

PERIMORTEM FRACTURE PATTERNS IN SOUTH-CENTRAL TEXAS:
A PRELIMINARY INVESTIGATION INTO THE
PERIMORTEM INTERVAL

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ABSTRACT

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Establishing a relationship between skeletal trauma and time since death is one of the most frequent requests made of forensic anthropologists. To this end, skeletal biologists and forensic anthropologists typically distinguish three gross timeframes when classifying traumatic episodes: antemortem, perimortem and postmortem. The perimortem interval, which occurs around the time of

death, is poorly understood (Sauer, 1998). There have been several studies investigating long bone fracture characteristics during the perimortem interval (Weiberg, 2005; Bell et al., 2006; Janjua and Roberts, 2008), but none have been undertaken in the unique climate of southwest Texas. To improve understanding of perimortem bone changes, 50 pig femora were allowed to weather at the Texas State Forensic Anthropology Research Facility at Freeman Ranch, in San Marcos, TX for up to 18 weeks (PMI=126 days. A portion of the sample was broken at regular 2-week intervals by application of a known dynamic force, and the resulting fracture outlines, angles, and edges, were examined and documented. Analysis showed that there was no statistically significant change in the frequency of fracture patterns or fracture angles between bones broken shortly after death (PMI=0), and those broken in the subsequent trials. There was, however, a statistical trend toward rougher fracture edges. This study demonstrates the difficulty in estimating whether fractures occurred during the perimortem interval. Future studies should examine whether these observations hold for different seasons and different environments.

CHAPTER I

INTRODUCTION

Establishing a relationship between skeletal trauma and time since death is one of the most frequent requests made of forensic anthropologists involved in the identification of skeletonized remains. To this end, forensic anthropologists typically distinguish three gross timeframes when classifying traumatic episodes: antemortem, perimortem, and postmortem. Issues arise because bone decomposition is a continuous process, but anthropologists typically rely on non-quantifiable indicators to establish largely arbitrary divisions separating these three timeframes. Though these temporal categories may be interpreted as discrete (e.g. Sauer, 1998), such categorization of a continuous variable creates uncertainty when it comes to assigning bone trauma to a particular state. Additionally, establishing when a fracture occurred during the postmortem interval (PMI) becomes particularly difficult when a traumatic modification is of unknown cause or origin. Although there has been research into the time that must elapse before bones cease to exhibit 'green' fracture characteristics (e.g. Wieberg and Wescott, 2008; Wheatley, 2008), none have been undertaken

in climates similar to central Texas. Establishing a weathering interval for this area is important in that weathering rates, the speed at which bones decompose, differ with climate (Behrensmeyer, 1978).

Additionally, the 1993 *Daubert* ruling regarding expert witnesses emphasizes the need for scientific methodology, peer review, known error rates, and general acceptance within the scientific community (Christensen, 2004). This research will aid forensic anthropologists who must testify in the courts regarding taphonomic damage and time-since-death estimation by providing time frames during which different fracture characteristics may be manifested.

The goal of my research is twofold. The first is to determine whether criteria can be established to distinguish perimortem fractures from postmortem fractures (discussed below). The second is to establish the time frame required for a bone to decompose from a moist condition to a dry one, which could be interpreted through the presence of postmortem-type fracture characteristics.

The questions addressed in this experiment are: 1) is there a difference in fracture characteristics seen in bones broken within 24 hours of death (PMI = 0 days) and those broken 18 weeks later (PMI = 126 days), 2) is there a distinct characteristic separation between perimortem and postmortem fractures, and 3) is there a visible change in the fracture characteristics as bones progress along the perimortem (fresh) to postmortem (weathered) interval.

This research has multiple implications. Foremost, it brings blunt force trauma analysis and timing in line with the *Daubert* criteria regarding expert

witnesses. This project should allow medical examiners and forensic anthropologists to make supportable statements regarding the timing of blunt force trauma. To this end, this experiment will also help medical examiners to ascertain whether a fracture is associated with the cause or manner of death by determining how soon after death it occurred. Finally, it will help to solidify the definition of how long the perimortem interval lasts in the unique environment of south-central Texas, as well as other comparable environments

As a function of the hot, subtropical climate characteristic of south-central Texas (Kjelgaard et al., 2008), it is believed that bones left exposed in this environment will dry faster (i.e., lose their moisture content and plasticity) than they do in regions where previous studies have been undertaken (e.g. Janjua and Rogers, 2008; Wieberg and Wescott, 2008). If the dry-bone state is achieved more quickly in this environment, it follows that fractures showing postmortem characteristics should appear sooner as well. I hypothesized that there would be no distinct temporal separation between perimortem fractures and early postmortem interval fractures. Despite this, I thought it likely that by the termination of the study at 18 weeks the majority of bones broken should exhibit postmortem-type fracture characteristics.

To test these hypotheses the macroscopic and microscopic blunt force fracture characteristics on pig femora were broken, after the bones were broken at two-week intervals. More specifically, I delineated the macro- and microscopic changes that occurred in bones broken at two-week intervals with

the goal of further delineating the changes that occur within the bone's structure that would influence fracture appearances as bone weathers and dries.

The following section provides an overview of the terminology and characteristics that will be employed throughout the remainder of this thesis. This introductory section is followed by a review of previous taphonomic fracture studies. Afterwards, the reader will find a detailed materials and methods section outlining procedures employed to collect and analyze the data for this research experiment. Results and statistical analyses may be found after the methods section, followed by a discussion of the data, the limitations and applications of this experiment, suggestions for further research, and implications for forensic anthropological practitioners and law enforcement agencies.

Functional Terminology and Characteristics

Perimortem injuries occur at or around the time of death, and are frequently believed to be associated with cause or manner of death. Komar and Buikstra (2008) state that since the perimortem period begins with the "interaction between [an] individual and his or her cause of death" (26) it may potentially span a long period both before and after death. Despite this ambiguous timeframe, perimortem fractures are typically diagnosed by observing that traumatized (i.e. fractured) bones broken during this interval will

react in a manner relatively consistent with living bone – a large organic component remains, and affords the bones plasticity and ductility that is absent in dry or weathered bones (Johnson, 1985).

Postmortem Trauma

Postmortem traumas occur after the time of death and may be caused by taphonomic forces (i.e., animal scavenging, soil pressure or movement) or even by excavation (Ubelaker, 1995). Forensic anthropologists (e.g. Maples, 1986; Sauer 1998) have established differences between postmortem and perimortem fracture patterns. Additionally, Piekarski (1970) observes that as vascularity and flexibility of a bone decreases due to weathering and desiccation, fractures tend to propagate more slowly. This is due to the fact that fracture fronts must navigate around the channels left by decomposed or dried organic structures, leading to jagged fracture surfaces and stepped, longitudinal fractures (Herrmann and Bennett, 1999).

Antemortem Trauma

Antemortem trauma, occurring before the time of death, is characterized by visible healing at the site of injury (Sauer, 1998; Galloway 1999). Antemortem fracture patterns have been relatively well-documented in both the anthropological and clinical literature (e.g. Sevitt, 1981; DiMaio and DiMaio, 1993). The initial injury is associated with hemorrhaging at the injury site and

necrosis of the damaged tissue (Cruess, 1984; DiMaio & DiMaio, 1993). Soon after, osteoclast activity smoothes the initial injury site, paving the way for osteo- and chondroblastic cells to begin the formation of new cartilage and bone tissues to bridge and unify the gap. The results of these repair processes become visible (without the aid of a microscope) as soon as seven days after injury (Sevitt, 1981).

Perimortem Trauma

Perimortem fractures, on the other hand, will typically show no evidence of healing, though traumas associated with the perimortem interval are typically classified as such because they exhibit “green” or “fresh” breakage patterns without visible healing (Galloway et al., 1996). But how long does this ‘perimortem interval’ last? Estimates vary. Janjua and Roberts’ (2008) research in Ontario indicates that it takes bone approximately 200 days to reach a stage of “advanced decomposition,” which they measured based primarily on weathering and color change. Conversely, Bell et al. (1996) claim that buried bones may remain in the ground for five years or more before they begin showing any sort of postmortem change.

Fracture Terminology and Morphology

Effective discussion of trauma (in this research, blunt force trauma specifically) necessitates the establishment of consistent, universal terminology. There are numerous terms employed when discussing fracture morphology, but

only definitions relevant to this experiment are included here. The terminology is adapted from and consistent with those used by Wieberg and Wescott (2008).

For the purposes of this research, trauma is considered to be any form of damage or modification. The fracture surface, or fracture edge, is the cross-section of compact cortical bone exposed when dynamic force passes through the bone and causes it to fail. Fracture angle is defined as the angle that is formed by the fracture surface and the outer surface of the bone. Fracture outline refers to the path taken by the fracture front resulting in the exposure of compact bone.

Typically, once the possibility of antemortem injury is ruled out based on the absence of healing evidence, the relative freshness of a break is determined largely based on three factors: color change, the shape of the fracture, and the angle of the fracture surface relative to that of the bone (Einhorn, 2005). Microscopic characteristics, such as the visibility of osteons, may also be considered (Maples, 1986).

Staining of the exposed surfaces of a bone may have several causes, including staining by decompositional fluid or blood, or by the sediments and minerals carried in soil or water (Pickering and Bachman, 2009). Staining customarily affects only the bone surfaces that are exposed to the staining agent; therefore, a fracture with the same coloration as the external bone may, under certain circumstances, be assumed to have occurred before the postmortem period. The fracture, in this case, may not be taphonomic in nature (Galloway, 1999).

Conversely, a fracture surface that presents a different color (i.e. lighter) from the cortical bone is likely taphonomic in nature, and occurred recently enough that the color of the fracture surface has not had enough time to equalize (Johnson, 1985). However, this is not necessarily true in cases of longer duration. For example, a burial of ten years will likely show the same bone color on all margins, regardless of whether fractures are the result of perimortem trauma or burial-related taphonomy.

Weathering affects both a bone's color and the way it fractures. The degree of weathering on a bone is strongly correlated with split line and helical (curvilinear, spiral) fracture formation, as well as the presence of a visible impact point (Johnson, 1985). As it dries, bone loses its flexibility and becomes harder, and therefore more resistant to penetration. This brittleness, however, also means that the bone responds to impact in a way that differs from fresh bone (Evans, 1973). Fresh bone retains high water content and flexibility of collagen fibers, which give the bone tensile strength that dry bone lacks (Johnson, 1985; Maples, 1986). When subjected to dynamic loading force, such as that produced by a dropped weight (i.e., point loading), the bone's inherent pliability distributes the force away from the site of impact. Fresh bone fractures are most frequently characterized as spiral, oblique, or circular in nature (Figure 1) (Galloway, 1999).

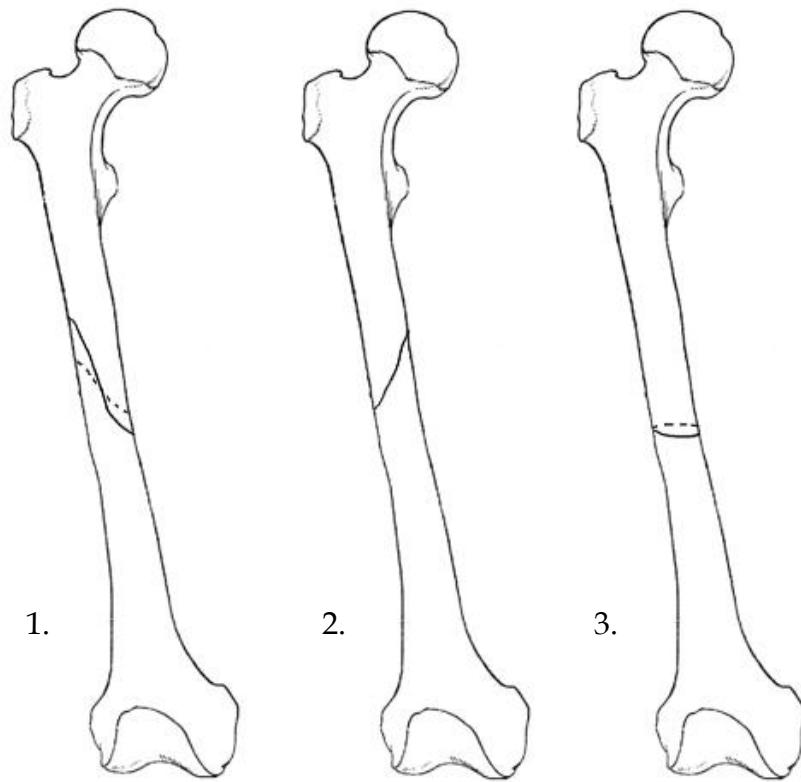


Figure 1. Typical fracture categories. 1 - spiral; 2 - oblique; 3 - circular.
(adapted from Newton, 1985)

Under a dynamic force, spiral fractures are caused by a tensile shear failure of the bone's collagen structure, (Evans, 1973; Frasca et al., 1977) although the fractures are prevented from spiraling all the way around the bone due to the longitudinal orientation of the collagen and osteon matrices. The distribution of force causes the bone to splinter into irregularly-shaped fragments, which are typically noticeably longer than they are wide (Bonnischen and Will, 1990). Thanks to the flexibility of the collagen matrix, the point of impact is often highly identifiable in fresh bone, though this visibility drops off quickly after the bone begins to show horizontal cracking (Johnson, 1985). Additionally, hackle marks,

or small fissures occurring near the impact site, may appear on green bones. These marks will typically run parallel to the direction of the fracture surface, and may not fully penetrate the cortical bone (Bonnischen and Will, 1990).

“Greenstick,” butterfly, or incomplete fractures (Figure 2) may also occur with some regularity during the perimortem period and may be used to assess whether a bone was fresh or dry when it was fractured (Galloway, 1999).

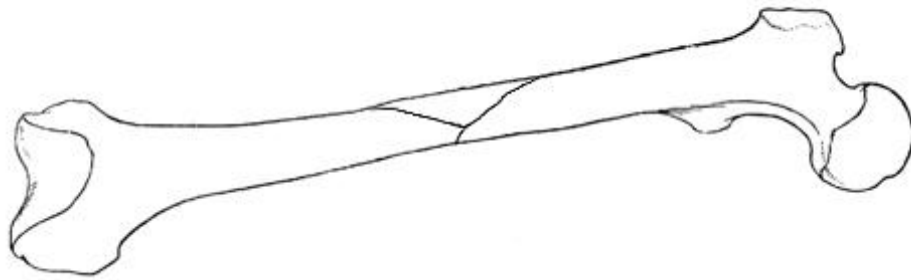


Figure 2. A “butterfly” fracture. Diagram of a “butterfly” fracture on a long bone. (*adapted from Newton, 1985*)

Drying associated with weathering prompts a change in fracture patterns on both a macro- and microscopic level (Amprino, 1958). In addition to a tendency to break into a larger number of smaller fragments, dry bones may also show cortical flaking and cracking. Where fresh bones exhibit tensile shear failure, dry or weathered bones experience horizontal tension failure in which application of dynamic force creates angular, stepped fractures across the diaphysis.

The edges of the resulting fragments may be horizontal or perpendicular to the long axis of the bone, or may run on a diagonal across (Johnson, 1985). As

bone loses its moisture and dries out, the outline of the fracture surface will change from curvilinear to a stepped pattern. This stepping occurs because dehydration prompts the formation of cracks in the cortical bone tissue; as force radiates out from the point of impact, it is interrupted upon intersection with these surface cracks. The force then travels along the crack, resulting in a stepped appearance (Figure 3) (Bonnischen and Will, 1990). Conversely, in fresh bones, fracture surfaces tend to align themselves along the grain of the collagen fibers, which are oriented along the long axis (Bonnischen 1979).

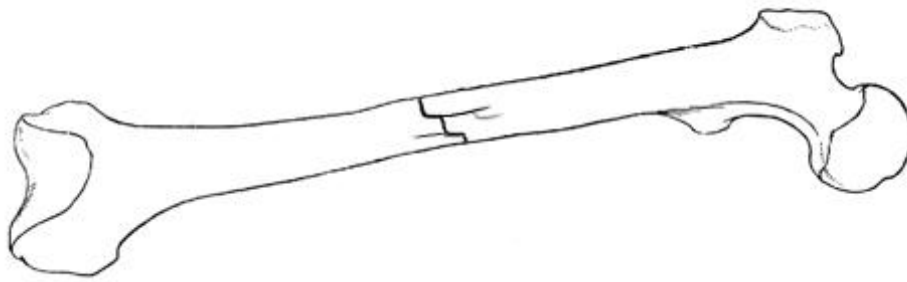


Figure 3. A transverse fracture. Diagram showing a stepped, transverse fracture outline on a long bone.

Despite these general patterns, it is difficult to consistently and firmly evaluate the outline of a given fracture. Johnson (1985) states that a fracture outline may fall into five different categories: curved/rounded, transverse/straight, converging, stepped, and scalloped. Villa and Mahieu (1990) condense Johnson's categories and identify three gross fracture patterns: 1) transverse, 2) curvilinear (U- or V-shaped), and 3) intermediate. Transverse

fractures are fractures that have fronts running parallel or perpendicular to the long axis of the bone. These may be associated with cortical cracking as discussed above. Curvilinear fractures come in two forms (Figure 4). U-shaped fractures can also be characterized as partial or complete spiral fractures encircling the diaphysis. V-shaped fractures are pointed. These two fracture types are the most difficult to consistently quantify due to the variety fracture outlines each possibly can produce. The third type, intermediate fractures, combines features of U- or V-shaped outlines with the stepping associated with transverse fractures.



Figure 4. A curvilinear fracture. Diagram showing a curvilinear fracture outline on a long bone.

Another tool employed to analyze fractures is the angle of the fracture surface itself. There is less of a consensus on the relationship between fracture surface angle and the freshness of the bone than there is on bone greenness and fracture shape (e.g., Bonnischen, 1979; Johnson, 1985). Fracture angles are characterized as acute, obtuse or right (Figure 5).

The term fracture angle refers to the angle formed between the exposed fracture surface and that of the exterior cortical bone (Villa and Mahieu, 1990; Wieberg and Wescott, 2008). Green bone fractures consistently exhibit both obtuse and acute angles (Villa and Mahieu, 1990). Right angles are ostensibly associated primarily with dry bone breaks (Johnson, 1985; Villa and Mahieu, 1990) but Bonnischen (1979) and Morlan (1984) both note that right angles may occur with some frequency in fresh bone as well.

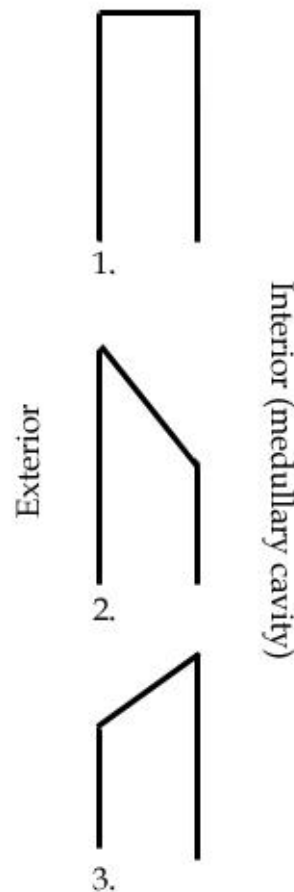


Figure 5. Cortical bone fracture angles. Diagram illustrating three different cortical bone fracture angles. 1 - right; 2 - acute; 3 - obtuse.

In addition to shape and angle, fractures can be characterized by the roughness of the fracture surface. Typically, green bones produce fractures with smooth surfaces (Villa and Mahieu, 1990). Dry bones will have fractures with rough, jagged, or stepped surfaces (Bonnischen, 1979; Morlan, 1984; Villa and Mahieu, 1990). This roughness extends onto the microscopic level as well because the fracture surface in dry bone frequently perpendicularly intersects the desiccated bundles of collagen.

As this brief outline demonstrates, while there has been clinical and anthropological research demonstrating characteristics that distinguish fresh from dry bone fracture, there has been little effort devoted to developing baseline sequences for bone decomposition rates. Until recently, there has been minimal investigation into the perimortem period or attempts to delineate the changes that occur in bones during the period immediately following death. This research project will attempt to address this data deficiency by examining how weathering and the passage of time affects the manifestation of blunt force skeletal traumas.

CHAPTER II

REVIEW OF PREVIOUS RESEARCH

The data from this experiment do not exist in a vacuum. There have been several investigations into how bone weathering and drying could affect the manifestation of blunt force taphonomic trauma, and this research is discussed below.

Janjua and Rogers (2008) examined bone drying in pig femora in southern Ontario, Canada. They observed that, in the temperate environment in which they were working, bones did not exhibit significant cortical drying until approximately 9 months after exposure. During the period from 2-6 months after death they observed that the bones had no odor and that, though there was some adherent soft tissue, the bones themselves were only moderately greasy.

Wieberg and Wescott (2008) performed a systematic investigation into how blunt force fractures changed in appearance as a bone weathers in central Missouri. In their research they employed various pig long bones (including ulnae, tibiae, and femora), which they allowed to weather outdoors for up to 141 days. The bones were broken at 28-day intervals and the fracture characteristics

of each bone were recorded. Additionally, the authors analyzed the ash percentage of each bone to assess moisture content. They found that bone moisture content declines rapidly in the month or so immediately following death, before leveling out to lower than that of living bone tissue. The association between bone moisture and fracture characteristics has been mentioned in previous research (e.g., Amprino, 1958; Johnson, 1985; Maples, 1986) but before the publication of Wieberg and Wescott's research there has been little attempt to associate particular bone moisture levels to the perimortem interval.

Changes in fracture pattern associated with bone weathering have also been investigated by Wheatley (2008) in central Alabama. This study differs from most other inquiries in that Wheatley employed deer femora rather than pig remains. Deer bones differ histologically from human and pig bones in that they have both plexiform and haversian bone tissue, whereas in healthy human bone only haversian tissue is present (Wheatley, 2008). Pigs, too, have only haversian-type bone tissue. One major limitation of this research is that the precise time of death is unknown since Wheatley acquired his sample from a taxidermy processing location. Wheatley's experiment suggested that "wet" or fresh bones are typified by a high number of fracture lines and greater fragmentation. This statement runs contrary to previous observations by Maples (1986), who observed that dry bones are more prone to trauma-related flaking and fragmentation than are moist bones.

The limited base of research related to perimortem fracture timing highlights the need for further investigation into this poorly understood interval. Additionally, where data from these experiments overlap with each other and previous (e.g. archaeological) research into the timing of fracture characteristics there are notable inconsistencies. These discrepancies may spring from several sources.

The first is that interobserver disagreement regarding the interpretation of fracture characteristics may occur, especially with reference to variables like fracture surface roughness that exist on a continuum. Another explanation may be the wide range of climatic zones in which research has been undertaken. Differing precipitation and humidity levels, along with sun exposure and myriad other factors, could affect the rates at which fracture characteristics change, or determine whether they appear at all. A third issue is nonuniformity in the elements used. Janjua and Rogers (2008) studied pig femora, as did Wieberg and Wescott (2008), although the latter pair also included forelimb elements and tibiae in their experimental design. Wheatley (2008) limited his sample to deer femora, but acknowledges that deer skeletal elements have structural differences that could make them a poor proxy for human remains.

In light of these concerns, I have attempted to maintain uniformity in the experimental design laid out in the following chapter. In addition to a detailed weather record, the precise postmortem interval of each sample element is known. Pig bones are acknowledged to be an acceptable proxy for human

remains in skeletal trauma research (Tucker et al., 2001), and only femora are included for consistency. The following section will lay out the precise sample and methods of analysis used in this experiment.

CHAPTER III

MATERIALS AND METHODS

Materials

Skeletal Elements:

This experiment utilized 50 femora from 200-250 pound domestic pigs (*Sus scrofa*). Pig bones were chosen because they provide an acceptable proxy for human bones in fracture research due to similarities in microstructure and bone development (Tucker et al., 2001). Additionally, pig bones have been used in previous research into taphonomic fractures (e.g., Janjua and Rogers, 2008; Wieberg and Wescott, 2008); the utilization of porcine materials for this experiment allows for comparison between the results of this research and earlier investigations. The bones were purchased from Granzin's butcher shop in New Braunfels, Texas, after the pigs were slaughtered for public consumption in a manner consistent with USDA Directive 6900.2 regarding the humane handling and slaughter of livestock (USDA FSIS, 2003). The majority of the soft tissues were removed from the bones at the butcher shop, leaving minimal muscle,

cartilage and fat attached at the proximal and distal ends. I chose to employ defleshed bones to better simulate the effect of weathering on already-skeletonized remains, and because decomposition of soft tissues was not a focus of this research. The periosteum was intact on all of the bones.

All bones were purchased from the butcher and frozen within 24 hours of the pigs' death. As bones were acquired, they were immediately frozen by wrapping them in plastic bags and placing these bags into paper sacks to prevent freezer damage. This also significantly reduced differential decomposition or drying, such that the beginning of the postmortem interval for this experiment was the same for all bones, regardless of the date of purchase. Freezing and subsequent controlled thawing does not create a statistically significant change in bone mechanics, and is therefore an acceptable way to maintain the bones before the beginning of the experiment (Tersigni, 2006).

Research Design

At the beginning of the experiment the bones were removed from the freezer and allowed to thaw in a temperature-controlled room at the Grady Early Forensic Anthropology Research Laboratory (GEFARL) at Texas State University-San Marcos until they reached the ambient air temperature of 76° F (24° C). An initial sample of 5 bones was fractured using an apparatus immediately after thawing was complete (Figure 3.2). Damage on these bones represented perimortem trauma occurring at or around the time of death.

The remaining 45 femora were transported to the Forensic Anthropology Research Facility (FARF), an outdoor human decomposition laboratory at Freeman Ranch in San Marcos, TX and arranged in a 1-meter-by-2-meter steel-frame cage located on a flat area of ground at the FARF where they were allowed to weather (Figure 6). The cage received full sun during the day, though it was shaded in the early morning and evening. The environment surrounding the cage is a mixture of dry grasses, live oak and prickly pear cactus, along with various species of local shrubs such as mesquite. The openings in the cage measured approximately 5cm x 3 cm, and were small enough to prevent large scavenger (e.g. coyote, raccoon, vulture) action, but still large enough to admit small rodents (e.g. rats, mice) and entomological agents. None of the bones were small enough to be removed through the openings in the cage.



Figure 6. Steel cage to protect bones from scavenger activity.

Daily precipitation, average precipitation for the month, average maximum and minimum temperatures, daily maximum and daily minimum temperatures were obtained from a weather station located in close proximity to the decomposition facility, and maintained by the Texas A&M University department of Soil and Crop Sciences. The experiment was continued over 24 weeks, with five bones removed and fractured every two weeks. This time frame was chosen based on previous research by Wieberg (2005) in which the bones in a similar experiment were broken every 4 weeks. Due to differences in the climates between the two experimental locations, namely the arid environment found in central Texas, the choice was made to fracture the bones more frequently to analyze finer gradations in weathering-related changes to the bones' fracture characteristics.

Bones removed from the cage at the FARF were assigned an identifying number according to the postmortem interval period under study, and a letter indicating the order in which they were removed from the enclosure. For example, bone 14a would represent the first sample removed for analysis after 14 days (2 weeks) of weathering. After they were removed, they were transported to the GEFARL for fracturing.

The fracturing apparatus was designed to produce a dynamic force capable of creating a complete midshaft fracture. The basic design of the apparatus was adapted from Wieberg's (2005) research. This apparatus consisted of a wood (pine) 2x4 upright screwed to a steel-plate base. The steel

plate measured approximately 1cm thick. The bone to be fractured was placed on this steel plate, against the wooden upright. Attached to the upright was a length of PVC piping, intended to serve as a guide to the weighted pipe that struck the bone. The weighted pipe itself consisted of a 0.95 meter galvanized steel pipe filled with #9 lead shot and sealed at each end, weighing 6.4 kg. When released, the weight dropped through the PVC guide-pipe to impact a bone positioned against the wooden upright (Figure 7).

The weight was dropped from a height of 1.48m, measured from the surface of the steel plate to the bottom of the pipe. This height was calculated using the formula ghm/A to compute dynamic force, where g = acceleration due to gravity (m/s^2), h = height (m), m = mass (kg) and A = surface area (m^2). The surface area of the pipe where it impacts the bone is $0.0085 m^2$. Doblare (2003), along with Frost (1967) and Evans (1973) observe that a dynamic force of at least $10500 kg/m^2$ is required to cause a complete fracture in bone tissue when the impact occurs perpendicular to the long axis of the bone. For this apparatus, the dynamic force was calculated to be $10920.66 kg/m^2$:

$$[(9.8m/s^2)(1.48m)(6.4kg)]/0.0085m^2 = 10920.66 kg/m^2$$

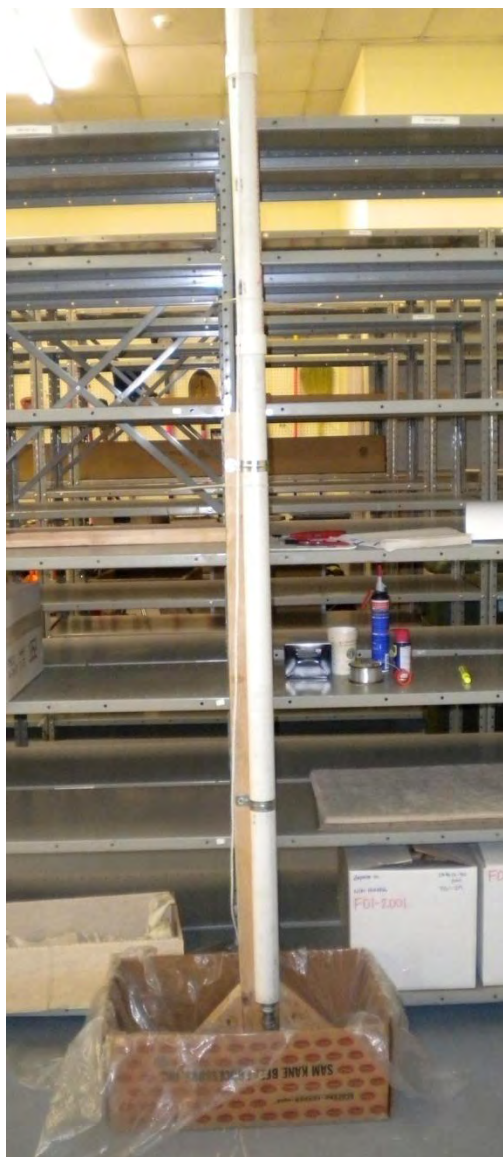


Figure 7. Bone-breaking apparatus. The box is intended to contain any fragments that separate when the bone is broken.

Methods of Analysis

Variables Observed:

The observed variables used to evaluate the bones were: weathering, fracture angle, fracture outline, and fracture surface smoothness. These characteristics were consistent with the macroscopic observations used in previous studies (Morlan, 1984; Johnson, 1985; Villa and Mahieu, 1991; Sauer, 1998).

Additional macroscopic and microscopic features were also analyzed. Macroscopic observations included the approximate number of fragments produced by the fracture apparatus, the approximate size of these fragments, the general condition of the bone, the presence of mold or other organic activity, and any other notable irregularities in the specimen. These criteria, too, were selected based on their use in other similar research undertakings (Johnson, 1985; Villa and Mahieu, 1991; Sauer, 1998). Microscopic analysis focused on the smoothness of the fracture surface.

Bone weathering was determined using a table adapted from both Behrensmeyer's (1978) and Todd's (1987) published works on weathering. Where Behrensmeyer's table included only fresh, "moist" bone (Stage 0), and dry, cracked bone (Stage 1), Todd expanded upon this to include a weathering stage where the bone is neither fresh nor cracked, and I have followed both Todd

and Wieberg (2005) in including this stage in my analysis. Table 1 below employs Todd's stages but also incorporates Behrensmeyer's descriptive characteristics (after Wieberg, 2005).

Table 1. Bone weathering stages. Adapted from Behrensmeyer (1978), Todd (1987) and Wieberg (2005)

Stage	Weathering	Descriptives
0	Unweathered and moist	Soft tissues may be present
1	Unweathered and dry	Articular surfaces intact, no flaking
2	Minimal surface weathering	Some cortical & longitudinal cracking
3	Moderate weathering and minimal flaking	Articular surface deterioration, deeper cracks, majority of surface intact
4	Severe weathering and moderate flaking	Limited areas of intact cortex (<50%); crack depth <1.5mm
5	Severe/extensive flaking	No intact surface, splintered/rounded cracks,
6	Loss of bone viability	Trabeculae exposed, severe deterioration

Following Villa and Mahieu (1991), the outline of each fracture produced by the apparatus was characterized as either transverse (parallel or perpendicular to the long axis of the bone), U- or V-shaped, or as intermediate (containing characteristics of both fracture outlines). This determination was based upon fracture outlines for all fragments produced rather than any particular fracture.

The fracture angle is considered the angle between the outer cortical bone and the fracture surface. Fracture angles were characterized as acute, obtuse, or right. Both acute and obtuse angles are associated with fresh, green bone, whereas right angles are a characteristic of dry bone fractures (Villa and Mahieu, 1991; Galloway, 1999). Three angles were analyzed on each specimen, from

different fracture surfaces when it was possible. It is possible for two different fracture angles to exist along a single fracture curve; where this occurred, it was noted.

Microscopic analysis of the fracture surface was carried out using a stereoscopic microscope. Microscopic analysis was focused on determining the smoothness of the fracture surface. The microscopic fracture surface was coded as either smooth or ragged, with ragged surfaces associated with older, drier bone (Weiberg, 2006).

Categorical Statistical Analysis:

All statistical analyses were performed using the predictive analysis statistics program PASW 18.0 (SPSS Inc., 2009). An ANOVA test was used to determine correlations between fracture outline and PMI, fracture edge morphology and PMI, and fracture angle and PMI. ANOVA tests operate with certain assumptions: first, that all items within a sample may change independently, and second, that there is a normal sampling distribution (Sharp, 1979).

Statistical tests were performed after first numerically coding the fracture characteristics (Table 2). Since postmortem interval is already a numeric count of the days elapsed since death, it was left as-is. Fracture edge morphology was scored as follows: Smooth surface = 1, Intermediate surface = 2, Rough/Jagged

surface = 3. For the fracture outline variable, a U- or V-shaped outline = 1, Intermediate outline = 2, Transverse/Stepped outline = 3.

Fracture angle was dealt with in a slightly different manner. Because both acute and obtuse angles (or a combination of the two) are considered to be the fresh-bone state, all of these states were coded as 1. Fracture angles showing a combination of acute, obtuse and right angles were considered to be the intermediate state, and were coded as 2; bones showing only right angles were coded as 3.

Table 2. Codes employed in analysis of fracture characteristics. Fresh-bone characteristics (1), dry-bone characteristics (3), and intermediate characteristics (2).

Code	1	2	3
Fracture Edge	Smooth	Intermediate	Jagged
Fracture Outline	U-/V-shaped	Intermediate	Transverse/Stepped
Fracture Angle	Acute and/or Obtuse	Combined A/O & R	Right only

ANOVA, or Analysis of Variance tests, allow for the testing of multiple variables without compounding the incidence of Type I error. Type I error leads to the rejection of the null hypothesis when it is actually true (Sharp, 1979).

ANOVA tests all variables at once, and therefore reduces the chance that small errors will be inflated by subsequent tests. This test provides both an F-value and an R²-value. These two variables together are helpful in determining the

strength of the relationship tested by an ANOVA analysis. The F-value indicates whether there is a likely dependency between two variables. If the F-value is greater than 1, it suggests that there is a dependency between the variables; the larger the F-value, the stronger the indication. F-values, however, can be easily skewed by anomalous values. R^2 -values are therefore valuable because they present the consistency of the inter-variable dependency. An R^2 -value will be a number between -1 and 1. The closer the value is to either the positive or negative integer, the more consistent the relationship indicated by the F-value (Madrigal, 2008).

CHAPTER IV

RESULTS

Bones were fractured by the application of a dynamic force of 10920.66 kg/m² perpendicular to the long axis of the bone. The majority of specimens showed complete fractures in which the bone was broken into two or more fragments along all PMI/time intervals. Of these complete fractures, the majority were comminuted-type fractures composed of three or more fragments. Bones primarily broke into two larger pieces and multiple smaller fragments, which typically ranged in size from 5mm to 30mm maximum length. No bones showed evidence of fracture or trauma unassociated with this study.

Bones broken at PMI=0, immediately after death, all showed a U- or V-shaped fracture outline and acute or obtuse fracture angle (Table 3). The fracture surface had a smooth texture both macroscopically and when viewed with a binocular microscope. These fracture characteristics formed the baseline for all further analyses, as they represented the state of bones broken immediately after death.

Weathering-Related Changes:

During the weathering period from 0 to 18 weeks the bones underwent some visible external changes. After the largely-defleshed bones were placed into the weathering enclosure they experienced rapid surface darkening which persisted through the duration of the experiment.

Fatty tissue remained on the distal ends of the bones, and this tissue remained greasy and pliable. During week 5 of exposure, small animal scavenging removed the remains of these fatty tissues though the bones themselves were not damaged and there was no presence of gnawing marks. Additionally, insect (fire ant) activity was observed at several points during the weathering period, notably immediately following periods of rainfall. Fly larvae (maggots) were never observed on the bones.

The bones never progressed beyond weathering stage 0 (unweathered and moist, with soft tissues present) as laid out by Behrensmeyer (1978), Todd (1987) and Wieberg (2005) (Table 1).

Table 3. Monthly temperatures and precipitation. Monthly average high and low temperatures and total precipitation over the course of the experiment in San Marcos, Texas.

Month	Avg. Daily Low (°C/°F)	Avg. Daily High (°C/°F)	Precipitation Total (mm)
July 2009	22.24/72.03	38.25/100.85	20.22
August 2009	20.54/68.97	37.88/100.19	3.73
September 2009	16.51/61.78	29.56/79.80	147.50
October 2009	10.92/51.66	23.42/74.17	299.52
November 2009	4.01/31.22	19.56/67.21	108.45

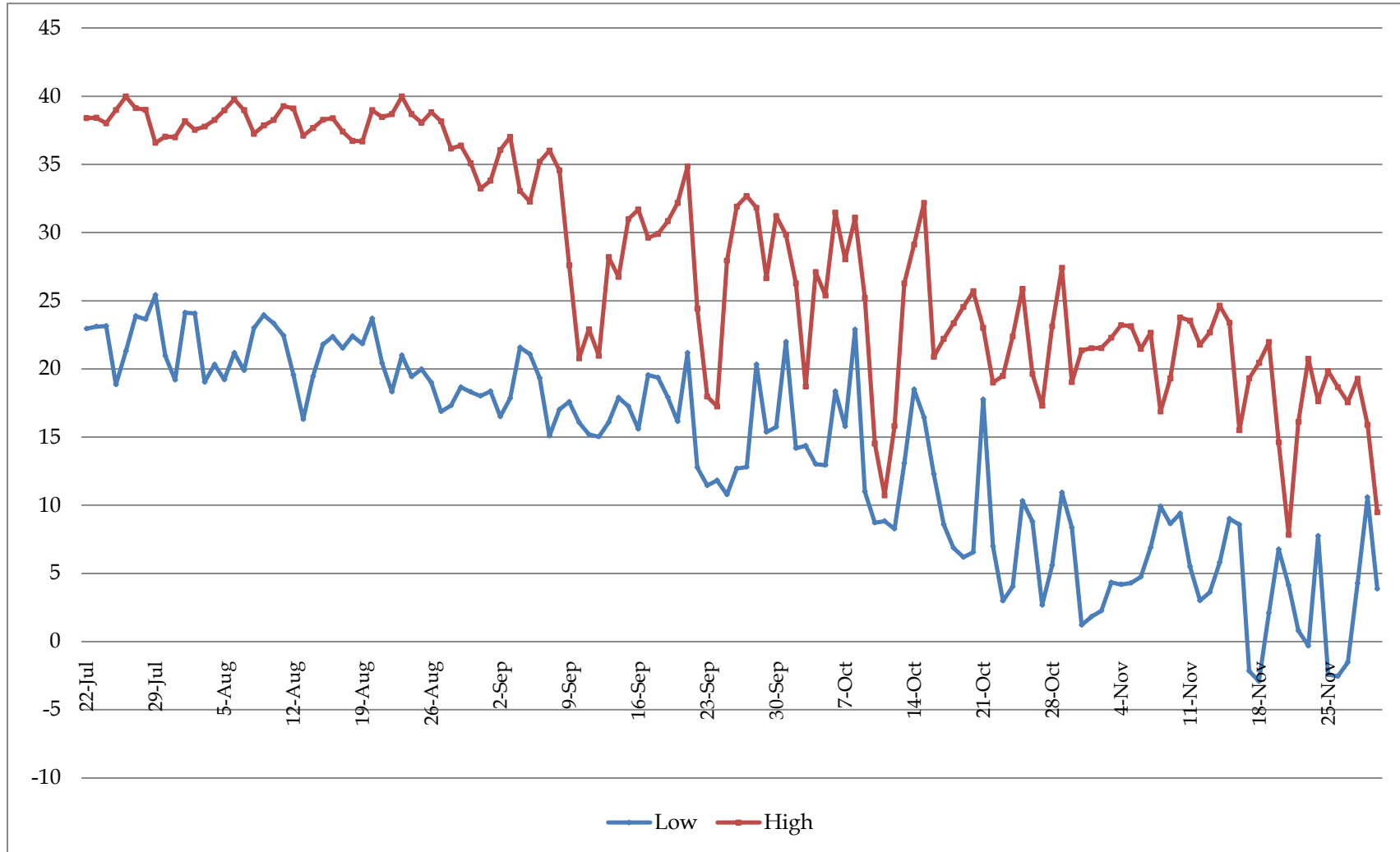


Figure 8: Daily High and Low Temperatures. Daily minimum and maximum temperatures during the decomposition interval (July 22-November 30) recorded by a weather station at the decomposition site.

Fracture Characteristics

Fracture surfaces tended to change over time from a smooth surface to a jagged one, both macroscopically and microscopically, though initially jaggedness was only visible on a microscopic level. The fracture outline transitioned from U- or V-shaped to transverse. Some bones showed an intermediate hybrid outline that incorporated characteristics of both fracture outlines. Table 4 outlines the ratio of 'fresh' (i.e. V-shaped) to 'old' (i.e. transverse) fractures for each PMI period.

Overall, there was a trend toward increased incidence of transverse fractures as time progressed, though V-shaped fractures continued to occur even through the final test (Table 5). The majority of the fracture outlines were V- or U-shaped, or intermediate between V-shaped and transverse.

Statistical Analysis

Statistical tests focused on the correlation between fracture edge, fracture outline, fracture angle, and the postmortem interval. Both fracture edge roughness and fracture outline showed a positive correlation with time elapsed since death, though the statistical strength of this correlation varied (Table 5). Fracture outline proved to have a stronger correlation than fracture edge. Because fracture angle did not show significant change over the course of the experiment, no further statistical tests were run on this variable.

Table 4. Summary of bone assessment counts. Including surface appearance, fracture angle, fracture outline, and overall assessment.¹

Trial	Surface appearance			Fracture angle			Outline Appearance			Assessment	
	Jagged	Smooth	Inter.	Acute & Obtuse	Right	Mix	U-/V-shaped	Transv.	Inter.	Peri.	Post.
PMI = 0	0	5	0	5	0	0	5	0	0	5	0
PMI = 14	0	5	0	3	0	2	4	0	1	5	0
PMI = 28	0	4	1	2	0	3	4	0	1	5	0
PMI = 42	0	1	4	2	0	3	3	1	1	2	3
PMI = 56	0	2	3	1	0	4	2	0	3	3	2
PMI = 70	1	1	3	0	2	3	1	1	3	2	3
PMI = 84	2	1	2	1	2	2	1	2	2	2	3
PMI = 98	1	2	2	1	1	3	1	1	3	2	3
PMI = 112	2	1	2	1	1	3	2	2	1	1	4
PMI = 126	2	0	3	2	1	2	2	1	2	2	3
Total	8	22	20	18	7	25	25	8	17	29	21

¹ Inter. – intermediate; Mix – combination of right, acute, obtuse angles; Transv. – transverse;
Peri. – perimortem; Post. – postmortem

Table 5. Summary of ANOVA values. Postmortem interval (2 month intervals) is the primary variable.

Variable \ Value	F-value	Prob. >F	R ² -value
Angle	1.410	0.254	0.199
Outline	7.557	0.001	0.329
Edge	1.087	0.008	0.422

When statistical tests were run on shorter temporal intervals (e.g. data collected every 2 weeks), different features proved significant (Table 6).

Table 6. Summary of ANOVA values. Postmortem interval (2 week intervals) is the primary variable.

Variable \ Value	F-value	Prob. >F	R ² -value
Angle	2.032	0.061	0.569
Outline	1.263	0.287	0.480
Edge	2.316	0.033	0.880

Change in fracture characteristics

Fracture surface morphology was the first feature to show change from the perimortem state to the postmortem state. Though exclusively jagged fracture surfaces did not appear until PMI = 70 days, fracture surfaces began showing jagged patches after 28 days of exposure. After this point, the number of bones showing a smooth fracture surface declined steadily. By PMI = 126

days, the conclusion of the experiment, there were no bones showing an exclusively smooth fracture surface.

The second significant trend was the change from curvilinear to transverse fracture fronts. Longitudinal cracking, one feature of transverse fractures, was first noted at PMI=28 days, though it was associated with retention of the V-shaped fracture outline (Figure 9). As longitudinal cracking is typically associated with failure of collagen fibers (Bonnischen and Will, 1990) it is somewhat unusual that it occurred in conjunction with a V-shaped fracture outline. Longitudinal cracking remained confined to the diaphysis until PMI=56 days, when the first longitudinal fracture intercepted the distal epiphysis on one femur. However, this occurred only once, and in the remainder of the samples with longitudinal cracking it was restricted to the diaphysis.

The number of fragments produced by each bone remained relatively constant. Typically, each bone broke into two larger portions, which occasionally remained joined by the periosteum. In addition to the two large pieces, there were usually 2-4 fragments ranging from 15-30mm in length. The relatively large size of the impact surface (1 cm²) resulted in some crushing at the point of impact. This stands in opposition to Maples (1986), who stated that drier bones consistently produce more fragments. It is possible that this does become the case when bones are extensively weathered (i.e. have reached Behrensmeyer's Phase 4 – Phase 6).



Figure 9. Specimen 37. Broken after 14 weeks, showing a largely curvilinear fracture surface associated with longitudinal cracking.

Timing of Trauma

When data were combined into 8-week groups, statistical analysis produced different results than analysis on data in 2-week groups. This indicates that changes over the short-term are different from those over the long-term.

The most significant change when fractures were grouped into 2-week intervals was in fracture surface roughness. The frequency at which jagged patches appeared on the fracture surface increased in a more-or-less linear

manner such that during the first 2 weeks (PMI=0 days to PMI=14 days) all fracture surfaces were entirely smooth (Figure 10). This suggests that if a bone presents any jagged fracture surface, the fracture likely occurred more than 2 weeks after the time of death. Exclusively-jagged fracture surfaces begin to appear after 70 days of weathering, though at no point during this experiment do they appear to the exclusion of smooth or intermediate (mixed smooth and jagged) fracture surfaces. If an exclusively jagged fracture surface appears on a bone (Figure 11), it is probable that the fracture occurred at least 10 weeks after the death event.



Figure 10. Specimen 13. Broken after 4 weeks, showing a curvilinear fracture outline and smooth fracture edge.



Figure 11. Rough fracture surface. Specimen 39, broken after 14 weeks, showing jagged, rough fracture surface.

Fracture outline showed no significant change when observed in 2-week intervals, though there was significant change in the frequency of transverse fractures between the first 8 weeks and the following 8 weeks. Exclusively-transverse fracture outlines do not appear until 42 days of weathering have elapsed, and after 70 days there was no test that did not show at least one bone with a solely-transverse fracture front.

In finely-gradated statistical tests (2-weeks), fracture angle was only weakly significant, and when partitioned into longer-term groups (8-weeks) it was not significant at all. This suggests that, although previous researchers have

stated that right-angled fractures are characteristic of drier bones, over the course of 5 months of this study the ratio of right-angled fractures to acute and/or obtuse fractures did not change in a meaningful way. The results of this present research suggest that, unless one is considering a long postmortem interval, fracture angle does not change in a manner that would lend itself to establishing whether a fracture occurred soon or long after the time of death.

These trends suggest that there are two 'peaks of activity' when it comes to timing perimortem fractures in south-central Texas and similar climates/environments. The first peak occurs around 28 days, and is characterized by the first appearance of a jagged fracture surface, the first appearance of longitudinal cracking, and the beginning of a transition from curvilinear to intermediate fracture outlines. The second peak occurs around 70 days, and is distinguished by the absence of any smooth fracture surface after that point. The peak at 70 days also marks the first appearance of an exclusively right-angled fracture surface, but as stated previously, fracture angle does not seem to change in a manner that lends itself to the timing of fractures in the short term (Table 7). Despite this, there was no bone that, at any point, manifested exclusively postmortem-type fractures.

Table 7. Appearance of fracture characteristics. First appearance (/) and complete appearance (X) of fracture characteristics¹.

PMI	Jagged Surface	Transv. Outline	Cracking	R. Angled fracture
0 days				
14 days		/		/
28 days	/		X	
42 days		X		
56 days				
70 days	X			X

¹ E.g. the first sign of jagged surface appeared at PMI=28, and the first exclusively-jagged surface appeared at PMI=70.

CHAPTER V

DISCUSSION

No single fracture characteristic proved diagnostic of a particular time since death. Fracture surface morphology showed the most consistent correlation with time since death. On the other hand, fracture outline, one of the most frequently cited factors (Wieberg, 2005) for time-since-death estimation, showed no statistical correlation with PMI.

The absence of a definitive point differentiating fresh from old bone is likely due to the fact that bone is formed from a complex combination of organic and inorganic structures. While much of a bone's tensile strength is afforded by flexible collagen fibers and its load-bearing rigid structure is formed from inorganic compounds such as hydroxyapatite, there is individual variation in the distribution of these molecules within the bone diaphysis (Johnson, 1985). Dry bone fractures in a manner similar to other inorganic compounds because of drying and degradation of the collagen molecules within the osteons. The dessication of these collagen fibers occurs slowly, and as such bones may react either as living, or recently deceased, tissue as long as four weeks after the actual

death event. This is reflected in this experiment by the fact that, after four weeks of weathering, no bones showed exclusively fresh-type fracture characteristics.

Fracture characteristics in bones at either end of the continuum are distinct from each other. Bones broken immediately after death consistently showed features associated with fresh bone – most notably smooth fracture surface, a curved fracture outline, and acute and obtuse fracture angles (although the combination of these angles varied) (Bonnischen, 1979; Morlan, 1984; Johnson, 1985; Villa and Mahieu, 1990). Conversely, bones broken after an extended period of weathering exhibit features that have been previously identified as indicative of postmortem breakage. These features include a jagged, rough fracture surface and right-angled fractures. Fracture outline, as noted previously, did not show significant change over time, and ‘fresh’ U- or V-shaped fracture outlines occurred through the final test.

Bones broken in the intermediate period, however, between the two ends of the weathering spectrum, showed a mixture of fresh and weathered bone characteristics. For example, a bone broken after 70 days of exposure (PMI = 70) had both right and sharply acute angles, fully jagged fracture surfaces, and an intermediate fracture outline in which a V-shaped fracture outline occurred with associated longitudinal cracking.

It is clear that not all characteristics are equally diagnostic when it comes to estimating during what period after death a fracture occurred. Part of the issue in stating that a fracture occurred in the perimortem interval may be

associated with the fact that the term perimortem does not have a universally-understood meaning. When discussing fractures, the term perimortem seems to indicate that a fracture event took place when the bone was green, or moist. This experiment, however, indicates that bones remain green for an extended period after the time of death.

Even if a fracture occurs more than a month after the time of death, it may still exhibit perimortem features, leading to incorrect classification of that fracture as perimortem. It is true that bones laid out for surface decomposition will begin to manifest postmortem characteristics – most notably a jagged fracture surface – approximately 2 months after death in south-central Texas. The time it takes for a bone to decompose from the green state to a fully dried state in south-central Texas is still not fully delineated. Depending on precise environmental conditions, this time could range from several months to up to a year as evidenced by previous research undertaken in Ontario, Alabama and Missouri (Janjua and Rogers, 2008; Wheatley, 2008; Wieberg and Wescott, 2008).

The questions posed in this research included whether there was a relationship between fracture characteristics (including fracture edge morphology, fracture outline, and fracture angle) and the time elapsed since death. Additionally, this research project addressed the question whether it was possible to determine whether a fracture occurred near the time of death or at some unknown later point in time.

The results of this experiment have shown that there is a statistically measureable change in fracture characteristics when they are compared with time since death. While it is true that there is no precise way to draw a sectioning point along the continuum after which fractures exhibit postmortem fracture patterns and before which they exhibit perimortem fracture patterns, this experiment indicates that there are trends in the variables tested. It is likely that these trends can be applied to help forensic anthropologists determine when a fracture occurred in relation to the death event.

Validity of fracture characteristics

Anthropologists employ a variety of features in attempts to determine whether a fracture occurred perimortem or postmortem. Wieberg (2005) comments that, in an interobserver study, the most commonly cited features are: a fracture surface color that differs from cortical coloration, fracture outline, fracture surface morphology, and fracture angle. As stated previously, fracture angle did not show a significant change over the course of this study, and its diagnostic value has not been investigated further and remains unknown. Additionally, color change analysis was not undertaken due to the limitations of experimental design.

Piekarski (1970) states that both fracture propagation and fracture outline are influenced by bone dryness, and that dryness is associated with the absence

of organic compounds in the bone. In her analysis of bone ash weight, Wieberg (2005) found that bone moisture content experiences an initial rapid decrease, and then seems to stabilize at a level significantly below that of fresh bone. It is highly likely that the precise rate of moisture loss is influenced by local climatic conditions, including general humidity, temperature and rainfall. Additional variables include the condition of the remains at the time the fracture was produced, and the size of the bone itself. Due to a low surface-to-volume ratio, larger cylindrical bones may be expected to retain moisture for a longer period than small or flat bones, which have a higher surface-to-volume ratio. For this experiment, the bones were defleshed immediately after the pig's death occurred. Therefore, the insulating or moisture-trapping effects of soft tissue cannot be remarked upon in this instance.

Of the remaining variables, change in surface roughness proved the most significant variable, with smooth fracture surfaces firmly associated with fractures in fresh bone. As the bones were exposed to the elements and allowed to decompose, the fracture surface became progressively rougher. This first occurred in patches, such that a single fracture surface would have jagged areas and smooth areas that abutted one another. As time went on, however, the fracture edges gained progressively rougher topography, such that in the final test no smooth areas appeared on the fracture surface. Statistically, fracture surface morphology was correlated with PMI. As time passed, the frequency of jagged patches increased in a decidedly linear manner.

Fracture angle, too, shows a trend consistent with previous research. Johnson (1985), Sauer (1998) and Galloway (1999) all state that acute and obtuse angles are consistently associated with perimortem fractures, and right angles with postmortem fractures. While it is true that no right angles occurred during the perimortem period (for the purposes of this experiment defined as PMI=0 to PMI=28), acute and obtuse angles occurred (sometimes in conjunction with right angles) through the final test at PMI=126. The frequency of acute and obtuse angles decreases over time, but it is likely that right angles do not occur exclusively until all organic material has decayed and the bone is fully mineralized. Fracture angle shows high statistical correlation with PMI as well as with assessment.

Limitations

Pig Models

The bones for this study come from domestic pigs (*Sus scrofa*). Pig remains are frequently used in lieu of human cadavers in decomposition research because both humans and pigs have similar bone-muscle-fat ratios (Tucker et al., 2001). It has been theorized that canid bones are the best proxy for human skeletal remains in experimental research due to structural and growth similarities, but they are rarely accessible in large enough numbers for research purposes. Regardless, there are undeniable structural differences between

human and pig remains. Faunal bones tend to have shorter, more robust diaphyses than do human elements. Conversely, human bones usually have a proportionally thicker cortex. These differences doubtless have an impact on the rate of decomposition of a bone's organic components, as well as on the way a dynamic force moves through the cortical bone to produce a fracture.

Sun Exposure

To maintain a constant environment and to diminish the impact of scavenger activity, the bones were placed together in a 6' x 3' cage. To avoid issues of variable shading, the cage was set out in an area of full sun. This would not, however, alter the impact of changing seasons and the angle of the sun. At the inception of the experiment in mid-July, south-central Texas received an average of 13.75 hours of sunlight each day; by conclusion in late November, this number dropped to 10.35 hours of sunlight per day, a difference of just over 3 hours (NOAA, 2009). The damaging effect sunlight has on bone has been well-documented (i.e., Behrensmeyer, 1978), and exposure to the sun is known to increase the rate of bone drying and mineralization. Though seasonal changes in sun exposure would, of course, also affect decomposition in a forensic context, decreasing sun could slow the rate of bone decomposition. This limitation could be remedied by carrying out the experimental protocol during different seasons.

Weather and Precipitation

Weather is another potential limitation that must be addressed. During the summer and early fall of 2009, central and south-central Texas experienced record-setting high temperatures, combined with record low precipitation measurements. These abnormally hot, dry conditions could have affected the weathering of the bones. September, October and November of that year also saw high levels of rainfall. Bones collected immediately following extended periods of rainfall (especially PMI=56 and PMI=98) showed a somewhat increased incidence of perimortem fracture characteristics (e.g. smooth fracture surface). This statement cannot be made definitively; small sample size could exaggerate what was actually a random occurrence.

The United States encompasses an enormous variety of climatic zones, ranging from arctic to subtropical. The climate in south-central Texas falls into the subtropical zone, and typically experiences hot, humid summers and cool, wet winters (Kjelgaard et al., 2008). Though the results of this experiment may prove applicable to other, similar environments, they will probably not be consistent with results obtained using bones decomposed in significantly different biomes. Similar experiments, therefore, should be carried out in different environments in attempts to ascertain how long it takes for skeletal remains to decompose to the dry-bone state.

Sample Size

In no test was the sample size greater than 5 specimens for each trial. This small sample size greatly reduces the strength of statistical tests. ANOVA analyses can indicate that a statistically significant relationship between variables exists, but cannot determine where the relationship lies (Sharp, 1979). Sample size in this experiment was too small to allow for post hoc analyses, which could have illuminated precisely where similarities in measurements or trends occurred. Additionally, it leads to an increased incidence of sampling bias (Madrigal, 2008). Weak statistical tests in turn limit the strength of any statements that can be made using statistical results. Further tests should incorporate a larger sample size to alleviate this issue.

Current vs. Previous Research

Janjua and Rogers (2008) observed that, in Ontario's temperate environment, bones did not exhibit significant cortical drying until approximately 9 months of exposure although they lost odor after as little as 2 months of weathering. In south-central Texas, the bones did not seem to follow this pattern. Through the final trial the bones themselves were very moist and fragrant, and the adhering soft tissue was still moderately pliable. These differences in weathering and decomposition rates strongly indicate that a

different weathering timeline must be developed for the unique climate of south-central Texas and similar environments.

The results of this experiment are somewhat consistent with the research that Wieberg undertook in 2005. Both her research and this experiment demonstrated that fracture surface roughness is the first characteristic to show change from a fresh-bone to dry-bone state. There were also points of discrepancy: namely that the shape of the fracture itself does not change significantly enough to be of diagnostic value. Statistical analyses of the data from this experiment in two month (8 week) intervals showed that there is a significant difference in fracture outline conformation between the first 8 week period and the second 8 week period. In fact, change in fracture outline proved to be statistically more significant than did change in fracture surface roughness or fracture angle over a longer interval. However, when change was observed over shorter intervals (2 weeks), changes in jaggedness proved to be the only feature to show statistically significant, consistent change over time. Though Wieberg's research tested a different correlation than this one, the discrepancy in fracture characteristic changes indicates that bones decompose at different rates in these two environments. In south-central Texas, fracture surface jaggedness may prove more temporally diagnostic in the short term, and fracture outline over an extended weathering period. If this is the case, a change in fracture outline should be consulted only when there is suspicion that the remains in question have experienced an elongated outdoor weathering interval.

CHAPTER VI

CONCLUSION

There is a period of time after death that a fracture, despite occurring postmortem, may manifest fracture characteristics typical of a bone broken immediately before or after death. It is unclear for how long after death bones will continue to exhibit at least one feature characteristic of fresh bone, but in south-central Texas this period lasts more than 5 months. Even during the final test, no bone manifested exclusively postmortem fracture characteristics, a fact which indicates that even after 5 months of weathering, bones are still green.

A jagged fracture surface proved to be the feature most strongly indicative of postmortem drying in the short term, appearing approximately a month after death and appearing at consistently high rates in all subsequent tests. The shape of the fracture front did not change rapidly, but a significant change in the frequency of curvilinear versus transverse fracture outlines separates the first two months of the experiment from the following period. This suggests that, after approximately 8-10 weeks of weathering, bones dry enough to begin manifesting transverse fracture outlines on a relatively consistent basis. No one

feature proved to have extraordinarily high diagnostic value, but fracture characteristics analyzed in conjunction with one another have the potential to time the occurrence of a fracture with some accuracy.

One of the major issues anthropologists face when confronted with blunt force trauma is a lack of consensus regarding which features are of greatest value when it comes to determining when a fracture occurred relative to time of death. A review of the literature indicates that there is no standard method of interpreting blunt force trauma; analysis is strongly based on individual experience rather than on research-derived timelines. To address this issue, future research should be carried out with a focus on standard experimental design in various climates. A database should be developed to compile information on blunt force trauma characteristics over myriad timeframes and in varied environments. Information derived from these experiments could be intertwined with research regarding bone decomposition in aquatic and marine environments to ascertain the effects that water might have on fracture patterns, and help to highlight the impact of external moisture on the manifestation of blunt force taphonomy.

The results of this experiment highlight the need to develop a shared knowledge base regarding the interpretation of blunt force trauma, backed by statistically supportable research. This replicable experimental design and method of quantitative trauma analysis will help to bring blunt force trauma interpretation in line with the *Daubert* (1993) ruling, as well as aid in

standardizing trauma analysis criteria and terminology. Additionally, the intervals laid out by this research may help medical examiners to make better-informed statements regarding blunt force skeletal traumas by establishing whether a fracture could be classified as perimortem and therefore associated with the cause or manner of death.

As the results of this research demonstrate, it is unadvisable for forensic anthropologists, skeletal biologists or bioarchaeologists to make absolute statements regarding the timing of blunt force injury in relation to time of death without more robust and comprehensive studies. However, until further studies are completed, the following generalizations may be of use to forensic anthropologists when attempting to distinguish the timing interval of blunt force fractures on bone:

1. If a bone presents any jagged fracture surface, the fracture likely occurred more than 2 weeks after the time of death.
2. Exclusively-jagged fracture surfaces begin to appear after 70 days (10 weeks) of weathering.
3. Exclusively right-angled fractures begin to appear after 70 days (10 weeks) of weathering.
4. Longitudinal cracking can appear as early as 4 weeks after the time of death, and may be associated with the retention of a curvilinear fracture outline.
5. Fracture edge roughness proved more diagnostic over the short-term

(approximately 2 months or less), and fracture outline proved more diagnostic when bones are believed to have been weathering for a longer period of time.

6. Over a period of approximately 20 weeks, fragment number did not change in a diagnostic fashion and should not be used to establish the timing of a fracture.

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