stage, callus maturity and presence of fracture line. may be difficult to asses from a histology thin section. Concurrently, histological examination of a fracture may provide information lost on gross examination such as very early cellular changes associated with healing and atypical cellular response suggestive of a pathologic condition. Grossly, healing is not recognized until the formation of SPNBF. Therefore, examining fractures both histologically and grossly may provide the greatest amount of information.

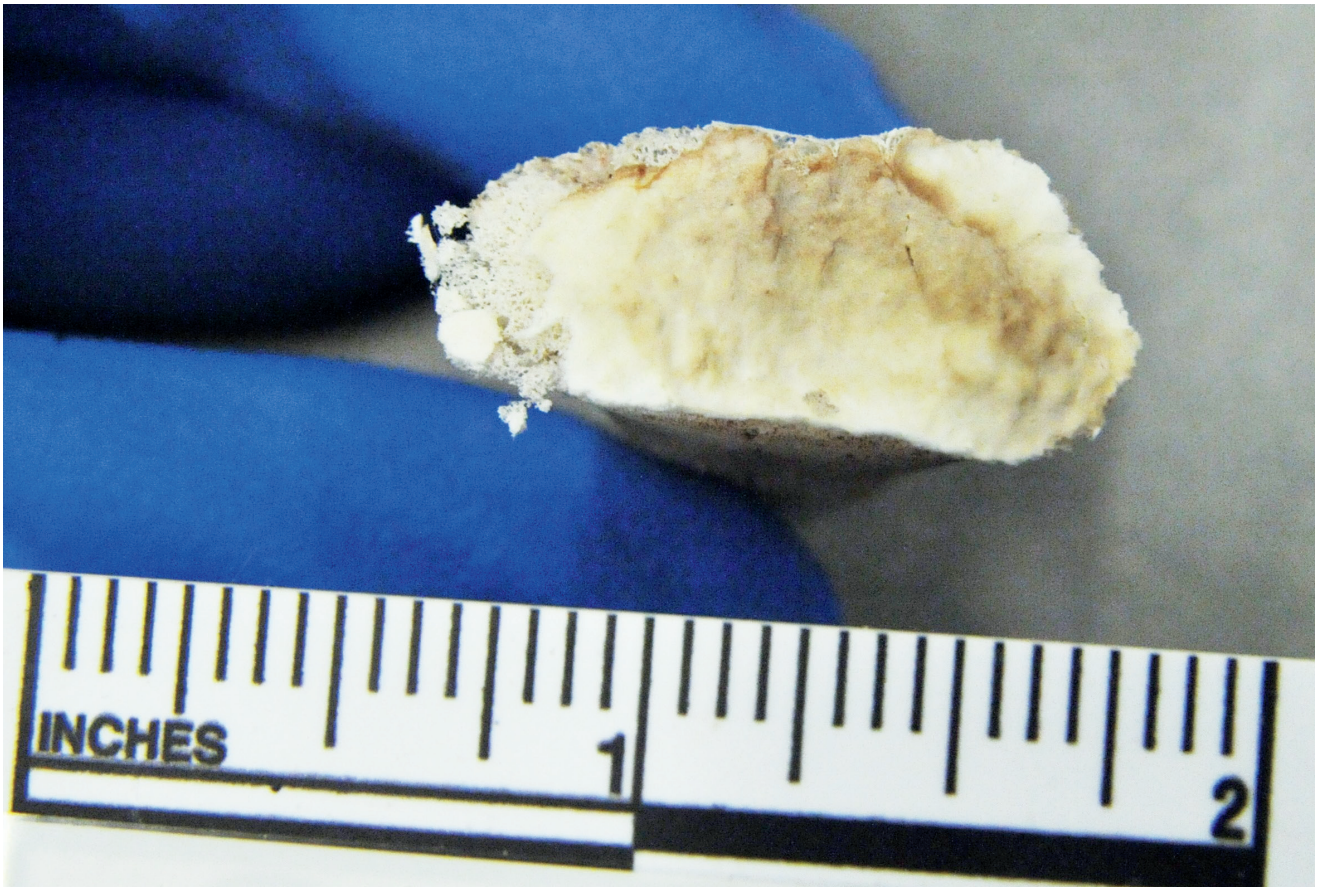

Image 1: Incomplete metaphyseal fracture of the distal femur. Note that only a focal area of trabeculae is visible.

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Fracture Pattern Interpretation

Forensic anthropologists' understanding of bone biomechanics enables them to assess the fracture pattern and distribution in nonaccidental injury cases. For example, Love presents a case of a three-month-old nonaccidental injury victim (21). Paramedics were called to the home after the mother found the child "*gasping for breath*." Paramedics initiated cardiopulmonary resuscitation and transferred the infant to the emergency department. The infant was pronounced dead 20 minutes after arriving at the hospital. During the autopsy, the child was found to be healthy and of normal size and weight. Subtle contusions and subcutaneous hemorrhages were noted on the head, neck, shoulders, and knees. All organs appeared normal and without injury. The pathologist requested a PSE due to the bruising patterns and what appeared to be healing rib fractures. No hemorrhage was present at any of the rib fractures.

During the PSE, 24 rib fractures were found and were located on the costochondral junctions as well as the anterior, lateral, and posterior regions of the ribs. The fractures were bilateral and serial. They were in two healing stages: open fractures with initial SPNBF and hard calluses with organizing lamellar bone. Metaphyseal fractures were found on the distal metaphysis of the right humerus, unla, radius, left femur, tibia, fibula, and radius. Also, metaphyseal fractures were found on the proximal right humerus and left femur, tibia, and fibula. At each metaphyseal fracture the exposed trabeculae were thickened and the shafts were encased in

Image 2: Rib fracture in soft callus formation stage of healing. Note that the callus does not fully encircle the bone and the fracture line is visible.

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SPNBF. No acute skeletal injuries were identified on the infant. The anthropologist interpreted the fracture pattern of the ribs to be consistent with anterior/posterior constriction of the chest and posterior levering of the ribs over the transverse processes of the vertebrae. She concluded that the long bone fractures were consistent with tractive forces applied to the limbs such as forces occurring with flailing of the limbs. Further, the anthropologist stated that the healing observed on the ribs was consistent with a minimum of two traumatic episodes.

Ultimately, the pathologist classified the cause and manner of death as undetermined. No acute injury, pathological condition, or toxicological finding that may have caused the death was identified. The pathologist stated within the autopsy report that healing skeletal injuries of various ages were identified and that an asphyxial mechanism of death could not be excluded based on the autopsy findings.

Tools and Databases

In addition to biomechanical research and consistent nomenclature, anthropologists have provided several tools to pathologists investigating pediatric deaths. Love et al. created a well-illustrated atlas of skeletal injury recognized in child abuse cases (21). The text showcases pediatric skeletal injury *in situ* exposed during the autopsy as well as after processing. Also, the textbook illustrates gross signs of early, middle, and late stages of fracture healing. The authors present an overview of the literature of injury mechanics and describe the limitation of particular injury interpretation. The book includes a chapter dedicated to several conditions that are invoked as mimics of child abuse in courtroom settings as well as therapeutic skeletal injuries.

Ross and Abel's edited volume, *The Juvenile Skeleton in Forensic Abuse Investigations*, presents advancements in anthropologic analysis of pediatric skeletal remains by leading experts in the field (22). The textbook covers key topics such as skeletal anatomy and growth and development. Chapters are dedicated to birth trauma, nonaccidental skeletal trauma, and biomechanical principles of fracture pattern interpretations. Finally, a portion of the book is dedicated to technological advancements applicable to child abuse investigation such as the use of dual-energy X-ray absorptiometry (DEXA) to measure bone density in a decomposed child.

The anthropologists at HCIFS have amassed a large database of injuries identified during autopsies of infant decedents (23). The Infant Injury Database includes injuries, therapeutic and nontherapeutic, recognized during autopsy, review of medical history, and review family history, as well as circumstances surrounding the death. During periods of data collection, all infant deaths investigated by HCIFS were included in the study. The only selection criterion was age at death. The 100% inclusion methodology protects against selection bias, a common problem in child abuse studies. Furthermore, the database was designed from a descriptive approach; all injuries regardless of source (i.e., therapeutic, accidental, or nonaccidental) were entered in the database without interpretation. Injuries include skeletal fractures, contusions, abrasions, lacerations, intracranial hemorrhages, and petechiae. The descriptive approach and inclusion criterion were paramount to developing a powerful tool applicable to statistical analysis and valuable to building evidence-based research. Currently, the database is not available publicly, but the research group is working to make it available.

CONCLUSION

In summary, anthropologists' role in medicolegal death investigation of pediatric nonaccidental injury has increased in recent years. Anthropologists have become instrumental in some medical examiner offices, working alongside the pathologists during the autopsy employing novel techniques. Also, anthropologists have conducted research in fracture biomechanics increasing our understanding of injury mechanisms. Finally, anthropologists have provided standard nomenclature and description schema allowing for more consistent and accurate fracture descriptions and multisite collaboration.

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The Laryngohyoid Complex in Medicolegal Death Investigations

Deborrah C. Pinto

ABSTRACT

The laryngohyoid complex, composed of the hyoid bone and laryngeal cartilages, can be of interest in the autopsy setting, particularly when injuries are observed. Analysis of trauma to this structure can assist in establishing cause and manner of death. In many situations, the forensic anthropologist, with their expertise in analyzing bone and cartilage trauma, can assist in analyzing trauma to this complex. Although researchers have tried to study the relationships between causes of trauma to the osseocartilaginous structure and the observed injury pattern, they have not been successful in identifying unique signatures associated with different causes of trauma. This is because different causes can result in the same or similar injury patterns. In addition, variation due to growth and development or due to remote injury may change the structure's biomechanical response. The goal of this paper is to address issues that a forensic pathologist may encounter when assessing potential trauma to the osseocartilaginous structures of the laryngohyoid complex; in particular, it focuses on anatomical variants and trauma resulting from various causes. *Acad Forensic Pathol. 2016 6(3): 486-498*

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INTRODUCTION

Neck trauma observed during an autopsy typically requires closer examination of the laryngohyoid complex. Such trauma can be the result of a variety of actions including violence, therapeutic interventions, accidents, or postmortem processing. These cases include all types of manners where trauma is caused by direct pressure to the neck (e.g., hanging, strangulation, sharp/blunt/ballistic impact to the neck) or indirect pressure from causes like blunt force trauma (e.g., falls, assault, explosion), or sharp force trauma or ballistic trauma to the head, which can cause hyperextension of the neck with subsequent injury to the laryngohyoid complex (1). Although the laryngohyoid complex is well studied in terms of types and locations of injuries, there is a lack of information regarding the forces needed to cause injury to these structures. There are several reasons for this paucity including variations in morphology, biomechanics, and external forces applied. Fractures of the complex may not directly relate to the cause of death; however, it should be considered carefully when other mechanisms are also involved (1). Understanding the anatomy and variations present in the human laryngohyoid complex is valuable when assessing cause and manner of death. As such, this section provides a brief description of anatomy, anatomical variants, and various types of mechanisms leading to trauma that can assist a forensic pathologist in assessing cause and manner of death from the osseocartilaginous structures of the laryngohyoid complex.

DISCUSSION

Anatomy and Development

The laryngohyoid complex is comprised of two structures: the hyoid bone and the cartilaginous larynx (i.e., "voice box"). The hyoid bone makes up the superior boundary of the complex and is located near the base of the mandible, anterior to the cervical spine. The cricoid cartilage of the larynx forms the inferior boundary of the complex. The hyoid bone and larynx are bound together by three ligaments: the thyrohyoid membrane and two lateral thyrohyoid ligaments (2).

Hyoid

The hyoid is a U-shaped bone located at the base of the mandible. It is suspended by the styloid processes of the temporal bone through the stylohyoid ligament (2). The hyoid functions as an attachment site for lingual, pharyngeal, and anterior neck muscles (3). It is composed of five segments: one quadrilateral-shaped central body; two long, tapered greater horns (cornu major); and, two short, tapered lesser horns (cornu minor) (2, 4). The greater horns articulate with the superolateral surfaces of the body and form a synchondrosis (**Image 1**). This synchondrosis may be mistaken for a fracture in radiographs (5) (**Image 2**). The lesser horns are small bones or cartilages that articulate on the superior aspect of the synchondrosis on each side of the body (3). There are two groups of muscles that insert into the hyoid: the suprahyoid and infrahyoid (6). The suprahyoid muscles include the mylohyoid, geniohyoid, stylohyoid, and digastric muscles. The infrahyoid muscles include the sternohyoid, omohyoid, sternothyroid, and thyrohyoid muscles.

Embryologically, the hyoid develops from the second and third branchial arches (3). By the end of the embryonic period, all segments of the hyoid are present in their cartilaginous form. The body and greater horns can begin ossifying as early as 30 weeks gestation; however, the lesser horns do not ossify until puberty (7). Although the tendency is for the segments to fuse with increasing age, the fusion rates and patterns are highly variable (8-10). Sexual dimorphism has been noted in the shape and size of the bone, with females having smaller hyoid bones with wider angles (11-13). The degree of fusion in addition to the overall shape has been suggested to be a factor in fracture risk. In a study of 20 hyoid bones, primarily from females, Pollanen and Chiasson found that longer and more steeply sloped hyoid bones were more susceptible to fracture (14). This is in agreement with Mukhopadhyay, who did a prospective study of 100 cases of hanging and found that longer and wider hyoid bones were more susceptible to fracture (15).

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Larynx

The larynx is located anterior to the third through sixth cervical vertebrae. It is composed of cartilages, ligamentous membranes, and muscles that are situated below the hyoid bone and above the trachea (3). Together, these structures work to facilitate breathing and sound production. The intrinsic muscles of the larynx include the cricothyroid, posterior cricoarytenoid, lateral cricoarytenoid, thyroarytenoid, transverse arytenoid, oblique artenoid, and vocalis muscles (6). In addition to the muscles, there are nine cartilages (paired and unpaired) that form the larynx.

Image 1: Superior view of a fused hyoid bone. The white arrows indicate the fused synchondrosis connecting the body and the greater horns. The bone has been chemically processed to remove all soft tissue.

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Viewed anteriorly, the thyroid cartilage is the largest laryngeal cartilage (**Image 3**). It has two laminae (dextra/sinistra) that are fused at the laryngeal prominence ("Adam's apple"), two superior horns (cornu superior) that extend from the superolateral margins of each laminae, and two inferior horns (cornu inferior) that extend from the inferolateral margins of each laminae. Inferior to the thyroid cartilage is the cricoid cartilage, a signet ring-shaped structure (**Images 3 and 4**). The two cartilages are connected via the cricothyroid membrane. The wider portion of the cricoid—the lamina—is located posteriorly while the narrow portion, the arch, is located anteriorly.

The seven remaining laryngeal cartilages are best viewed from the posterior. The arytenoid cartilages are paired pyramid-shaped structures situated on the posterosuperior laminae of the cricoid cartilage. The paired corniculate cartilages are two small conical structures located at the apex of the arytenoid cartilages. The cuneiform cartilages are small, paired elongated structures that connect the arytenoid cartilage to the epiglottis. Finally, the epiglottis is a leaf-shaped cartilage that is connected to the thyroid cartilage by the thyroepiglottic ligament and to the hyoid by the hyoepiglottic ligament. In terms of trauma analysis, the arytenoid cartilages, cuneiform cartilages, and epiglottis are less important, likely due to their lack of susceptibility to fracture (4).

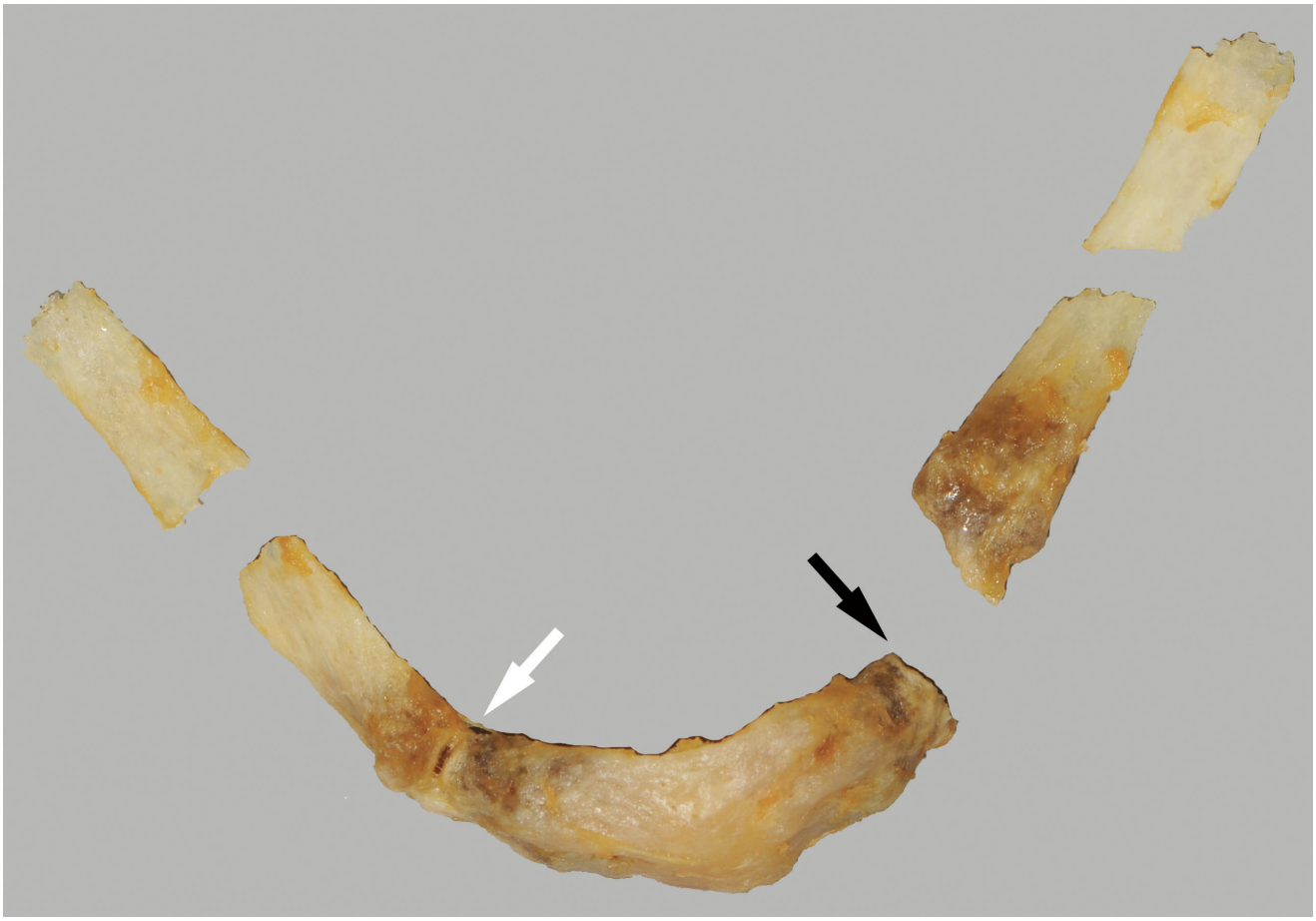

Image 2: A fractured hyoid from a case of a suicidal hanging. The greater horns are fractured. The white arrow indicates a partially fused synchondrosis. The black arrow indicates an unfused synchondrosis. The bone has been chemically processed. Without removal of all soft tissue, the unfused synchondrosis could be mistaken for a fracture.

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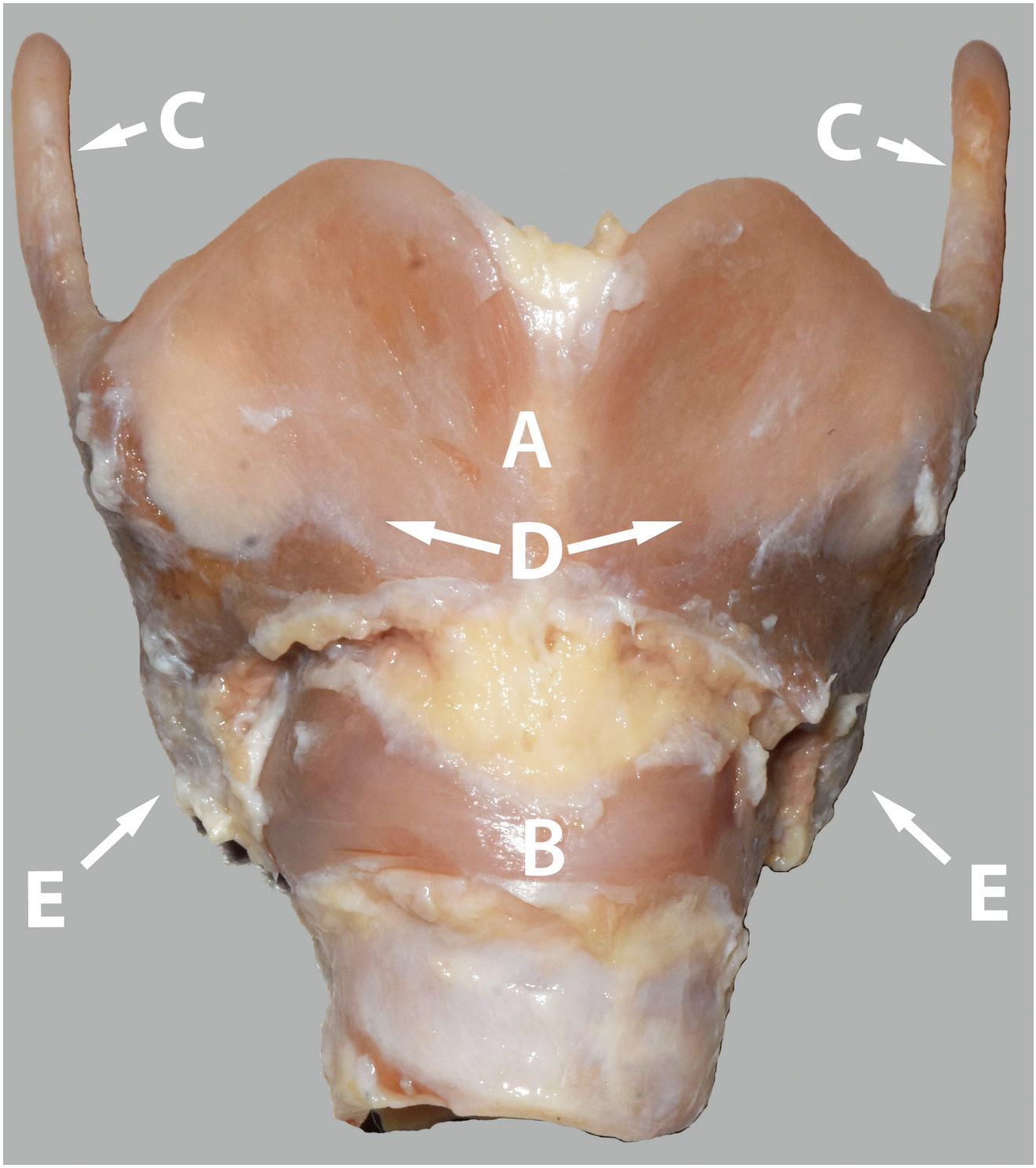

Image 3: Anterior view of the articulated thyroid and cricoid cartilage. The perichondrium has been removed. A = thyroid cartilage, B = cricoid cartilage, C = superior horns of the thyroid cartilage, D = laminae of the thyroid cartilage, and E = inferior horns of the thyroid cartilage.

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Image 4: A lateral view of the thyroid-cricoid cartilage complex. Note that the structures are closely connected. The perichondrium has been removed.

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Embryologically, the laryngeal structures form from the 4th and 6th pharyngeal arches. This chondrification begins at the eighth embryonic week and by the end of the second trimester, they have acquired their neonatal form (3). Age-related ossification of the thyroid and cricoid cartilages has been well studied; however, the variation in ossification rates precludes this method as a good means of estimating age (16). A study done by Bockholdt et al. using 120 thyroid cartilages showed that high rates of fracture are observed in cases where ossification is incomplete while completely ossified cartilages had no macroscopic injuries (17). The same study demonstrated that in an isolated thyroid cartilage, the mean weight that a superior horn can sustain before fracturing is 3 kg (force = 28.5 N). In a study of 28 cases where the decedent was under the age of 18 years, Verma found seven cases of fractures, five cases of thyroid horn fractures, and two cases of hyoid bone fracture (18). Injuries in both bone and cartilage were not found in any of the cases.

Anatomical Anomalies

Anomalous laryngohyoid structures can result in erroneous diagnosis of trauma, whether acute or remote. The practitioner should be aware of what anomalies exist and how they may potentially affect normal functioning as well as trauma analysis.

Hyoid Anomalies

Anomalies of the hyoid bone involving differential development of the greater and lesser horns can result in the asymmetrical development of greater horns (8, 19) or agenesis of the lesser horn (8, 19, 20). Atypical morphology can even include differences in shape of the hyoid bone. Klovning and Yursik reported on a nearly circumferential hyoid bone from a 28-year-old male who was difficult to intubate (21). Osseous extensions, possibly resulting from Eagle Syndrome (ossification of the stylohyoid ligament) or from unknown etiology, have also been reported (19, 20). Practitioners should be aware of such anomalies as they can affect not only medical intervention, but also medicolegal death investigations.

Laryngeal Anomalies

The presence of triticeal cartilages has been noted in studies addressing variations in the larynx. These cartilages are located within the thyrohyoid ligament, which connects the distal end of the greater horn of the hyoid and the superior thyroid horns. Di Nunno et al. noted that 30% of examined cases had the presence of unilateral or bilateral triticeal cartilages and Naimo et al. found it in 23% of examined cases (8, 22). When palpated, these cartilaginous bodies can appear to be a fractured superior thyroid horns (**Image 5**). Careful dissection is needed to investigate this finding. Sometimes abnormal congenital defects can result where the greater hyoid horn and superior thyroid horn become disconnected. An ossified hyothryoideal bridge may then be found later on in life (4). Congenital malformations can also affect the larynx. The presence of a laryngeal cleft, an opening along the posterior region of the larynx extending anywhere from the pharynx to the trachea, have been reported in individuals; however, the presence of the cleft anteriorly, suggests a history of neck trauma (19). Differential development of the superior thyroid horns that result in unilateral or bilateral agenesis have also been observed (19, 22, 23)

Trauma

Neck injuries observed in autopsy cases are typically the result of blunt force injuries due to sharp force trauma (24), athletic activities (25, 26), hanging (27, 28), falls from variable heights (29), vomiting (30), and strangulation (13). It is the purview of the forensic pathologist to determine the cause of death. The problem with this determination is that these closely tethered structures are subject to similar patterns of injury when different mechanisms are used. To further complicate matters, the incidence of hard tissue injury associated with a mechanism has been variably reported, therefore, making it difficult for the practitioner to interpret certain injuries. In a study of 1930 cases autopsied including all manners of death, Dunsby and Davison found fractures in the larynx or hyoid in only 78 cases (1). Pinto and Oleske found that out of 114 cases including all manners of death, only 50% had fractures in the larynx or hyoid (31). However, their

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Image 5: A unilateral triticeal cartilage (black arrow). These can also occur bilaterally.

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sample was biased toward cases where a suspicion of fracture resulted in additional processing and examination. DiMaio looked at all cases of homicide due to asphyxia over a three-year period (32). He found that out of 133 cases, 48 cases were ligature deaths with 12% having laryngeal trauma and 41 cases were manual strangulation cases with over 66% of the cases having laryngeal trauma.

The main indicator of trauma in the larynx is the presence of hemorrhage. Macroscopic inspection of the neck structures allows identification of overt hemorrhage; however, several researchers have demonstrated utility in microscopic investigations as well (33- 35). Rajs and Thiblin examined histological sections from 29 adult autopsy cases with nonartifactual superior thyroid horn fractures and 19 autopsy cases with artifactual fractures and found that the presence of occult hemorrhage can be used to identify nonartifactual fractures (34). Pollanen and McAuliff examined sagittal sections from 12 thyroid cartilages subjected to strangulation and found multifocal acute hemorrhages at the base of the superior horn, suggesting that the blood vessels can be disrupted during elastic deformation (33). Laryngeal microfractures have also been associated with intracartilaginous laryngeal hemorrhage, subepithelial laryngeal hemorrhage, and intralaryngeal muscular hemorrhage (36). Although a useful indicator, hemorrhage is not always present, particularly in cases involving children and adolescence, due to cartilage avascularity (37). Furthermore, some researchers have suggested that hemorrhage could be due to processing defects (37, 38). In addition, forensic pathologists may encounter cases where soft tissue is unavailable and the only structures remaining for assessment are the osseocartilaginous structures of the larygohyoid complex. Understanding the variety of causes that can result in fractures of these structures can help the forensic pathologist whittle down the list of possible candidate causes (**Table 1**).

Hanging

Hanging is a condition where hyoid bone and/or laryngeal cartilage fractures have been observed. In a study of 189 cases of hanging, greater horn fractures of the hyoid bone were found in 2.7% and thyroid cartilage and superior thyroid horn fractures were found in 5.3% of cases (27). A literature review by Khokhlov of hangings demonstrated that the superior thyroid horns are the most commonly injured structure, with fractures usually located in the base or shaft of the horn (28). These fractures of the superior horn have a unilateral higher occurrence. Laminae were not typically injured in cases of hanging. The review also reported that cricoid fractures are unusual for hanging. In a retrospective study of 557 cases of suicidal hangings, Nikolić et al. found that the osseocartilaginous structures of the layrngohyoid complex were injured in approximately half the cases (39). Out of the injured cases, 45% had thyroid-only injuries, 26% had

Table 1: Summary Table of Injured Structures Reported in the Literature Based on Cause of Death

Cause	Hyoid Bone	Thyroid Cartilage	Cricoid Cartilage
Hanging	Observed	Observed	*Observed
Strangulation	Observed	Observed	Observed
Falls	Observed	Observed	Not observed
Athletic activities	Observed	Not observed	Not observed
Self-vomiting	Observed	Not observed	Not observed
Therapeutic intervention	Observed	Observed	Not observed

* Observed in only one out of 2700 cases in the literature.

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hyoid-only injuries, and 27% had both structures injured. These injuries were primarily seen in individual older than 30 years of age.

Strangulation

The majority of strangulation cases are homicidal in manner and they typically present with injuries to the largyngohyoid complex (**Image 6**). In an experimen-

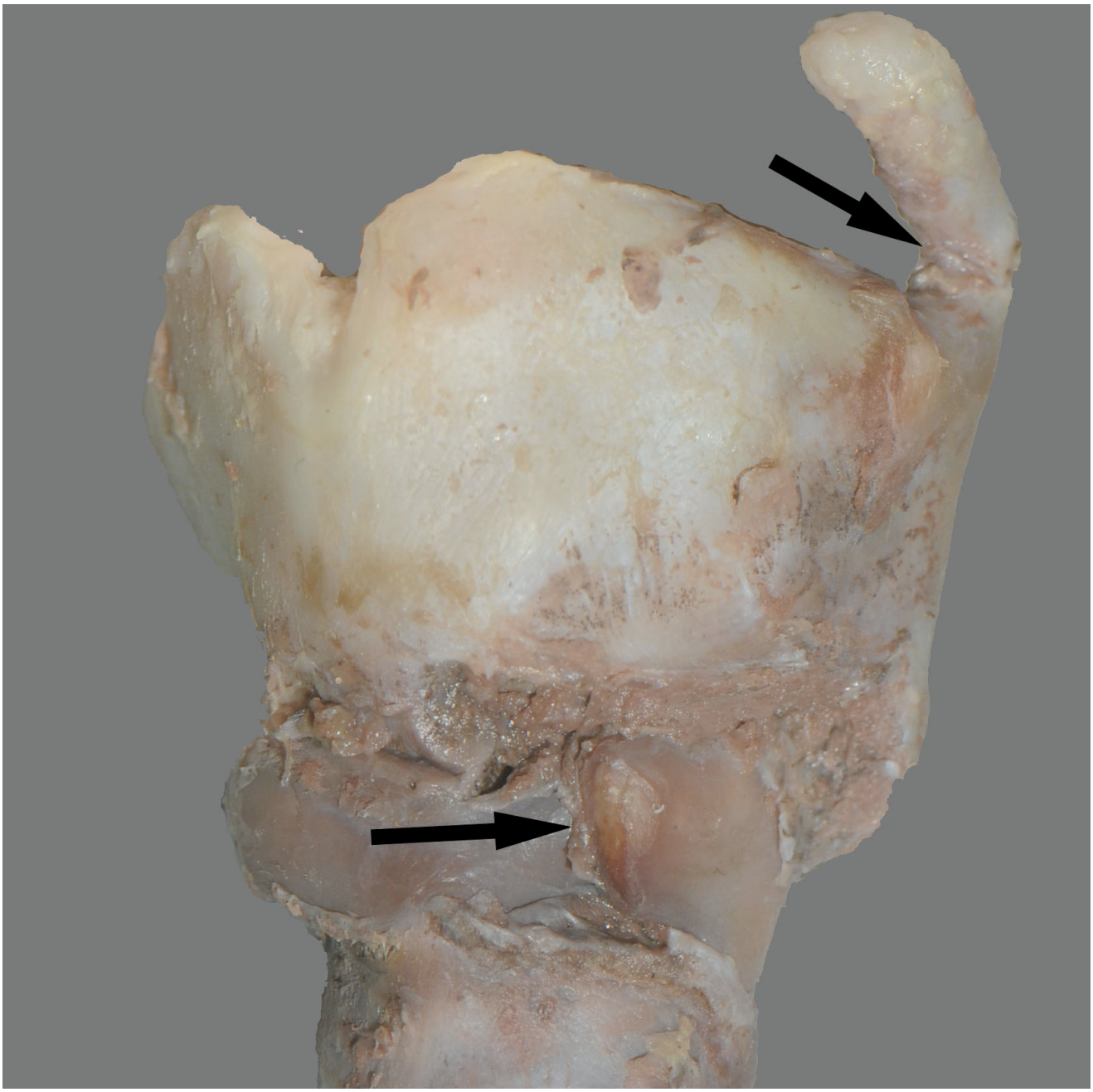

Image 6: Fractured thyroid and cricoid cartilages from a homicide case involving asphyxia with neck compression. The black arrows indicate the fractured left superior thyroid horn and left anterior arch of the cricoid cartilage.

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tal study simulating manual strangulation, Lebreton-Chakour et al. found that a majority of the fractures were observed in the hyoid bone, at the synchondrosis or on the greater horns (13). In a small percentage of specimens, they observed a fracture through the body. They found that the grip strength of a healthy man or woman is sufficient to generate a fracture by direct contact. However, the reader should take note that this study was done with the hyoid bone embedded in resin; therefore, these results reflect the amount of force needed to fracture the hyoid bone only. When surrounded by muscle and other soft tissue, a greater force may be needed. Godin et al. did a retrospective study of 287 cases of suicidal hangings, homicidal hangings, and homicidal strangulations and compared their results to 21 published studies totaling 2700 suicidal hanging cases (40). They found that cricoid fractures were only observed in homicide strangulations (5-20%) and are therefore a potential indicator of homicide. Only one case out of the 2700 suicidal cases in the literature had a report of a cricoid fracture. Injuries due to homicides also tend to be more extensive, with the presence of more fractures and hemorrhage (41). The problem that a forensic pathologist may encounter is differentiating whether the osseocartilaginous injuries of the larygohyoid complex are consistent with hanging or with strangulation. Without other supporting evidence from surrounding soft tissue, this differentiation may not be possible. Caution is needed when relying solely on interpreting trauma to this structure when trying to establish a cause of death.

Falls

Fractures due to falls can complicate matters when assessing cause and manner of death because such injuries may raise suspicion of nonaccidental inflicted trauma. Furthermore, in cases of falls, fractures occur at a lower frequency than in cases of hanging or strangulation and therefore, are not necessarily associated with this mechanism. Laryngohyoid fractures due to falls can result from low heights (i.e., less than 3 m) (1, 29, 42, 43), as well as from high heights greater than 3 m (1, 44). These fractures can be unilateral or bilateral and involve the hyoid bone and thyroid cartilage; however, the incidence of both structures being involved is low.

Athletic Activities

Fractures due to athletic activities are rare. Cutuk et al. report on two football players who sustained hyoid bone fractures resulting from direct impact to the anterior neck (25). Others have also reported similar injuries in lacrosse players, also due to direct impact (26, 45).

Miscellaneous

Hyoid bone fracture has been reported to possibly be associated with self-induced vomiting (30) and therapeutic intervention (19, 46). Hashimoto et al. state that fractures of the inferior thyroid horns are seen more commonly in resuscitation attempts (46).

CONCLUSION

Interpreting injuries to the osseocartilaginous structures of the laryngohyoid complex can be complicated. Anatomical variants not typically observed in the general population may result in an erroneous assessment of trauma. In addition, different causes of trauma may result in the same or similar pattern of injury, primarily because the basic mechanism is the same. The forensic pathologist must be aware of these confounding issues and should use all the information available from the surrounding soft tissue as well as the circumstances of the case when assessing the cause and manner of death.

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The Utility of Advanced Imaging in Forensic Anthropology

Heather M. Garvin, Michala K. Stock

ABSTRACT

Imaging technologies play an integral role in forensic anthropology cases. Advances in digital photography allow the anthropologist to photo-document the scene and skeletal remains in exceptional detail. Traditionally, radiographs have been used to document remains, potential trauma, and any individualizing characteristics such as healing trauma and frontal sinus morphology. Given technological advances, some forensic anthropologists have begun to incorporate more advanced imaging methods in their case analyses and research, such as computed tomography and three-dimensional (3D) surface scans. These advanced imaging technologies provide a means to document skeletal remains and trauma, and can be used to create 3D replicas of the elements for archival and illustrative purposes. Researchers have begun to develop novel methods for estimating biological parameters from these 3D virtual models, using new variables such as surface areas and volumes, and advanced statistical methods (e.g., geometric morphometric analyses) to quantitatively analyze skeletal variation for sex and ancestry estimation. The use of these technologies in forensic anthropology remains somewhat limited, however, due to required costs, expertise, and the time involved in collecting and processing the data. Newly developed methods require further validation, and some areas of advanced imaging, such as photogrammetry, remain relatively unexplored in the field. Interdisciplinary collaborations between forensic anthropologists and other medicolegal professionals can help alleviate some of these resource constraints and facilitate advancements in forensic case analysis and research. *Acad Forensic Pathol. 2016 6(3): 499-516*

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INTRODUCTION

Technological advances, particularly in medical and engineering fields, have resulted in a wide array of advanced imaging techniques, such as computed tomography and three-dimensional (3D) surface scans. As these imaging techniques become more commonplace and the costs associated with them begin to decrease, we are seeing them more frequently incorporated into the field of forensic anthropology. Beyond the traditional use of photographs and radiographs, forensic anthropologists are now using virtual 3D models of skeletal material for case analyses, documentation, and research. This paper reviews the types of traditional and advanced imaging technologies that are currently incorporated into forensic anthropological analyses in order to familiarize professionals in associated disciplines with these recent advancements and their utility to the field. Despite their potential benefit, not all forensic anthropologists employ these technologies, and the current limitations with regards to cost, access, and utilization of advanced imaging will be discussed. One way to alleviate many of these limitations involves interdisciplinary collaborations between researchers and professionals, particularly with forensic pathologists. Through such collaborations, advanced imaging can be a valuable tool not only for case documentation, but may also be used to help identify the deceased and provide insight regarding circumstances surrounding their death.

DISCUSSION

Photography

All professionals within forensic disciplines understand the importance of photography for the purpose of case documentation. Forensic anthropologists and forensic pathologists each work with human remains. Those remains are expected to be returned to family members in a timely fashion, at which point any evidence is lost if it is not thoroughly documented through written notes and photography. For this reason, forensic anthropologists are trained to document everything photographically. If the forensic anthropologist is called to the scene to search for and recover human remains, the photographic documentation begins immediately at scene arrival. The entire search and recovery procedure is photo-documented by a member of the team and thus can be used to reconstruct the actions and timeline of the search and recovery. These photographs can be useful when describing the recovery procedures in the report, as well as in courtroom testimony. In addition, any discovered material or biological evidence is photographed *in situ*, before it is collected. In this manner, the original position of the remains and evidence and their context to the scene are preserved. The context of the remains may provide information regarding the position of the body, time since death, whether it is a primary or secondary depositional site, and whether the remains have been moved by taphonomic agents. Once the remains are transported to the laboratory, they are photographed again in order to document their initial condition (e.g., amount and condition of soft tissue). Any suspicious defects are also photographed at this point so that it can be shown that the defects were present upon arrival to the lab and are not an artifact of any subsequent processing procedures. Of course, scales are included in all photographs so that size is documented. After the remains are processed and cleaned, another round of photographs is taken to capture the postprocessing condition of the remains. Any individualizing features, traumatic defects, or taphonomic modifications are thoroughly documented photographically. It is standard operating procedure (SOP) to also photograph all six views of the skull, the dentition, and all skeletal features used in sex, age, and ancestry estimation. A well-equipped laboratory may have a microscope from which digital microscopic or macroscopic images can be captured. These images may be used to document sharp force trauma (e.g., cut marks and characteristics of those cut marks such as striations and kerf floor), characteristics of compression and tension on fracture surfaces, periosteal reactions, or characteristics of taphonomic modifications (e.g., rodent and carnivore damage) (**Image 1**). Given that digital photographs are easy to take, can be reviewed immediately, and stored easily, it is not uncommon to take over 100 photographs of a single case. All photographs, even those of poor quality or those taken erroneously, are saved in order to show the continuity

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in the sequence of photograph numbers and illustrate that no photographs had been deleted (either mistakenly or intentionally). Of course, all photographs must have a backup file and be stored in a secure location.

Photographs taken throughout the case may be used to support written documentations in case reports, although the amount of detail provided in forensic anthropology case reports varies by institution. If ques-

Image 1: Example of photo-documentation of sharp force trauma (and associated blunt force trauma) to right radius and ulna. Insets A-D were taken with a Leica MZ16A stereo microscope.

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tions arise about the case after the remains have been returned, the forensic anthropologist can refer back to the photographs. If a case goes to court, the photographs can be used in conjunction with the report to refresh the anthropologist's memory of the case and provide useful visualizations during testimony so that judges and jurors can see for themselves the recovery procedures or skeletal characteristics being described by the forensic anthropologist. Images can, and arguably should, be shared between the medical examiner and forensic anthropologist. In forensic anthropological cases in which a prior autopsy was performed, photographs from the autopsy will help the anthropologist understand the original condition of the remains and identify any skeletal modifications which may have occurred during or post-autopsy. Skeletal regions associated with any soft tissue defects can also be identified and closely evaluated by the forensic anthropologist. By sharing photographs of the findings, forensic anthropologists and pathologists can also continue to learn from one another. The body acts as a single functional unit, with the soft tissues and skeleton closely integrated, and as such, both the soft and hard tissues should be considered, as well as their relationship, when interpreting human skeletal variation and trauma.

Radiographs

Although radiography may no longer be considered a form of advanced imaging given current technological advancements, it is the most highly utilized imaging modality in forensic anthropology besides basic photography. Most forensic anthropology laboratories are equipped with some type of X-ray machine, although the type of equipment may vary. Some laboratories are equipped with a closed, cabinet system, such as a Faxitron, while others have open X-ray systems similar to those used clinically in hospitals. If the laboratory is fortunate, then they have a digital X-ray system, which can result in immediate viewing of the radiographs, allowing the anthropologist to quickly assess whether the settings and position of the remains are optimal.

Documentation and Trauma

In many respects, the forensic anthropologist uses radiography in much of the same way as a forensic pathologist. In cases of suspected gunshot wounds, radiographs are taken not only to search for any potential bullets or bullet fragments, but also to identify any other areas of lead transfer. We have seen cases where even in completely skeletonized crania that have been exposed to the elements for a prolonged period of time, lead can still be observed radiographically around entrance and exit wounds, or on other endocranial surfaces impacted by the bullet. Thus, documentation of the lead transfer can help the forensic anthropologist decipher the bullet trajectory.

Radiographs are also used to search for and document other forms of trauma, such as fracture patterns. It should be part of every forensic anthropology laboratory's SOPs to radiograph all remains upon receipt, regardless of their condition. Not all of the cases received by forensic anthropologists are completely skeletonized. There may be mummified or decomposing tissue adhering to the remains, and in some cases the bodies may be mostly fleshed. By radiographing all remains upon receipt, the forensic anthropologist can later show that fractures or other skeletal trauma were present and documented prior to any processing. In other words, the anthropologist can empirically demonstrate that the trauma observed is not a result of maceration or other processing procedures. By radiographing any large masses of decomposing tissue, the anthropologist can confirm that all skeletal elements or potential evidence is recovered.

Even when remains are completely skeletonized, all elements should be radiographed. As mentioned previously, lead transfer has been found in cases in which the remains are completely skeletonized. In addition, the radiographs may reveal useful characteristics in the internal bone structures. For example, epiphyseal lines of fusion may be visible radiographically, supplying information about the age of the individual. Radiographs may reveal signs of bony remodeling or disruption in the trabecular bone pattern, which could be indicative of antemortem trauma, which in turn

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may be helpful in identifying the decedent or recognizing signs of potential abuse.

In cases of suspected child abuse, we recommend radiographing (and photographing) the remains on three separate occasions: 1) upon receipt, 2) after removal of the majority of soft tissue (but prior to any maceration or removal of the epiphyses), and 3) after processing. This is done regardless of whether clinical radiographs were taken, as we find that in many cases the anthropological radiographs may reveal additional evidence of trauma (1). The sequence of radiographs are important in illustrating that the trauma, such as periosteal reactions and metaphyseal fractures, was visible prior to any processing, especially given the fragility of infant and child remains (**Image 2**). Once the soft tissue is removed, the remains can be oriented in various positions to optimally capture any potential trauma, which is not always possible in clinical settings. For example, clinically there is a large amount of overlap in regions of the ribs. Once disarticulated, however, the ribs may be radiographed individually or spaced in such a manner that any potential antemortem or perimortem trauma can be easily evaluated.

Biological Profile and Identification

Forensic anthropologists may also use radiographs to help assess the age of an unknown individual. This is particularly true for infant or subadult individuals. The pattern of presence or absence of primary and secondary ossification centers and epiphyseal fusion can be used to age fetal, infant, and subadult remains (2-6). Partially fused epiphyses may appear fused macroscopically, but when viewed radiographically, a radiopaque line of fusion remains evident. Patterns of dental formation and eruption, which are also used for juvenile age estimation (7), are best evaluated radiographically in order to assess any unerupted dentition. In adults, where age estimation is predominantly based on deterioration of the skeleton instead of growth and development, the utility of radiographs for age estimation is more limited. Radiographic analysis of laryngeal and costal cartilage ossification may provide broad age estimates (8-10), and signs of osteoporosis and osteoarthritis may evaluated. Many of the traditional areas of the skeleton used for adult age estimation (i.e., cranial sutures, sternal rib ends, auricular surface, and pubic symphysis), however, undergo morphological changes that are not easily captured with conventional radiographs.

There is also a potential to use radiographs in cases of fleshed remains to estimate sex, ancestry, and stature. For example, previous studies have shown that costal cartilage ossification, as examined radiographically, may also be useful in estimating the sex of an individual (8, 10, 11). In general, however, radiographic methods in estimating biological profile parameters have yet to be thoroughly researched. Theoretically, most of the skeletal features that forensic anthropologists use to estimate these biological parameters should be visible in radiographs (e.g., greater sciatic notch or nasal aperture shape) and if these features could be evaluated radiographically, then it could possibly eliminate the need for more invasive methods such as maceration in certain situations. In order to develop and apply such methods, however, radiographic procedures would have to be standardized. In a radiograph, a three-dimensional object is projected into a two-dimensional (2D) space; thus, there are problems with superimposition of structures, which may obscure some features. Any variation in the positioning of the remains during the X-ray process will result in different angles in the features, making shape evaluation and any type of measurement collection problematic. Scales are also required if any type of measurements are to be collected and analyzed. Forensic anthropologists and pathologists may be able to work together to develop such protocols and potentially develop new radiographic methods to create a preliminary biological profile from radiographs in a fleshed individual. There is also the potential for distortion in radiographs caused by parallax and magnification error (12-14). There is a radiographic system called Lodox Statscan that uses a slot-scanning technology opposed to the normal cone-beam technology, thereby alleviating distortion issues (15-17). While this technology is becoming more common in medical examiner's offices (MEOs), it still cannot address the superimposition issues.

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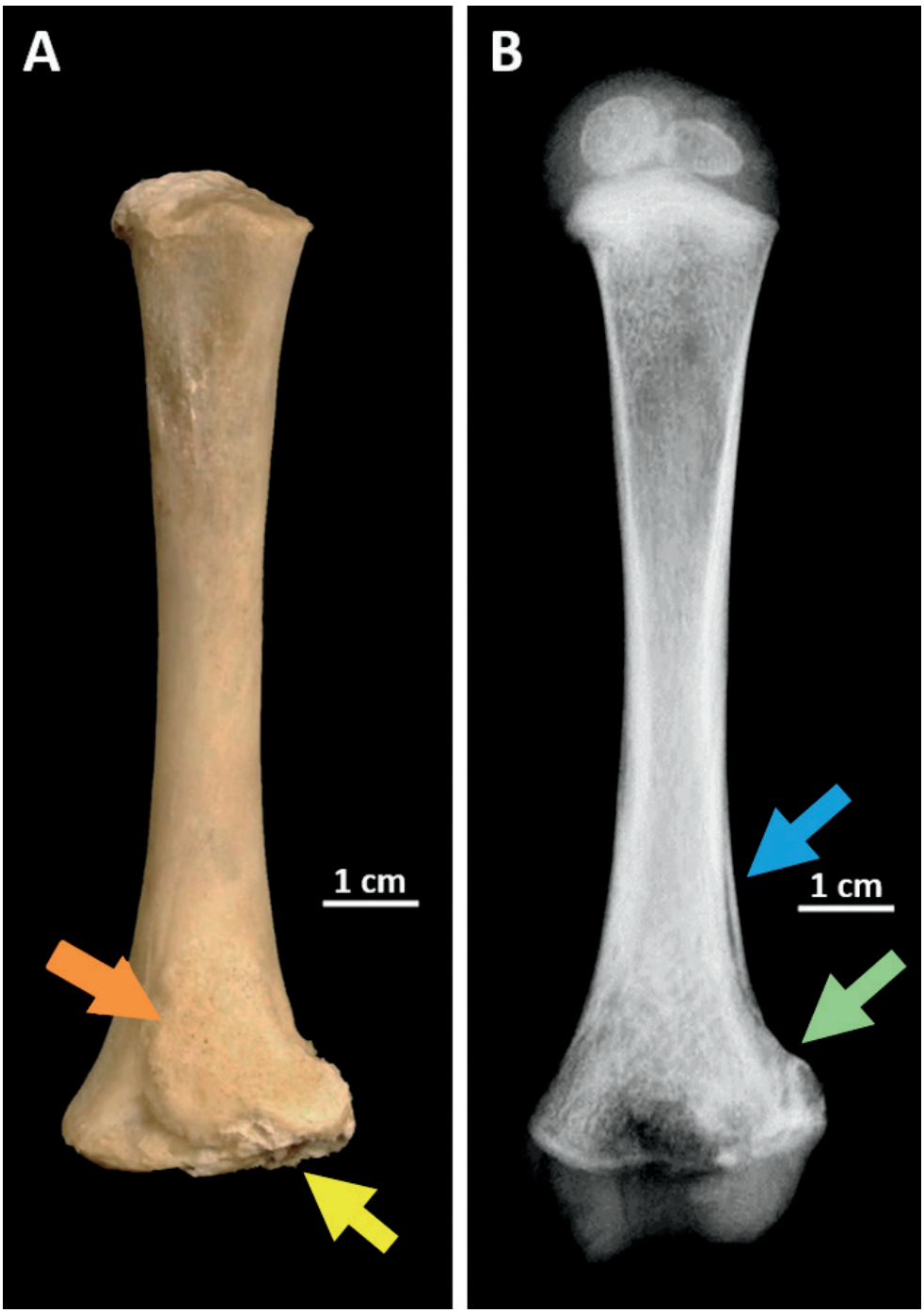

Image 2: Evidence of antemortem trauma to infant left humerus. **A)** Post-processing photograph illustrating a large bony callus (orange arrow) and abnormal remodeling to the distal metaphysis (yellow arrow). **B)** Mid-processing radiograph taken once the majority of soft tissue was removed but before the removal of the epiphyses. A healing metaphyseal corner fracture is evident (green arrow) which attributes to the metaphyseal remodeling, and an additional layer of bone has been laid down over the distal portion of the lateral diaphysis (blue arrow), suggesting additional trauma. Both the osteological and radiographic examinations corroborate one another, but each provides unique information.

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Forensic anthropologists have also utilized radiographs to assist with positive identifications. Just as forensic odontologists use comparisons of antemortem and postmortem dental radiographs to make an identification, forensic anthropologists can radiographically compare other regions of the skeleton. For example, a number of studies have illustrated that frontal sinus morphology, as viewed radiographically, is unique among individuals and can be reliably used for forensic identifications (18-21). Other radiographic studies have used unique bone shapes and features (22-31), suture patterns (32) or even trabecular bone patterns (33-35) to assist with identification. This can be particularly useful in mass disaster settings, where antemortem information can be gathered from the finite pool of potential victims (36). Arguably, skeletal variations in any region of the body may be useful for presumptive or positive identification, and thus it is important to provide copies of any antemortem radiographs to the forensic anthropologist along with the skeletal remains so that they might evaluate any unique morphologies.

Research

Given the ease of collection and availability of radiographs, they also provide an opportunity to create large radiographic databases for research purposes. For example, the Denver Growth Study (37, 38) and the Fels Longitudinal Study (39) consist of series of radiographs taken at regular intervals from infancy through adulthood in a sample of individuals. These studies provide a valuable opportunity for longitudinal studies in growth and development. Another database, known as PATRICIA (40) consists of pediatric radiographs from more than 9000 subadults collected from U.S. medical examiner's offices. A similar database, consisting of adult and juvenile radiographs acquired from the North Carolina Office of the Chief Medical Examiner, is available online through North Carolina State University (NCSU) (41). This database includes individuals with trauma, thus providing a comparative learning tool. Unlike with the Fels data, which was collected specifically for research purposes following specific research protocols, the radiographs in PATRICIA and the NCSU databases were collected retrospectively from MEOs. Typically in a MEO, radiographs are taken to best capture a specific region of interest (e.g., potential trauma defects), with the body positioned however will best elucidate that feature. This limits their utility somewhat, given that there is no standardization in subject positioning or radiographic settings even within an MEO, not to mention variation between MEOs. The creation of SOPs for radiographic procedures within and between MEOs, under consultation with radiologists, technicians, and forensic anthropologists, could lead to larger databases with greater utility for forensic research.

Computed Tomography

More advanced technologies have recently been, and continue to be, incorporated in the forensic anthropologist's arsenal of imaging techniques. One such technique, computed tomography (CT) scanning, was originally developed for use in the clinical setting, and is primarily used as a medical diagnostic procedure. Computed tomography scans essentially take a series of radiographs from a full complement of angles and the resultant images are then combined using digital algorithms to produce tomographic (i.e., cross-sectional) images that can be stacked to create a virtual 3D reconstruction of the object scanned. This procedure constitutes an essentially noninvasive and nondestructive method for visualization of both the external and internal structures of materials and organisms. Since CT scanning's introduction to the mainstream medical community, major advances in safety and resolution have occurred, and along with a concomitant reduction in cost, these factors have resulted in the increasing prevalence of patients receiving CT scans. For these reasons, CT scans are also gaining traction in the worlds of research and education, bolstered by a robust and growing body of scholarly work.

Despite the obvious benefits of this technology and its potential utility for both forensic casework and research, CT scanning remains limited in use within the forensic anthropological community. Many practitioners do not have access to facilities with the necessary equipment to perform CT scanning, and even for those who do, the relatively high cost of scanning may

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in itself be prohibitive. Furthermore, working with CT images requires access to specialized (and expensive) computer software as well as experience with manipulating 3D datasets.

Documentation and Trauma

In forensic anthropology, CT scans can be used in variety of different ways. When performing casework, CT scanning facilitates the documentation of human remains when the soft tissue is still present and the skeletal elements remain in articulation, as opposed to post-processing, which entails disarticulation of the skeleton and removal of all soft tissue. The ability to visualize the remains nondestructively is especially important in cases where trauma is suspected, and can be especially helpful in recognizing and analyzing fractures in situ (**Image 3**). As discussed, remains are often radiographed in forensic anthropological laboratories to facilitate the recognition of healing antemortem fractures, gunshot wounds and perimortem fracture patterns. CT scanning can accomplish these same goals, although perhaps with even better resolution and appreciation of the spatial relationships of the object in question given CTs' three-dimensionality and depth of field.

Once a CT scan is completed, the resulting data constitutes a 3D replica of the remains in question, which can then be saved and archived by the forensic anthropologist and/or forensic pathologist even once the remains have been returned to family members. This persisting digital documentation allows practitioners to refer back to a 3D digital model of the remains if any analyses are called into question, or if they testify in court. 3D printouts of the virtual skeletal models can also be created, allowing the forensic anthropologist to create a tangible example to illustrate points in court testimony as well as in the classroom. All of this can be done without extensive processing of the remains.

This idea that postmortem analyses can be completed with CT scans without invasive procedures, eventually led to the concept of virtual autopsies. Virtual autopsies, or Virtopsies, combine CT technology with magnetic resonance imaging (MRI), allowing forensic pathologists to perform a digital investigation to help determine cause and manner of death. CT scanning excels at discriminating between tissues of different densities (i.e., hard versus soft tissue) and MRI complements this with its proficiency at discerning between different soft tissue structures. The noninvasive character of Virtopsies make it beneficial, especially when

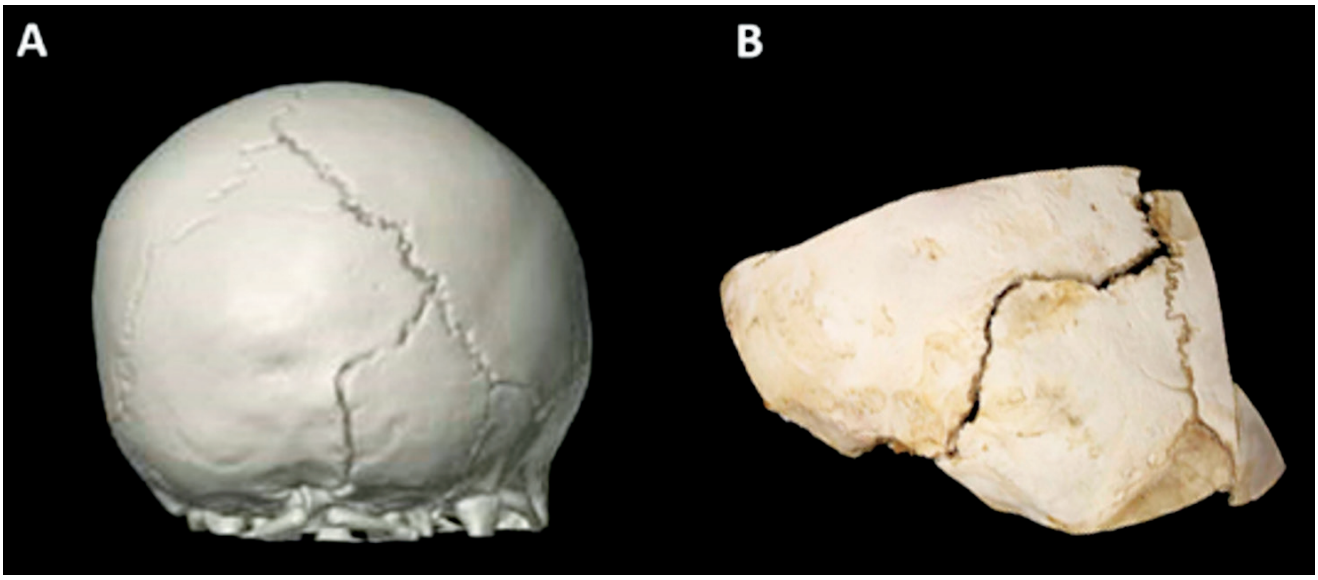

Image3: Comparison of a postmortem computed tomography scan **(A)** and the post-processing osteological specimen **(B)**, with a linear occipital fracture illustrated in each.

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cultural or religious concerns preclude a traditional autopsy. Although some pathologists have begun implementing virtual autopsies, there is still debate about its feasibility due to both the high requisite cost and level of technological expertise, as well as the scans' inability to discern coloration, which can play an important role in postmortem examinations (42-49). While U.S. MEOs have not begun to implement the full CT/MRI Virtopsy methods, many have begun to use CT scans as part of their autopsy procedure, given that costs and required expertise for CT technology has decreased considerably. Although such virtual autopsies fall under the purview of the forensic pathologist, the forensic anthropologist's skeletal expertise may still be required. Given that the data are digital, the forensic pathologist may be able to seek consultation from a forensic anthropologist anywhere on the globe.

Biological Profile and Identification

Any radiographic methods for estimating an individual's biological profile, such as the appearance of ossification centers, epiphyseal fusion, and dental eruptions patterns used in subadult analyses, can also be applied to CT data. Recent studies have also extended adult age methods in costal cartilage ossification to CT scans (50, 51). In addition, many of the skeletal analyses typically performed by forensic anthropologists on defleshed bone can also be performed on CT scans. From the 3D models created with the CT scans, standard osteometric landmarks and interlandmark distances traditionally taken with calipers on dry bone can be collected virtually. A number of studies have evaluated measurement errors when collecting craniometric landmarks and distances from CT data (52-58). Depending on the resolution of the CT scans, some researchers have found certain landmarks difficult to locate precisely, particularly those at suture intersections. CT scans do not preserve the color or texture of the objects, so suture location can only be discerned if the slice thickness is thin enough to pick up the slight indentation in those regions. Other measurements, such as maximum cranial breadth, can actually be taken semi-automatically in various software programs, removing a certain level of human error and potentially making them more accurate. Overall, results vary slightly between studies, but the general consensus is that measurements and landmark data collected from CT scans are reliable; however, many researchers advise caution when combining osteological and CT data as scan settings (e.g., slice thickness), measurement techniques (e.g., using slices versus 3D renderings), postprocessing methods (e.g., thresholds and smoothing), and even the software used to collect the virtual data may all result in measurement discrepancies (52, 54, 57). Studies combining CT and osteological data are typically required to include an error study, in order to document errors using those specific scanning and measurement parameters.

Although further validation studies are required, if these landmarks and measurements are accurate, then they can be used in forensic anthropological metric analyses of sex, ancestry, and stature as well as age at death in subadults (based on long bone lengths) just as any standard measurements would be. At present, forensic anthropologists remain cautious when it comes to using virtual measurements in software programs and equations derived from standard osteometric measurements, such as using CT measurements in Fordisc 3.1 (59). Given that a number of variables can affect error rates in landmarks and distances collected from CT scans (e.g., scan settings, processing methods, software, landmarks/measurements utilized), the impact of these errors on results obtained from osteologically derived equations will also vary. Further validation studies are required to evaluate whether the differences between CT and osteological data are great enough to impact forensic outcomes. At present, the osteological measurements are generally considered the gold standard, and the forensic anthropologist is presented with few scenarios in which virtual data are available and osteometric data are not. This is likely to change as forensic anthropologists take on a larger role in MEOs and the use of CT scanners during postmortem examinations continue to increase, creating a greater need for validation studies incorporating virtual data. As large samples of virtual 3D models are accumulated, we may see the creation of virtual-specific data collection methods, analyses, and databases of measurements, alongside the development of virtual skeletal collections.

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With an increase in research and validation studies using new technology, it may also be possible to apply nonmetric methods for estimating biological profile parameters that were originally designed for dry bone to CT scans. The pubic symphysis, a joint surface of the pelvis that forensic anthropologists commonly use to assess age at death, has been evaluated for age estimation purposes from CT scan models, and recent research has proved promising for these methods (60-62). Studies have also investigated the use of the auricular surface in CT scans for age estimation and found that although some of the traditional traits are difficult to score from CT scans, by modifying the traits scored or including new criteria they were able to obtain decent estimations (63, 64). Recent work has also demonstrated that estimating sex from nonmetric traits in the pelvis and skull from rendered CT models produce good results with low associated error rates (61, 65, 66). In particular, Phenice-derived traits of the pubis and the standard nonmetric traits for evaluating sex in the skull (including glabella, supraorbital margin, mastoid process, nuchal area and mental eminence) perform well when scored from CT scans (65, 66). These qualitative traits are not easily captured by simple landmarks or linear measurements, and therefore researchers are using more advanced geometric morphometric methods to 3D CT and surface scans in order to begin quantifying and statistically analyzing these traits. Geometric morphometric methods of analysis can be used to quantitatively capture and analyze the shape of object outlines, curves, and surfaces, eliminating the subjectivity involved in visual interpretation and ordinal scoring methods. For example, Garvin and Ruff use 3D models (created from surface scans) to isolate and quantitatively analyze sex and ancestry differences in brow ridge and chin shapes (67). Some researchers are even exploring automating data collection and analysis procedures using entire 3D models of the skull (68). As researchers continue to explore new methods of skeletal analysis using CT scan data, appropriate validation studies are required before use of these methods become mainstream. It is also worth noting that unless the CT-derived methods are also applicable on dry bone specimens, then their use is restricted to individuals with access to similar CT technology.

However, even with advances in resolution and the creation of sophisticated quantitative analytical techniques, there are still aspects of skeletal biology that are difficult to appreciate from digital models, including age indicators like cranial suture closure and subtle pathological signals such as periosteal bone reactions. This situation leads many forensic anthropologists to prefer physically examining remains themselves, rather than only having access to 3D scans or models, and this often means fully processing of the remains to better visualize the bones, even if advanced imaging techniques are available.

Postmortem CT scans may be compared to antemortem scans of potential decedents if they are available, enabling analysts to assess the morphology of internal individualizing characteristics such as the frontal sinuses. Postmortem radiography is much more accessible and widespread among forensic anthropologists, but because of the superimposition inherent in radiographs, it is not difficult to compare a 2D slice from a CT scan to a traditional radiograph. Because of issues with superimposition, orientation, and distortion, any comparison between a radiograph and CT scan may not be definitive enough for positive identification. Luckily, however, scout images that commonly accompany CT scans may allow for an analogous comparison. Given the advantages of CT scans over traditional radiography and the fact that more individuals are receiving CT scans during their life, we may find antemortem and postmortem comparisons of CT data becoming a more popular means of positive identification.

If any antemortem CT scans are available or postmortem CT scans are taken during autopsy, the forensic pathologist should share that data with the forensic anthropologist. The forensic anthropologist's trained eye may identify certain skeletal features from the scans that can be useful for identification or assist in reconstructing the circumstances surrounding their death. Because the CT scans essentially represent a 3D virtual replication of the skeleton, individualizing skeletal traits and morphologies evident on antemortem CT scans can be compared to the bone specimens to assist with positive identification (**Image 4**). In addition, the

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forensic anthropologist can review those scans prior to any processing, noting regions of interest (e.g., potential trauma) that may need to be processed with additional care and documentation.

Although it is not generally part of the role of forensic anthropologists, it is worth noting that 3D models created from the CT scans can also be utilized in facial reconstructions. Forensic artists can either create a virtual facial reconstruction, allowing certain features such as eye and hair color to be easily exchanged, or they may use a 3D printout of the skull to build their reconstruction (69-72). In this manner, the actual skull does not need to be retained in custody during the reconstruction.

Research

In the realm of forensic anthropological research, CT scans are playing a growing role for data collection purposes. Not only are digital scans more easily accessible for researchers, but they also constitute a more appropriate data source for forensic research. Unlike radiographs, CT scans do not suffer from issues of 2D superimposition or parallactic distortion. Individual decedents scanned for inclusion in CT scan samples also come from more modern and diverse populations than are available at the majority of skeletal collections, allowing a greater appreciation of human intraspecific variation as well as mitigating the effects of secular change. Furthermore, modern digital skeletal collections are generally accompanied by thorough demographic and life-history data, which many (pre) historical skeletal collections lack, however this greater access to information must also be tempered by ethical concerns about privacy.

On the other hand, robust digital skeletal collections are difficult to acquire due to the time and cost constraints associated with producing the scans. Therefore, when forensic anthropologists conduct research using CT scans, they have almost always been taken

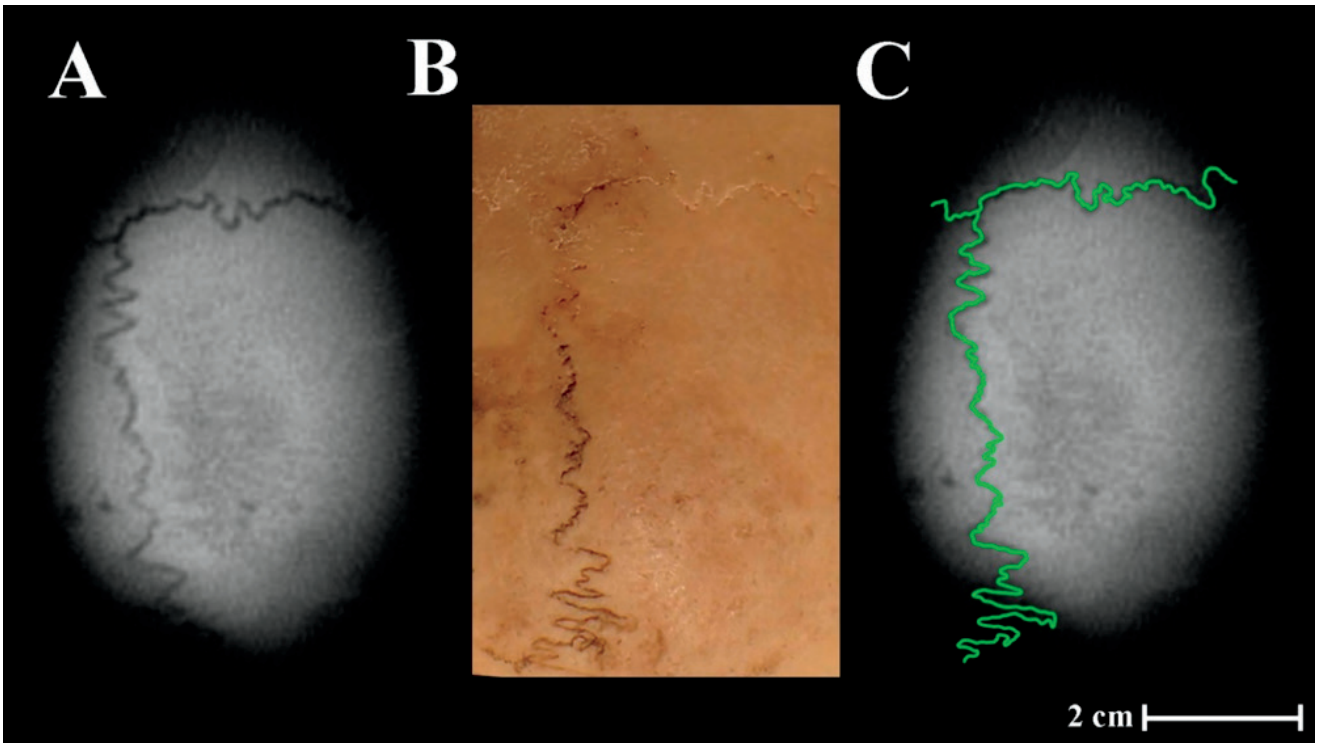

Image 4: Comparison of an antemortem computed tomography slice illustrating sagittal and coronal suture patterns **(A)** to a photograph of the sutures post-processing **(B)**. An overlay of the suture patterns was used to help corroborate the identity of the individual **(C)**.

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for other reasons, such as diagnostic imaging in the clinical setting or postmortem for medicolegal purposes. Protecting decedents' privacy is also a concern, especially when CT scans are used for research purposes, and therefore methods for deidentifying scans are becoming commonplace, although additional funding must be sought, usually by the anthropologist, in order to cover the cost of scan anonymization. Collaboration and partnerships between MEOs and forensic anthropologists are beginning to form in order to create these types of digital database collections (73), which constitute a valuable step forward for this type of research and advances in the field.

Surface Scans

Three-dimensional models of skeletal material can also be produced using surface scanners. There are a variety of 3D scanners currently on the market. These surface scanners use either lasers or structured light patterns to capture and reconstruct the 3D surface of an object. Unlike with CT scans, where X-rays are involved, the 3D surface scanners can only capture the external surfaces, and those surfaces must be in the line of sight of the scanner. It is impossible to capture the internal structures or surfaces and complex surfaces with large projections or deep crevasses can be challenging or at times unfeasible to capture with a surface scanner. If the goal is to create 3D models of skeletal remains, all soft-tissue must first be removed. Some surface scanners are hand-held and can be moved freely around the object of interest, while with other scanners, the object must be moved. Automated turntables, which rotate a specified number of degrees between scans, simplify this process, and are commonly included with stationary 3D surface scanners. Most 3D surface scanners will also take photographs of the object, which are then overlaid on top of the 3D model, replicating the original coloration of the object (referred to as "texture") (**Image 5**). Because the laser or light source can only capture the exposed surfaces, multiple scans must be taken from different orientations, which are then aligned and merged (either manually or automatically using the scanning software) to create a complete 3D model. The benefit of using 3D surface scanners over CT scanners to create 3D models is that 3D surface scanners are cheaper, more accessible, more mobile, and have resolutions higher than the CT slice thickness used by most clinical institutions, even during postmortem examinations. Keep in mind, however, that surface scanners cannot collect any information about internal structures, only the external surfaces that the lasers or light can reach.

Of the 3D surface scanners utilized by researchers, the NextEngine Desktop 3D scanner is the most widely used and is owned by numerous academic, research, and medicolegal institutions. Its popularity is, in part, due to its affordability (~$3000), user-friendly interface, and overall accuracy (up to 0.13 mm in macro

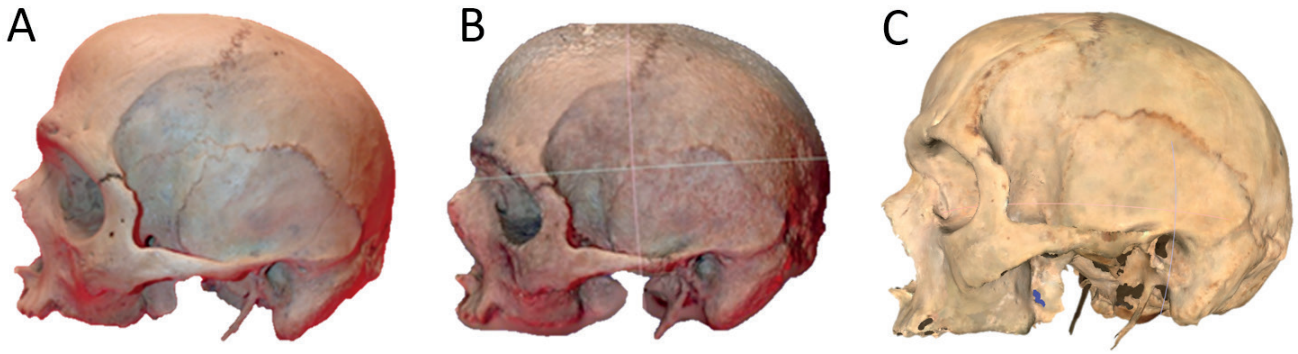

Image 5: A photograph **A)**, screenshot of a 3D model created using digital photos and photogrammetry software **B)**, and screenshot of a 3D model created using a NextEngine desktop surface scanner **C)** of the same cranium. Note that the photogrammetry model was created using only 15 photographs and represents the authors' first trial with the software.

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mode) (74). The NextEngine can collect up to 29 000 points per square inch in the wide mode, and up to 268 000 in the macro mode. It is also fairly small (~28 cm x 22 cm x 9 cm), making it relatively portable. Although the act of creating a 3D scan using the NextEngine and associated ScanStudio software is fairly simple, there are a number of settings and preferences that can be adjusted in order to obtain scans of varying quality and file size. At present, there are no published standards for scanning forensic anthropological skeletal material, and preferred methods and scanner settings utilized vary amongst researchers. There are also a number of more expensive 3D scanners available (e.g., Breuckmann SmartScan, DEIOS Prototype, Descam Model Maker). These scanners can run upwards of $200 000. A few studies have compared NextEngine scan results to those of higher-end scanners (75, 76) and found that for most purposes, the NextEngine scanner provides high enough resolution.

Documentation and Trauma

Essentially, 3D surface scans can be used in much of the same manner as CT scans. The 3D scans can be used to create a 3D replica of a skeletal element for documentation and archival purposes. A 3D virtual model of the skull, os coxae, and any other region of interest can be created and stored. Even after the remains are returned, the anthropologist can refer to the 3D model, should new information arise or previous information come into question. Because the surface scanners also capture the texture and coloration of the surface, taphonomic modifications such as sun bleaching and soil staining can also be preserved. The scan resolution is generally high enough to be able to accurately document most fracture patterns (especially those displaying plastic deformation or separation at the fracture margins) and gunshot wounds. It is generally more difficult to capture evidence of sharp force trauma using 3D scans, unless the defects are a couple of millimeters wide. Narrower incisive wounds and shallow cuts might be able to be captured using higher-end scanners, but will depend on the resolution and settings. Overall, the utility of 3D surface scans in documenting and analyzing trauma defects has not been thoroughly explored and requires further experimentation. As with the CT scans, any virtual models created from 3D surface scans can then be printed with a 3D printer, providing a tangible replica. The 3D print may then be used for illustrative purposes in court testimony or when teaching in the classroom and training the next generation of forensic anthropologists.

Surface scanners can also be utilized to document the crime scene in forensic cases. This technology has been utilized by various agencies in indoor crime scenes, outdoor crime scenes, and in crash reconstructions. The surface scanner can be used to create a 3D replica of a crime scene, thereby digitally preserving the scene. Besides obvious archival and evidentiary purposes, the 3D crime scene may be used for scene reconstructions and analyses. Measurements and angles can be collected from the 3D models to aid in such analyses as blood spatter and bullet trajectories. They also cut down on scene processing time, as much of the traditional information collected from the scene can be collected virtually after the fact, allowing agencies to clear scenes in a more timely manner. Finally, the 3D crime scenes can be used for explanatory purposes in the courtroom. Most forensic anthropologists, however, have not had the opportunity to work with this technology. Laser scanners utilized for scene documentations (such as the popular Leica ScanStation) cost upwards of $115 000, which is typically outside the forensic anthropologist's budget. These scanners can create a 360 degree reconstruction of a scene with up to 3 mm accuracy at a distance of 50 m. The National Institute of Justice recently published the results of a study entitled "*Landscape Study on 3D Crime Scene Scanning Devices*", in which various 3D scene scanning devices are compared (77). Overall, the results of the study emphasize the utility of 3D scanning devices at crime scenes, but also stresses the time requirements in post-processing the data and required funds and resources for analysts, as well as the maintenance and upkeep of the equipment and software. Given these limitations, it may be best for forensic anthropologists to identify where the closest regional access to such technology may be and collaborate with those agencies if 3D scanning of an outdoor scene is required.

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Biological Profile and Identification

At this point, 3D surface scans do not contribute much directly to forensic anthropological case analyses. Although landmarks and measurements can be collected from the surface scans and have been shown to be accurate (78), there is not much point in taking them from the surface scans when the actual element is available and can be measured directly. This is also true when applying traditional age, sex, and ancestry estimation techniques. However, as mentioned previously, 3D virtual models provide an opportunity to use new variables, such as surface areas, volumes, outlines, surface relief, and semilandmarks (i.e., landmarks placed along curves or surfaces in order to capture shape) in skeletal variation analyses. Because surface scans are generally more accessible than CT scans, many of the novel quantitative methods are being developed from samples of surface scans (67, 79-82).

Research

The research potential for 3D surface scans mirrors that of CT scans. The use of craniometric landmarks from 3D surface scans has been approached a little more cautiously than those from CT scans, as the quality and resolution of the surface scans have been known to vary. Experimentation with various scanning equipment and software should be systematically conducted, the results of which may be used to create SOPs for scanning skeletal elements for forensic purposes. Statistical advances in the field of geometric morphometrics are also allowing researchers to explore new variables in skeletal analyses, and this new research is well-represented in the literature. A cursory literature search reveals over 100 articles in the *Journal of Forensic Sciences*, *Forensic Science International*, and the *American Journal of Physical Anthropology* in which 3D models (from surface or CT scans) were used in some form of skeletal analysis since 2001. Forensic skeletal analyses will continue to advance as researchers investigate new methods of analyzing features which could not be easily quantified in the past.

Unlike CT scans, which are commonly collected and archived at medical institutions and therefore are theoretically accessible for research purposes, we have yet to reach the point where there are large repositories of modern human 3D surface scans available for researchers. It is anticipated that this will change in the near future as 3D scanning becomes more affordable and practical and data analysis software continues to improve. Instead of travelling to skeletal collections to physically take measurements and landmarks for research, 3D scans of skeletal elements can be sent over the internet or uploaded onto servers. Three-dimensional surface scans thus offer another opportunity for researchers to share data and the potential for growing virtual skeletal collections if the time and resources can be allocated to collecting and processing those scans. Before this can occur; however, SOPs need to be developed for scanning processes and ethics for data sharing of such sensitive material should be considered.

Photogrammetry

Another affordable option for the production of 3D models is the use of photogrammetry. Although the concept of photogrammetry was developed well before 3D surface scanning and CT scans were available, photogrammetry methods have recently become increasingly popular as camera technology has advanced. Recent publications demonstrate its versatility in several fields, including applications to biological anthropology (83, 84). Essentially, photogrammetry allows for the reconstruction of the position, orientation, shape, and size of an object from digital photographs and thus requires no expensive hardware other than a decent digital camera (84). A number of fee-based and free software programs are currently available (e.g., Agisoft PhotoScan, 123DCatch, 3DFlow, Acute3D) that use algorithms to more or less automatically align multiple photographs of an object into a 3D model. Theoretically, the outcome would be equivalent to a 3D surface scan; however, the accuracy of the 3D photogrammetry reconstructions has not yet been evaluated for forensic use. Given that the reconstruction is built from a series of photographs (which do not even need to be taken in a

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particularly systematic order), instead of the lasers or structured light source in a 3D surface scanner, it may be assumed that photogrammetry methods will result in less accurate models. Overall, photogrammetry is a new area for forensic anthropologists to explore for use both in the laboratory and at the scene. This is particularly true for laboratories or agencies that may not have the funds for more advanced technology.

CONCLUSION

Over the last decade, the use of advanced imaging in forensic research and case analyses has exponentially increased. That being said, these technologies are not yet commonplace and their full potential is not yet being exploited in the field of forensic anthropology. One of the major limiting factors is cost. Computed tomography scanners and high-end laser scanners will likely be outside the forensic anthropologist's budget. Some forensic anthropology labs may not even have access to digital X-ray systems. Even affordable imaging options, such as the NextEngine scanner, may require additional software to perform certain analyses. Programs such as AMIRA, GeoMagic, and Polyworks which are commonly used to view, collect, and analyze 3D data, cost thousands of dollars, with annual maintenance fees. The use of the advanced imaging equipment and associated software is also a limiting factor as these require expertise, and postprocessing of CT or surface scan data is time consuming. Despite these limitations, those with access to advanced imaging technologies have begun to incorporate them into forensic anthropological analyses and research. As there are continued advances in 3D technologies, we should expect to see the continued development of novel, more quantitative methods, including movements towards automating data collection, processing, and analyzing procedures. Given the high monetary and time cost of traveling to collections to physically collect data and the ease of accessing digital data, we should also expect to see growing trends of institutions using these advanced imaging techniques to create virtual collections for research and teaching purposes. The formation of these virtual collections is already proving time-consuming, and therefore it may take years to render even modest collections fully digital, but despite these drawbacks, several museums and other institutions are forging ahead and steadily adding specimens to their virtual collections. The real key to promote the continued implementation and improvement of advanced imaging techniques is to increase collaboration between forensic anthropologists, law enforcement, and forensic pathologists and other clinicians. Open communication and the sharing of information, data, and resources will facilitate these interdisciplinary collaborations, ultimately supporting our common goals in medicolegal investigations.

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Association of Antemortem Central Nervous System Symptoms and Location of Aortic Dissections; A Retrospective Study from 2001-2014

Wendy MacKerricher, Robert R. Klein, David C. Winston

ABSTRACT

Aortic dissections (AD) are a frequent cause of sudden death and are typically associated with chest, back, and/or abdominal pain. Several cases of AD with neurologic presenting symptoms, such as paresthesia, headache, and seizures were noted at the Pima County Office of the Medical Examiner (PCOME) in Tucson, Arizona. Our aim was to compare the location of AD with central nervous system (CNS) versus classic symptoms. Retrospective data were collected from the archives at the PCOME from 2001-2014. There were 61 natural death cases involving the aorta with known antemortem symptoms; 43 cases of AD with classic (non-CNS) symptoms and 18 cases with CNS symptoms. The cases were classified based on Debakey and Stanford classification systems. Patients with CNS symptoms had a greater proportion of Debakey type II dissections (44%) than without CNS symptoms (16%). This association was statistically significant (p = 0.0337, chi-square test). Seventeen percent of cases with CNS symptoms had AD involving the carotid arteries, and involvement of the carotid arteries was significantly associated with CNS symptoms (p = 0.0227, Fisher's exact test). There were a higher percentage of females with CNS symptoms (44%), than without CNS symptoms (23%). Our findings suggest a need for a higher index of suspicion and further investigation of cases with neurologic symptoms, focusing particularly on the aortic arch and its branches. *Acad Forensic Pathol. 2016 6(3): 517-523*

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KEYWORDS

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INFORMATION

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INTRODUCTION

The first aortic dissection (AD) was documented in King George II of Great Britain in 1760, who died from pericardial tamponade due to an ascending AD (1). The term aortic dissection, however, was not coined until the early 1800's by René Laennec, a French physician, who notably invented the stethoscope (1). In 1954, the first successful dissecting aortic aneurysm repair was performed by Dr. Michael DeBakey and his team, who also created one of the most common classification systems for ADs (1). Ironically, DeBakey himself later suffered from an acute AD (1).

Aortic dissections are a rare but serious condition that primarily occur in older men. The incidence of ADs is 6000-10 000 cases per year (2, 3), with a prevalence of 3-4% in those over 65 years of age (4). The International Registry of Acute AD (IRAD) was established in 1996 and consists of 30 large referral centers in 11 different countries. This substantial database assesses the etiology, presentation, clinical features, treatment, and outcomes of patients with acute ADs (5). Due to the size of this database, many epidemiological and interesting facts have been discovered, including a predisposition for ADs to present in the morning (six o'clock in the morning to noon) and in the wintertime (5). Some theories suggest this is due to rhythmic variation in sympathovagal balance (6).

The risk factors for ADs are divided into two broad categories. The first category includes conditions that lead to medial degeneration: Marfan syndrome, Loeys-Dietz syndrome, Ehlers-Danlos syndrome (type IV), inflammatory diseases of the aorta, Turner syndrome, bicuspid aortic valve, familial thoracic aortic aneurysm, and dissection syndrome (4, 7, 8). Patients with Marfan syndrome (incidence of one in 3000 - 5000), caused by a mutation in one of the genes coding for fibrillin-1, are the largest group of genetically predisposed individuals, accounting for approximately 10% of all cases of ADs (4, 7). Those with Marfan syndrome have a 50% risk of AD in their lifetime (9). The second category involves conditions that lead to increased aortic wall stress, such as hypertension, physical trauma, and smoking (7).

The Stanford classification system places dissections into two categories based on involvement of the ascending aorta: type A involves the ascending aorta, and can extend into the descending aorta; whereas type B is confined to the descending aorta. The DeBakey classification system splits AD into three groups: type I originates in the ascending aorta, but can extend into the aortic arch and descending aorta; type II is confined to the ascending aorta only; and type III is limited to the descending aorta.

Aortic dissections are often asymptomatic, with only 5% of people reporting symptoms before an acute event, while for the remaining 95% the first symptomatic presentation often results in death (9). The IRAD found that of those who described symptoms, 79% had chest pain and 90% described the pain to be "severe" or the "worst ever" experienced (5). Due to the generalized symptom of chest pain and difficulty in diagnosis, ADs are missed in 16-38% of emergency department presentations (10, 11). The delay in diagnosis can result in extremely detrimental outcomes, including death. One study found the mortality of untreated type A dissections increases by 1-2% every hour in the first 48 hours, reaching 50% mortality by day three, and 80% mortality by two weeks (1). Type B dissections have a better prognosis, with a mortality of 10% at 30 days for low risk patients and 70% for those at high risk (1).

While the findings of the sequelae of AD at autopsy (hemothoraces, hemoperitoneum, hemopericardium) almost always cinch the cause of death, often the presenting symptoms are overlooked. The limited publications documenting neurologic symptoms in ADs have reported that neurological deficits can be found in 17-40% of all patients with ADs (3). Our aim was to identify and compare the location of ADs in patients presenting with central nervous system (CNS) versus classic symptoms. The Pima County Office of the Medical Examiner (PCOME) in Tucson, Arizona had two cases with CNS symptoms (paresthesia and altered mental status) within a two-week period, which prompted this study.

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METHODS

Retrospective data were collected from the archives at the PCOME between January 2001 and December 2014. Information was gathered from death investigation reports, emergency services notes, hospital notes, and autopsy reports. The initial search included all natural deaths that had the terms "aorta," "dissection," "hemopericardium," "hemothorax," or "hemoperitoneum," or some variant in the cause of death statement. Those without a dissection, witnesses to relay antemortem symptoms, or autopsy were removed. In the remaining deaths, data were collected to include age, race, sex, symptoms, location of dissection, involvement of carotid arteries, heart weight, left ventricle thickness, comorbidities including other heart diseases, and body mass index (BMI). The cases were classified based on location according to the DeBakey and Stanford classification systems for ADs.

All statistical tests and analyses were performed using JMP Pro Statistical Discovery software version 11.2 (SAS Institute Inc., Cary, NC, USA).

RESULTS

The original broad search criteria yielded 185 cases. Of these, 124 cases were eliminated with either non-dissection causes of death including aortic stenosis, aortic valve repair, endocarditis, aortitis, and myocardial infarction, or did not have documented antemortem symptoms. The remaining 61 cases of ADs were confirmed to be natural deaths and meeting our criteria of having known antemortem symptoms and an autopsy. Of these 61 deaths, Stanford type A dissections (n=39) accounted for 64%, with an average age of 54.4 years. Stanford type B (n=22) were found in 36%, with an average age of 65.1 years. Using the DeBakey classification system, ADs in this study were: type I = 39% total (71% male, 29% female) with an average age of 50.9 years; type II = 25% total (73% male, 27% female) with an average age of 58.8 years; and type III = 36% total (68% male, 32% female) with an average age of 65.7 years.

Of the 61 cases, 43 had classic (chest, back and/or abdominal pain) symptoms and 18 had CNS symptoms. Within the non-CNS or more classic symptoms, chest pain (n=17) was the most common finding, followed by abdominal pain (n=13), nonspecific pain (n=10), and back pain (n=9). The most common symptoms found among the CNS group included: paresthesia/pain in extremities (n=6), dizziness (n=5), headache (n=4), confusion/altered mental status (AMS) (n=4), back pain (n=3), syncope (n=2), and abdominal pain (n=1). Except for syncope and back pain, all these symptoms had a statistically significant association with either the presence or absence of CNS symptoms (**Table 1**).

Table 1: Symptoms

Central Nervous System				Classic			
Symptom	Number	Percent	*p* value*	Symptom	Number	Percent	*p* value*
Paresthesia	6	29%	0.0003	Chest pain	17	35%	0.0012
Dizziness	5	24%	0.0014	Abdominal pain	13	27%	0.0469
Headache	4	19%	0.0059	Nonspecific pain	10	20%	0.0261
Confusion /Altered mental status	4	19%	0.0059	Back pain	9	18%	0.6989
Back pain	3	17%	0.6989				
Syncope	2	9%	0.0836				
Abdominal pain	1	6%	0.0469				

* Fisher's exact test

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Documentation of where death occurred was available for all cases and were separated into three groups: death at home, death enroute or upon arrival to hospital, and death after several hours of hospital stay. It was found that more patients exhibiting classic symptoms (30%) survived in hospital than those with CNS symptoms (22%). Death at home accounted for the majority of cases in both groups, with classic symptoms accounting for 54% and CNS symptoms, 39% (**Table 2**).

There was a higher percentage of females with CNS symptoms (44%) than with classic symptoms (23%). The median age was similar in both categories: CNS symptoms at 58.5 years and classic symptoms at 57.3 years. Ninety-four percent of patients with CNS symptoms were Caucasian compared to 65% of patients with classic symptoms. Patients with CNS symptoms had a greater proportion of Debakey type II dissections (44%) than those without CNS symptoms (16%). This association was statistically significant (p = 0.0337, chi-square test). Seventeen percent of cases with CNS symptoms had dissections involving the carotid arteries, and involvement of the carotid arteries was significantly associated with CNS symptoms (p = 0.0227, Fisher's exact test). Of the cases involving the carotid arteries, 66% were male and had an average age of 57.7 years. Symptoms included confusion/AMS (n=2), syncope (n=1), and paresthesia/pain in extremities (n=1). Hemopericardium was present in 67% of cases with CNS symptoms, with an average volume of 271 mL versus 47% of cases with classic symptoms, with an average volume of 388 mL. Patients with classic symptoms had larger heart sizes and thicker left ventricular walls: 547 g and 1.62 cm versus 470 g and 1.46 cm, respectively as compared to those with CNS symptoms (**Table 3**).

Table 2: Location of Death

	Central Nervous System		Classic	
Disposition	Number	Percent	Number	Percent
Died at home	7	39%	23	54%
Died enroute or upon arrival to hospital	7	39%	7	16%
Died after several hours in hospital	4	22%	13	30%

Table 3: Central Nervous System vs. Classic Symptoms Comparisons

	Central Nervous System	Classic
Total Number	18	43
Female (% total)	44%	23%
Caucasian (% total)	94%	65%
Age (mean)	58.5 years	57.3 years
Hemopericarium	67%	47%
Hemopericardium volume	271 mL	388 mL
Heart weight	470 g	547 g
Left ventricle thickness	1.46 cm	1.62 cm
Hypertension	89%	93%
Body mass index (kg/m^2)	24.9	28.2
Debakey type II	44%	16%
Stanford type A	78%	58%

Aortic aneurysms (any location) were associated with an aortic dissection in 36% of all cases. Twenty-eight percent of CNS symptom patients had an associated aortic aneurysm versus 40% of classic symptom patients; however, the presence of an aortic aneurysm was not found to be statistically significant. Body mass index (weight in kg/height in m^2) of patients with CNS symptoms was more likely to be normal compared to those with classic symptoms. The classification scheme of normal (BMI <25), overweight (BMI=25-30), obese (BMI=30-40), and morbidly obese (BMI >40) was utilized. Fifty-five percent of patients with CNS symptoms had a normal BMI, 28% were overweight, and 17% were obese. Thirty percent of classic symptom patients had a normal BMI, while 35% were overweight, 30% were obese, and 5% were morbidly obese.

There was an overall higher incidence of hypertension in overweight and obese patients (97%) than those with a normal BMI (82%). Hypertension was defined as having antemortem clinical documentation of hypertension or increased heart weight at autopsy (12).

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When classified based on CNS symptoms there was a higher incidence of hypertension in the normal (90%) than in the overweight group (80%), in direct opposition to those with classic symptoms, who showed a higher proportion of hypertension in the overweight (100%) than normal group (75%).

A diagnostic decision tree was produced using a partition model. A partition model recursively partitions data using classic statistical tests in order to classify a case. In this context, a decision tree to predict patients with CNS symptoms was produced. This tree included four branch points or key questions used to predict CNS symptoms: Chest pain, nonspecific symptoms, Debakey type II dissection and BMI ≥ 26.6. When these four questions are answered, all but five cases (89%) were classified correctly (**Figure 1**).

Only one patient had a connective tissue disease (Ehlers-Danlos syndrome).

DISCUSSION

Aortic dissections are a relatively common cause of sudden death within the medical examiner's office. Classically thoracic and abdominal ADs present with abrupt, severe chest, back, and/or abdominal pain, followed by sudden death. Our findings are consistent with those found in the literature that Stanford type A dissections account for two-thirds of cases versus

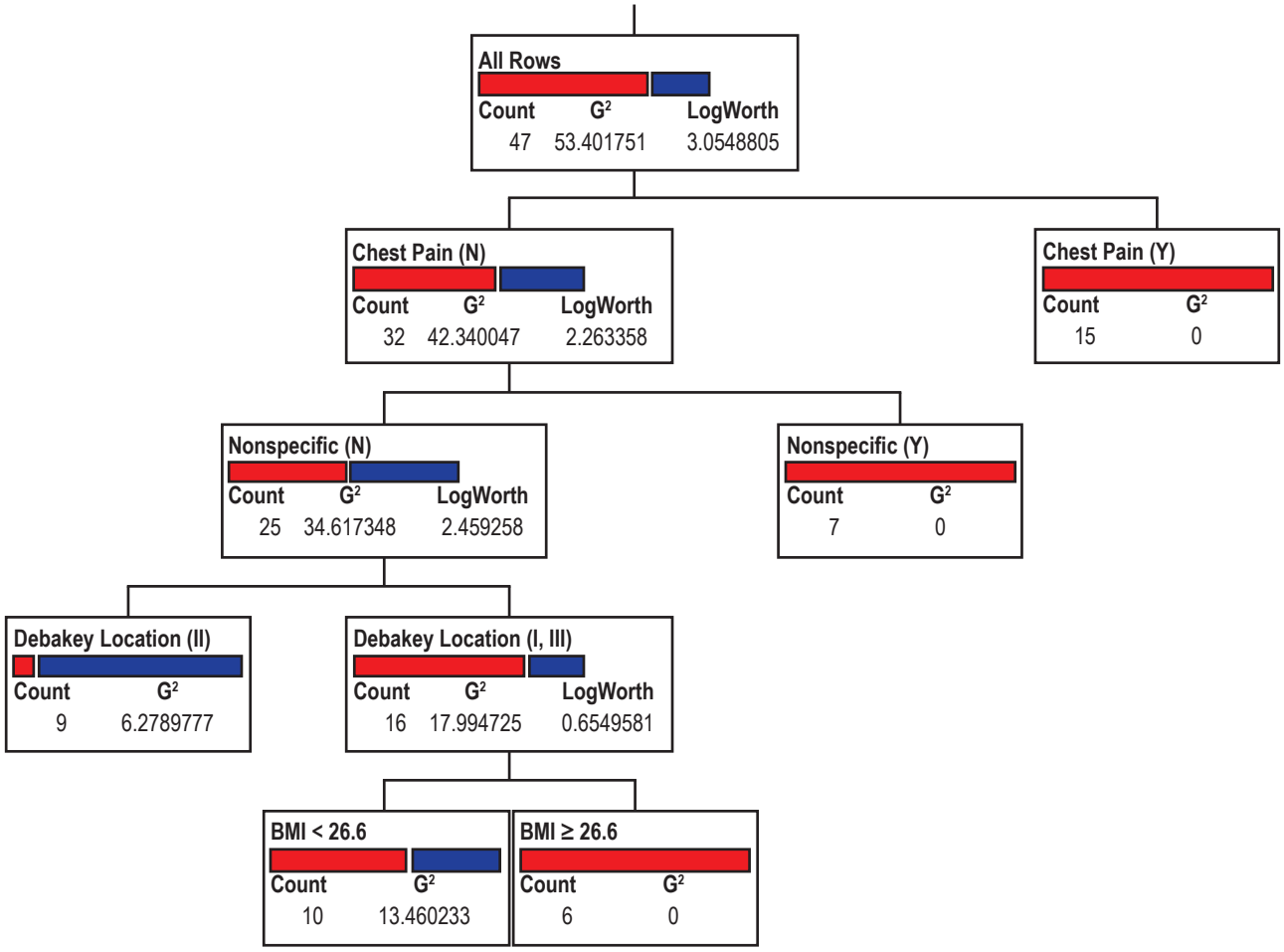

Figure 1: Decision tree (central nervous system symptoms – blue; classic symptoms – red).
Y = Yes; N = No; BMI = Body mass index; G^2 = Likelihood-ratio chi-square.

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type B representing one-third of ADs; our findings are type A (64%) vs. type B (36%) (3, 5). This finding holds true for the Debakey classification system: type I and II represents two-thirds of cases, and type III one-third; compared to our results of type I/II (64%) versus type III (36%).

There are relatively few journal articles which address the association between neurological symptoms and ADs. One paper describes a variety of neurological deficits that were found in 17-40% of all ADs studied (3). Syncope has been reported in up to 17% of patients presenting with type A dissections (13). Mortality of those with syncope was found to be higher (34%) than those who did not have syncope (24%) (14). Our study found syncope in only 11% of patients (n=2) with CNS symptoms. Acute neurological deficits or coma were found in 30% of people with type A dissections, which is slightly less than our reported results of 36% (13). The median age is similar between both the CNS and classic groups: 57.3 years and 58.5 years, respectively.

A greater proportion of decedents with CNS symptoms had an AD involving the ascending aorta (Stanford type A, 78%; Debakey type I/II, 83%) than those with classic symptoms (58%; 56%). A significant relationship was found between those who had CNS symptoms and Debakey type II dissections (p = 0.0337, chi-square test). These findings may be due to alterations in blood flow to the brain and/or spinal cord causing acute neurological symptoms. We found that CNS symptoms were associated with dissections involving the carotid arteries (p = 0.0227, Fisher's exact test). Seventeen percent of our cases with CNS symptoms had involvement of the carotid arteries. Previous studies noted that focal neurological findings may be seen in patients with a dissection that extends to the spinal or carotid arteries; however, the percentage of patients was not reported (3). One retrospective study found that 94% of patients without neurological symptoms experienced pain, while only 66% of patients with neurological symptoms had chest pain (15). Interestingly, none of our patients with CNS symptoms had a history of chest pain.

Symptoms were documented in all cases, as well as location of death/hospital stay prior to death where applicable. The majority of decedents within the CNS and classic symptom groups died at home or enroute/on arrival to the hospital. Thirty percent of those with classic symptoms died after several hours in hospital, as opposed to 22% of CNS symptoms.

One report found that altered mental status was more common with pericardial tamponade (14). At autopsy, we were unable to determine if the decedents experienced pericardial tamponade; however, hemopericardium was found in 67% of cases with CNS symptoms (average volume of 271 mL), compared to 47% of cases with classic symptoms (average volume 388 mL). All patients with altered mental status were found to have a hemopericardium.

The male to female ratio of ADs has generally been noted in the literature as 3:1 (3, 6); however, more recent studies have found the incidence may in fact be closer to the findings in our study of 2.4:1 (16, 17). We found there is an increased frequency of females with CNS symptoms (44%; ratio 1.25:1) than without CNS symptoms (23%; ratio 3.3:1).

An interesting finding within our patient population is the high prevalence of Caucasians with CNS symptoms (94%) versus non-CNS symptoms (64%). This may be due to a familial link or genetic predisposition that is not yet elucidated, thought to be in up to 20% of patients with sporadic ADs (4, 9). Body mass index, heart size, left ventricular thickness, and hypertension were found to be higher in patients with classic symptoms. Within the classic symptom group hypertension was more commonly seen in patients who were overweight or obese, as opposed to the CNS symptom group where a higher proportion of those with hypertension had a normal BMI.

CONCLUSION

Antemortem CNS symptoms are probably more common than most forensic pathologists would predict in patients who die from AD. The ADs in these patients

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are most likely to be proximal (Stanford A or DeBakey I/II). Our findings show that AD should be on the differential diagnosis when presented with a decedent who exhibited antemortem neurological symptoms.

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A 27-Year Retrospective Study of Pediatric Suicide Cases Referred to the Medical University of South Carolina (1988-2014)

Balvir Singh, Cynthia A. Schandl, Lee M. Tormos

ABSTRACT

Suicide by individuals under 18 years of age is a tragic reality of society. To assess local trends and demographics, we retrospectively reviewed all pediatric cases referred to our institution from 1988-2014 (27 years). Pediatric cases were defined as individuals younger than 18 years of age. The incidence of reported suicides declined from 3.8 cases per year to 2.4 cases per year as compared to observations at our institution over a previous ten-year period (1988-1998). In concert with the overall decrease in cases were increases in the proportion of adolescents younger than 15 and the female demographic. Furthermore, a shift in suicidal methodology was noted, with an increase in suicide by hanging. Indeed, for females, hanging became the most common suicide modality, replacing firearms. Our findings are congruent with national trends and underline the need for global suicide preventive interventions targeted toward increasingly younger adolescents and females. *Acad Forensic Pathol. 2016 6(3): 524-531*

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This article does not contain any studies conducted with animals or on living human subjects

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INTRODUCTION

Suicide in children under the age of 18, or pediatric suicide, is a serious public health challenge and is often cited as the second or third leading manner of death, depending on the age range studied. Factors that reportedly place this age group at risk include psychiatric disorders, social stress, alcohol, drug use, and access to firearms (1, 2).

Pediatric suicide is preventable. It is surmised that better understanding of its root causes and increased accessibility to avenues of interventions should decrease the incidence. To these ends, multiple perspectives are needed to disentangle the complexities of pediatric suicidal ideation and completed suicide. The forensic pathologist perspective focuses on the cause of death and has the unique advantage of surveying many cases over time. Such a perspective may highlight areas amenable to intervention. For instance, studies implicating firearms as the leading suicide modality led to efforts to limit firearms access. Furthermore, this perspective promotes awareness of common trends associated with suicide among the forensic community, physicians and the general public.

A previous retrospective analysis of pediatric suicide cases presenting for autopsy to the Medical University of South Carolina from January 1988 to January 1998 has been published (3). The study analyzed pediatric suicide with respect to demographics, location, mechanism of death, alcohol and drug use, medical history, and factors preceding the suicide such as documented suicidal ideation, previous attempts, and presence of a suicide note. Now, we extend that analysis by 17 more years, until December 2014, encompassing a total period of 27 years. We further compare the findings from the initial study of ten years with the findings from the subsequent 17 years. We also compare our results to national trends.

METHODS

This study is a case series of 78 individuals under the age of 18 years whose manner of death was determined to be suicide after a complete autopsy. All forensic pathology pediatric suicide autopsy cases referred to the Medical and Forensic Autopsy Section of the Department of Pathology and Laboratory Medicine at the Medical University of South Carolina by surrounding county coroner offices from January 1, 1988 to December 31, 2014 were reviewed.

Seventy-eight cases met age and manner of death criteria and were analyzed with respect to demographics, method of suicide, location of suicide, and documented psychiatric history. Thirty-one cases overlapped with the prior study of 1988-1998 (3); however, additional cases were located and included. Trends over time were assessed using all available data, from 1988-2014, and linear trend lines were generated using Microsoft Office Excel 2010 software by regression analysis: $y = mx + b$.

RESULTS

Thirty-eight (n=38) cases were identified from January 1, 1988 to January 1, 1998 and forty (n=40) cases were identified from January 1, 1998 to December 31, 2014. During 1988-1998, the average incidence was 3.8 pediatric suicide cases per year, while during 1998-2014 the average incidence was 2.4 cases per year. Overall average incidence during the 27-year period was 2.9 per year. The incidence of reported cases is demonstrated in **Figure 1**. Of note, 1993 demonstrated an unusual peak incidence of suicides. However, with this data point excluded, the trend continues to demonstrate a slight downward slope although the association is largely neutralized (current $R^2 = 5\%$ with 1993 ten cases of suicide; if 1993 = 0 suicides, $R^2 = 1\%$).

The majority of cases during both time periods were Caucasian males between 15 and 17 years of age. During the 1988-1998 period, 76% of suicide victims were of ages 15-17, 79% were male, and 71% were Caucasian. A relative decrease in this demographic group was noted in the 1998-2014 period: 65% were of ages 15-17, 70% were male and 62.5% were Caucasian. Therefore, over time, the proportion of children under 15 years of age and females increased. In the 1988-1998 period, 24% were under 15 and 21%

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were female. However, during 1998-2014, 35% were younger than 15 and 30% were female (**Table 1**).

Firearm use and hanging persisted over time as the most common causes of pediatric suicide, responsible for a combined 92% of the 78 total deaths (**Table 2**). However, a demonstrable shift away from firearm use and toward hanging was noted. While firearm use resulted in 84% of the deaths and hanging resulted in 7.9% during the 1988-1998 period, only 45% of deaths resulted from firearms during 1998-2014 and the percentage of hanging deaths increased to 47.5%. Thus, hanging replaced firearms as the most common cause of death in the last 17 years studied (**Table 2**).

The data suggest that gender and age influences the modality of suicide selected by the victim. In the 1988-1998 period, 90% of males and 62.5% of females committed suicide by firearm use. During the same period, 3.3% of males and 25% of females were hanging deaths. In the subsequent 17-year period, the trend reversed for females, with firearms causing 25% of deaths and hanging causing 67%. For males, firearm use decreased to 54% and hanging also increased to 39% (**Figure 2**). A similar trend was noted for the most vulnerable age group of 15-17 years: in the 1988-1998 period, 86% of this group committed suicide through firearm use and 3.4% through hanging; in the 1998-2014 period, firearm use declined to 46.2% and hanging increased to 42.3% (**Figure 3**).

DISCUSSION

Investigation of pediatric suicide requires evidence-based interprofessional cooperation. Prevention with appropriate evaluation and treatment of suicidal ideation is key to reducing deaths while identification of demographic trends and changes over time in methods of suicide can assist primary care and mental health professionals to better identify children at risk. In addition, a comparison of our findings with national data may provide insight into our select population and identify areas of preventative success while uncovering areas requiring increased surveillance.

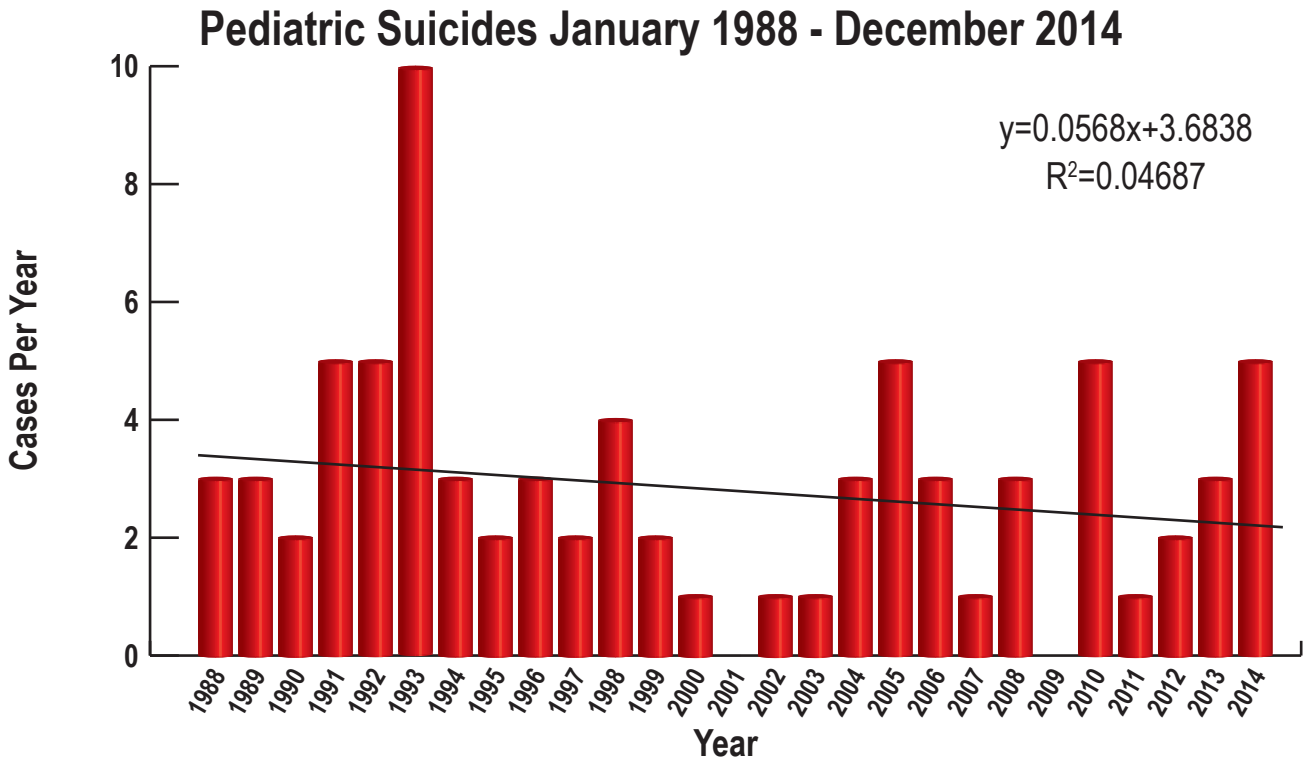

Figure 1: Decreasing trend of pediatric suicides.

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We limited our study population to individuals under 18 years of age to compare findings with a previously published study which analyzed suicide victims of the same age range (3). However, national and state statistics frequently group individuals between 10-14 and 14-19 years of age together. This and the relatively small size of the study, as well as the fact that not all suicide cases are referred for autopsy, are key limitations of our research. These limitations and the significant yearly fluctuations are highlighted by the weak R^2 values of the trend line.

Table 1: Pediatric Suicide Demographics

	Jan 1, 1988 – Jan 1, 1998		Jan 2, 1998 – Dec 31, 2014		Overall	
	Number of Cases	Percentage of Cases (%)	Number of Cases	Percentage of Cases (%)	Number of Cases	Percentage of Cases (%)
Total	38	100	40	100	78	100
Age						
≤11	0	0	2	5.0	2	2.6
12	2	5.3	1	2.5	3	3.8
13	3	7.9	5	12.5	8	10.3
14	4	10.5	6	15.0	10	12.8
Total Below 15	9	23.7	14	35.0	23	29.5
15	7	18.4	5	12.5	12	15.4
16	12	31.6	9	22.5	21	26.9
17	10	26.3	12	30.0	22	28.2
Total 15-17	29	76.3	26	65.0	55	70.5
Gender						
Male	30	78.9	28	70.0	58	74.4
Female	8	21.1	12	30.0	20	25.6
Race						
Caucasian	27	71.1	25	62.5	52	66.7
African American	10	26.3	10	25.0	20	25.6
Hispanic	0	0	4	10.0	4	5.1
Other	1	2.6	1	2.5	2	2.6

Table 2: Suicide Modalities

	Jan 1, 1988 – Jan 1, 1998		Jan 2, 1998 – Dec 31, 2014		Overall	
	Number of Cases (n = 38)	Percentage of Cases (%)	Number of Cases (n = 40)	Percentage of Cases (%)	Number of Cases (n = 78)	Percentage of Cases (%)
Firearm Use	32	84.2	18	45.0	50	64.0
Hanging	4	7.9	19	47.5	22	28.2
Drug Overdose	1	2.6	2	5.0	3	3.8
Thermal Injury	2	5.3	1	2.5	3	3.8

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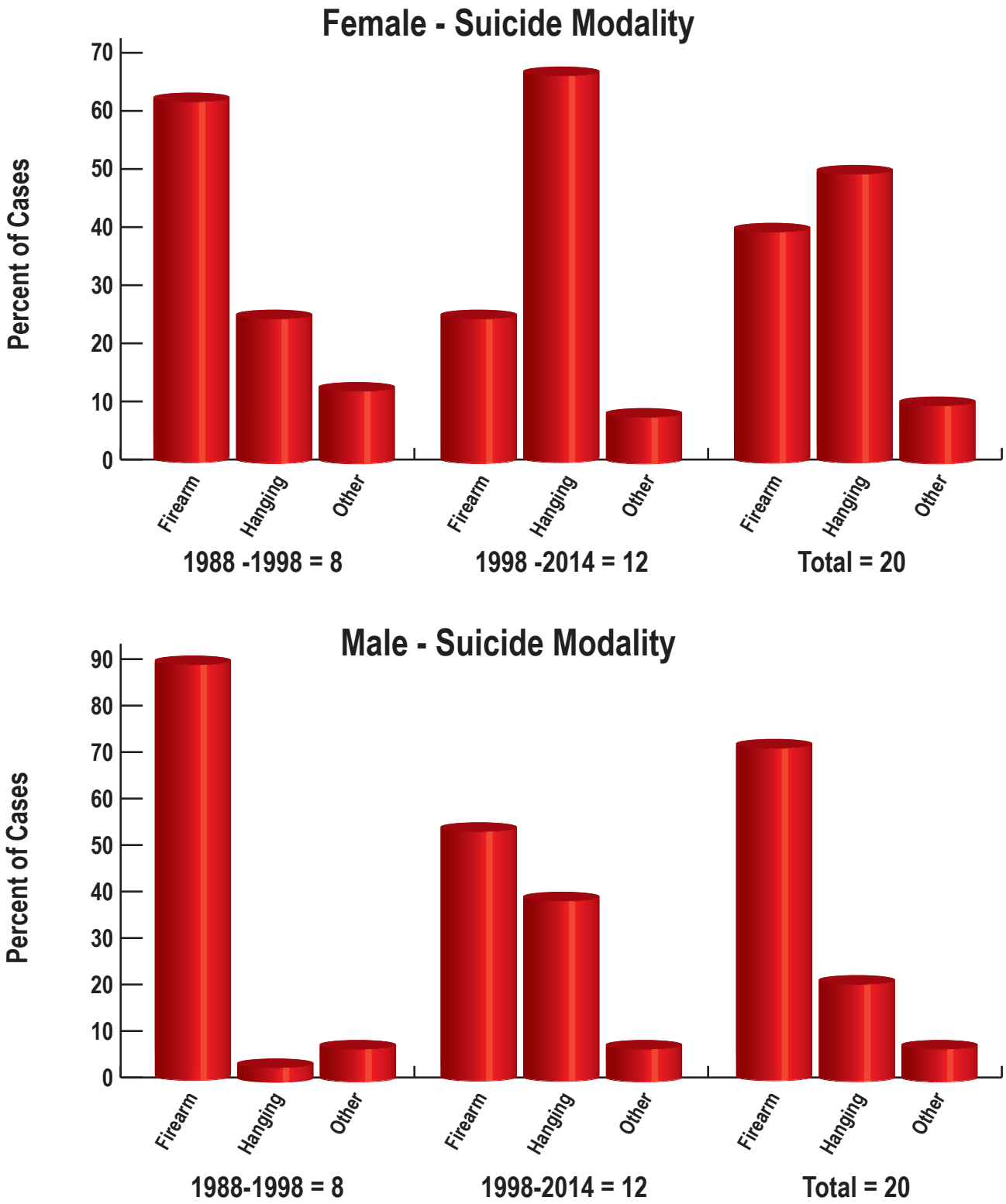

Figure 2: Impact of gender on mechanism of suicide.

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Shifting Demographics

Relative success in curbing suicide is apparent in national and state trend data and is somewhat recapitulated by our experience. According to the Centers for Disease Control and Prevention (CDC) Web-Based Injury Statistics Query and Reporting System (WISQARS), national suicide rates for youths aged 15-19 declined steadily from 8 per 100 000 in 1999 to 7.2 in 2008 and since 2010 have begun to increase (4, 5). In South Carolina, a similar pattern was noted where rates declined from 9.8 in 1998 to as low as 3.7 in 2007. Specific to South Carolina, a Suicide Prevention Task Force was organized by Department of Health and Environmental Control in 2003 to promote suicide awareness and develop support for suicide prevention (6). Although we cannot directly gauge the impact of this program, the small decline in overall suicide rate noted in our study could potentially, in part, have been affected by this program. This is especially true given that this program targeted males, and that we observed a decline in proportion of males.

The increase in proportion of suicides of those less than 15 years of age in our study is concerning and is consistent with nationwide statistics. For example, in 1999, the suicide rate nationally for 10- to 14-year-olds was 1.2 per 100 000. The rate has since fluctuated, but has been increasing since 2010, and in 2013 was 1.9 per 100 000 (4).

Also worrisome is an increased rate of suicide amongst females (7, 8). Suicide rates for all those aged 10-19 years of age was declining since the 1990s, but increased sharply between 2003 and 2005 (8). A Morbidity and Mortality Report by the CDC in 2007 attributed this increase in large part to a surge in female suicides, both in the 10-14 and 14-19 age groups (7). Nationally, for females aged 10-14, the rate increased steadily from 0.5 per 100 000 in 1999

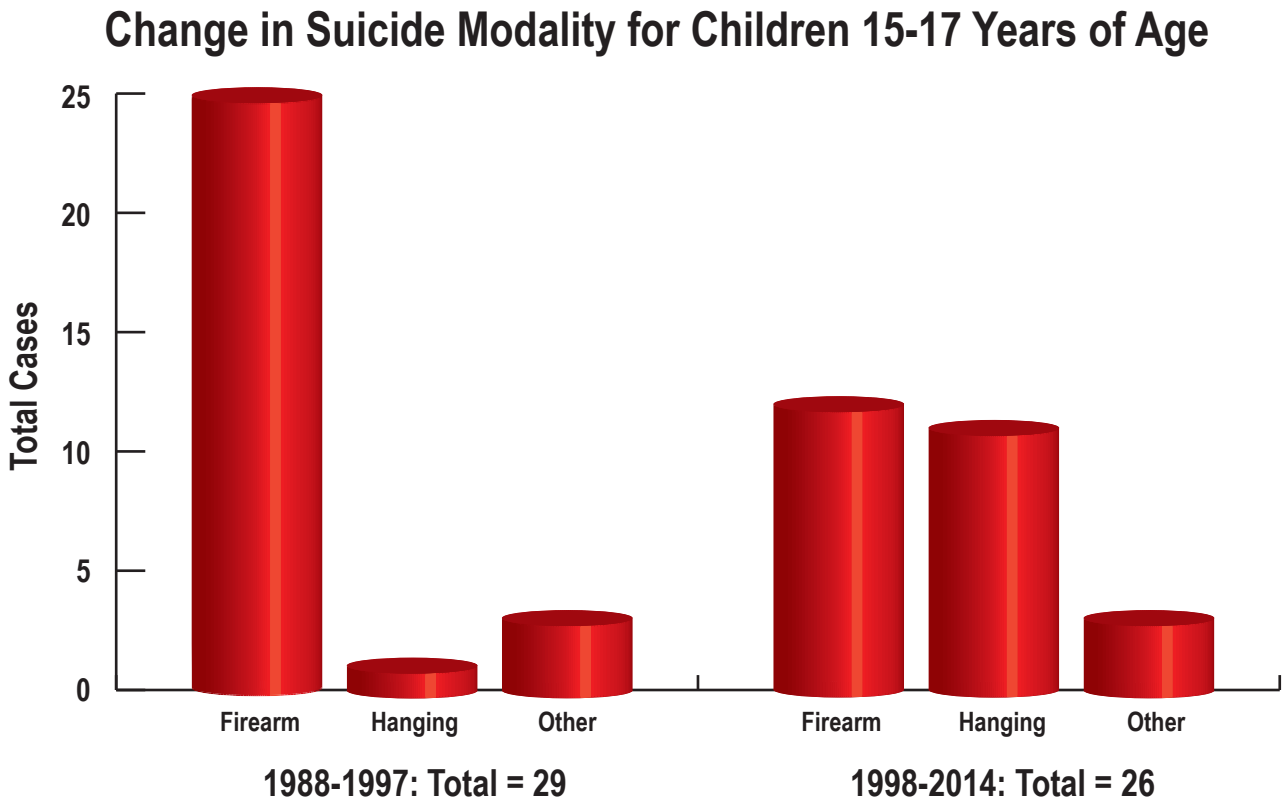

Figure 3: Change in mechanism of suicide for the most vulnerable age group.

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to 1.4 per 100 000 in 2013. Similarly, for females aged 14-19, the rate surged persistently from 2.75 to 3.86 per 100 000 from 1999 to 2013 (4). We weren't fully able to capture this national trend in our small study. However, we observed that females contributed to a larger proportion of total suicides over time.

Changes in Suicide Modality

A drift away from firearm use and toward hanging occurred in our population. This trend was also seen across South Carolina and the United States. South Carolina reported that for adolescents aged 10-19, the suicide rate by firearm use declined from 3.4 to 1.8 per 100 000 from 1999 to 2010, while the rate by suffocation (the CDC category that includes hanging) increased from 1.64 to 2.2 per 100 000 from 2004 to 2010 (data prior to 2004 not available). Of note, most forensic pathologists would consider hanging to be a form of asphyxia, but not a subset of suffocation. In our population, hanging was the only cause of death that fit into the CDC suffocation category. The CDC National Vital Statistics System mortality data for periods 1990-2004 and then 1994-2012 demonstrated a continuing increase in suicides by suffocation for youth aged 10-14, 14-19 and 19-24 (4, 5, 7). This pattern was particularly noteworthy for young females, and in 2003-2004, a disastrous year for pediatric suicide in our region, the rate of suffocation more than doubled for females aged 10-14 (5).

This shift is concerning but may simultaneously point to success in interventions targeting prevention of suicide in males as well as prevention of access to firearms by youth. No significant changes in the gun sales laws occurred during the study period in South Carolina. Purchase of firearms through private vendors remains essentially unregulated aside from permits granted through the South Carolina Law Enforcement Division for concealable weapons. Several states in the United States do not require a permit for carrying a concealed weapon. Under United States federal law, individuals cannot lawfully purchase handguns if they are under age 18. Interestingly, long gun possession has no age limitation by U.S. federal law. Regardless, parent and guardian supervision of weapons in the home remains paramount to limiting ready access. Theoretically, the relative ease of access to materials needed for hanging and instructions via the Internet may play a role in the trend away from firearm use.

Need for Interventions

Based on our findings and their congruence with national data, there are three key areas of pediatric suicide requiring attention: 1) burgeoning rates of suicides in adolescents younger than 15, 2) rising rates amongst females, and 3) the surging trend of hanging.

As depression plays a major role in pediatric suicide, these three areas cannot be addressed without improvement in recognition and treatment of depression. It is therefore not surprising that successful prevention programs have targeted increased awareness of depression. A notable example is the Garrett Lee Smith program, which trains teachers and physicians, among others, in recognizing warning signs of suicide ideation. It has resulted in significant reduction in suicide rates in individuals aged 10-18 years as well as those aged 19-24 years (9). Currently in draft form, The U.S. Preventive Services Task Force demonstrates grade B evidence (defined by as "*high certainty that the net benefit is moderate or there is moderate certainty that the net benefit is moderate to substantial*") for recommending that those from 12 to 18 years of age undergo "*screening for major depressive disorder (MDD) when adequate systems are in place for diagnosis, treatment, and monitoring*" during the course of each well child examination. However, they found insufficient evidence for a similar recommendation for those 11 years old and younger (10). Another study proposed increasing both access to mental health care and continuity of such care after a suicide attempt in an effort to enhance diagnosis and treatment of depression in youths (11). However, each suggestion requires significant community and healthcare infrastructure. Children should also be routinely informed about the dangers inherent in using choking in play. The "choking game" is not considered herein since the manner of death would not be classified as "Suicide," but rather "Accident" or "Undetermined."

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Challenges of New Technology

The ease of access to the Internet, especially since the advent of smart phones and tablets, has created newer challenges. A growing number of children and adolescents have digital devices at their fingertips at younger ages, including cell phones, tablets, and laptops. This allows unlimited access unless parental controls are in place. One consequence is ready availability of countless suicide methods. Another is cyberbullying, an intentional and repetitive form of virtual violence causing psychological distress in the victim. Studies analyzing the effects of cyberbullying have demonstrated an increase in depression, suicidal ideation, and suicide attempts in victims (12, 13). Cyberbullying is both more difficult to monitor and is able to reach more victims than its conventional counterpart. In our state, it is troubling that a search of "cyberbullying" at the South Carolina Department of Education website returns no matches. Children in this state are protected from "*harassment, intimidation, or bullying*" by the Safe School Climate Act, which was signed into law in 2006. The law does not specifically address cyberbullying nor does the amended 2012 version. Cyberbullying allows the perpetrator to hide behind a computer identity and such anonymity has led to unbridled misuse of these systems. In fact, blogs exist for the sole purpose of posting insulting commentary (14).

CONCLUSION

Trends are apparent in the pediatric suicide population served by the forensic pathologists at the Medical University of South Carolina. Between 1988 and 2015, there has been an increase in suicides amongst younger adolescents and females. Concurrently, there has been an increase in suicides by hanging. These changes over time are similar to those seen statewide and nationwide. However, our small population size and the large fluctuations from year to year make generalizations regarding the trends difficult. Interventions targeted at increasing timely recognition and treatment of depression and improvement in children's access to well child and mental health care facilities may further enhance pediatric suicide prevention.

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Additive Effects of Cointoxicants in Single-Opioid Induced Deaths

Marcella H. Sorg, D. Leann Long, Marie A. Abate, James A. Kaplan, James C. Kraner, Margaret S. Greenwald, Thomas A. Andrew, Steven L. Shapiro, Jamie A. Wren

ABSTRACT

A forensic drug database (FDD) was used to capture comprehensive data from all drug-related deaths in West Virginia, with deaths also included from the northern New England states of Maine, Vermont, and New Hampshire. All four states serve predominantly rural populations under two million and all have similar state medical examiner systems that employ statewide uniform death certification policies and practices. This study focused on 1482 single opioid deaths (fentanyl, hydrocodone, methadone, and oxycodone) in the FDD from 2007-2011. We modeled relationships between the opioid concentrations and the presence or absence of the following commonly occurring non-opioid cointoxicants: benzodiazepines (alprazolam and diazepam), alcohol, tricyclic antidepressants, selective serotonin reuptake inhibitors, and diphenhydramine. Additional covariates of state, age, body mass index, and sex were included. Results showed that the presence of alcohol, benzodiazepines, and antidepressants were each associated with statistically significant lower concentrations of some but not all of the opioids studied, which may obscure the interpretation of postmortem toxicology results alone. Fentanyl concentrations appeared to be the least associated with the presence or absence of the variables studied, and cointoxicant alcohol appeared to be associated with lower concentrations in opioid concentrations than were most of the other factors in the model studied. These findings underscore the importance of documenting all potential cointoxicants in opioid-related deaths. *Acad Forensic Pathol. 2016 6(3): 532-542*

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INTRODUCTION

Many accidental drug-related deaths involve opioid analgesics in combination with multiple cointoxicants. Despite the frequency of these polydrug deaths, there has been no significant large data research into the complex interrelationships among the cointoxicant drugs present (1, 2). The study of these interrelationships is further complicated by differences in how medical examiner systems of varying types and available resources identify and certify drug-related deaths (3). For example, in acute opioid fatalities with cointoxicant benzodiazepines or antidepressants, some medical examiners mention only the opioid on the death certificate (4). This limits the use of death certificate data alone to study population drug use and abuse-related behavioral changes. The National Association of Medical Examiners and American College of Medical Toxicology Expert Panel presented carefully reasoned guidelines that encourage the mention of all cointoxicants on death certificates for drug-related deaths (3). Yet, questions remain about the potential impact of the individual cointoxicant drugs in such deaths.

Cointoxicants often present with opioids in drug-related deaths include benzodiazepines, alcohol, and antidepressants (5-7). Diphenhydramine was also found to be a cointoxicant in almost 6% of West Virginia drug-induced deaths (8). It is well known that alcohol and drugs with central nervous system depressant effects can exert additive or synergistic toxic effects when used in conjunction with opioids (5). However, the relative contribution of these drugs as causes or contributors to death when present as cointoxicants in opioid-induced deaths has not been well characterized.

In addition to potentially differing effects of cointoxicants when combined with opioids, it is also possible that individual opioids might differ in their propensity to cause adverse effects, including death. A cohort analysis by Solomon et al. found that the risk of cardiovascular events, fracture, and overall mortality differed among opioids (9). Oxycodone users were found to have a stronger association with cardiovascular disease (CVD) related death than non-opioid users, and interestingly, female opioid users were found to have a significantly greater risk for CVD death compared to male opioid users, particularly in females with underlying CVD (10). A systematic review of the comparative safety and efficacy of extended-release opioids for managing cancer pain concluded that one cannot confirm or rule out differences among the opioids due to a paucity of data from well-designed studies (11). Thus, it is important to determine whether individual opioids might have varying potentials for causing harm, particularly when combined with alcohol or drugs with central nervous system or respiratory depressant effects.

The objective of this study was to determine and quantify, using linear regression models, the relationship between various cointoxicants and decedent characteristics such as age and sex on the opioid concentrations identified in single opioid-induced deaths.

METHODS

Study Population

Drug-related deaths from West Virginia and the northern New England states of Maine, Vermont, and New Hampshire were analyzed. A forensic drug database (FDD) was initially created in 2005 to compile data from all drug-related deaths in West Virginia (WV). Data from 2007-2011 from the northern New England states of Maine (ME), Vermont (VT), and New Hampshire (NH) were later added to the WV data.

Each case in the FDD includes demographic information about the decedent (age, sex, zip code location of death), condition of the body, body mass index (BMI), cause and manner of death, contributory factors to death, all drugs identified as a direct cause or contributor to the death, the known or suspected route of drug administration, whether the decedent had a prescription for any controlled substances identified (available during this study period only for WV from the Controlled Substance Automated Prescription Program [CSAPP] database), medical history (for most decedents), key autopsy findings, and toxicological analyses (for each drug implicated in the death).

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All four states in the study are served by centralized state medical examiner systems that perform comprehensive screening and quantification toxicology testing in all suspected drug deaths. All states maintain comprehensive digital and/or paper files, and each has statutes in place that require investigation and certification of all deaths suspected to be the result of, or that are associated with, drug intoxication. Although not an explicit policy during the study period, in all four states the usual practice of certification was to include potential cointoxicants on the death certificate.

Suspected drug deaths are investigated in a similar manner among the states, including examination of the body by a medical examiner or a certified death investigator who obtains peripheral blood samples and possibly additional body fluids for toxicological analysis. Data summarizing all medications belonging to the decedent, including unlabeled drugs, are submitted to the respective state's Office of the Chief Medical Examiner (OCME). During the study period, all deaths resulting from drug intoxication received an autopsy in WV; the majority of such cases were autopsied in the northern New England states.

All four states are largely rural, with large areas of low population density, and have populations that are under two million and are overwhelmingly white. During the study period, both Maine and West Virginia had functioning prescription drug monitoring programs.

Study Sample

All drug-related deaths in the FDD from 2007-2011, defined as those deaths for which the medical examiner determined that at least one drug was a direct cause of death or a contributor to death, and the manner of death was ruled accidental, were included. The specific FDD subpopulation used for this study included accidental deaths involving any one of four opioids (oxycodone, methadone, hydrocodone, or fentanyl), along with at least one or more of the following selected cointoxicants: alcohol, alprazolam, diazepam, tricyclic antidepressants (TCAs), selective serotonin reuptake inhibitor antidepressants (SSRIs), and diphenhydramine (DPH). Eliminating all cases in which the body was noticeably decomposed further restricted the study sample.

Single opioid deaths involving oxycodone, methadone, hydrocodone, and fentanyl were selected because these opioids occurred most frequently in drug-related deaths in all four states. Multiple opioid deaths were removed for this study to reduce the potential for confounding during the analyses of potential cointoxicant associations, although these types of deaths are frequent enough to warrant additional future research. Of unintentional, nondecomposed cases with at least one of the four opioids named above, there were 744 deaths with two opioids mentioned on the death certificate, 141 deaths with three opioids, and nine deaths with four or more opioids. The most common multiple-opioid combination causing death involved hydrocodone and oxycodone, with 132 cases.

Variation among states, and between northern New England (NNE) and West Virginia, were initially examined to determine whether data from all the states could be combined. Neither the states nor the regions differed significantly with regard to median age, sex, BMI, or the prevalence of deaths involving TCAs, SSRIs, or alcohol. Nor did states differ when selecting decedents for toxicology analyses; all suspected drug-induced deaths received full toxicology testing. Because of these similarities, samples were combined for the purpose of examining cointoxication patterns. Our regression models do, however, adjust for the region of data collection, since the overall prevalence of opioid deaths was substantially higher in West Virginia than in Northern New England.

Toxicological Analyses

All involved states routinely screen blood or urine samples from each case for a panel of abused drugs using enzyme immunoassay, with confirmation analyses conducted based upon the substance(s) identified. Toxicological analyses of different body fluids/tissues are used as appropriate to confirm drug involvement in the deaths. Important metabolites of drugs identified are also measured and reported to further clari-

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fy the roles of specific drugs in the deaths as well as chronicity of use. Opioids and cointoxicants were detected in blood or urine by gas chromatography mass spectrometry (GC/MS), liquid chromatography-tandem mass spectrometry (LC/MS/MS) or liquid chromatography time-of-flight mass spectrometry (LC/TOF-MS) screening. The analyses in this study were limited to subclavian or femoral blood samples, which are routinely used for toxicological analyses in each included state.

Statistical Analyses

Regression models were selected to examine the relationships between the opioid concentrations in the study cases and the following cointoxicants identified during toxicological analysis: benzodiazepines (specifically, alprazolam and diazepam, the most common benzodiazepine cointoxicants), alcohol, TCAs, SSRIs, and diphenhydramine. Additional covariates of state, age, BMI, and sex were included. Multiple regression is an extension of basic correlation to multiple dimensions and allows us to examine the associations after accounting for the other variables in the model. This method permits examination of multiple variables at once in order to explore relationships among them; it does not establish causation.

Due to the skewed nature of the opioid concentrations, log-opioid concentrations were modeled to satisfy the assumptions of linear regression. For each of the four opioids of interest, individual associations between log-opioid concentrations and each factor (sex, age, BMI, alprazolam presence, diazepam presence, alcohol level, TCA presence, SSRI presence, and diphenhydramine presence) were assessed using unadjusted linear regression. Additionally, a multiple linear regression was applied for each opioid to examine associations between each of these factors adjusting for the remaining factors. All regression models accounted for the state of data collection (NNE [ME, NH, VT] and WV).

Descriptive and empirical analyses were performed using SAS 9.3 (SAS Institute, Cary, NC). Findings were considered statistically significant for $p < 0.05$.

RESULTS

A total of 4702 drug-induced deaths were recorded in the FDD during the study period. The manner of death in most cases was certified as accidental (3884 cases) with the remainder undetermined (359 cases) or suicide (445 cases). Of the accidental drug-induced deaths, 1624 cases involved one or more pharmaceutical opioids specified on the death certificate as a cause or contributing factor in the death, along with at least one benzodiazepine (limited to diazepam or alprazolam), one antidepressant, alcohol, and/or diphenhydramine. As noted previously, we eliminated all cases observed to be decomposed. Of 1482 single opioid-cointoxicant deaths, 477 (32.2%) were from northern New England and 1005 (67.8%) were from West Virginia. The opioids present in this sample were: oxycodone (n=482), methadone (n=630), hydrocodone (n=183), and fentanyl (n=187). Cointoxicant alprazolam was present in 341 deaths, diazepam in 265 deaths, alcohol in 257 deaths, TCAs in 72 deaths, SSRIs in 104 deaths, and diphenhydramine in 71 deaths. Alcohol was further stratified according to whether the concentration was below or above the legal limit for driving intoxication of 0.08% utilized in the United States.

Table 1 summarizes the characteristics for each opioid subsample in the study. Although the NNE and WV regional populations differed significantly in terms of the prevalence of opioid, benzodiazepine, and alcohol involvement, they were not significantly different in median age, sex ratio, and median BMI, as well as involvement of TCAs, SSRIs, and diphenhydramine. Thus, regions were combined to build the cointoxication model described below.

For the regression models, some records with missing factors (e.g., BMI) were excluded, as well as a small number of extreme opioid concentration measures (i.e., fentanyl 9.4 μg/mL; hydrocodone 32 μg/mL, 49 μg/mL, 190 μg/mL, and 1000 μg/mL; oxycodone 17 μg/mL and 50 μg/mL) that might have reflected erroneous data entry. **Table 2** reports the estimated model effects of the factors analyzed upon log-opioid concentrations in log-μg/mL. The average differences

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from the adjusted models in **Table 2** are presented in **Table 3** using the more familiar µg/mL and showing the average magnitude and directionality of the association with opioid concentrations. Potentiation was not observed for benzodiazepine and alcohol alone for the concentrations of any of the four opioids studied, but the magnitude of the associations shown in the tables are additive. Somewhat unexpectedly, the patterns of significant association differed among the four opioids.

Utilizing the findings in both **Table 2** (significance of the association for the study factors, focusing on the values adjusted for all other factors) and **Table 3** (average model effect on opioid concentration in µg/mL), increasing age was the only non-drug factor significantly associated with decreased fentanyl concentrations (p=0.0218). The presence of a cointoxicant TCA was significantly related to lower fentanyl concentrations (p=0.0008) in the model, with an average 0.0075 µg/mL lower fentanyl concentration. None of

Table 1: Cointoxication Factors and Subsample Sizes By Key Opiates

	Fentanyl	Hydrocodone	Methadone	Oxycodone	*p*-value
Categorical Factors*	n (Column%)	n (Column %)	n (Column%)	n (Column %)	
Region					< 0.0001
Northern New England 3 270 572 (64%)	44 (23.5)	20 (10.9)	270 (42.9)	143 (29.7)	
West Virginia 1 852 994 (36%)	143 (76.5)	163 (89.1)	360 (57.1)	339 (70.3)	
Total 5 123 566 (100%)	187 (12.6)	183 (12.4)	630 (42.5)	482 (32.5)	
Male	120 (64.2)	115 (62.8)	440 (69.8)	329 (68.3)	0.2185
Alprazolam Present	24 (12.8)	72 (39.3)	90 (14.3)	155 (32.2)	< 0.0001
Diazepam Present	36 (19.3)	41 (22.4)	102 (16.2)	86 (17.8)	0.2598
Alcohol Concentration†					0.0010
Absent	156 (83.4)	142 (77.6)	547 (86.8)	380 (78.8)	
< 0.08%	14 (7.5)	5 (2.7)	19 (3.7)	26 (5.4)	
≥ 0.08%	17 (9.1)	36 (19.7)	64 (10.2)	76 (15.8)	
TCA Present	8 (4.3)	8 (4.4)	24 (3.8)	32 (6.6)	0.1692
SSRI Present	16 (8.6)	14 (7.7)	42 (6.7)	32 (6.6)	0.7975
Diphenhydramine Present	9 (4.8)	14 (7.7)	31 (4.9)	17 (3.5)	0.1724
Continuous Factors‡	Median (IQR)	Median (IQR)	Median (IQR)	Median (IQR)	
Age	40 (31, 48)	45 (36, 52)	36 (27, 46)	41 (33, 48)	<0.0001
BMI§	28.5 (24.8, 33.4)	29.2 (25.4, 36.1)	27.5 (23.7, 32.3)	28.0 (24.5, 33.4)	0.0072

* Pearson chi-square tests
† Mantel-Haenszel tests, incorporating the ordered nature of alcohol level categories
‡ Kruskal-Wallis nonparametric tests
§ Some decedents were missing a valid height or weight; BMI could be calculated for the following cases: fentanyl (N = 182), hydrocodone (N = 178), methadone (N = 614), oxycodone (N = 470)
TCA = tricyclic antidepressant, SSRI = selective serotonin receptor inhibitor, BMI = body mass index, IQR = interquartile range

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the other cointoxicants in our model had a significant association with fentanyl concentrations.

Decreasing hydrocodone concentrations were significantly (p=0.0489) associated with increasing age, as well as the presence of several cointoxicants. Alprazolam presence was significantly (p=0.0064) associated with an average reduction in hydrocodone concentration by 0.0215 µg/mL in this model. Alcohol presence at or above 0.08% was significantly (p=0.0033) associated with a lower concentration of hydrocodone averaging 0.1641 µg/mL; alcohol presence below the legal level was associated with lower hydrocodone levels averaging 0.1164 µg/mL. Diphenhydramine presence was significantly (p=0.0437) associated with a lower average hydrocodone concentration of 0.0276 µg/mL.

Table 2: Estimated Factor Effects (Unadjusted and Adjusted) on Log-Opioid Concentration (log-µg/mL)

	Fentanyl (n=181)		Hydrocodone (n=174)		Methadone (n=612)		Oxycodone (n=469)	
	Unadjusted*	Adjusted†	Unadjusted*	Adjusted†	Unadjusted*	Adjusted†	Unadjusted*	Adjusted†
Factor	Standard Error	Standard Error	Standard Error	Standard Error	Standard Error	Standard Error	Standard Error	Standard Error
Sex (Male)	**-0.349 (0.17) *p*=0.0450**	-0.220 (0.19)	0.013 (0.15)	0.130 (0.15)	**-0.258 (0.07) *p*<0.0001**	**-0.197 (0.07) *p*=0.0030**	0.010 (0.09)	-0.010 (0.09)
Age	0.014 (0.007)	**0.019 (0.01) *p*=0.0218**	0.011 (0.006)	**0.012 (0.1) *p*=0.0489**	**0.006 (0.003) *p*=0.0330**	**0.006 (0.002) *p*=0.0228**	-0.003 (0.004)	-0.003 (0.004)
BMI	-0.018 (0.01)	-0.016 (0.01)	0.002 (0.01)	0.004 (0.01)	-0.006 (0.004)	-0.006 (0.004)	-0.003 (0.005)	-0.002 (0.005)
Alprazolam	-0.106 (0.26)	-0.187 (0.26)	-0.200 (0.15)	**-0.460 (0.16) *p*=0.0064**	-0.046 (0.09)	-0.083 (0.09)	0.136 (0.09)	0.106 (0.10)
Diazepam	-0.232 (0.22)	-0.282 (0.22)	-0.132 (0.18)	-0.320 (0.19)	-0.117 (0.08)	-0.113 (0.08)	0.063 (0.11)	0.068 (0.12)
Alcohol	*p*=0.4056	*p*=0.3500	*p*=0.1031	***p*=0.0033**	***p*<0.0001**	***p*<0.0001**	***p*=0.0182**	***p*=0.0066**
<0.08% vs. Absent	-0.112 (0.32)	-0.109 (0.32)	-0.002 (0.44)	**0.004 (0.43)**	**-0.401 (0.17)**	**-0.376 (0.17)**	**-0.388 (0.19)**	**-0.485 (0.19)**
> 0.08% vs. Absent	-0.388 (0.29)	-0.469 (0.30)	-0.387 (0.18)	**-0.655 (0.19)**	**-0.619 (0.10)**	**-0.584 (0.10)**	**-0.247 (0.12)**	**-0.247 (0.12)**
TCA	**-1.137 (0.44) *p*=0.0099**	**-1.651 (0.48) *p*=0.0008**	-0.418 (0.35)	-0.339 (0.37)	-0.025 (0.16)	-0.141 (0.15)	**-0.526 (0.17) *p*=0.0017**	**-0.558 (0.17) *p*=0.0012**
SSRI	0.093 (0.30)	0.039 (0.30)	-0.120 (0.27)	-0.263 (0.28)	-0.051 (0.12)	0.004 (0.12)	-0.112 (0.17)	-0.069 (0.17)
DPH	0.266 (0.39)	0.048 (0.39)	**-0.556 (0.28) *p*=0.0473**	**-0.588 (0.29) *p*=0.0437**	0.074 (0.14)	-0.020 (0.14)	**-0.449 (0.23) *p*=0.0478**	-0.387 (0.23)

Concentration effects in bold are statistically significant

BMI = body mass index, TCA = tricyclic antidepressant, SSRI = selective serotonin receptor inhibitor, DPH = diphenhydramine

* Adjusted only for region of data collection

† Adjusted for sex, age, BMI, presence of alprazolam, presence of diazepam, alcohol level, presence of TCA, presence of an SSRI, presence of diphenhydramine and region of data collection

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Male sex was significantly (p=0.0030) associated with a 0.0531 µg/mL lower methadone concentration on average. Any alcohol presence was significantly (p<0.0001) associated with lower methadone concentrations, ranging from approximately 0.12 µg/mL 0.1641 µg/mL on average. Neither alprazolam nor diazepam presence had a significant model effect on the average methadone concentration, nor did age or BMI.

The average oxycodone concentration was significantly (p=0.0066) associated with a lower cointoxicant alcohol concentration, ranging from an average of 0.0846 µg/mL when alcohol was less than 0.08% and 0.0482 µg/mL when alcohol was ≥ 0.08%. TCA presence was significantly (p=0.0012) associated with an average 0.0974 µg/mL lower oxycodone concentration.

DISCUSSION

Forensic pathologists face a daunting task in certifying overdoses as a cause of death, particularly when addressing complications of preexisting comorbidities and development of tolerance. Although it has been general practice of giving greater consideration to the probability of drug-associated deaths when multiple, potentially synergistic drugs are present, no systematic inquiry into the magnitude of this phenomenon on a drug by drug basis has been previously reported using large numbers of data as compiled by this study.

When opioids are present with cointoxicants, particularly other central nervous system and respiratory depressant drugs or alcohol, toxicity can be enhanced (12, 13). As a result, the opioid concentration found in decedents might be anticipated to be lower than expected and often in a nontoxic range (13-16). Minett et al. studied the association between high and low concentrations of psychoactive cointoxicants present in morphine-related deaths but did not find a significant relationship between high and low concentrations of cointoxicant benzodiazepines and alcohol and morphine concentrations (1). Interestingly, they found a significant positive association between morphine and antidepressant concentrations, with higher morphine concentrations associated with higher antidepressant concentrations. This finding is contrary to what would be expected with a synergistic central nervous system effect. Based on animal studies, the authors speculated it might have resulted from a chronic antidepressant inhibitory action on opioid effects, per-

Table 3: Average Differences in Predicted Concentrations (µg/mL)

	Fentanyl	Hydrocodone	Methadone	Oxycodone
Male	-0.0009	0.0060	**-0.0531**	-0.0018
Alprazolam Present	-0.0008	**-0.0215**	-0.0225	0.0183
Diazepam Present	-0.0012	-0.0149	-0.0304	0.0117
Alcohol Concentration*				
< 0.08% vs. Absent	-0.0005	**0.0002**	**-0.1164**	**-0.0846**
≥ 0.08% vs. Absent	-0.0019	**-0.0276**	**-0.1641**	**-0.0482**
TCA Present	**-0.0075**	-0.0157	-0.0380	**-0.0974**
SSRI Present	0.0002	-0.0122	0.0011	-0.0120
Diphenhydramine Present	0.0002	-0.0276	-0.0053	-0.0672

Concentrations in bold are statistically significant
TCA = tricyclic antidepressants, SSRI = selective serotonin reuptake inhibitor antidepressants
* Statistical significance related to alcohol presence or absence; model analyses did not differentiate between lower and higher alcohol concentrations

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haps resulting from a decrease in opioid receptors in the cerebral cortex. However, the explanation for their finding is unknown and the study was limited by small numbers of cases.

Our study is unique in determining and quantitating the association of various cointoxicants and other decedent characteristics while adjusting for the presence of the other factors. Several interesting findings in our study merit discussion. First, significant associations were found between lower opioid concentrations and the presence of various cointoxicants, although considerable variability was found for fentanyl, hydrocodone, methadone, and oxycodone. Fentanyl and oxycodone concentrations were both found to be significantly lower with cointoxicant TCAs, but not the concentrations of the other two opioids. Methadone was the only opioid whose average concentration was significantly associated with the decedent's sex. Increasing age was significantly associated with increases, not decreases, in fentanyl, hydrocodone, and methadone concentrations, but not in oxycodone concentrations. Alprazolam presence was only associated with a significant lowering of the average hydrocodone concentration, while no significant association was found between diazepam and concentrations of any of the four opioids. The presence of alcohol was significantly associated with lower concentrations of hydrocodone, methadone, and oxycodone, but not fentanyl.

Second, only hydrocodone levels were significantly associated with the presence of diphenhydramine, with a lower level comparable to the alcohol and alprazolam association. However, small sample sizes for diphenhydramine in the other opioid subsets, particularly for oxycodone, might have resulted in insufficient power for detecting significant associations. The potential additive effects of diphenhydramine as a cointoxicant in opioid-related deaths should be further studied.

Third, fentanyl was found to be rather unique in this study. This powerful opioid appeared to have been influenced to a lesser extent by cointoxicants in the fatalities, except, somewhat surprisingly, when tricyclic antidepressants were present. However, there were only eight cases with fentanyl and a cointoxicant TCA. More research on fentanyl and its relationships to other cointoxicants is needed, but the possibility for interactions with TCAs points to the importance of listing all potentially interacting drugs on the death certificate.

Alcohol was significantly associated with lower opioid concentrations for hydrocodone, methadone, and oxycodone, regardless of whether the alcohol concentration was above or below 0.08%. The effect of alcohol in the model was relatively strong for methadone and oxycodone. Interestingly, the alcohol association with oxycodone concentrations was greater for concentrations < 0.08% compared to higher alcohol concentrations. Since a fairly small subset of oxycodone decedents had the lower alcohol concentrations, they might not have reflected that actual population. Previous studies have reported that alcohol concentrations significantly decreased as the number of cointoxicants increased (13), and the presence of alcohol has been associated with lower concentrations of opioids such as methadone and heroin compared to those opioids alone (13, 17, 18). Thus, the potential cointoxicant effect of alcohol when present in opioid-related deaths should not be underestimated.

However, it was somewhat surprising that the quantitative association of alcohol with methadone and oxycodone concentrations was substantially greater than the association of benzodiazepines with the concentrations of those opioids. Diazepam presence was not associated with statistically significant differences in any of the opioid concentrations in this study, and alprazolam presence was only associated with a lower hydrocodone concentration. This latter finding might be at least partly explained by the fact that about 62% of hydrocodone deaths involved a benzodiazepine, predominantly alprazolam, which was a higher percentage than for the other three opioids.

The associations of the various factors and cointoxicants with opioid concentrations were found to be additive in this study. As a result, even though some of the individual associations appear to be fairly small,

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their possible additive contributions in opioid-related deaths could be substantial. For example, a previous analysis of DPH deaths found that over half of the DPH-related fatalities involved four or more drugs, with antidepressants often found as cointoxicants (8). Thus, in a hydrocodone-related death with a concentration of 0.08 μg/mL found on toxicological analysis, if DPH, a TCA, and alprazolam were also found to be cointoxicants, the additive effects of those cointoxicants in our model (-0.028 + -0.016 + -0.022), respectively, on the hydrocodone concentration might be comparable to an actual hydrocodone concentration of 0.146 μg/mL, almost double the concentration actually found.

One limitation of the current study is that it did not examine the potential contribution of underlying comorbid diseases such as heart disease or respiratory conditions (e.g., sleep apnea) on the concentration relationships reported. Methadone fatalities were reported to be significantly more likely to have underlying systemic diseases, particularly heart disease, compared to heroin users (18), and sleep apnea might be a predisposing factor to opioid toxicity (6). In addition, although efforts were made to ensure that data entry from the medical examiners' files was accurate, this study was retrospective and errors in data extraction and entry are possible. Although this study included 1482 decedents, stratification by opioid and by cointoxicant substantially reduced the size of the subgroups, weakening the model. More research is needed to refine and test the associations found in our model. Large samples will be required to examine more complex polydrug cases, such as those involving more than one opioid with multiple cointoxicants.

CONCLUSION

The potential for additive effects of cointoxicant drugs and alcohol in opioid-related deaths should be considered when interpreting their roles in causing or contributing to those deaths. The presence of alcohol, benzodiazepines, and antidepressants was associated with significantly lower opioid concentrations, which may obscure the interpretation of postmortem toxicology results alone. The findings from the models used in this study can assist with such interpretations, especially in opioid deaths due to fentanyl, hydrocodone, methadone or oxycodone.

Opioids should not be treated as a homogenous group since specific opioids could vary in how they interact with cointoxicants. In particular, associations between fentanyl and TCAs and between hydrocodone and DPH require more research attention. This study underscores the importance of documenting all potential cointoxicants in single opioid-related deaths when entering cause of death on the death certificate. Future research efforts need to address the potential relationships among cointoxicants when multiple opioids are present.

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Amyloidosis and Unexpected Death: A Review of Seven Cases

Susan E. Presnell, Cynthia A. Schandl

ABSTRACT

Amyloidosis, deposition of improperly folded insoluble proteins, may affect one organ or may be systemic. Although plasma cell dyscrasia is frequently implicated in etiology and is due to immunoglobulin light chain production (AL amyloidosis), age-related amyloidosis is believed to be secondary to transthyretin production (ATTR), chronic inflammation-related amyloidosis is thought due to acute phase reactants (AA amyloidosis), and dozens of others are also described. Clinical presentation is dependent upon the organ(s) involved and those associated with unexpected death are expected to involve the cardiovascular system. All cases received for forensic postmortem examination at the Medical University of South Carolina from 2008 to May 15, 2015 were searched to identify any in which amyloidosis was listed as a final diagnosis. Seven cases were identified that met the criteria and were reviewed for demographic information, presentation, cause and manner of death, and assessment of pertinence of the diagnosis of amyloidosis to the cause and manner of death. Interestingly, gross examination of the heart was suggestive of amyloidosis or other infiltrative process in only two of the cases reviewed and a history of myeloma was only noted in one individual. Common gross and microscopic findings are described and relevant medical history and toxicology findings are compared. *Acad Forensic Pathol. 2016 6(3): 543-554*

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No identifiable personal data were presented in this manuscsript

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KEYWORDS

Forensic pathology, Amyloid, Amyloidosis, Fatal, Postmortem, Restrictive cardiomyopathy, Sudden death, Transthyretin

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INTRODUCTION

Amyloidosis results from the deposition of improperly folded insoluble proteins in the extracellular space. These insoluble proteins may interfere with the normal function of organs either due to physical disturbance of organ function or through direct toxicity of circulating proteins. The protein can be identified histologically because of its chemical nature (nonbranching fibrils arranged in a cross-β-pleated sheet) via Congo red staining and characteristic "apple-green" birefringence with polarized light. Formalin-fixed paraffin embedded sections stained with Congo red will also demonstrate positive red emissions filter fluorescence by ultraviolet light examination. In fact, the fluorescence assay provides higher sensitivity (1, 2). Electron microscopy demonstrates nonbranching 7.5 -10 nm diameter rigid fibrils (3).

Plasma cell dyscrasias with consequent immunoglobulin light chain accumulation are frequently implicated in the etiology of amyloidosis (AL amyloidosis). Other causes include age-related amyloidosis secondary to normal or abnormal transthyretin (ATTR) and chronic inflammation-related amyloidosis due to acute phase reactants (AA amyloidosis). In fact, dozens of precursor proteins are described (4). Direct toxicity is more common in AL amyloidosis (3), particularly lambda subtype, which is significantly more common than the kappa subtype. AA amyloidosis and ATTR amyloidosis may be more difficult to identify clinically due to lack of known concurrent disease process (e.g., plasma cell dyscrasia in AL amyloidosis). Since symptoms are not specific, a high index of suspicion is needed and appropriate biopsies of affected tissue pursued.

More than 100 transthyretin mutations have been identified and may be pathogenic, neutral, or even protective (5). However, age-related accumulation of wild type transthyretin appears to be more common than any inherited event (6). In the absence of an inexpensive panel assay or positive family history with a known variant, identification of specific defects via molecular analysis remains low yield. However, the African-American population, which is reportedly more vulnerable to amyloidosis after age 60, frequently demonstrates the V221I TTR mutation. In one autopsy series, more than 20% of African-Americans with cardiomyopathy due to amyloidosis demonstrated this mutation (7, 8). Variable penetrance of amyloidosis and significant differences in population prevalence of familial variants compounds the difficulty of the molecular approach to diagnosis.

Clinical presentation is dependent upon the organ(s) involved and may be localized or systemic. The kidneys are most commonly affected and renal failure may occur. Spleen and liver involvement may result in organomegaly. Cardiac amyloidosis is classically described as a restrictive process but may also affect the conduction system and precipitate arrhythmias. Rapezzi et al. described several physical diagnostic clues:

> *…carpal tunnel syndrome in ATTR (particularly if bilateral in a male), history of unexplained neuropathic pain, orthostatic hypotension, and a diagnosis of 'hypertrophic cardiomyopathy' after the sixth decade* (6).

At autopsy, if medical records are available, the presence of these findings may increase the pathologist's index suspicion for ATTR.

Amyloid fibril typing may be accomplished by mass spectrometry, which is commonly performed clinically on endocardial biopsies that have been shown to be Congo red-positive. However, the utility of subtyping amyloid in the postmortem setting is unclear unless a heritable form is identified. The costs of this reflex testing would be prohibitive for most forensic pathology offices.

The forensic autopsy database at the Medical University of South Carolina was searched for cases citing amyloid in the final diagnosis, and these cases were reviewed for demographic information, presentation, autopsy findings and cause and manner of death.

METHODS

The electronic database housing all forensic autopsies performed at the Medical University of South Caroli-

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na (MUSC) from 2008 to May 15, 2015 was searched using keywords including "amyloid" and "amyloidosis" within either the cause of death statement or the final diagnosis section. Seven cases out of a total of 5055 forensic autopsies were identified and reviewed.

RESULTS

Case 1: A 74-year-old black male presented to the hospital following a fall down three stairs. Multiple rib fractures, *Klebsiella oxytoca* urinary tract infection, elevated troponin I, decreased urinary output and an elevated creatinine of 2.3 mg/dL (which progressed to 4.4 mg/dL) were noted upon evaluation. Respiratory distress and arrest ensued and he died on hospital day three despite resuscitation attempts. Medical history was significant for congestive heart failure with an ejection fraction of 30%, mitral regurgitation, systemic and pulmonary hypertension, and chronic obstructive pulmonary disease.

Findings at autopsy included a calculated body mass index (BMI) of 26.8 kg/m^2, cardiomegaly (650 g) with chamber dilation and diffuse pale brown coloration, and increased ventricular wall thicknesses (left ventricle, 1.7 cm; right ventricle, 0.8 cm; and interventricular septum, 2.3 cm). No significant coronary artery atherosclerosis was present. The lungs weighed 660 g together and bilateral pleural effusions were noted. Microscopy demonstrated cardiac myocyte hypertrophy and patchy, amorphous pink material in the myocardial interstitium (**Image 1**). This material stained positively with Congo-red and was also present in the pulmonary arterial walls and interstitium, and focally

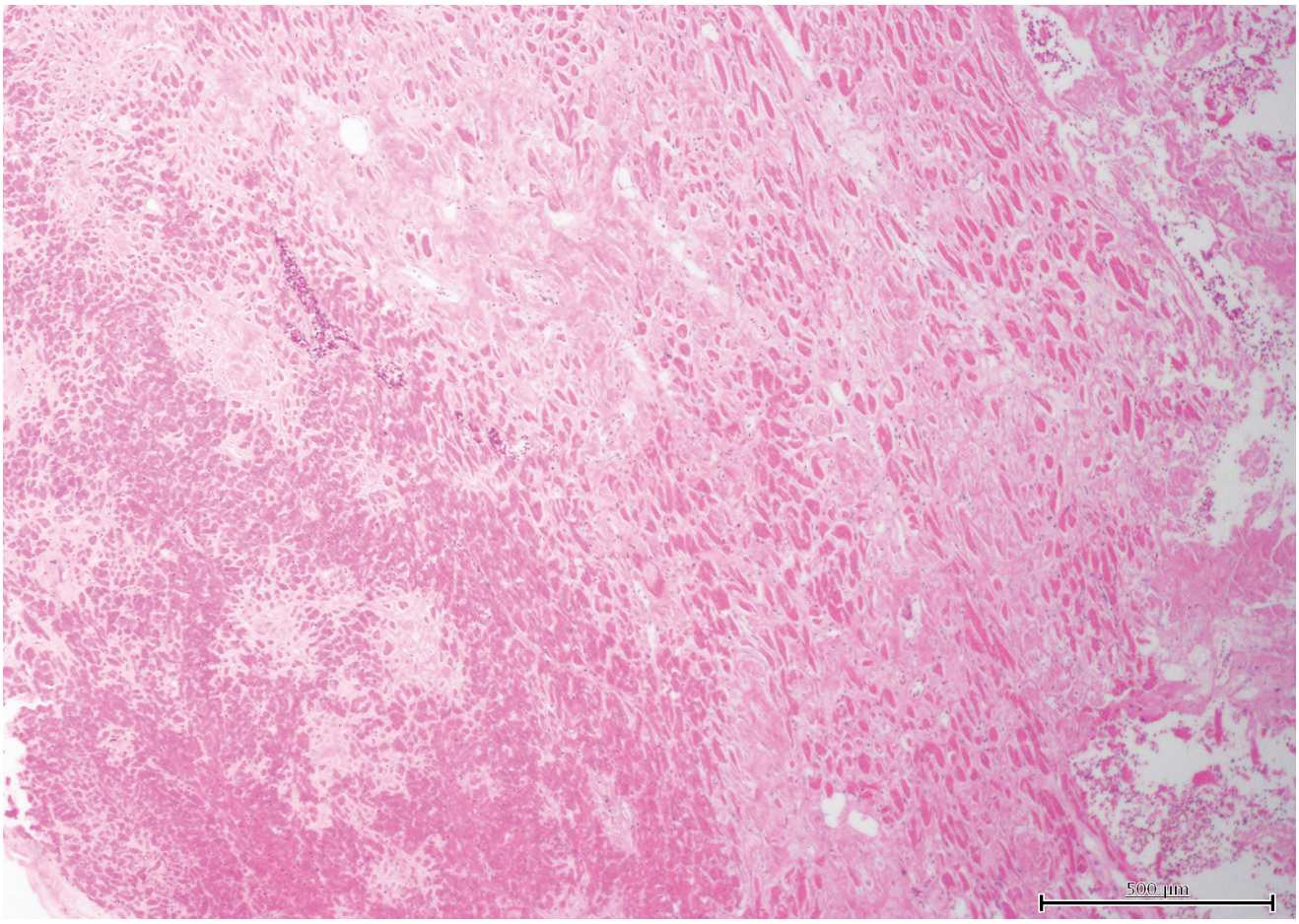

Image 1: Case 1, heart with patchy, interstitial amyloid pattern (H&E, x40).

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in the renal vasculature. Emphysematous changes of the lungs, focal bridging hepatic fibrosis, and chronic changes of the kidneys (interstitial fibrosis and tubular atrophy) were also described. Toxicology was not performed due to the extended hospitalization and lack of admission specimen. The cause of death was acute renal failure complicating cardiopulmonary amyloidosis. The fall down stairs with resultant rib fractures was considered contributory in this case, presumably due the musculoskeletal injury contributing to renal and pulmonary compromise. Therefore, the manner of death was best classified as accident.

Case 2: A 63-year-old white female presented to the hospital with loss of appetite and shortness of breath. Laboratory data demonstrated acidosis, acute renal failure with a serum creatinine of 16.2 mg/dL, urea nitrogen of 142 mg/dL, and anemia for which a red blood cell transfusion was provided. She died within 24 hours of hospitalization.

Findings at autopsy included a BMI of 30.2 kg/m^2, cardiomegaly (560 g) with normal appearing parenchyma on sectioning, fibrinous exudate on the pericardial and epicardial surfaces, no significant coronary artery atherosclerosis, and combined lung weight of 1540 g. The ventricular wall thicknesses were increased (left ventricle, 1.7 cm; right ventricle, 0.6 cm; and interventricular septum, 2.0 cm). Additional findings included pleural and peritoneal effusions, cholelithiasis, and colonic diverticula. Histologically, numerous organs sampled, including kidney, heart, liver, thyroid, and lung, demonstrated pink globular material in the blood vessel walls and interstitium. No Congo red stain was performed. Toxicology was not performed due to the length of hospitalization and lack of admission blood sample. The cause of death was acute renal failure due to systemic amyloidosis and the manner was natural.

Case 3: A 64-year-old black male was found dead on the floor of his residence bathroom. Medical history included hypertension, gout and back pain. Autopsy showed a BMI of 28.3 kg/m^2, cardiomegaly (640 g) with a normal heart appearance (no wall measurements documented), no significant coronary artery atherosclerosis, edematous and emphysematous lungs with a combined weight of 1490 g, and, cystic "end-stage" kidneys. Small pleural and pericardial effusions were present. Histologically, serofibrinous acute pericarditis, peripheral pulmonary thromboemboli, and cardiac myocyte hypertrophy and interstitial fibrosis were identified (**Image 2A**). A Congo red stain demonstrated amyloid deposition in lung vessels, myocardium (**Image 2B**), and renal glomeruli and arterioles. Vitreous creatinine was 11.4 mg/dL. Toxicological analysis of peripheral blood demonstrated presence of delta-9 tetrahydrocannabinol, caffeine, theobromine, and cyclobenzaprine. The cause of death was complications of systemic amyloidosis and hypertensive cardiovascular disease was contributory; the manner was natural.

Case 4: A 72-year-old white female presented with severe fatigue, sweats, body aches, and light-headedness. Upon hospitalization, an abnormal electrocardiogram was noted and troponin was elevated at 0.38 ng/mL. B-type natriuretic protein concentration was 955 pg/mL and the serum creatinine was 1.0 mg/dL. Medical history was significant for hypertension, hypothyroidism, new onset atrial fibrillation, recent rotator cuff surgery, and remote multiple myeloma. She died within 24 hours of admission.

Gross findings at autopsy included a BMI of 18.9 kg/m^2, heart weight of 300 g with a normal appearance of the parenchyma, and no significant atherosclerotic coronary artery disease. The combined lung weight was 1430 g. Pleural and peritoneal effusions, pulmonary edema, and severe spinal scoliosis were present. Histologically, amyloidosis confirmed by Congo red stains was in all organs examined, including heart, kidneys (**Image 3**), lungs (**Images 4A and 4B**), and spleen. The heart also showed myocytolysis and focal granulation tissue formation. Toxicological analysis of blood revealed the presence of acetaminophen, atenolol, and caffeine. The cause of death was acute myocardial ischemia due to systemic amyloidosis due to multiple myeloma and the manner was natural.

Case 5: A 67-year-old black male was found in an early state of decomposition in his residence yard.

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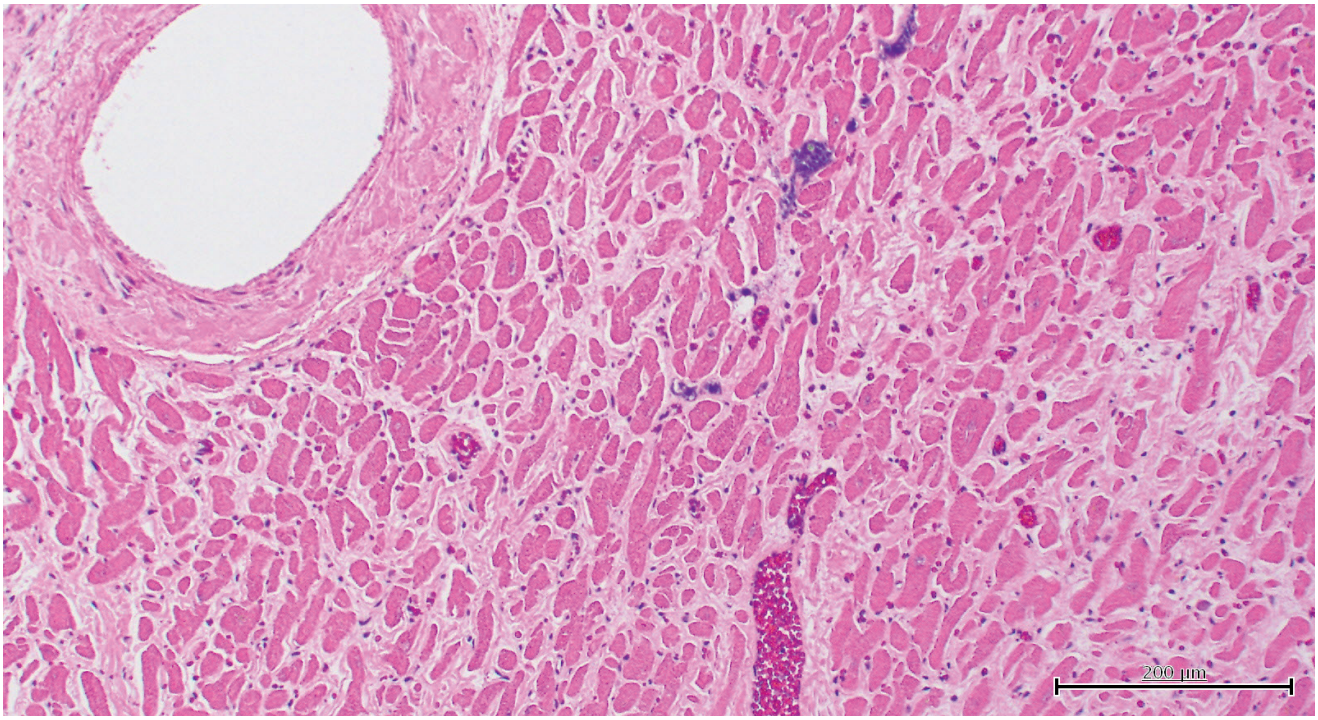

Image 2: A) Case 3, heart with interstitial amyloid pattern (H&E, x100).

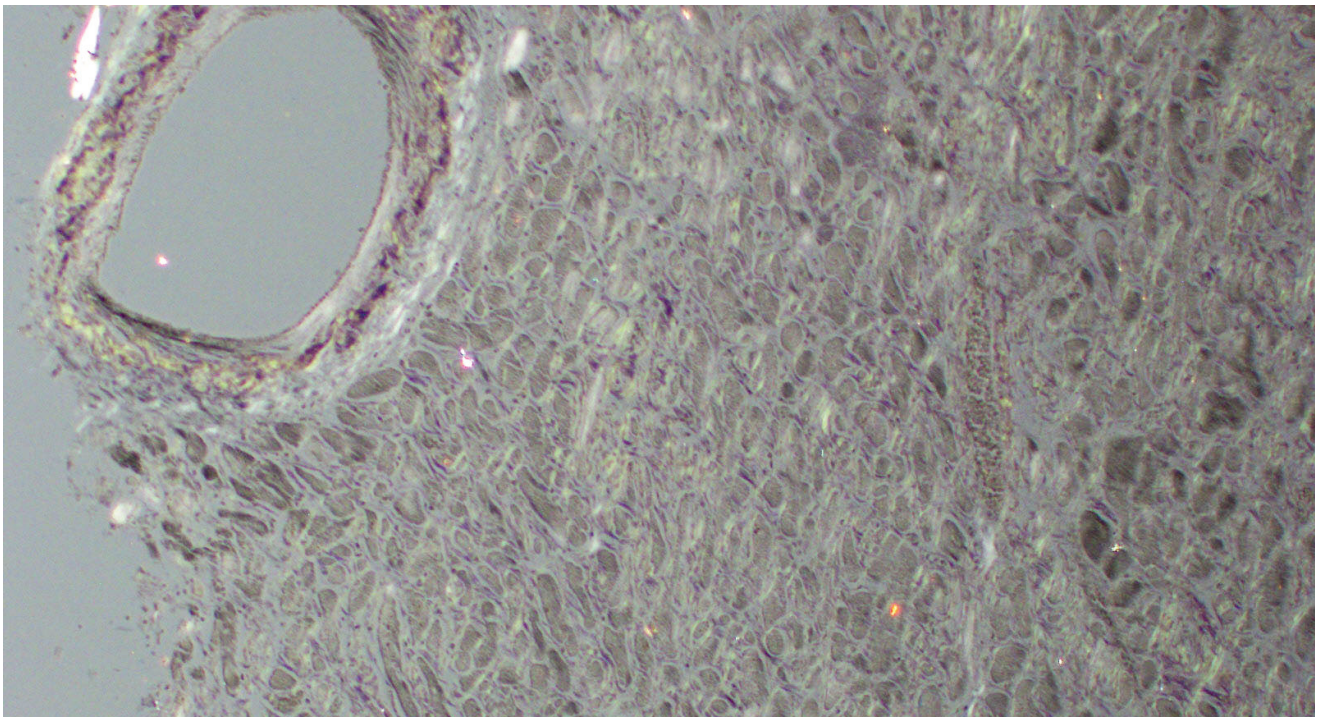

Image 2: B) Case 3, heart under polarized light (Congo red, x100).

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Medical history was significant for dyspnea upon exertion, hyperlipidemia, and hypertension, and a continuous positive airway pressure machine or CPAP was at the scene. Gross findings at autopsy included a BMI of 29.6 kg/m^2, cardiomegaly (810 g), dark red brown and markedly firm and rubbery heart parenchyma, thickened heart wall thicknesses (left ventricle, 1.9 cm; right ventricle, 0.5 cm; and interventricular septum, 1.8 cm), no significant coronary artery atherosclerosis, and a combined lung weight of 1450 g. Bilateral pleural and pericardial effusions recorded. Histology demonstrated amorphous pink substance in the cardiac interstitium (**Image 5A**), Congo red stain highlighted the heart vessel walls and interstitium as did rhodamine fluorescence (**Image 5B**). No toxicology was performed. The cause of death was cardiomegaly due to amyloidosis and hypertensive cardiovascular disease was contributory. The manner was natural.

Case 6: A 70-year-old black male with was found dead in a bathtub without immersion of his face. Medical history included hypertension, diabetes mellitus, and congestive heart failure as well as cocaine use. At autopsy, the BMI was 21.7 kg/m^2 and the heart weighed 450 g and appeared normal on sectioning. Coronary artery atherosclerosis impeded the left anterior descending coronary artery lumen by 20% and

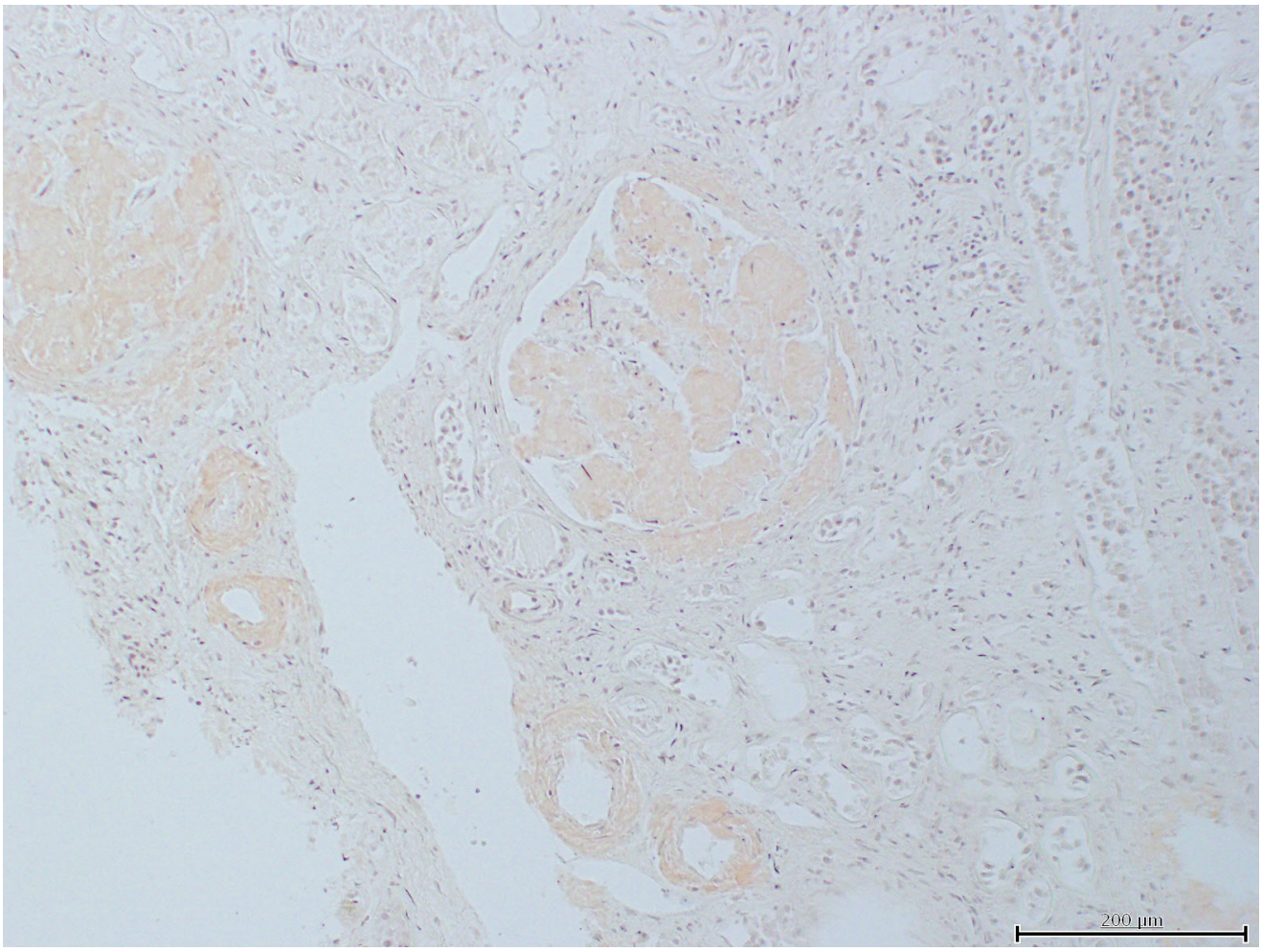

Image 3: Case 4, renal amyloidosis with vascular and glomerular involvement (Congo red, x100).

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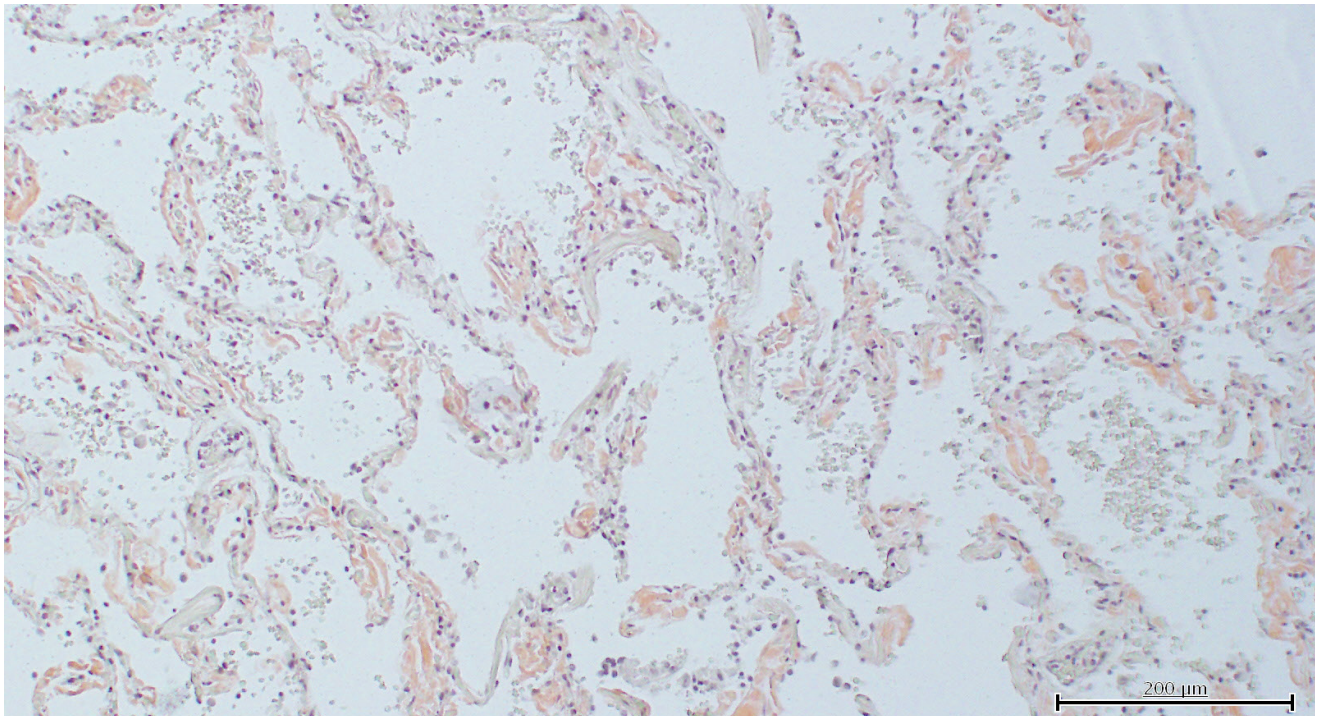

Image 4: A) Case 4, lung with alveolar wall involvement (Congo red, x100).

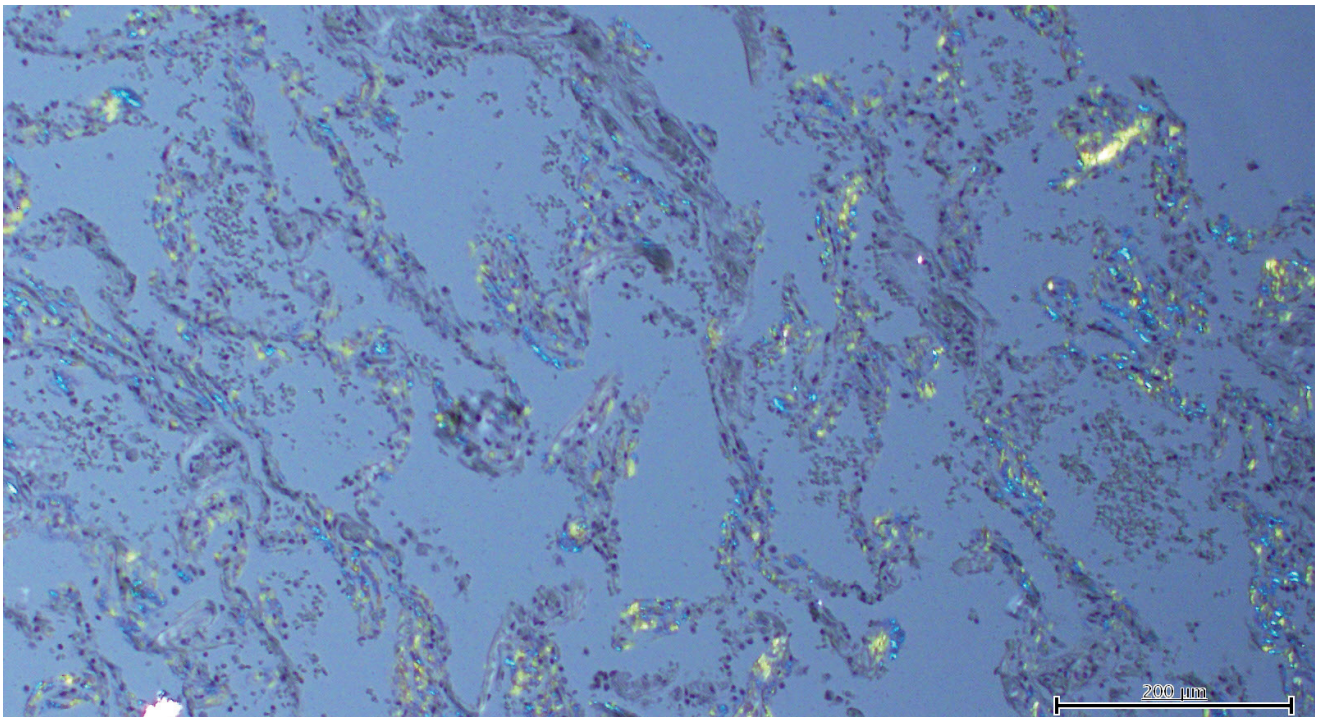

Image 4: B) Case 4, lung under polarized light (Congo red, x100).

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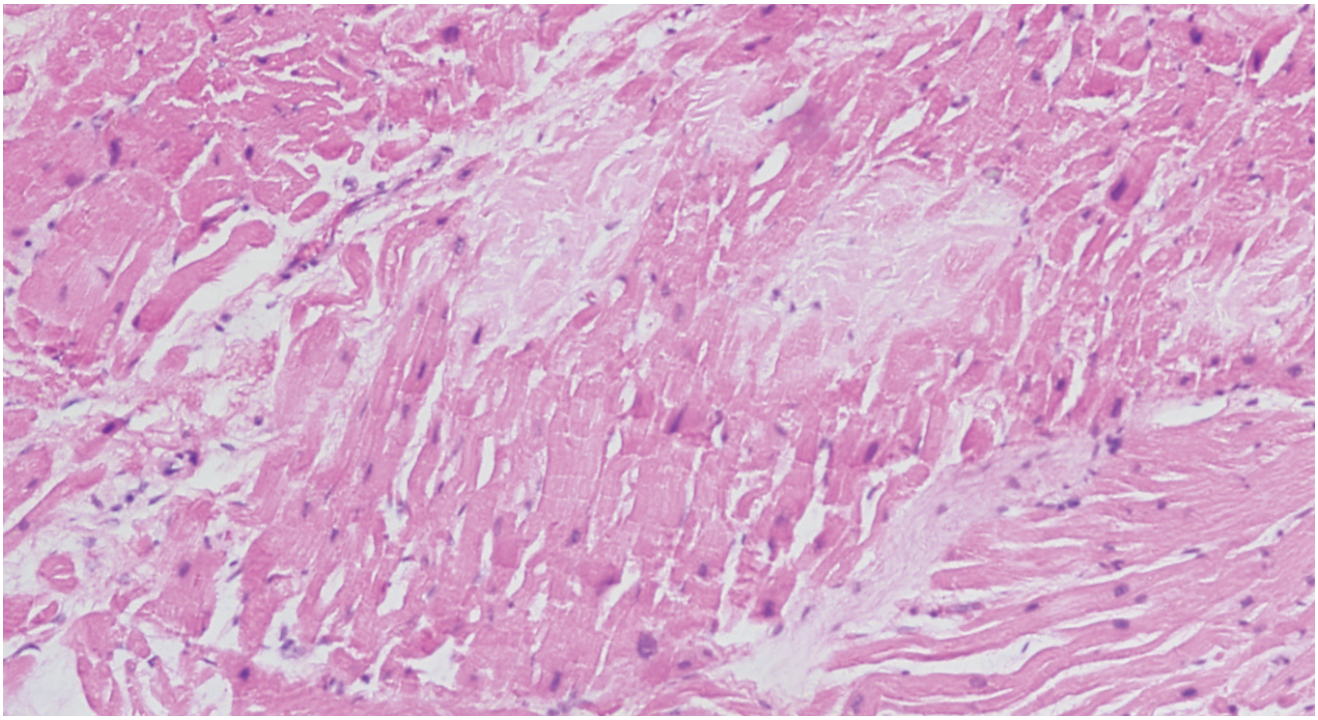

Image 5: A) Case 5, heart with patchy interstitial amyloid pattern (H&E, x100).

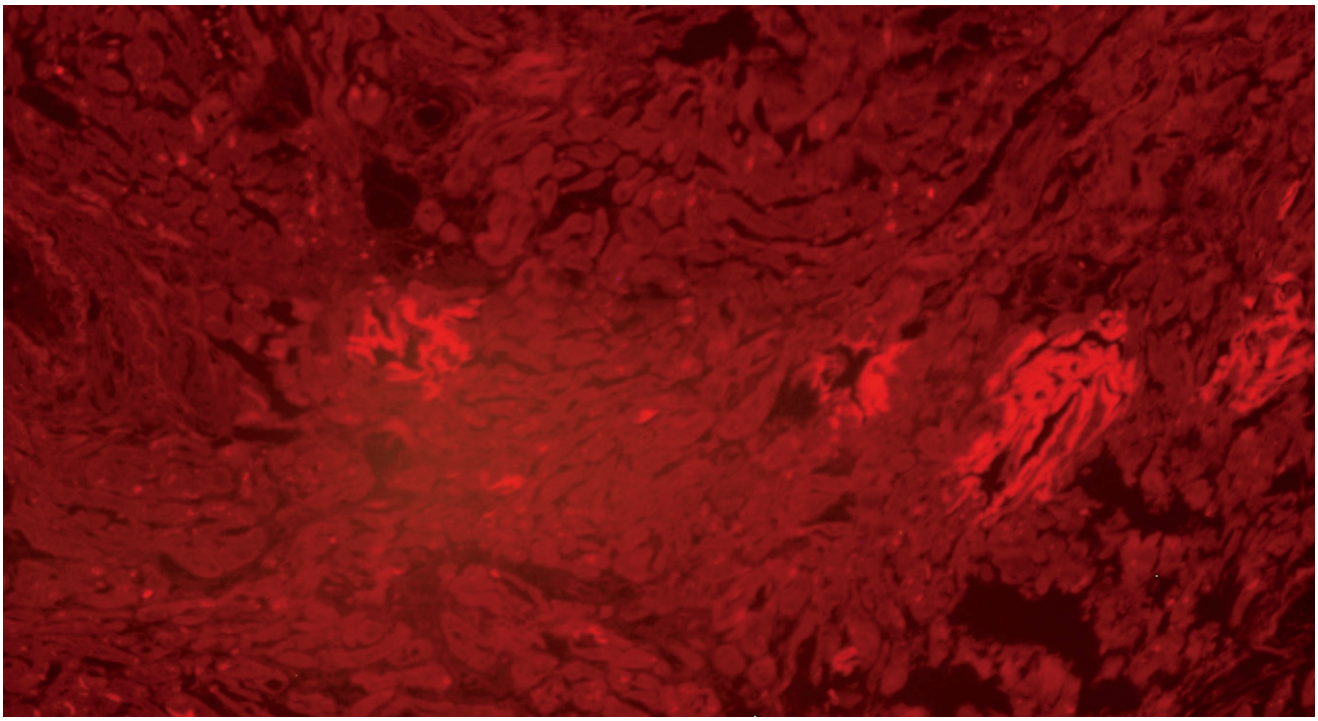

Image 5: B) Case 5, heart under rhodamine fluorescence (Congo red, x100).

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the right coronary artery lumen by 60%; no heart wall measurements were documented. The combined lung weight was 1260 g and bilateral pleural and peritoneal effusions were noted. Histology of the heart demonstrated perivascular and interstitial fibrosis and granulation tissue as well as patches of pale pink fibers with amorphous pink material in vessel walls that was Congo red-positive (**Image 6A and 6B**). Renal glomeruli and vessel walls were also Congo red-positive. Vitreous creatinine was 0.7 mg/dL. Toxicological analysis of peripheral blood was positive for cocaine at 29 ng/mL, benzoylecgonine, levamisole, and trazodone at 0.63 µg/mL. The cause of death was acute cocaine toxicity and the manner was accident. Amyloidosis was considered an incidental finding in this case, and not contributory to the cause of death.

Case 7: An 81-year-old white male was found dead after a nine foot fall off of a residence balcony. Medical history was significant for hyperlipidemia. Autopsy demonstrated a BMI of 25.8 kg/m^2, blunt head trauma with subdural and subarachnoid hemorrhages, cerebral contusions and skull fracture, 300 mL hemopericardium, a superficial myocardial laceration, and sternal and rib fractures. The heart was 430 g and had a normal appearance. Mild coronary artery atherosclerosis and a 2380 g combined lung weight were recorded. Histology showed cardiac myocytolysis and multifocal areas of Congo red positivity in the myocardium surrounding myocytes. Vitreous creatinine was 0.4 mg/dL. Toxicology was positive for caffeine. The cause of death was blunt force trauma to the head due to a fall from height. The manner of death was accident. After review of the scene and circumstances surrounding the death, cardiac amyloidosis was considered contributory in that it presumably precipitated an arrhythmia resulting in the fall. No other pathology, intoxication, psychiatric disorder, or alternative explanation accounted for the decedent's fall from the balcony.

The details for the seven cases regarding presentation, medical history, autopsy findings, and cause and manner of death are summarized in **Table 1**.

DISCUSSION

During a 7.4-year period, only seven cases of amyloidosis were identified in our forensic autopsy population (0.1% of cases). Of these, amyloid was the cause of death or contributory to cause of death in 86% of cases (six of seven) and all demonstrated cardiac involvement. Not surprisingly, the manner of death was classified as natural in the majority of cases. However in the remaining 43% (three of seven), the manner of death was classified as accident. Two accidental deaths were at least partially attributable to blunt trauma sustained in falls and the third accidental death was due to cocaine toxicity with amyloidosis an incidental and noncontributory finding.

The majority (five of seven) of the deaths presented with apparent collapse or a fall with trauma. Sudden collapse is consistent with acute cardiac compromise that may be attributable to cardiac amyloidosis in these cases. Of the two cases presenting with a fall, one resulted in trauma that was nonfatal but considered contributory to the cause of death, and one resulted in fatal trauma that was thought to have been precipitated by a cardiac event secondary to amyloidosis. Cardiac amyloidosis precipitating an arrhythmic event clarified the context of the fall, as other circumstances did not adequately explain such (i.e., case 7).

All decedents were more than 60 years of age. The average age was 71 years with a range from 63 to 81 years. There was a slight African-American predominance (57%) and a male predominance (71%). None of the individuals had a medical history of amyloidosis and only one had a history of multiple myeloma. Only two decedents showed systemic symptoms such that medical attention was sought immediately prior to death. Creatinine levels showed renal dysfunction in three of the six for whom this datum was available.

The average heart weight was 548 g and the range was from 300 to 810 g. Surprisingly, the cardiac parenchyma appeared grossly normal in 71% of cases. No significant atherosclerotic disease was noted in the coronary circulation of any. However, histopathologically, all cases demonstrated involvement of the heart

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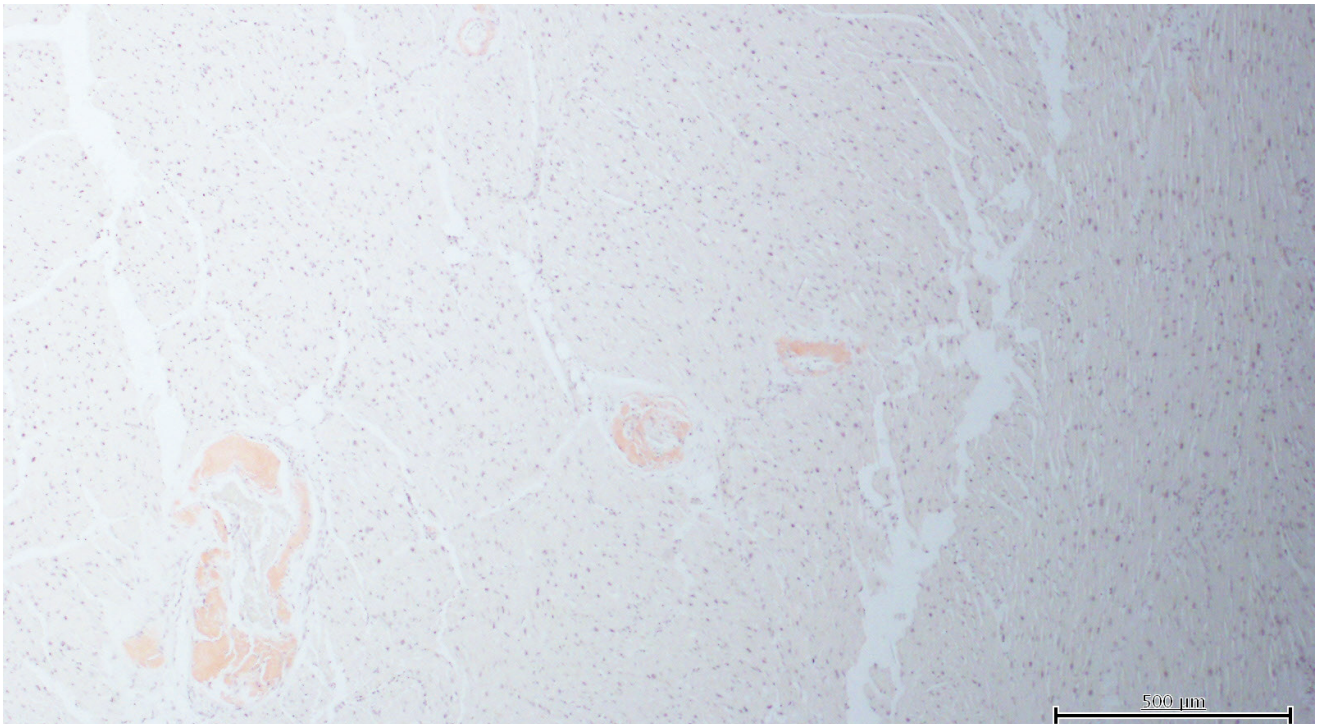

Image 6: A) Case 6, cardiac amyloidosis with vascular pattern (Congo red, x40).

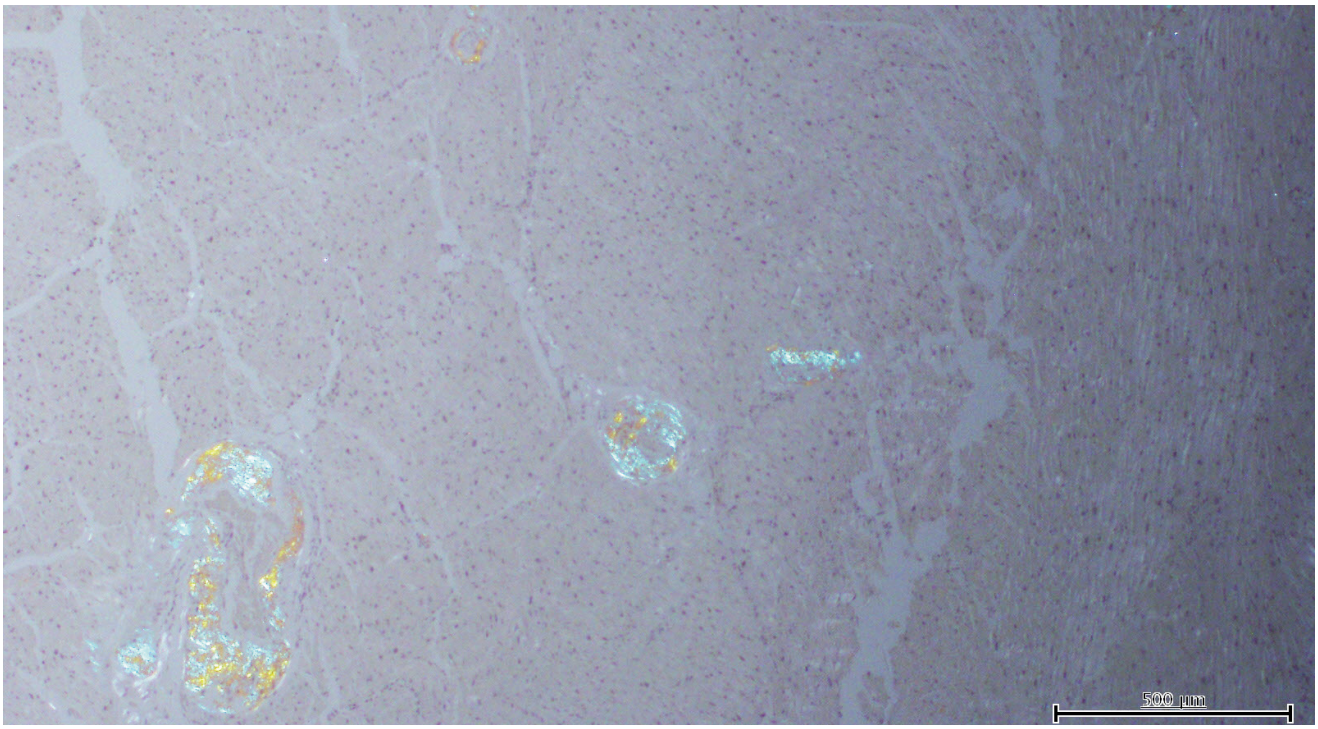

Image 6: B) Case 6, heart under polarized light (Congo red, x40).

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Table 1: Details For the Seven Cases

Case	Presentation	Medical History	Cardiac Weight (g), Description	Amyloid	Other findings	Cause of Death	Contributory to Cause of Death	Manner of Death
1	Hospitalized for fall down stairs; elevated troponin; increasing creatinine	Congestive heart failure, ejection fraction=30%, mitral regurgitation, chronic obstructive pulmonary disease, hypertension	650 Dilated, pale	Heart Lung Kidney	Pleural effusions Emphysema Hepatic fibrosis Toxicology not done	Acute renal failure complicating cardio-pulmonary amyloi-dosis	Fall down stairs with rib fractures	Accident
2	Hospitalized with loss of appetite, dyspnea, acidosis and renal failure	None	560 Fibrinous pericarditis	Heart Lung Kidney	Pleural effusions Peritoneal effusion Toxicology not done	Acute renal failure due to systemic amyloi-dosis	None	Natural
3	Found dead at home	Hypertension, gout, back pain	640 Fibrinous pericarditis	Heart Lung Kidney Spleen	Pleural effusions Pericardial effusion Cystic kidneys Emphysema Peripheral pulmonary thromboembolism Toxicology: tetrahydrocan-nibinol, cyclobenzaprine, caffeine, theobromine	Complications of sys-temic amyloidosis	Hypertensive cardio-vascular disease	Natural
4	Hospitalized for fatigue, elevated troponin and B-type natriuretic peptide	Hypertension, hypo-thyroidism, new onset atrial fibrillation, remote history of myeloma	300 Normal	Heart Lung Kidney Spleen	Pleural effusions Peritoneal effusion Pulmonary edema Nephrosclerosis Toxicology: caffeine, acet-aminophen, atenolol	Acute myocardial infarct due to systemic amyloidosis due to multiple myeloma	None	Natural
5	Found dead in yard with mild decompo-sition	Dyspnea on exertion, hyperlipidemia, hyper-tension, sleep apnea	810 Firm and rubbery	Heart Lung Kidney	Pleural effusions Pericardial effusion Toxicology not done	Cardiomegaly due to amyloidosis	Hypertensive cardio-vascular disease	Natural
6	Found dead at home	Hypertension, con-gestive heart failure, diabetes, cocaine +	430 Normal	Heart Lung	Pleural effusions Pericardial effusion Peritoneal effusion, mild coronary artery disease Toxicology: cocaine, ben-zoylecgonine, levamisole, trazodone	Cocaine toxicity	None	Accident
7	Fell from 9' balcony	Hyperlipidemia	430 Normal	Heart Lung Kidney	Hemopericardium Blunt head and chest trauma, Mild coronary artery disease Toxicology: caffeine	Blunt head trauma due to fall from height	Cardiac amyloidosis	Accident

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by amyloidosis. The pattern was variable with interstitial, patchy, and vascular deposition patterns noted. All patients showed multiple organ amyloid deposition including lung, kidney, and spleen when these organs were sampled.

Limitations of this series include the small number of cases, lack of toxicological analyses in three of seven cases, and the inability to distinguish a purported cardiac arrhythmia as hypertensive in nature or due to cardiac amyloidosis.

CONCLUSION

Amyloidosis is a rare cause of sudden unexpected death. Cardiac involvement classically results in a restrictive cardiomyopathy, but patients may also present with a hypertensive, ischemic appearance, or arrhythmia. Renal dysfunction is common. Since the organs may look grossly normal, microscopic sections and special stains may be justified, even in traumatic cases, to fully elucidate the circumstances surrounding the death. Despite the rarity of amyloid in the forensic setting, proper death certification is essential for epidemiological purposes. Additionally, diagnosis may have genetic implications for the family. The authors hope this short series increases the awareness of amyloidosis as a cause or contributory cause of death in a subset of the forensic population.

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