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PAPER

ANTHROPOLOGY

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Novel Classification System of Rib Fractures Observed in Infants*

ABSTRACT: Rib fractures are considered highly suspicious for nonaccidental injury in the pediatric clinical literature; however, a rib fracture classification system has not been developed. As an aid and impetus for rib fracture research, we developed a concise schema for classifying rib fracture types and fracture location that is applicable to infants. The system defined four fracture types (sternal end, buckle, transverse, and oblique) and four regions of the rib (posterior, posterolateral, anterolateral, and anterior). It was applied to all rib fractures observed during 85 consecutive infant autopsies. Rib fractures were found in 24 (28%) of the cases. A total of 158 rib fractures were identified. The proposed schema was adequate to classify 153 (97%) of the observed fractures. The results indicate that the classification system is sufficiently robust to classify rib fractures typically observed in infants and should be used by researchers investigating infant rib fractures.

KEYWORDS: forensic science, forensic anthropology, forensic pathology, child abuse, rib fractures, infants

Rib fractures are recognized as a significant thoracic injury in the medical and medico-legal fields. In adults, the number of rib fractures has been positively correlated with morbidity and mortality rates (1–4). In children, rib fractures are considered highly suspicious for nonaccidental injury (5–11). Rib fractures have also been used as evidence of lethal trauma in homicide victims (12). Despite the importance of rib fractures, little research has focused on the correlation between fracture type, location, and causal mechanism. In an effort to initiate research in this area, we have developed a concise classification system for rib fractures that identifies both the location and type.

Comprehensive classification systems for long bone fractures have been developed and are well-published in the orthopedic literature (13–17). Classification systems are valuable in facilitating concise descriptions of injury location and extent, and are often tied to a specific mechanism of injury (18). In contrast, rib fractures have not been afforded the same attention in the orthopedic literature. A concise and uniform vernacular classification system increases both the precision and accuracy of clinical care and research.

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Extensive research has been conducted on rib fractures in the medico-legal fields driven by the necessity to differentiate accidental from nonaccidental injury in infants and children. Despite this, most studies do little more than list rib fractures as either "present" or "absent." There is a growing appreciation in the child abuse clinical literature for the importance of rib fracture location, in that posterior rib fractures are considered a stronger indicator of non accidental injury than anterior rib fractures (10,19). Kleinman and Schlesinger (11) hypothesize that a squeezing mechanism applied to a child's chest (as opposed to straight compression) is the cause of posterior rib fractures. As the chest is manually constricted, the ribs are forced posteriorly against the transverse processes of the vertebrae creating a classic level 1 lever. The rib heads are pulled away from the vertebral bodies, creating avulsion forces through the costovertebral ligaments. This mechanism results in fractures occurring at the rib heads and tubercles (11). Furthermore, studies on first rib fractures show they tend to occur at the subclavian groove, a weak spot in the rib (20,21). The first rib is tucked under the clavicle and scapula and thus is protected from direct impacts. However, the attachment of the scalene muscle to the anterior rib body subjects the bone to muscle contractions. Some authors speculate that first rib fractures in infants are caused by muscle contractions associated with violent shaking (22). Absent from this body of research is an evaluation of the type of rib fracture (i.e., transverse, oblique, buckle) which can be used to further reconstruct the mechanism of injury.

The buckle fracture of the rib is an example of how additional information is obtained when the fracture type is considered. Love and Symes (23) define the buckle fracture as an incomplete fracture that occurs on the pleural surface of the anterior region of the rib from an anterior to posterior directed force, such as the forces associated with cardiopulmonary resuscitation (CPR). Yang et al. (24) examined postmortem computed tomographies

(CTs) of decedents with a nontraumatic death, who received CPR and also identified buckle fractures in the anterior region of the ribs. In contrast, Daegling et al. (25) found that ribs fail along the anterior region when experimentally loaded in an anteroposterior direction. This mechanism produced various types of fracture including buckle, transverse, oblique, and butterfly. Of note, the authors used rehydrated bone specimens, which may have different biomechanical properties than bones *in situ.* Further research using standardized rib fracture type and location definitions will provide clarity to study conclusions, and ultimately aid in assessment of suspected child abuse injuries.

To develop a concise rib fracture classification system we performed a comprehensive, prospective study involving infants. During a sequential 12-month period all infant deaths investigated by the Harris County Institute of Forensic Sciences (HCIFS) received an *in situ*, comprehensive rib examination by a forensic anthropologist. The definitions of the fracture types were defined *a priori* as well as a system to identify the location. The primary aim of the study was to characterize the variation in rib fractures observed during medico-legal autopsies of infants and develop a meaningful classification system to improve precision and accuracy for future research and clinical care. Acute and remote fractures were included in the study. Future evaluation of data from this study will include assessing the association of acute rib fractures with cause of death, manner of death, and the occurrence of perimortem CPR.

Method

The study sample included all infant deaths investigated by HCIFS during the 12-month interval of July 15, 2010 through July 14, 2011. Infant deaths are investigated by HCIFS pursuant to Chapter 49.01 of the Texas Code of Criminal Procedure and Chapter 264, Subchapter F of the Family Code, which state an inquest shall be conducted on any child under the age of 6 years in which the death appears to have occurred without anticipation or forewarning and was caused by trauma, suspicious or obscure circumstances, sudden infant death syndrome, abuse or neglect, or an unknown cause.

The medical history, autopsy findings, and investigative reports were reviewed for each case. Documents reviewed included emergency medical services records, law enforcement reports, child protective services reports, medical records of all hospitalizations as well as primary care visits, HCIFS investigator reports, autopsy reports, and anthropology consultation reports. Data were coded and entered into a Microsoft Access database designed for the study.

Each infant received a rib examination after the autopsy following the method previously described by Love and Sanchez (26). All examinations were performed by a forensic anthropologist. Briefly, the pleura was stripped and the periosteum and intercostal muscles were incised with a scalpel from the tip of the rib head to the costochondral interface. The soft tissue was lifted from each bone using a periosteal elevator. The bone was visually examined for fractures as well as areas of subperiosteal new bone formation in a standard fashion as described below. All observed fractures were recorded. At the request of the pathologist, a traumatized rib(s) was removed from the decedent and chemically processed to remove all soft tissue. In these instances, the fractures were documented after examination of the rib in the dry state. In some cases, a sample of an anterior portion of one rib was obtained for histological analysis prior to the rib examination. Care was taken by the pathologist not to sample fractured ribs.

All rib fractures were systematically documented as to their location and type. To achieve this, the rib was divided into four regions, the definition of which was standardized (Table 1 and Fig. 1). The division of the rib into the four regions was based on bony features and spatial relationships. The posterior region of the rib was defined by the tip of the rib head and the lateral margin of the rib tubercle. The posterolateral, anterolateral, and anterior regions were determined by visually dividing the body of the rib into segments. The posterior and posterolateral regions

TABLE 1—*Definition of fracture location and type.*

Location of Fracture	Definition
Posterior	Area from the lateral margin of the rib tubercle to the medial tip of the rib head
Posterolateral	Area from the lateral most point of the rib body to the lateral margin of the rib tubercle
Anterolateral and anterior	The anterior and anterolateral regions of the rib span from the most lateral point of the rib body to the sternal end. The interface of the anterior and anterolateral regions is the midpoint of this section of the rib
Type of Fracture	
Buckle	Incomplete fracture on the pleural surface of the rib
Transverse	Complete fracture with a vertical (superior-inferior) orientation
Oblique	Incomplete or complete fracture with a superolateral to inferomedial orientation or vice versa
Sternal end plate	Fracture of the sternal end plate or rim

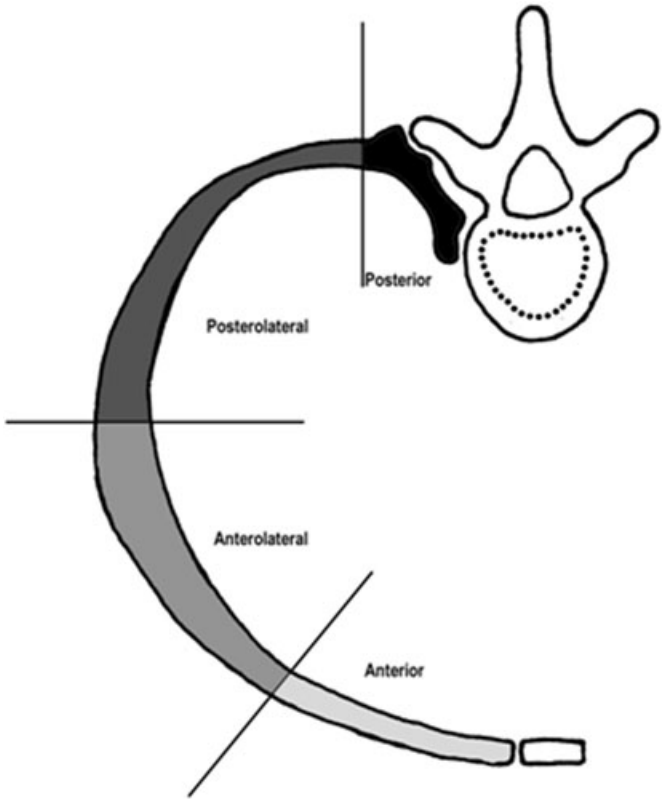

FIG. 1—*Diagram of the four regions of the rib. The illustration is reprinted with kind permission of Springer Science+Business Media (27).*

of the ribs remain constant; however, the anterior and anterolateral regions of the ribs become increasingly shorter from rib six through 12. In this way, ribs 11 and 12 do not have an anterior or anterolateral region. Any fracture observed on ribs 11 or 12 were coded as posterior or posterolateral. Fracture types were coded as transverse, oblique, buckle, or sternal end plate (Table 1) (Figs 2–5). These were defined *a priori* as well. When the healing obscured the fracture type, the fracture type was not documented.

The total number of rib fractures was calculated for each subject. The distribution of the rib fractures was broken down by the decedent's age and fracture type and location. Descriptive statistical analysis was performed using the Microsoft Office Excel 2007 statistical package (Redmond, WA).

Results

A total of 85 infants were included in the study. Table 2 details the demographic description of the infants and the manners of death. The age range of the sample was 0 days to 1 year (median age was 3.8 months) (Fig. 6). Nonviable fetal births and infants surviving in the hospital less than 24 h postnatal were excluded from the study. One full-term live birth born outside of the hospital and surviving for an unknown period of time was included in the study.

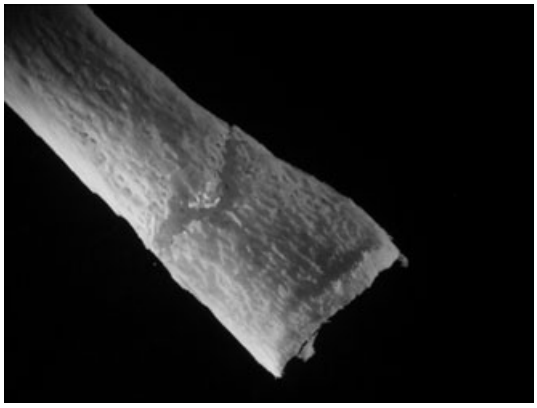

FIG. 2—*Buckle fracture in the anterior region of left rib 5, view of the pleural surface. The incomplete fracture involves only the pleural surface.*

FIG. 3—*Transverse fractures of posterior region of right ribs 2 and 7 (arrow heads) and anterior regions of right ribs 4–5 (arrows).*

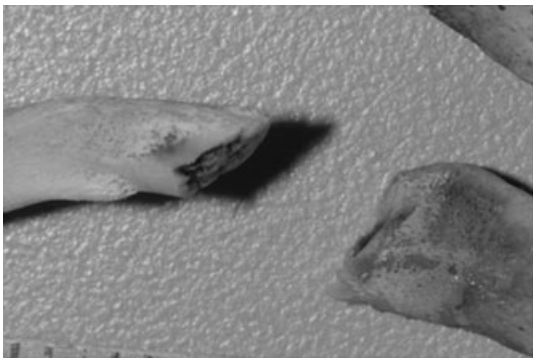

FIG. 4—*An oblique rib fracture. The fracture is classified as oblique even though the angle of the fracture is slight.*

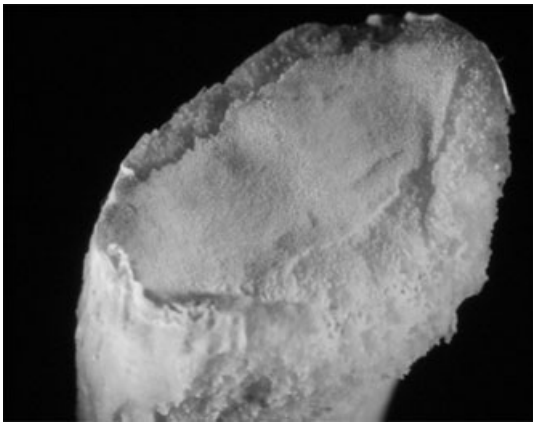

FIG. 5—*Sternal end fracture of a rib. Note the visible trabeculae around the outer rim of the surface.*

TABLE 2—*Demographic description and manner of death of the sample population.*

Gender	Ancestry	Manner of Death
Female – 33	Asian – 5	Homicide – 6
Male – 52	Black – 27	Natural – 32
	Hispanic – 31	Accident – 7
	White – 21	Undetermined – 38
	Unknown – 1	Pending – 2

Rib fractures were found in 24 (28%) of the 85 cases included in the study. A total of 158 fractures were documented during the study. Of these fractures, 153 (97%) were able to be classified using the proposed system. Advanced healing precluded fracture type classification of three fractures. Two of these fractures were located in the anterolateral region of the rib and one was located in the posterolateral region. Two additional fractures did not conform to the four fracture types included in the classification system (see Discussion). Both of these fractures were located in the posterolateral region.

The average number of fractures per case was 6.5. There were 76 transverse, 45 buckle, 1 oblique, and 31 sternal end plate

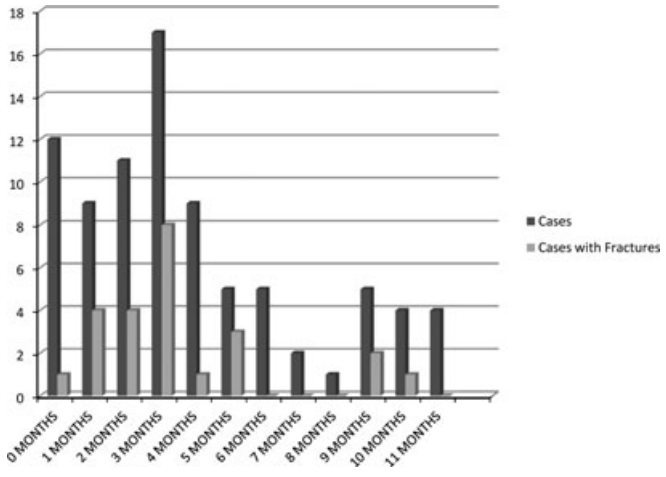

FIG. 6—*The distribution of the sample by age. Also included in this figure is the number of cases with rib fractures per age group.*

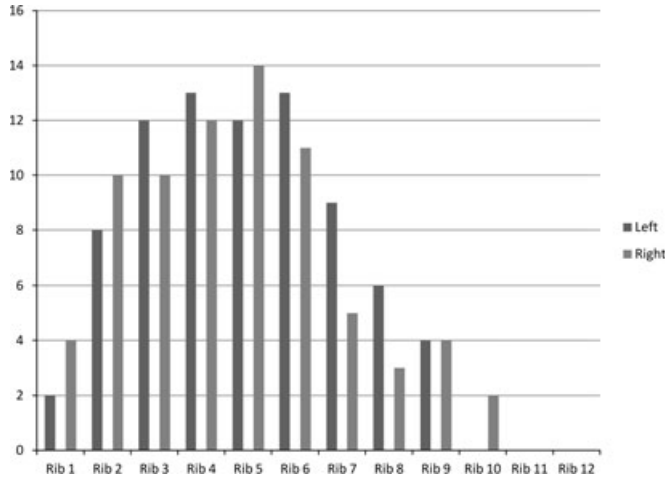

FIG. 8—*Distribution of fractures by rib number and side.*

fractures (Fig. 7). The distribution of the fractures throughout the four regions is as follows: 81 anterior; 41 anterolateral; six posterolateral; and 30 posterior (Fig. 7). The distribution of the fractures throughout the ribs took a bell curve shape with the majority of the fractures occurring on rib 5, and no fractures occurring on ribs 11 and 12 (Fig. 8). Using a two-way paired *t*-test, no significant difference was found between the number of fractures occurring on the right side compared to the left side ($p = 0.59$). Three-month-old infants had the highest incidence of rib fractures, at least one fracture was found in 47% of the cases within this age group (Fig. 6).

Discussion

The objective of our study is to prospectively characterize the location and type of rib fractures observed in infant deaths investigated by a medical examiner's office in a major urban area. We developed a simplified framework for categorizing rib fractures by two well-defined variables: location and fracture type. The successful application of the classification system to 97% of the rib fractures observed during the study indicates that the presented schema can reliably capture the vast majority of rib fractures seen in infants.

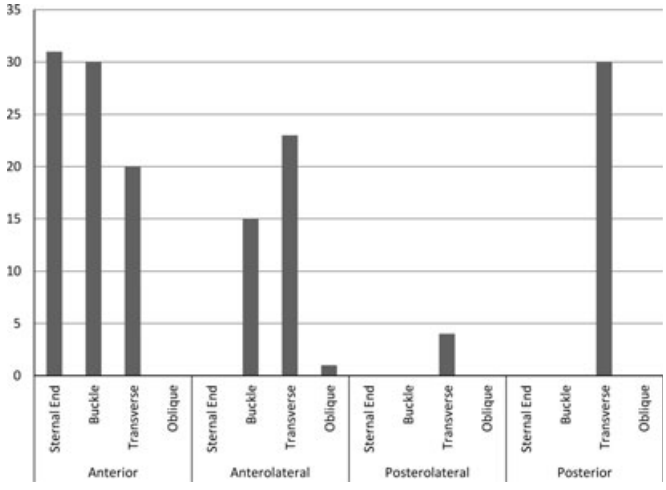

FIG. 7—*Distribution of rib fractures by type and location. The five fractures that were not classified using the proposed schema were located in the anterolateral region of the rib* (n = *2) and posterolateral region of the rib* (n = *3). These are not included in the graph.*

The prospective study design of autopsied infant cases provides an opportunity for far more objective and comprehensive data collection on rib fractures as compared to the retrospective design of radiological and medical records often used in the child abuse literature. Retrospective studies using preexisting records are subject to inconsistent terminology within the records, reduced sensitivity, and introduction of sampling bias. In contrast, this study utilized terminology and data fields developed *a priori.* We also increased the rib fracture recognition sensitivity through systematic visual examination by forensic anthropologists, a more sensitive method than limiting observations to radiological modalities (28–30). This increased sensitivity is reflected in the striking number of rib fractures identified in the cohort. A similar increase in fracture identification was documented by Kleinman and colleagues after histological examination of long bone metaphyses (31). Finally, the prospective design enabled inclusion of all cases that met the age criterion, limiting potential sampling bias. Retrospective studies often use previously categorized populations (such as cases in trauma tracking databases), which introduce the potential for sampling bias.

Ninety-seven percent ($n = 153$) of the rib fractures observed during the study were easily classified into the four defined fracture types. Of the five fractures which were unclassified, three could not be classified due to advanced healing. The remaining two fractures did not clearly fit into any of the predefined types. Both of these fractures were found in the posterolateral region of the rib and were described as incomplete transverse fractures, but were not buckle fractures. These fractures were similar in morphology to torus fractures found on long bones in that the cortical bone ballooned out at the fracture site (Fig. 9). One fracture was located on right rib 7 and the other on left rib 6, both in the same decedent.

The division of the rib into four regions enabled reporting the location of the rib fracture with both precision and accuracy. A distribution pattern of serial buckle fractures that included both anterior and anterolateral regions of the ribs was found in several decedents. This finding suggests that the subdivision of the anterior one-half of the rib body into two regions may not be necessary for classifying rib fractures observed in infants. We feel it is important to retain this level of granularity prior to collapsing

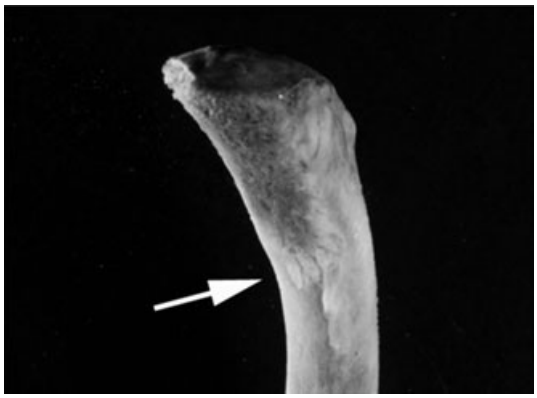

FIG. 9—*Incomplete fracture located in the posterolateral region of left rib 6. The cortical bone is ballooned out at the fracture site.*

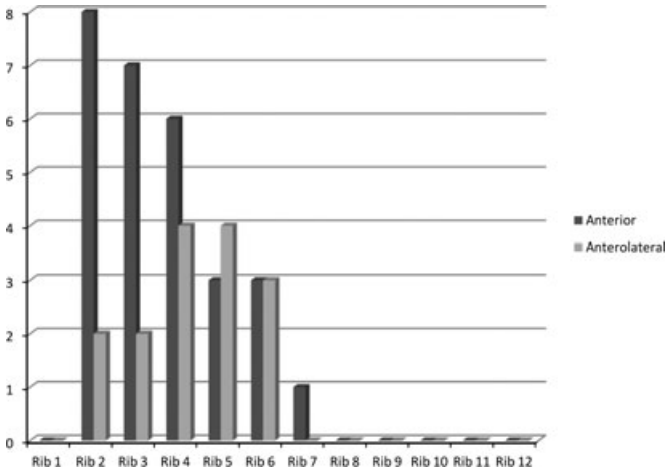

FIG. 10—*Distribution of buckle fractures by rib number and location.*

these two anatomic locations in our schema until clinical correlation between biomechanical forces and location and type of rib fractures is more clearly established.

The mechanism of force (i.e., CPR nonaccidental injury, and accidental injury) was not included in this report. However, the presence of buckle fractures in the anterior and anterolateral regions of the rib and the concentration of them in the upper and mid-range ribs (2–7) does support previous studies linking buckle fractures with anterior to posterior compression of the chest, such as with CPR (Fig. 10) (24).

The primary aim of this report is to create and propose a rib fracture classification system that is adequately robust to capture the typical variation observed in infant rib fractures, both acute and remote fractures. Based on previous research (32), the proposed rib fracture classification system is inadequate to characterize the rib fractures observed in adults. As such, the proposed system fills a very specific clinical and research gap within the biomechanical literature.

We anticipate that the increased level of consistency will improve the methodological rigor of future research involving rib fractures. This will lead to an increase in both precision and accuracy articulating the clinical implications of rib fractures in infants. From here, rib fracture classification system development must expand in at least two directions: to correlate the mechanism of trauma to the type and location of an acute fracture and to account for the variation observed in rib fractures at all ages.

Limitations

We do recognize some important limitations to our study. First, the cohort described in this study may not be truly reflective of all infant deaths in the general population. We believe that our cohort is a reasonable representation of infants seen in a large urban medical examiner's office, but there may be differences in offices operating in less populated areas.

We also recognize that the absence of correlation with imaging may limit the applicability to clinical practice in living infants. As noted earlier, our cohort has a higher incidence of rib fractures identified due to improved examination sensitivity afforded by the forensic anthropologists. Most rib fractures are identified in living infants via plain film or CT scanning. While repeated delayed imaging has been demonstrated to increase fracture identification by 8.5–37%, it is not clear how our findings would compare with concordant imaging studies (33,34). Furthermore, dividing the rib into four regions may not be possible when examining a plain film. The addition of an oblique angle provides the vantage point necessary to discriminate between posterolateral and anterolateral regions. The division of the rib into regions should be directly applicable to transverse CT images.

Last, although we feel that the simple rib fracture characterization schema we developed would contribute to the field by systematizing the clinical and research nomenclature, we recognize that there are many potential variations encountered in practice which may not cleanly fit our framework. For example, the classification system would benefit from expansion to include a torus fracture defined as an incomplete fracture with outwardly displaced cortical bone for future studies.

Conclusion

This study proposes a novel rib fracture classification system for typing and locating rib fractures observed in infants. The system is adequate for classifying the majority of rib fractures observed during medico-legal autopsies of infants. Future research must be conducted to expand the classification system beyond infants and to correlate biomechanical forces to fracture type and location.

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