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TECHNICAL NOTE

Bruce P. Wheatley, Ph.D.

Perimortem or Postmortem Bone Fractures? An Experimental Study of Fracture Patterns in Deer Femora*

ABSTRACT: The determination of perimortem trauma is important for forensic anthropologists. Characteristics of bone fractures such as sharp edges, presence of fracture lines, the shape of the broken ends, fracture surface morphology, fracture angle on the *Z*-axis, and butterfly fractures are said to differentiate perimortem from postmortem trauma. A Drop Weight Impact Test Machine was used to break 76 deer femora of various ages since death. The results of this study suggest that the characteristics listed above are unreliable at differentiating a perimortem fracture from a postmortem fracture in a forensic case. There are, however, statistically significant differences between fresh bones broken less than 4 days old and dry bones broken 44 days or 1 year old after death.

KEYWORDS: forensic science, forensic anthropology, bone fracture patterns, perimortem trauma, postmortem trauma

Forensic scientists have a great interest in the perimortem interval because it may provide important information about the cause and manner of death. A perimortem injury is usually defined as an injury at, near, or around the time of death (1,2). The perimortem interval, however, is often viewed as an ambiguous and elastic interval of unspecified duration (3,4).

Perimortem injuries to bone are often based on the patterns formed when bone is fresh or green. Wet or green bone has high moisture and fresh marrow that greatly increases the ability to absorb stress. It therefore has high elasticity and plasticity and can withstand great amounts of strain and deformation before failure. Dry bone, however, has less water and is more stiff and brittle, requiring much less energy to fracture (5,6). There are also many other variables besides moisture content that affect fractures. The skeleton has many functions and it is, therefore, a compromise fulfilling many demands including mechanical and physiological ones (7,8). These other variables include bone mass and bone architecture that include such things as cortical bone thickness and diaphyseal diameter, the percentage of compact and spongy bone, porosity, presence of non-osseous tissues, age and epiphyseal union, and mineral to collagen ratios, to name a few (1,5,8).

The fracture patterns of bones are also a function of the different types of force applied to bones. A bone will break when it cannot absorb all of the traumatic energy. Bone is weakest in tension and strongest in compression. A tensile failure of bone can occur under bending when the surface of the outside of the bow in a long bone undergoes elongation resulting in a transverse fracture. A long bone subjected to torsion can fail in a spiral fracture. A butterfly fracture can occur under a combination of bending and compression.

A common characteristic of perimortem bone fractures is purported to be sharp edges whereas right-angled edges are characteristic of dry bone fractures (1,6,9–11). The presence of fracture lines and the jagged surface of the broken ends are also said to distinguish perimortem from postmortem injuries (1). Other features of perimortem bone fractures are the presence of butterfly fractures and the presence of diagonal fracture angles on the *Z*-axis (9,12). Smooth or even and fine texture is said to be characteristic of fresh bone whereas the fracture surface of dry bones may have a rough, bumpy texture (6,9).

Do the differing qualities of bones and the differing forces impacting them affect the fracture patterns? Unfortunately, there is little actualistic research on these characteristics of bone fractures and the biomechanics of fractures on whole bones is also limited (13).

The purpose of this report is to clarify and to demonstrate how elastic the perimortem interval can be by reporting the results of an experimental analysis of fracture patterns in deer (*Odocoileus virginianus*) femora. Fracture studies on other species besides human have not reported major differences in properties or responses (6), however, *Odocoileus virginianus* has both plexiform and Haversian bone tissue, whereas, plexiform bone may only be present in human fetal or pathological bone (14).

Methods

The femora of white-tailed deer (*Odocoileus virginianus*) were obtained from a local processing plant during hunting season. Seventy-six femora were divided into two groups: a fresh or wet group of 42 femora and a dry group of 34 femora. Bones exposed for a few days can be considered to be fresh (6) and this group is defined as less than 4 days since death at the time of fracture. Twenty-one of these bones were less than 2 days old and 21 bones were less than 4 days old. They were defleshed prior to breakage. The dry group of 34 femora were either

Department of Anthropology and Social Work, University of Alabama at Birmingham, Birmingham, AL 35294-3350.

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44 days (n = 14) or 1 year (n = 20) since death at the time of fracture. The bones of the dry group were placed on a wooden platform beneath trees in the author's backyard until fractured. Forty-six femora were adult, i.e., completely fused, whereas 30 femora were not completely fused.

A Dynatup 8250 Drop Weight Impact Test Machine applied 13.63 kg of concentrated and sudden compressive force to the anterior surface of the midshaft of each bone. The impact variables used in this study are: energy to failure, impact energy, and impact velocity. Energy to failure is the energy that the specimen has absorbed up to the point of specimen failure. It is the area under the load/deflection curve from the test start to the failure point. Impact energy is the energy value developed by the drop weight/pendulum at the point of impact. It is calculated by the software as a function of drop height and weight. Impact velocity is the velocity of the drop weight/pendulum at the point of impact at time 0.

The striking surface of the impactor measured three inches by four inches. The proximal end of each bone was held in a vice and the other end rested on phone books. This layout along with dynamic rather than static loading is supposed to give some twist to get a tensile-shear failure (6). The drop height varied slightly because greater velocity was needed to break the fresh bones. Only bones that broke on the first impact are used in this study. The broken bones were cleaned and processed using water, powdered detergent, sodium carbonate, and ammonia (15). Some year-old bones, however, were not processed.

Both the proximal and the distal ends of each fractured bone were visually examined according to various attributes. Only if the bone broke cleanly in half was one bone scored. The scored attributes are as follows:

(1) The first scored attribute is the angle formed by the fracture surface and the bone cortical surface. Three states of the fracture edge were recorded: sharp or obtuse or acute angles, right-angled, and mixed. Mixed edges are defined as those with both sharp and right-angled edges.
(2) The second scored attribute is the presence or absence of fracture lines. These lines tend to radiate out from the point of impact.
(3) The third scored attribute is the shape of the broken ends. Four states were recorded: jagged, curved, intermediate, and transverse. The definitions, except for jagged, follow Villa & Mahieu, (11) i.e., curved fractures are spiral or portions of spiral fractures combined with V-shaped or pointed fractures; intermediate includes fractures that have a straight morphology but are diagonal and fractures with a stepped morphology; transverse are fractures that are straight and transverse to the long axis. Jagged refers to the irregular shape of the broken ends.
(4) The fourth scored attribute is the preponderant texture/morphology of the fracture surface or edge. A fracture surface with an even and fine texture is noted as smooth, whereas, an uneven or "bumpy" texture is noted as rough (6,9).
(5) Another scored attribute is the fracture angle on the Z-axis (9). The two recorded states are parallel and diagonal. Parallel is defined as "the fracture surface(s) occurs at right angles to the surface of the graph paper" and diagonal is defined as "the fracture surface(s) occurs at a diagonal to the surface of the graph paper" (9).
(6) Another scored attribute is the presence or absence of a butterfly fracture. This fracture is described in Tencer (16) as follows: "The butterfly fracture results from a combination of bending, which causes the transverse fracture line, and compression, which results in both the oblique fracture, and wedging and splitting off a fragment of bone, termed the butterfly fragment."
(7) The last recorded attribute was the number of fragments produced from the impact. A fragment is arbitrarily defined as greater than 10 mm in any one dimension.

The Pearson chi-square statistic tested the association between categorical attributes. T-tests for equality of means and the Pearson correlation were also used in this study. All statistics are calculated using SPSS 14.0 (SPSS Inc., Chicago, IL) and they are two-tailed. The Pearson chi-square test along with the correction for continuity was used when the smallest expectation was at least one (17). The states of three attributes were minimal and had to be combined in order to meet the minimum expected counts within cells. The rare frequencies of the cells were always combined with the intermediate or mixed cells. Thus, right-angled was combined with mixed in both the proximal and distal edges. Jagged and transverse were put into the intermediate outline for distal fracture outline (shape of broken end) and transverse was combined with intermediate for the proximal fracture outline. Parallel was combined with mixed on the proximal ends of the attribute angle on the Z-axis.

Results and Discussion

Quantification of the differences between wet and dry bones was examined by testing the relative impact velocity and the energy at impact and at failure. Wet bone requires significantly more velocity to break and it absorbs significantly more energy at impact and at failure than dry bone (Table 1; 5,6).

Only one characteristic of perimortem fractures, a jagged fracture outline, was unique to the chronological interval around death and it occurred only once. Only two characteristics of postmortem fractures were unique to dry bones: transverse fractures and right-angled edges, but these were rare. Only two dry bones exhibited the former and only three dry bones exhibited the latter (Fig. 1). Only four butterfly fractures were observed: three on dry bones and one on a wet bone. Postmortem butterfly fractures have also been noted by Ubelaker and Adams (18).

Statistical comparisons between groups of wet and dry bones, however, do exhibit significant differences (see Tables 1 and 2). Wet bones have significantly more smooth surfaces, more fracture lines, and more pieces whereas dry bones have significantly more rough surfaces and fewer fracture lines. Wet bones also had significantly more sharp edges, curved shapes at the end, and diagonal angles on the Z-axis than dry bones, but only on their proximal ends, not their distal ends (Fig. 2). These differences were also more likely to be significant on the proximal ends rather than the

TABLE 1—*Variables at impact; T-tests for equality of means.*

	Bone Type	n	Mean	Std. Dev.	Std. Error Mean	T*	Sig. (two-tailed)
Energy to fail (J)	Wet	42	41.8	31.8	4.9	5.06	0.001
	Dry	34	15.1	11.3	1.9		
Impact energy (J)	Wet	42	88.4	12.2	1.9	5.42	0.001
	Dry	34	63.5	24.4	4.2		
Impact velocity (m/sec)	Wet	41	3.6	0.311	0.05	5.28	0.001
	Dry	34	3.0	0.621	0.11		
Number of pieces	Wet	42	12.5	4.42	0.68	6.08	0.001
	Dry	33	7.2	3.26	0.57		

*Equal variances not assumed.

FIG. 1—*A transverse fracture outline with right-angled edges and a rough surface morphology on a dry left proximal femur, broken 44 days since death.*

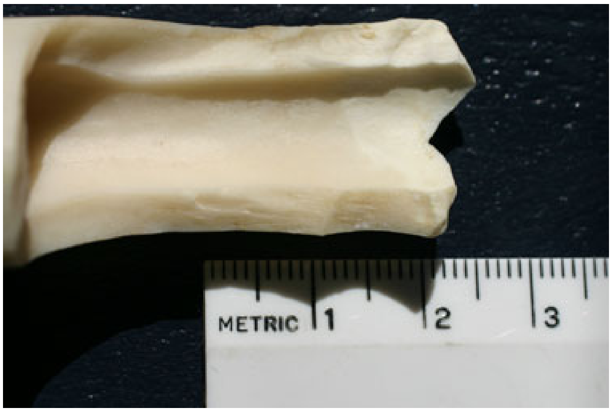

FIG. 2—*A curved fracture outline with sharp edges and a smooth surface morphology on a wet left proximal femur, broken less than 4 days since death.*

TABLE 2—*Attribute comparisons between groups.*

	Bone Type	*n* & Attribute State	χ^2*	*p*-value†
Edges, proximal	Wet	36 sharp; 6 mixed	5.69	0.017
	Dry	20 sharp; 14 mixed		
Edges, distal	Wet	23 sharp; 19 mixed	0.48	0.49
	Dry	15 sharp; 19 mixed		
Fracture lines, proximal	Wet	21 present; 21 absent	4.51	0.034
	Dry	8 present; 26 absent		
Fracture lines, distal	Wet	35 present; 7 absent	8.18	0.004
	Dry	17 present; 17 absent		
Broken end shape, proximal	Wet	39 curved; 3 intermediate	12.24	0.001
	Dry	19 curved; 15 intermediate		
Broken end shape, distal	Wet	25 curved; 17 intermediate	1.85	0.174
	Dry	14 curved; 20 intermediate		
Surface morph., proximal	Wet	38 smooth; 4 rough	15.18	0.001
	Dry	16 smooth; 18 rough		
Surface morph., distal	Wet	25 smooth; 17 rough	5.70	0.017
	Dry	10 smooth; 24 rough		
Angle on *Z*-axis, proximal	Wet	39 diagonal; 3 mixed	9.14	0.003
	Dry	21 diagonal; 13 mixed		
Angle on *Z*-axis, distal	Wet	31 diagonal; 11 mixed	0.77	0.382
	Dry	21 diagonal; 13 mixed		

*Pearson chi-square value with continuity correction.
†Asymptotic significance (two-sided).

TABLE 3—*The significant effects of fusion on the fracture attributes.*

	Fusion	Bone Type	*n* of Attribute	χ^2*	*p*-value†
Proximal edges	No	Wet	17 sharp; 2 mixed	9.49	0.002
	No	Dry	3 sharp; 8 mixed		
Proximal outlines	No	Wet	17 curved; 2 intermediate	9.49	0.002
	No	Dry	3 curved; 8 intermediate		
Proximal surface morph.	No	Wet	18 smooth; 1 dry	15.09	0.001
	No	Dry	2 smooth; 9 dry		
Proximal angle on *Z*-axis	No	Wet	16 diagonal; 3 mixed	7.43	0.006
	No	Dry	3 diagonal; 8 mixed		
Distal fracture lines	Yes	Wet	18 present; 5 absent	5.74	0.017
	Yes	Dry	9 present; 14 absent		
Distal surface morph.	Yes	Wet	16 smooth; 7 rough	5.56	0.018

distal ends of bones. A study by Villa and Mahieu (11) also found long bone fracture outline and fracture angle morphology attributes to have diagnostic value in differentiating green from postdepositional breakage at the statistical or assemblage level.

The variables, epiphyseal fusion, and velocity were also tested to see if they had an effect on fractures. These two variables were examined as layer effects on the fracture attributes (See Table 3). It is the lack of complete fusion rather than the presence of complete fusion, for example, that significantly affects proximal but not distal edges. That is, there are 14 fewer sharp proximal edges in partially fused bones than in completely fused bones. The lack of complete fusion is also a factor in proximal fracture outlines, proximal fracture surface morphology, and the proximal angle on the *Z*-axis. The presence of complete fusion affects distal fracture lines and distal fracture surface morphology. It is the effect of partially fused bones and not completely fused bones that makes proximal surface morphology significantly different between wet and dry bones. The number of pieces of bone at impact is also significantly correlated to the impact velocity (Pearson correlation, $p = 0.01$). Impact velocity is not, however, significantly associated with the presence or absence of proximal or distal fracture lines (*T*-tests, $p = 0.213$ and $p = 0.536$, respectively).

Several additional "unique" features of fractures typical of wet or dry bones were also noticed, although, again, their frequencies were low. Two breaks through the epiphyses occurred only on dry, year-old bones. Breaks through the epiphyses are said to only occur in dry bones and not in wet bones (9). In addition, so-called "true helical fractures" were also noticed in wet bones, but not in dry bones. Helical fractures include features, such as: a radial pattern circling around the diaphysis, a loading point, negative flake scarring, obtuse and acute angles, and radiating fracture fronts (6,9,13). The meaning of the term, "green break" may also vary with climate and/or depositional text (19). Helical fractures and jagged fracture outlines, for example, have occurred in a batch of deer femora that were frozen, thawed, and then broken 18 days after death (pers. obs.). Some forensic anthropologists might use the term perimortem as a taphonomic time interval expressed as a function of the condition of the remains such as those mentioned above, rather than as a chronological time interval expressed in days (4).

Forensic anthropologists must use techniques that meet the Daubert criteria of peer review, reliability, testability, and of known error rates. This report empirically tested and quantified some of the previously recognized features of fracture patterns used in the determination of the chronological time interval of perimortem or postmortem trauma. While the attributes of the fracture patterns used in this study were found to be reliable at differentiating perimortem fractures from postmortem fractures at the statistical level, they were unreliable at differentiating a perimortem fracture from a postmortem fracture on a bone for forensic investigation. For example, in this study, with the exception of one jagged fracture outline, all seven of the features of so-called wet bone fractures were seen on year old bones. A perimortem determination should therefore be made with caution and it should include many of the other important features not tested in this study to make such a determination such as, differential staining or color differences between the fracture surface and the outer cortical surface, hinging, hematoma stains and greenstick fractures (1,4).

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Additional information and reprint requests:
Bruce Panton Wheatley, Ph.D.
Professor, Department of Anthropology and Social Work
University of Alabama at Birmingham
Birmingham, AL 35296-3350
E-mail: bwheat@uab.edu