Fracture Characteristics of Perimortem Trauma in Skeletal Material
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Citation

Abstract
Death investigation is a multi-disciplinary effort employing the skills of different forensic specialists from fields as diverse as pathology, anthropology, odontology and entomology. In the examination of skeletal trauma, the contribution of the analysis by the forensic anthropologists is essential. Such an analysis helps determine whether skeletal injuries are temporally associated with the events surrounding death and the mechanisms that were involved in their production. The aim of this study was to investigate the perimortem nature of various bone fractures by assessing their particular morphological characteristics. A total of 111 perimortem skeletal injuries observed in 16 skeletons from a documented skeletal collection and a series of forensic cases were examined for this purpose. The perimortem trauma investigated was limited to blunt force trauma. The absence of an osteogenic response remains a basic characteristic of a perimortem injury but not the only diagnostic criterion. It was concluded that fracture patterning, the morphology of fractured edges and the presence of particular skeletal and non-skeletal attributes may substantially contribute to the diagnosis of perimortem trauma. Postmortem bone alterations such as abrasion due to sediment action or whitening resulting from sun exposure, observed in certain perimortem fractures, can cause considerable problems in trauma analysis by removing important indicators of perimortem trauma.

INTRODUCTION
Forensic pathologists frequently seek the expertise of forensic anthropologists while conducting death investigations. Anthropological consultation is not limited to cases where skeletal remains are examined, but increasingly involves investigations of recent deaths. In such cases the anthropological analysis may offer assistance in forming opinions about the length of the postmortem period and the cause of death.1 Equipped with knowledge of the taphonomic processes and their effects on the human body, anthropologists can estimate time since death with greater accuracy than other experts whose focus is on the early postmortem period. An analysis that documents injuries to the skeleton is a very powerful tool in the examination of violent deaths. The anthropologist will first identify these injuries, determine the relative time at which they were produced and the mechanisms responsible for their formation. Antemortem injuries on bone exhibit evidence of healing and therefore can be distinguished from those produced around the time of death. The distinction between perimortem and postmortem injuries however, is challenging, as it depends on more subtle attributes of bone tissue.2,3

The purpose of this study was to investigate the perimortem nature of various skeletal injuries from a documented skeletal collection and a series of forensic cases by assessing their particular morphological characteristics. The necessity of the study lies in the fact that skeletal trauma is usually the only available source of information on cause and manner of death from skeletal remains.

MATERIAL AND METHODS
A total of 111 perimortem skeletal injuries observed in 16 skeletons from a documented skeletal collection and a series of forensic cases were examined. From the 16 skeletons studied, 9 belonged to the skeletal collection and 7 came from a forensic context. The skeletal collection, known as the “Athens Collection”, currently consists of 225 skeletons of known sex, age and cause of death. It is housed at the Department of Biology and is used for teaching and research in skeletal biology.4 The forensic cases were submitted by law enforcement authorities to the Department of Forensic Medicine and Toxicology of the University of Athens for anthropological examination. Only cases involving blunt force trauma were considered in the study. For the forensic cases, the sex and age of the individuals had been estimated during the initial anthropological examination.
The perimortem nature of each fracture pattern was possible to be ascertained by examining the death certificates of the individuals from the reference collection or the case file of each forensic case. In most forensic cases the circumstances of injury, investigation reports and scene photographs were available. Partially skeletonized remains had been processed prior to the examination for evidence of blunt force trauma. Although blunt force injuries are distinguished into abrasions, contusions, lacerations and skeletal fractures\textsuperscript{5,6} only the last type of injury was of interest in this study.

Interpretations of skeletal trauma were based on gross examination of each fracture pattern and each fracture was described in detail and photographed. An attempt to identify the mechanism of delivery of any apparent traumatic lesion was made. Observations of subtle fracture attributes or indications of an osteogenic response required a careful scrutiny of all fracture edges under suitable lighting and magnification, using a low-powered stereomicroscope.

RESULTS

Data about the demographic profile of the remains are summarized in Table 1. From the 16 skeletons examined, 11 (69\%) were males and 5 (31\%) females. Ages ranged from 16 to 77 years although some ages at death were unknown. Table 2 shows the distribution of perimortem trauma by skeletal element.

Table 1: Demographic data of the skeleton samples studied

<table>
<thead>
<tr>
<th>Case</th>
<th>Origin</th>
<th>Sex</th>
<th>Age</th>
<th>Manner of death</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>R</td>
<td>M</td>
<td>16</td>
<td>Accident - fall from height</td>
</tr>
<tr>
<td>2</td>
<td>R</td>
<td>F</td>
<td>46</td>
<td>Accident - cranio-cerebral injury</td>
</tr>
<tr>
<td>3</td>
<td>R</td>
<td>M</td>
<td>77</td>
<td>Unknown</td>
</tr>
<tr>
<td>4</td>
<td>R</td>
<td>Unknown</td>
<td></td>
<td>Accident - cranio-cerebral injury</td>
</tr>
<tr>
<td>5</td>
<td>R</td>
<td>M</td>
<td>36</td>
<td>Accident - neck injuries</td>
</tr>
<tr>
<td>6</td>
<td>R</td>
<td>M</td>
<td>64</td>
<td>Accident - basilar fracture, cerebrum hemorrhage</td>
</tr>
<tr>
<td>7</td>
<td>R</td>
<td>F</td>
<td>58</td>
<td>Accident - cerebrum hemorrhage</td>
</tr>
<tr>
<td>8</td>
<td>R</td>
<td>M</td>
<td>24</td>
<td>Accident - cranio-cerebral injury</td>
</tr>
<tr>
<td>9</td>
<td>R</td>
<td>Unknown</td>
<td></td>
<td>Accident - fall from height</td>
</tr>
<tr>
<td>10</td>
<td>F</td>
<td>F</td>
<td>40-44 est.</td>
<td>Accident - fall from height</td>
</tr>
<tr>
<td>11</td>
<td>F</td>
<td>F</td>
<td>32</td>
<td>Accident - cranio-cerebral injury</td>
</tr>
<tr>
<td>12</td>
<td>F</td>
<td>M</td>
<td>26-30 est.</td>
<td>Undetermined</td>
</tr>
<tr>
<td>13</td>
<td>F</td>
<td>M</td>
<td>28-33 est.</td>
<td>Accident - fall from height</td>
</tr>
<tr>
<td>14</td>
<td>F</td>
<td>F</td>
<td>34-30 est.</td>
<td>Accident - fall from height</td>
</tr>
<tr>
<td>15</td>
<td>F</td>
<td>M</td>
<td>31</td>
<td>Accident - fall from height</td>
</tr>
<tr>
<td>16</td>
<td>F</td>
<td>M</td>
<td>26-37 est.</td>
<td>Undetermined</td>
</tr>
</tbody>
</table>

* R - reference collection, F - forensic case, ** est - estimated age

The absence of an osteogenic reaction remains a basic attribute of a perimortem injury but certainly not the only diagnostic criterion that indicates the perimortem nature of a skeletal injury. In the present study, fracture patterning, the morphology of fractured edges and the presence of particular skeletal and non-skeletal attributes indicated the perimortem origin of an injury.

Figure 1

FRACTURE PATTERNING

Perimortem skeletal trauma was indicated in some cases by the unique fracture pattern that is commonly seen on bones fractured while they were fresh (“living” bone) or recently defleshed (green bone). A stellate fracture observed on the frontal bone in Case 1 indicated that the bone was fresh at the time of injury. A contrecoup injury was observed in one case (Case 4) as evidenced by the bilateral orbital roof fractures. This fracture resulted from blows transmitted via the frontal lobes of the brain and is not usually visible at autopsy unless the dura matter is removed. A complex midfacial fracture known as Le Fort type-III fracture was ascertained in Case 9. The cranial vault was fragmented, while the facial skeleton was completely detached from the rest of the skull (craniofacial disjunction) across the upper orbits and nasal region.
The perimortem nature of an injury was sometimes evidenced by the complexity of the fracture pattern. For instance, a laminar fracture on a 4th cervical vertebra was associated with an ipsilateral hairline fracture of the pedicle (Case 2). Additionally, two burst fractures noted on a 4th and 5th lumbar vertebrae resulted in comminution of the vertebral bodies but also involved the posterior elements such as the pedicles, the laminae, the transverse and the spinous processes (Case 1).

Another fracture pattern usually associated with perimortem trauma was the butterfly fracture observed on several long bones such as the humerus (Case 15), tibia (Case 5,15) and fibula (Case1) (Figure 1). Such a fracture pattern, termed due to its distinctive shape, consisted of two fragments of bone and a small triangular bone fragment broken away at the point of impact.

**Figure 3**

Figure 1: A perimortem butterfly fracture located at the distal metaphysis of a fibula. Note the unfused epiphysis of the bone (Case 1)

**MORPHOLOGY OF THE FRACTURED EDGES**

Analysis indicated that smooth, often beveled, fracture edges with sporadic sharp projections and uniform coloration were associated with perimortem trauma. Additionally, evidence of bone remodeling concurrent with healing normally seen as rounding of the fractured edges was not observed in such fractures.

The morphology of the fractured edges seemed to depend on the grain i.e. the texture made by the collagen fibers of the bone. When a fracture ran parallel with the arrangement of the collagen fibers, the fracture edges were linear (Figure 2A), while when the fracture ran vertically or obliquely from them, the edges were usually irregular to jagged (Figure 2B). This morphology was noticed mainly in injuries of the vertebral arches (Case 2), in the ribs and also in fractures of the scapular body (Case 15), indicating in some cases the type of force acted upon the bone. For instance, in bending fractures ascertained in radial (Case 5) and metatarsal fractures (Case 1) the linear part indicated compression, while the irregular part was consistent with breaking under
tension. The sharp fractured edges noticed on the anterior aspect of the greater horn in a hyoid fracture (Case 15) provided some clues regarding the force applied. In this case, the synchondroses between the body and the greater horns were completely ossified.

**Figure 4**

Figure 2: The fractured edges of a perimortem fracture may appear linear or irregular to jagged depending on whether the fracture runs (A) parallel with the grain of the bone (Case 13, 6th left rib) or (B) obliquely (Case 8, 1st left rib).

Additional postmortem alteration was evident in several perimortem fractures causing considerable difficulties in the skeletal analysis. In a skeleton recovered from a rocky shore (Case 15) the fractured edges of two butterfly fractures were rounded off due to abrasion of the exposed bones by the current-driven, sediment-laden water. Whitening of a fractured humerus due to sun exposure was present in an animal-scavenged skeleton (Case 10). The proximal exposed part of the bone was bleached white, while the unexposed distal part was darkly stained.

**SPECIFIC IDENTIFYING ATTRIBUTES**

The diagnosis of perimortem trauma was also facilitated by the presence of fracture-related features such as bone tear, break-away notch, plastic deformation etc., observed in 34.2% of the cases as shown in Table 3.

**Figure 6**

Table 3: Specific perimortem attributes

<table>
<thead>
<tr>
<th>Perimortem attribute</th>
<th>N = 111</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bone tear</td>
<td>18 (16.2)</td>
</tr>
<tr>
<td>Break-away notch</td>
<td>1 (0.9)</td>
</tr>
<tr>
<td>Secondary fracture lines</td>
<td>8 (7.2)</td>
</tr>
<tr>
<td>Plastic deformation</td>
<td>6 (5.4)</td>
</tr>
<tr>
<td>Adherent bone fragments</td>
<td>2 (1.8)</td>
</tr>
<tr>
<td>Adherent material</td>
<td>3 (2.7)</td>
</tr>
<tr>
<td>Total</td>
<td>38 (34.2)</td>
</tr>
</tbody>
</table>

*Values in parentheses are percentages*

An area of delamination or bone tear associated with an oblique symphyseal fracture of the mandible was noted in Case 6 indicating the perimortem origin of the injury. The flaking away of the bone layer left a distinctive pattern seen as a roughened surface adjacent to the fracture site (Figure 3). Bone tear has been observed also in fractures of vertebral arches (Case 1), the scapular body (Case 15), tibia (Case 15) and fibula (Case 5). A Salter-Harris fracture type II involving the distal metaphysis of a radius was associated with delamination and also with exposure of the underlying cancellous bone (Case 1). No fracture has been observed in the unfused distal epiphysis of the bone. Detachment of a metaphyseal fragment and exposure of the cancellous bone was also noticed in fractures through the base of the 4th and 5th metatarsal of the same young individual.

Another fracture-related feature known as break-away notch, characteristic in perimortem angulation fractures of long
bones, was noted in a transverse malleolar fracture of a fibula (Case 15), indicating the compression side of the bone. Additionally, secondary fractures originating from the primary fracture were displayed in a 1st rib fracture (Case 9) and in a diaphyseal transverse fracture of a fibula (Case 5).

**Figure 7**
Figure 3: Bone tear associated with an oblique mandibular fracture (Case 6).

Fracturing with associated permanent deformation of bone fragments, represent slow loading and crushing trauma to the bone. The affect of slow loading on fracture morphology was evidenced mainly in cranial (Case 7,9) and scapular body (Case 15) fractures. In Case 15 the cranial fragments were permanently deformed –bone fractured while in plastic deformation– and difficult to refit making the reconstruction almost impossible. Specific fracture patterns were observed in the transverse processes of a victim who fell from a height (Case 14). The vertically oriented greenstick fractures produced on the posterior cortex of T12, L1, L2, and L3 were combined with permanent bowing of the opposite cortex.

Adhering small bone fragments adjacent to the fracture site were also connected with perimortem trauma (Case 16). Additionally, traces of desiccated soft tissue within fractured edges were also indicative of fracture occurring around the time of death (Case 5).

**DISCUSSION**

Skeletal trauma analysis is an essential contribution of the forensic anthropologist to death investigation. The identification, sequencing and interpretation of injuries to the skeleton may provide information that could be lost as a result of the decomposition of soft tissues. This information helps to reconstruct the events surrounding the death of an individual.7,8 One of the most challenging steps in the analysis of skeletal trauma is distinguishing between perimortem and postmortem injuries. The anthropologist must have a sound knowledge of fracture characteristics in fleshed and dry bone, as it reacts differently to stress. Living bone tissue has a high proportion of collagen and moisture which gives it more elasticity and leads to a specific pattern when disrupted.2,9,10 Similarly, dry bone has less tensile strength and a different set of attributes when fractured.

In this study, stellate (Case 1), contrecoup (Case 4) and butterfly fractures (Case 1,5,15) were associated with perimortem trauma. However, several authors showed that fracture patterns of the “butterfly” type can also be produced postmortem.3,11 In this case, fractured edges coloration and interpretation of the direction of forces acting on bone were important factors in distinguishing perimortem from postmortem butterfly fractures.

Green bone fractures are characterized by smooth fractured edges, usually of the same color as the rest of the bone.12,13 In long bones, the broken end is usually angled with a jagged surface.14 Specific fracture characteristics such as bone tear, plastic deformation etc. were of particular diagnostic value. Bone tear as a perimortem indicator of a bone broken while in a green state was also described as flaked fracture or peeling by other authors.15,16 Plastic deformation is presented also as another attribute of perimortem trauma. Although postmortem warping due to soil pressure can result in changes of bone shape after burial15, plastic deformation following trauma is usually seen as a gradual curvature, if compared with the contralateral bone, affecting usually individual bones. Furthermore, in buried remains, the compressional collapse of the bones due to poor preservation of the skeleton must be excluded. Staining of fractured edges by hemorrhage, decomposition fluids, or occasional postmortem contaminants such as soil, dirty water or leaf stains indicates that the injury preceded particular postmortem events.2,14,17,18 Smith19 could prove the perimortem nature of a hyoid fracture from the adipocere deposited on fractured edges. Furthermore, traces of desiccated soft tissue within the fracture (Case 5) and adherent bone fragments (Case 16) indicated that the breakage was not the result of postmortem damage. As pointed out by Ortner and Putschar20 small bone fragments adherent to adjacent fractured bone are indicative of a fracture occurring while the periosteum and other soft tissue are still intact.
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In dry bones, that have a reduced collagen and moisture content, the fractured edges are irregular and blunt. In addition, the edges are lighter in color than those of the surrounding bone, as they are exposed to the environment at a later stage. In long bones, postmortem fractures exhibit breakage nearly at right angle to their long axes with almost flat ends. 14

In skeletonized cases, postmortem alteration must be added to the list of considerable problems affecting the forensic analysis of skeletal trauma. Abrasion of bone due to sediment action in aquatic environments can remove important indicators of perimortem trauma by rounding off the fractured edges, as was seen in Case 15. Abrasive modification of bones has been also reported by other authors. 13, 24, 25 Whitening of bones as a result of sun exposure can alter the previous coloration of the fractured edges. The result of sun exposure is usually diffuse, although the difference between affected and unaffected bone surfaces can be dramatic. 13, 26 Scavenging activity and the resulted scattering of bones in sun exposed or unexposed areas are responsible for the sharp contrast between the proximal and distal part of the fractured humerus seen in Case 10. As pointed out by Ubelaker 27 consideration of taphonomic factors is fundamental to the forensic analysis of trauma.

The speed of bone drying may also have an impact on the visual characteristics of perimortem trauma. For example, in hot and arid environments bone will dry in a very short period. In wet environments such as burials below the water table, moisture may be retained for long periods of time. Similar moisture retention from body fluids may occur in the core of a mass grave. 28 Such conditions may produce changes that mimic “perimortem” bone damage for an extended time period.

CONCLUSION

The identification of perimortem trauma and its differentiation from antemortem injuries and postmortem modification is essential in skeletal trauma analysis.

In this study, fracture patterning in combination with fractured edge characteristics proved to be the most useful method for the assessment of perimortem skeletal trauma on a documented skeletal sample. Future studies utilizing experimental models may provide additional insights on this complex issue.

References

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