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

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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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Roles: Project conception and/or design, manuscript creation and/or revision, approved final version for publication, accountable for all aspects of the work

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ETHICAL APPROVAL

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

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The author, reviewers, editors, and publication staff do not report any relevant conflicts of interest

FINANCIAL DISCLOSURE

The author has indicated that she does not have financial relationships to disclose that are relevant to this manuscript

KEYWORDS

Forensic pathology, Forensic anthropology, Nonaccidental injury, Pediatric death

INFORMATION

ACADEMIC FORENSIC PATHOLOGY: THE OFFICIAL PUBLICATION OF THE NATIONAL ASSOCIATION OF MEDICAL EXAMINERS

©2017 Academic Forensic Pathology International • (ISSN: 1925-3621) • <https://doi.org/10.23907/2016.048>

Submitted for consideration on 21 Jun 2016. Accepted for publication on 25 Aug 2016

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 dorsal 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 periosteum are reflected from the long bones, clavicles, and scapulae. The pleurae, musculature, and periosteum are reflected from the internal surface of the ribs. Reflecting the musculature and periosteum 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 flap 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 injuries 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,

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 fracture missed when a PSE is not performed. Difficulties in recognizing metaphyseal fractures stem from the limited osseous disruption. The fracture occurs through the primary spongiosa 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

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

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 assess 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.

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, ulna, 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.

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 bio-

mechanical 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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