AN EXAMINATION OF THE PROGRESSION OF FRACTURE PROPOGATION IN LONG BONES DURING THE POSTMORTEM PERIOD IN CENTRAL FLORIDA

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ABSTRACT

The forensic anthropologist is often tasked with analyzing skeletal trauma and determining time since death. Differentiating between perimortem and postmortem fractures can be difficult when bone retains fresh characteristics in the postmortem interval. As a result, it is important to conduct research that investigates timing of injury in the postmortem period by observing fracture characteristics created at known postmortem intervals. Investigation into the timing of injury was undertaken in this study over a four month time period. By fracturing bones using a custom impact device, specific morphological characteristics that are typically used in trauma analysis were created for analysis. Long bones of pigs (*Sus scrofa)* (N=140) were placed in two separate outdoor environments: full sun and full shade. Five bones were collected from each environment weekly and subsequently fractured. A control group consisting of 5 fresh bones was fractured to simulate perimortem trauma. Analysis of fracture characteristics was completed using a standardized protocol that was modified from previous studies, evaluating the fracture angle, fracture surface, and fracture outline. Statistical analyses were performed to investigate the relationships between and among these variables. The results of this study denote a discernable relationship between fracture characteristics and the postmortem interval, indicating a significant shift in the occurrence of these variables as the postmortem interval increases. As the postmortem interval increases, there is a trend toward primarily dry fracture characteristics. Additionally, statistical analysis indicates that the environment in which the bones are deposited has a significant effect on the fracture surface and outline as the postmortem interval increases. This study found that intrinsic dry fracture characteristics were observed as early as two weeks postmortem. These results suggest that it is possible to distinguish wet from dry fracture characteristics earlier in the Central Florida region than previously reported in the literature. These findings support the use of taphonomic models developed according to geographic region. Environmental factors are regionally specific, potentially complicating reconstruction of post-depositional history. The use of taphonomic models and standardized protocols for analysis provides increased accuracy in taphonomic analyses and estimation of the post-mortem interval in forensic casework.

For Brett and Rex.

For helping me to always follow my dreams, no matter how big they are.

I love you.

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LIST OF ABBREVIATIONS

PMI = Postmortem Interval

MNI = Minimum Number of Individuals

TSD = Time Since Death

Fx = fracture

h = height

m = mass

m^2 = meters squared

cm^2 = centimeters squared

a = surface area

kg = kilogram

g = acceleration due to gravity

$\geq$ = greater than or equal to

$\leq$ = less than or equal to

± = plus or minus

$\sum$ = Sum

β = Beta

π=Pi (3.14)

α= alpha level

X^2= Chi-square

ANOVA = analysis of variance

CHAPTER 1: INTRODUCTION AND STATEMENT OF TOPIC

The discipline of forensic anthropology is primarily concerned with the identification and subsequent analysis of recovered skeletal material, often for law enforcement purposes. The sequence of analysis typically requires the material to initially be classified as osseous or non-osseous, and second, as human or non-human. These classifications are followed by determination of forensic significance, which includes identification of the origin of the skeletal remains. A sub-discipline of forensic anthropology, forensic taphonomy investigates the changes that human remains undergo in the post-mortem period, providing information regarding the post-mortem interval (PMI), as well as cause and manner of death (Haglund, 1991; Sorg and Haglund, 2002). Forensic anthropologists rely on specific contextual information to guide their analyses of human skeletal material and provide information related to how the skeletal remains have been altered by varying forces (Pokines, 2014).

Skeletal trauma analysis is one aspect of taphonomy with which the forensic anthropologist must be intimately familiar. This process may provide information, having left traces of its causation on the skeletal remains. Forensic anthropologists are commonly called upon to classify the type of trauma as blunt force, gunshot, or sharp force, as well estimate the timing of injury, classifying the trauma as having occurred antemortem, perimortem, or postmortem. The difficulty in this task arises when confronted with the elastic perimortem period (Maples, 1986). It has been concluded by multiple authors (Maples, 1986; Nawrocki, 2008; Symes et al., 2014) that the definition of the perimortem period, as given by the forensic pathologist is lacking, being described as “at or around the time of death”. This is potentially problematic as bone may retain its “fresh” or “wet” properties long after death, complicating the estimation of the postmortem interval and the timing of skeletal trauma. The retention of fresh properties after death allows bone to exhibit characteristics consistent with perimortem trauma for a longer period of time, though the trauma may have actually occurred in the postmortem period (Wieberg and Wescott, 2008; Shattuck, 2010). Therefore, the definition proposed by Nawrocki (2008), and later by SWGANTH (2011), has been adopted by the anthropological community in an attempt to clarify the elasticity of the perimortem period, and reads as such: “perimortem trauma refers to an injury occurring around the time of death (i.e., slightly before or slightly after). Within the anthropological realm, perimortem is determined on the basis of evidence of the biomechanical characteristics of fresh bone and *does not take into consideration the death event”*. This contributes to the proposed elasticity of the perimortem period, and lends support to the idea that bones should be discussed in terms of “wet” and “dry”, rather than perimortem and postmortem (Wieberg and Wescott, 2008; Coelho and Cardoso, 2013).

It has also been proposed by multiple authors (Wieberg and Wescott, 2008; Shattuck, 2010) that the local climate may play a considerable role in the timing of both fractures and the retention of moisture content. Investigation into this variability by region will provide a framework by which the forensic anthropologist may more accurately estimate the timing of injury, taking into consideration local climactic and environmental factors. Although investigations into the timing of fractures in long bones have been undertaken in previous studies, the literature regarding the subject is still limited. Specifically, the timing at which a shift in the intrinsic properties of bone from wet to dry occurs has been investigated, but remains variable dependent upon factors related to the depositional environment (Symes et al., 2014).

Therefore, research investigating the retention of the intrinsic wet properties of bone must be undertaken according to region in order to explore the variability presented according to geographic location. To date, there has been no published research regarding the specific geographical region of Central Florida and the respective timing of long bone fractures in this unique environment. Furthermore, there has been no research published regarding the differences in fracture patterns long bones display when discovered in different microenvironments, specifically environments consisting of full sun and full shade exposure in the Central Florida region. This information is essential to the forensic investigation as knowledge of the progression of taphonomic processes in the unique environment Central Florida offers will aid the forensic anthropologist in accurate estimation of both timing of injury and the postmortem interval.

The purpose of this study is to evaluate the estimate for the time frame in which skeletal remains lose their intrinsic fresh properties in the peri- and postmortem periods in Central Florida in order to accurately estimate timing of injury. While there have been other studies conducted on this topic in different areas of the country and world (Wieberg, 2006; Wieberg and Westcott, 2008; Shattuck, 2010; Zephro, 2012; Coelho and Cardoso, 2013), they may not necessarily be proper analogues for the Central Florida environment, as the climate of Central Florida differs significantly from these other areas. The time frame in which fractured long bones placed in full sun exposure will lose their intrinsic fresh properties as compared to those placed in full shade will be evaluated. To examine these factors, adult pig (*Sus scrofa*) long bones were placed in an outdoor environment at the University of Central Florida in Orlando for a specified period of time. The bones were deposited in two separate microenvironments, and subsequently fractured by way of blunt force trauma, to investigate the timing of the shift in the intrinsic properties of bone from wet to dry. The three main objectives of this research project are:

1. To determine which fracture characteristics are more accurate for understanding the transition of the intrinsic properties of bone from wet to dry.
2. To compare two separate microenvironments to determine if there are differences in the rate at which bone loses its intrinsic wet properties.
3. To differentiate wet from dry characteristics of bone during the fourteen week postmortem period in the sub-tropical region of Central Florida in order to fill a gap in the literature.

To investigate these research questions, it is imperative to provide an introduction to the field of forensic taphonomy, as well as to provide background information regarding the anatomy and biology of bone composition, information regarding the biomechanical properties of bone and its response to stressors, as well as the intrinsic properties of wet and dry bone. An overview of the literature surrounding investigation into the transition of bones from wet to dry properties will be presented, followed by discussion of the materials and methodology inherent to this experiment, including analysis of fracture characteristics. The results of this study will then be presented and discussed regarding the implications to the field of forensic anthropology.

CHAPTER 2: BACKGROUND

The Evolution of Forensic Taphonomy

The term “taphonomy” was coined by paleontologist Isaac Efremov (1940:92) and was defined as “the study of the transition (in all its details) of animal remains from the biosphere to the lithosphere”. Forensic taphonomy is a sub-discipline of forensic anthropology, born from the existing paleontological field of taphonomy, which originally included study of all processes undergone by an organism between death, decomposition, transportation and subsequent burial. According to Haglund (1991), forensic anthropologists sought to amend the scope of taphonomy to include differentiation among processes occurring within the ante-, peri-, and postmortem periods, as well as more accurate estimation of the post-mortem interval. Knowledge of these taphonomic processes is invaluable to the forensic anthropologist, as they are often called upon to investigate and provide analyses regarding skeletal material, where there is little to no information provided.

Discussion of the post-mortem interval became forefront with Krogman (1962) and T.D. Stewart’s (1979) investigations, which included analysis of the postmortem period into their forensic investigations. Though the postmortem interval was being discussed in a fashion, it was not considered integral until these authors began to call for inclusion into the forensic investigation as necessity (Haglund, 1991). Lyman’s (1994) publication is the point at which principles of taphonomy became “normalized” and accepted into modern archaeological practice (Dirkmaat, 2008). Haglund and Sorg (1997:3) were close behind with the application of taphonomic principles to the field of forensic anthropology, subsequently re-working the definition of taphonomy to reflect this shift in practice, stating forensic taphonomy is “the use of taphonomic models, approaches, and analysis in forensic contexts to establish the time since death, reconstruct the circumstances before and after deposition and discriminate the products of human behavior from those created by the earth’s biological, physical, chemical, and geological subsystems.”

Anatomy of Long Bones

Bone is a robust material, primarily responsible for the structural integrity of the human body; supporting the weight of the body, shielding vital organs from damage, functioning as a system of levers for muscular contraction, and serving to regulate the metabolism of calcium (Schenk, 2003; Turner, 2006; White et al., 2012). Adult long bones are arranged in two main segments, the epiphyses and the diaphysis, which are joined by the metaphysis. The epiphyses are located at the proximal and distal ends of the long bone, while the diaphysis, or shaft, connects the two and contains a hollow cavity known as the medullary cavity (Figure 1) (White et al., 2012). Long bones are comprised of two bony structures: cancellous bone and cortical bone (White et al., 2012). Both cancellous and cortical bone are also referred to as lamellar bone. Cancellous bone is organized in a lightweight, “honeycomb” structure, contained within the epiphyses, and is responsible for shock absorption and red marrow production (White et al., 2012). Cortical bone, however, is located in the diaphysis, is organized in a dense fashion, and houses a fat reserve called yellow marrow in the medullary cavity (White et al., 2012).

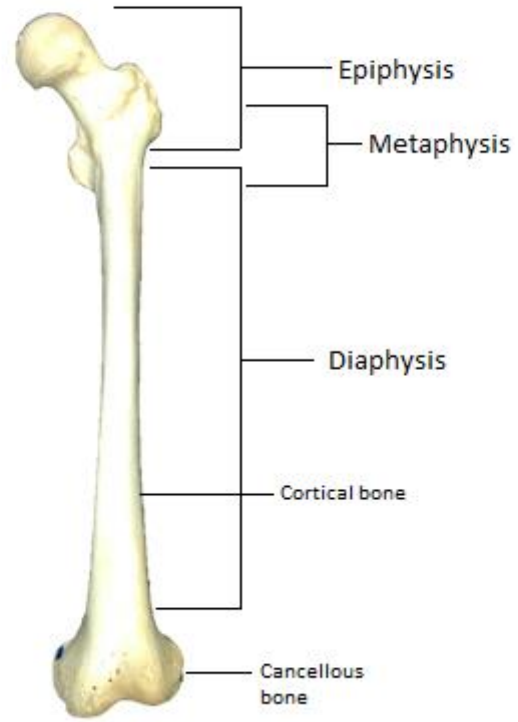


Figure 1: The structure of the long bone, epiphyses, diaphysis and metaphyses. The long bone is constructed of compact bone around the diaphysis and trabecular bone in the epiphyses.

Bone is both living, and vascular, able to change its shape in response to external stressors, depositing or reabsorbing bone as needed (White et al., 2012). Bone is a heterogeneous material, composed of both inorganic and organic materials. One of the organic components, collagen, comprises 90 percent of the bone’s organic material and is arranged in a longitudinal fashion, providing the bone with flexibility and elasticity (Galloway, 1999; Schenk, 2003; Pechnikova et al., 2011; Symes et al., 2012; White et al., 2012). Hydroxyapatite, a dense, crystalline structure comprised of 65 percent mineral content and formed from calcium phosphate, constitutes the inorganic component of bone, (Galloway, 1999; Schenk, 2003; Symes et al., 2012; White et al., 2012). Hydroxyapatite impregnates the collagen portion of bone, lending strength to the structure by providing rigidity, and hardness (Symes et al., 2012; White et al., 2012). Combined, collagen and hydroxyapatite provide bone with both strength and elasticity, allowing it to resist externally applied forces, and allowing some flexibility when faced with trauma (Symes et al., 2012). Despite bone's ability to resist external forces, failure will occur when external forces are applied to skeletal elements.

Biomechanical Properties of Bone

Failure of bone, either at the macro- or microscopic level, occurring when external force is applied, is referred to as skeletal trauma (Davidson et al., 2011). A failure or fracture occurs when the stress on the bone exceeds the strength of the bone, interrupts the structural integrity of the bone in one of three ways: a single event in which the application of force was sufficient enough to cause osseous failure, repeated static or dynamic stressful events, or through weakened bone resulting from certain disease processes (Schenk, 2003; Davidson et al., 2011).

Ozkaya and Nordin (1999:127) state "the extent of bone deformation will be dependent upon many factors, including the magnitude, direction, and duration of the applied force, the material properties of the object, the geometry of the object, and the environmental factors such as heat and humidity." Force, or load, as defined by Symes et al. (2012:345), is "any mechanical disturbance that causes an object to deform, change its state of motion, or both." Magnitude can be described as the area of the force being applied to the bone, its relative size, or extent of the force. A higher energy force is equivalent to greater magnitude, which in turn dictates the extent of injury (Gozna, 1982). The direction of the force refers to the line taken by the magnitude of the applied load. Stress is measured in force per unit of area, while strain refers to the deformation of the bone, or how it changes in volume, angle, or length.

Forces can be either intrinsic or extrinsic. According to Symes et al. (2012), intrinsic forces are those that act based on the biomechanics of the body and help to hold the body together (Komar and Buikstra, 2008). Extrinsic forces are those that act upon the body, and are typically classified into duration, magnitude, and rate (Moraitis and Spiliopoulou, 2006; Komar and Buikstra, 2008; Symes et al., 2014). Directional forces responsible for bone fracture can be classified as compression, tension, shearing, torsion, and bending (Galloway, 1999; Iscan and Quatrehomme, 2000; Schenk, 2003; Davidson et al., 2011; Symes et al., 2012; White et al., 2012).

According to multiple authors (Gozna, 1982; Galloway, 1999; Iscan and Quatrehomme, 2000; Galloway and Zephro, 2005; Symes et al., 2012; Symes et al., 2014), directional forces often act upon the body in combination to produce fracture. Compression acts to squeeze bone, forcing the material together. Tension, or tensile force, acts to pull bone apart. Shearing forces tear bone apart by forcing portions of the material to slide across one another. Torsion involves shearing forces combined with a twisting motion. Bending forces involve a combination of both tension and compressive forces.

The configuration of bone can be described in terms of its response to stressors. Bone is able to adapt to stressors by changing shape and size and is able to resist tension, compression, shearing, torsion, and bending forces (Turner, 2006; Symes et al., 2014). It is considered to be anisotropic, heterogeneous, brittle, viscoelastic, and weak under sources of tension (Symes et al., 2012; Symes et al., 2014). Bone can be described as heterogeneous in regards to its configuration and shape, its structure in relation to location within the bone, and the arrangement of bone cells within trabecular and cortical bone (Symes et al., 2012; Symes et al., 2014). It is anisotropic in that its response to specific load types is dependent on both the direction of the load and the location at which impact occurs on the bone (Galloway, 1999; Symes et al., 2012; Symes et al., 2014). According to Symes et al. (2012; 2014), long bones are able to resist axial loads more effectively than transverse loads. This is related to the longitudinal organization of collagen fibers in the diaphysis of the long bone.

Bone is considered brittle because of the high mineral content, causing it to fail prior to other tissues in regards to rapid loading forces (Gozna, 1982; Symes et al., 2014). Viscoelasticity refers to both the viscosity, and the elasticity of bone, as well as the response to the speed and time period at which an externally applied force occurs (Gozna and Harrington, 1982; Symes et al., 2014). Elasticity is the capacity of bone to return to its primary form after resisting a loading force. Bone is considered viscoelastic in regards to its reaction to a loading force (Galloway, 1999; Symes et al., 2012). The speed of a load force can be divided into two categories: slow load and rapid load. Examples of slow load forces include blunt force trauma, falls, motor vehicular accidents, and air disasters, while rapid load forces are attributed to ballistic trauma (Symes et al., 2012). Lastly, bone is considered weak under tensile forces because it is twice as strong under compressive forces as under tension (Gozna and Harrington, 1982; Ebacher et al., 2006; Komar and Buikstra, 2008; Passalacqua and Fenton, 2012; Symes et al., 2012). Therefore, bone will fail first in tension when subjected to bending loads (Komar and Buikstra, 2008; Davidson et al., 2011; Symes et al., 2012).

Strain, or the response of bone to a load force, depends upon multiple factors. The velocity and the magnitude of the force applied both affect the response of the bone, suggesting that the speed in which a load is applied to a bone is an integral component (Komar and Buikstra, 2008; Symes et al., 2012; Symes et al., 2014). Plasticity is defined as “the threshold at which the elastic limit has been reached and at least some permanent deformation occurs” (Symes et al., 2012:346). Therefore, if a load is applied to a bone, subsequently removed, and the bone returns to its original shape, then it was stressed within its limit of elasticity (Symes et al., 2012; Symes et al., 2014). If the load is removed and the bone retains some deformation, it was stressed beyond its elastic limit and has entered the plastic phase (Davidson et al., 2011; Symes et al., 2012; Symes et al., 2014).

Bone is able to resist rapid loading forces better than slow loading forces. Slow loading forces stress the bone for longer periods of time, stressing the bone to its physical limits through both elastic and plastic phases, whereas rapid loading forces cause bone to resist to a certain point before shattering, resulting in little to no plastic deformation (Figure 2) (Komar and Buikstra, 2008; Davidson et al., 2011; Symes et al., 2012; Symes et al., 2014). Slow loading forces will result in one of three outcomes: the bone will retain deformation, the bone will regain its original shape, or the bone will fail (Symes et al., 2012). If the applied force continues beyond the point where the bone can resist, failure occurs (Davidson et al., 2011; Symes et al., 2014).

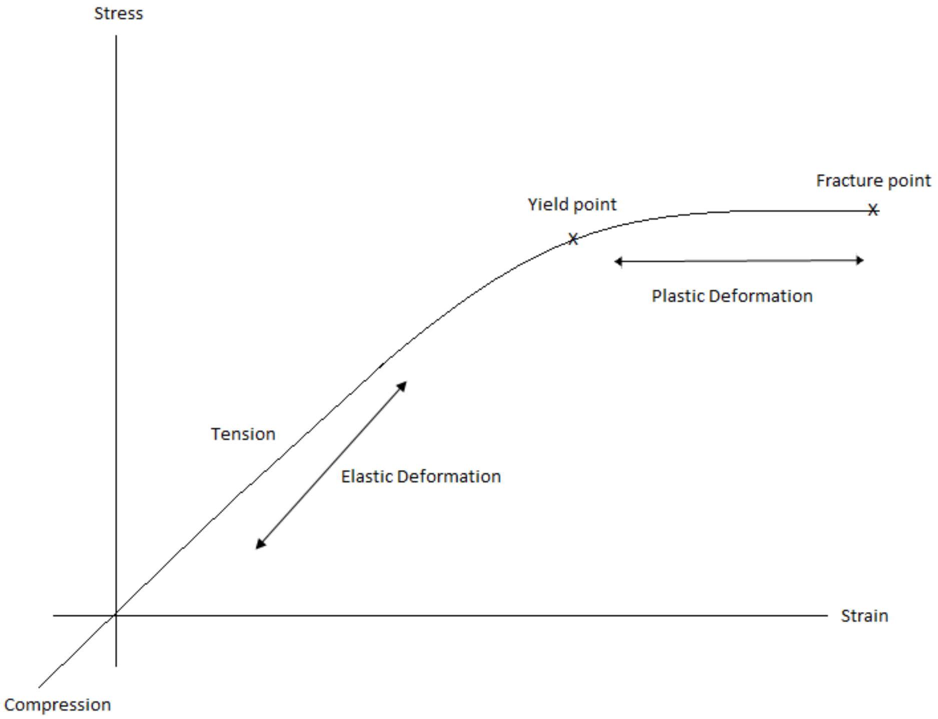


Figure 2: Young's modulus of elasticity is a graphic representation of the measure of stiffness of bone.

The point of failure, also called the yield point, results when the bone is no longer capable of resisting the load applied and permanent damage is caused (Turner, 2006). According to Turner (2006), when load forces are applied, energy is transfered into the bone. When the bone can no longer absorb the amount of energy being transferred, it breaks. A higher level of energy transferred into bone will result in the bone fragmenting, while lower levels of energy transfer result in a simple fracture without fragmentation. Bone's ability to withstand applied force and dissipate energy transfer is the primary way in which it prevents early failure (Ebacher et al., 2006).

Wet and Dry Bone

The properties of wet bone and dry bone differ in accordance with their viscoelastic composition (Symes et al., 2014). The loss of organic content and moisture, which causes dry bone to be more brittle and stiff, rather than elastic and stiff, is what causes dry bone to be less adept at resisting strain (Sauer, 1998; Wheatley, 2008; Symes et al., 2014). According to Symes et al. (2012; 2014), dry bone may resist stress to a higher degree, however dry bone will fracture immediately when it reaches the point of failure, instead of resisting through the elastic and plastic deformation phases like wet bone. According to Sauer (1998), wet bone tends to splinter and produce irregular edged fractures, whereas dry bone tends to shatter and produce more regular fragments. There are numerous factors that have been used to aid the forensic anthropologist in differentiation between wet and dry fractures (Table 1). Some of these factors include morphological characteristics such as the fracture outline, the angle of the fracture, and the surface of the fracture, as well as color, and the termination points of fractures that radiate (Table 1). It has been shown by Coelho and Cardoso (2013) that analysis of the characteristics of fracture edges, combined with analysis of fracture patterns may be of the most use in modern forensic cases (Table 2).

Table 1: Characteristics of fractures in wet and dry bone (adapted from: Villa and Mahieu, 1992; Pshigios, 1995; Sauer, 1998; Wieberg and Wescott, 2008; Coelho and Cardoso, 2013; LaCroix, 2013; Symes et al., 2014)

Fracture Characteristic	**Wet Bone**	**Dry Bone**
Splinter	x	
Shatter		x
Jagged Edges		x
Smooth, beveled edges (curved/v-shaped outlines)	x	
Rough surface		x
Smooth surface	x	
Right angles		x
Obtuse/acute angles	x	
Longitudinal/transverse fractures		x
Vertical/oblique fractures	x	
Helical fractures	x	
Epiphyseal breaks		x

Table 2: Characteristics of Fracture Patterns in Wet and Dry Bone (Adapted from: Villa and Mahieu, 1992; Wieberg and Wescott, 2008; Wheatley, 2008; Zephro, 2012).

Fracture Characteristic	**Wet bone**	**Dry Bone**
Fracture angle	Obtuse or acute angle	Right angle
Presence of fracture lines	Greater	Fewer
Fracture surface	Smooth	Rough (jagged or stepped)
Fracture Outline	Curved or V shaped	Linear or perpendicular

Fracture characteristics of wet and dry bone have been divided into three categories: angle, outline, and surface (Table 2) (Symes et al., 2014). The term angle is used in reference to the slope exhibited between the internal and external surfaces of a cross sectional portion of a fracture (Symes et al., 2014). Outline refers to the gross observation of the appearance of the fracture, while surface refers to the texture (rough or smooth) of the edges of the cross-sectional portion of a fracture (Symes et al., 2014). According to Moraitis et al. (2008), fracture edges (outline) that are smooth and beveled are associated with perimortem trauma. Dependent upon the grain of the bone, the morphology of fractured edges changes according to the arrangement of collagen fibers. When fractures appear in a vertical or oblique presentation in relation to the grain, the edges of the fracture appear jagged and irregular in wet bone (Psihogios, 1995). Dry bone exhibits fractures that appear in a longitudinal or transverse fashion according to the grain (Symes et al., 2014).

Angle refers to the formation of a measureable angle in relation to the surface of the cortical bone and the surface created by the fracture (Villa and Mahieu, 1992). Originally it was thought that obtuse or acute angles were formed in relation to wet bone, and dry bone was associated with right angles (Villa and Mahieu, 1992). However, there is no consensus as of yet regarding obtuse and perpendicular angled surfaces of wet and dry bone (Symes et al., 2014). Symes et al. (2014) provide information regarding inconsistent findings surrounding the presentation of the surface of wet and dry bone. Dry bone may exhibit right-angled surfaces, however wet bone may also exhibit perpendicular surfaces and obtuse angled surfaces have been observed on both wet and dry bone (Table 1, Table 2). There is a generalized pattern of association between diagonally angled surfaces and wet bone, and right-angled surfaces with dry bone (Wheatley, 2008; LaCroix, 2013).

Lastly, it has been noted that cross-sectional fracture surface appears smooth on wet bone, and “stepped” on dry bone (Table 2) (Wieberg and Wescott, 2008; Symes et al., 2014). Stepped fractures in dry bone can form as a result of exposure to taphonomic factors such as weathering (Symes et al., 2014). In cases of blunt force trauma (BFT) in wet bone, the bone will fail along a spiral pathway, resulting in a smooth surface with obtuse angles (Table 2) (Wheatley, 2008; Coelho and Cardoso, 2013). Dry bone fractures in a linear fashion, resulting in a rough surface and right angles in relation to the micro-fractures occurring (Table 1)(Wheatley, 2008; Coelho and Cardoso, 2013).

Sauer (1998) has noted that the staining on a bone can yield important information regarding the question of whether or not the fractures occurred in the perimortem or postmortem period (Symes et al., 2014). Post-depositional color change as a result of soil staining affects exposed surfaces of bone, therefore there will typically be a significant change in color from the exposed surface to a newly fractured edge (Sauer, 1998; Symes et al., 2014). Symes et al. (2014) note that the reverse does not always hold true. A uniform coloration between the internal and external cortical surface does not innately imply perimortem trauma. Secondary depositions and alteration during the processes of interment or excavation can also yield similar characteristics. Therefore, without information regarding these processes, color change may not be a useful tool in evaluating the timing of perimortem versus post-mortem fractures.

Staining of fractured edges of bone may also occur as a result of processes other than soil staining. Decomposition fluids, blood, decomposing botanical matter, and contaminated water are examples of taphonomic factors that may also stain the bone in the depositional environment (Moraitis et al., 2008). Bones may also be whitened by sun bleaching, which may alter the color of fractured edges, further complicating the analysis (Moraitis et al., 2008).

Symes et al. (2014) note that multiple authors within the literature have described radiating fractures terminating at the epiphyses of long bones in wet bone. This is an important factor in determining whether bone was wet or dry at the time of injury, and thereby, determining perimortem or postmortem injury. Because trabecular bone located within the epiphyses of long bones is more effective at dispersing shock, the diaphyses are more likely to fracture and fragment in both wet and dry bone. Wheatley (2008) notes several characteristics of wet and dry fractures unique to each. Epiphyseal breaks were noted as occurring solely in dry bone, while “true helical fractures” were noted in wet bones, but not in dry bones. Helical fractures are those exhibiting fracture patterns circumscribing the diaphysis in a radial pattern, as well as radiating fracture fronts, an identifiable loading point, and obtuse and acute angles.

CHAPTER 3: REVIEW OF LITERATURE

Multiple studies have been conducted in an attempt to clarify the purported elasticity of the perimortem period as it pertains to the presence of long bone fractures. Examination of the inherent physical properties of wet and dry bone has been undertaken in multiple studies to assist in accurately estimating the timing of injury.

Villa and Mahieu (1992) compared breakage patterns caused by soil sediment and those created in fresh bone in cannibalistic human populations of the archaeological record (use of a hammerstone for percussion) (Table 3). The authors examined three sites in the South of France in which human long bones were discovered that had been fractured by distinctive means. Variables observed in these three sites include: fracture angle, fracture outline, shaft length, shaft circumference, and fragmentation of the shaft. The authors refer to "fracture edge" in reference to the surface texture, describing it as smooth or jagged. It was determined that the criteria used for analysis were statistically significant when differentiating between bones fractured as a result of hammerstone (fresh) and those fractured by sediment (dry), however, the criteria were not useful at the individual level, as use of the hammerstone was only identifiable based on presence of a specific type of impact notch.

In complete opposition to the other studies explored, Psihogios (1995) presented a study that utilized human cadaver long bones in order to investigate the correlation between type of load and resultant fracture patterns (Table 3). In this study, 558 human long bones (tibiae and femora) from a geriatric population were used. The bones were placed in a device utilizing pins to stabilize the bones. The bones were either pin-pin setup, in which the bones were supported at either end and impacted mid-shaft, or the pin-inertial setup, in which one end was stabilized with the pin while the foot hung freely. The two impact devices used were a wheeled cart with a pneumatic-based accelerator that propelled a steel cart (50kgs) into the bone, or a swinging pipe, which also impacted the bones at mid-shaft.

Psihogios (1995) notes that all fracture patterns were observable in this study aside from spiral fractures, which are induced by torsion. She concludes that first, fracture patterns seem to be considerably similar despite direction of impact. Second, tension wedge fracture patterns, which are the most common fracture pattern observed, can be indicative of the direction of impact. Finally, she concludes that transverse and oblique fractures have “jagged” edges, while spiral fractures exhibit a smooth edge.

Most notably, a study reported by Wieberg and Wescott (2008) utilizing Wieberg’s (2006) thesis was conducted to determine the timing of long bone fractures by examining how long bone retains fresh (perimortem) characteristics into the post-mortem interval (Table 3). Sixty fully fleshed long bones from adult pigs were used, primarily tibiae, femora, and ulnae. The bones were initially frozen until the entire sample was collected, then thawed to room temperature before being placed outdoors at a facility in Central Missouri. Ten bones were fractured immediately to simulate perimortem trauma and serve as a control group. The bones were placed on the ground surface, covered by a fenced enclosure to ensure that insect and microbial activity would not be inhibited, as well as to prevent scavenging of the bones by animals. Ten bones were removed from the enclosure every twenty-eight days for a time period of 141 days total, and subsequently fractured using a custom drop apparatus. The limb was positioned in the apparatus so that the strike bar would contact mid-shaft, ensuring a fracture through the diaphysis that was created perpendicular to the long axis.

After fracture production, Wieberg (2006) removed the soft tissue through maceration. Fracture characteristics such as outline, angle, surface, weathering stages and color were then analyzed. Fracture outline was described as being curved/V-shaped, transverse, or intermediate. Fracture surface was described as smooth, jagged, or intermediate. Angle was described as acute, acute and obtuse, obtuse, right and acute, right and obtuse, or right. These characteristics in categorical data were scored as either 1, 2, or 3 for later analysis in order to determine if the fractures appeared to have been created in the perimortem or post-mortem time periods, or intermediately.

Wieberg (2006) performed statistical analysis using regression analysis to determine the relationship between the ash weight measurements and days post-mortem, as well as ANOVA to determine relationship between multiple correlations: 1) overall assessment of fracture characteristics to post-mortem interval (PMI), ash weight percentage, fracture angle, and fracture surface, 2) PMI to fracture surface, angle, and ash weight percentage, 3) and ash weight percentage to fracture angle and surface. Chi-square analysis was used to compare PMI and fracture angle, PMI and fracture surface, fracture surface and overall assessment, and fracture angle and overall assessment.

From this, Wieberg (2006) and Wieberg and Wescott (2008) determined that there is a transition in fracture morphology that occurs continuously from the time of death onward. Fracture morphology transitioned from exhibiting features associated with fresh bone, such as smooth surfaces, curved and V-shaped outlines, and acute and obtuse angles, to those associated with dry bone, such as right angles, jagged surfaces, and fewer V-shaped or curved outlines. This transition occurred over a time period of 5 months, where bones fractured nearer to PMI 0 exhibit more fresh characteristics associated with perimortem trauma, and those fractured nearer PMI day 141 exhibited more characteristics associated with postmortem trauma. It was determined that bones fractured in the intermediate period between days 57-113 exhibited characteristics consistent with both perimortem and postmortem trauma. The authors state that the fracture surface exhibited the most significant difference and was the characteristic exhibiting the most useful application in determination of timing of injury, as fresh bone exhibits a smoother surface texture and dry bone exhibits a rougher surface texture. Further, it was determined that as the bone dries, the frequency of obtuse and acute fracture angles decreases, but bones will not exhibit singularly right angles until the bone has completely dried and begun mineralization. The authors conclude that bone does not cease to exhibit fresh characterizations associated with living bone immediately after death, but moisture content is not a causative agent in fracture production, but rather a factor related to the deterioration of collagen in the bone, which affects the reaction of bone to stressors. The authors (Wieberg, 2006; Wieberg and Wescott, 2008) state that bones do not exhibit post-mortem characteristics regularly until 141 days after death. Therefore, there is no single morphological characteristic that can be used to definitively determine timing of injury, but rather the forensic anthropologist should exhibit caution and use multiple characteristics in determining timing of injury. As is such, the authors also state that the terms "perimortem" and "post-mortem" are antiquated as they refer to a temporal period rather than the physical condition of the bone and use of the terms "fresh" and "dry" should be advocated for.

A study conducted by Wheatley (2008) in Alabama utilized deer femora to investigate the differences in fracture patterns between wet and dry bone, as well as the effect weathering has on the fracture patterns (Table 3). Wheatley (2008) diverged from the path of most other authors, utilizing deer femora instead of porcine long bones. De-fleshed bones were used and there was a large gap in the age of the bones being used for the dry group; the newest bones were 44 days postmortem, and the oldest bones were one year postmortem. All bones were fractured at the same time using a Dynatup 8250 Drop Weight Impact test machine, which provided 13.63kg of compressive force applied to the anterior mid-shaft of each femora. After fracture production, Wheatley (2008) scored the characteristics of each bone according to attribute such as angle, the presence or absence of fracture lines, the fracture outline, surface morphology, fracture angle on the Z-axis, number of fracture created, and presence or absence of a butterfly fracture. Chi-square analysis was used to determine association between each category of characteristics.

Wheatley (2008) determined that the only characteristic unique to the perimortem interval was the jagged fracture outline, and that two characteristics were unique to dry bone and the postmortem temporal period: right angles and transverse fracture outlines. Additionally, butterfly fractures occurred in both wet and dry bone, though it was previously thought that the butterfly fracture was characteristic of postmortem trauma (Ubelaker and Adams, 1995; Symes et al., 2014). Statistical analyses determined that wet bones tend to display more smooth surfaces, sharp edges, curved outlines, diagonal angles on the Z-axis, and a greater number of pieces when fractured, while dry bones display rough surfaces and a smaller number of fracture lines. Wheatley (2008) concluded that fresh properties of bone may extend significantly into the postmortem period, and while statistically useful in distinguishing between perimortem and postmortem, the morphological characteristics examined must be used cautiously by the forensic anthropologist when making a determination of perimortem trauma and must employ analysis of multiple characteristics of wet and dry bone to make such a determination.

In an experiment related to Wheatley's (2008) study, Wright (2009) examined perimortem and postmortem fracture patterns in deer femora in Alabama to investigate the correlation between fracture surface texture and bone condition (Table 3). Similar to Wheatley's (2008) experiment, Wright's (2009) sample consisted of two experimental groups of deer femora, a perimortem group and a postmortem group. The perimortem group consisted of 41 bones fractured less than two days after death, while the postmortem group consisted of 46 bones fractured at least 36 days after death. The postmortem group was left outside to dry naturally for two months. The bones were fractured with the same Dynatup impact machine as in Wheatley's (2008) study, though Wright (2009) stabilized the distal end of the femur in a vice and rested the proximal end on a foam pad in order to determine whether stabilization or bone condition had an effect on fracture pattern. The variables analyzed included either presence or absence of: acute angles, right angles, curved edges, jagged edges, rough surface texture, smooth surface texture, butterfly fractures, transverse fractures, the number of fracture lines, and the number of pieces created by impact. All categorical data was scored for MANOVA tests to determine statistical correlation between bone condition and fracture pattern.

From this, Wright (2009) determined that right angles are present more frequently in dry bones, while fresh bones exhibit acute angles more frequently. Jagged and curved edges were found to be present in both fresh and dry bone at similar frequencies, while rough surface texture was found predominantly in dry bone and smooth surface texture was predominant in fresh bone. Butterfly fractures were present in both dry and fresh bone with similar frequency, as were transverse fractures. Lastly, both dry and fresh bones exhibited a similar number of pieces present after being fractured. Wright (2009) concludes that these finding indicate support for a methodology used to distinguish between perimortem and post-mortem timing of injury, though more research is needed into variables that may be used to more accurately classify the timing of injury.

Similarly, a study conducted by Shattuck (2010) investigates the questions of whether there is a visible change in fracture pattern characteristics as bone progresses further into the postmortem period, whether there is a distinct difference in the characteristics of perimortem and postmortem fractures, and whether there is a noticeable difference between the characteristics of fractures produced at the time of death and those produced at a PMI of 126 days (Table 3). Fifty de-fleshed porcine long bones were placed outside in a fenced enclosure at the outdoor research facility of the Forensic Anthropology Research Facility at Texas State University-San Marcos. The bones were placed on the ground surface in full sun, covered by a steel cage that allowed access by entomological and microbial agents, but protected the bones from scavengers. Daily precipitation, monthly average precipitation, and daily and average temperatures (minimum and maximum) were recorded at the site. Five bones were removed from the enclosure every two weeks and subsequently fractured. Shattuck (2010) adapted the studies published by Wieberg (2006) and Wieberg and Wescott (2008) to fit the different environment of South-Central Texas, in order to observe changes related to weathering more frequently. As bones were removed from the enclosure, they were fractured using a custom drop apparatus, similar to the design from Wieberg's (2006) and Wieberg and Wescott's (2008) studies.

The variables analyzed in this study were the degree of weathering, fracture outline, fracture angle, fracture surface, number of fragments produced, presence of organic agents, the condition of the bones, and the size of fragments produced after fracture. ANOVA statistical tests were performed to determined relationships between fracture angle and PMI, fracture outline and PMI, and the morphology of fracture edges and PMI. Shattuck (2010) determined that timing of trauma could not be established by one characteristic alone. It was determined that surface morphology was the most reliable indicator of time since death, though fracture characteristics at each end of the temporal period showed distinct differences from one another. Bones fractured in the intermediate period displayed characteristics of both perimortem and postmortem trauma and bones did not consistently exhibit characteristics of dry bone until 5 months postmortem. Shattuck (2010) concludes that the forensic anthropologist should utilize analysis of multiple characteristics when attempting to determine timing of trauma and provides a guideline for generalizations that can be made safely regarding wet and dry characteristics of bone.

Karr and Outram (2012) utilized the same approach as other studies (Zephro, 2012), opting for the use of equine and bovine bones instead of porcine (Table 3). In this study, the authors sought to examine the rate of change in the properties of bone from wet to dry in two very different environmental conditions. The two environments examined were a frozen environment at temperatures of -20°C, and a dry, hot environment with temperatures of 40°C, simulating peri-glacial and desert environments, respectively. Six samples of equine bone were obtained, consisting of a de-fleshed radio-ulna, humerus, tibia, metatarsal, femur, and metacarpal each. Five of the samples of equine bone were immediately placed in the freezer, while the sixth was considered “fresh” and fractured immediately. The remaining five equine samples were frozen for 1, 10, 20, 40, or 60 weeks and then fractured. The bovine bone sample consisted of six samples of eight bones: two humerii, two tibiae, two femora, two radio-ulnae. Similar to the equine bones, one sample was retained as a control to simulate “fresh” bone and fractured immediately, while the five samples that remained were placed in a drying cabinet at a temperature of 40°C for 1, 3, 7, 14, or 21 days and then fractured. The fracture mechanism consisted of placing the bone on an anvil and using a cobble (wielded by the same individual) to create a controlled blow to the diaphyseal shaft. The bones were analyzed immediately after fracture using a modified version of the Freshness Fracture Index (FFI), which assessed fracture patterns based on: helical fracture outline, fracture surface texture, and the angle created by the fracture surface as compared to the surface of the cortical bone. Categorical data was scored and three different methods of analysis were used to interpret changes over time.

Karr and Outram (2012) conclude that bones that were exposed to an environment that is hot and dry are more difficult to fracture and exhibit extensive degradation in a short period of time, suggesting that bone will retain fresh characteristics for a markedly shortened period of time, and the occurrence of fractures exhibiting fresh characteristics may be significantly reduced after even a single day. Similarly, frozen bones degrade over time, though the rate of degradation is slowed compared to a hot, dry environment. Bones frozen for one week exhibited more fresh characteristics than the control group, and though the subsequent samples degraded over time, the rate was significantly slower than those in the hot, dry environmental group. Knowledge of the rates of degradation of bone in extreme environments lends to specific knowledge of observable processes and may aid future researchers in estimation of timing of injury, as well as aiding those investigating the archaeological record.

Similar to Karr and Outram (2012), Wheatley (2008), and Wright (2009), Zephro (2012) also chose to use a human proxy other than porcine bone, utilizing bovine bones to investigate both timing and mechanism of bone fracture (Table 3). Zephro (2012) examines both gunshot and blunt force trauma of bovine bones in differing preservation states in order to establish criteria for estimating timing of injury. Forty-four de-fleshed bovine long bone shafts (without epiphyses) were obtained from a butcher, 15 of which were immediately refrigerated, 15 immediately frozen, and 14 placed in an outdoor environment in California to dry for seven years. The refrigerated ("fresh") sample was fractured within one week of procurement and the frozen sample was fractured within one month of procurement, using either gunshot or blunt force trauma. Variables analyzed in this study included: fracture surface, angle, and cortical bone thickness. The fracture surface texture was assessed using casts made from microsil in order to determine the presence of ripples, vascularity, and "tree bark appearance". General surface texture was then assessed using a low powered microscope. Categorical data was scored for statistical analysis, using ANOVA, as well as Chi-square tests to determine relationships between the conditions of the bone, or type of trauma inflicted, and fracture angle.

Zephro (2012) determined that there was no statistically significant correlation between fracture angle and cortical bone thickness, though there is a positive correlation between surface texture and bone condition, despite difference in trauma type. Dry bone exhibited rough surfaces the most frequently, while smooth surfaces were exhibited most frequently by fresh and frozen bone. Zephro (2012) notes that historically, fracture angle has been used as an indicator of bone condition, however she found no significant correlation between the two and recommends that use of this characteristic be suspended pending further investigation into different species of bone. Zephro (2012) indicates that surface texture exhibits the strongest correlation with bone condition, though its definition is ambiguous at best.

Lastly, Coelho and Cardoso (2013) examined the effects of using different bone types as a proxy for human bone, the length of the postmortem interval, and macro-environments on estimating the timing of blunt force trauma applied to long bones (Table 3). The authors note that moisture content has a significant effect on the morphology of fracture characteristics, contributing to the elasticity of the perimortem interval. They advocate for use of the terms “fresh” and “dry” as opposed to perimortem and postmortem as these terms relate to the physical properties of the bone being described rather than a temporal period. In this study, juvenile pig and goat limb segments were obtained and placed outdoors in three different macro-environments (ground surface, buried, underwater) using an inverse scheme, every 28 days for a total time period of 196 days. At the end of the 196-day period, all bones were collected and fractured simultaneously using a custom drop impact device. Variables analyzed in this study included fracture outline, fracture angle, and fracture surface, as well as classification according to the Fresh Fracture Index (FFI) as previously described by Outram (1998) and Karr and Outram (2012). The FFI is used to determine whether fractures are fresh or dry, based on characteristics of the fracture such as angle, surface and outline (Coelho and Cardoso, 2013). Categorical data was scored and then analyzed using linear regression models and Spearman’s correlation coefficient to test relationships between FFI and PMI.

Coelho and Cardoso (2013) conclude that fracture morphology varies according to the environment in which the bones are located, adding a contributing factor to the post-mortem interval. Using the FFI, the authors were able to differentiate between fractures produced at PMI 0 and those produced at day 56, which suggests that the FFI scale may be a useful factor in determining timing of injury, allowing for earlier detection of morphological changes in the transition from wet to dry. In regards to the different macro-environments tested, the only difference was found between buried and submerged samples of goat bones, and buried or submerged samples of pig bones. In these two examples, there was no correlation between FFI and PMI noted. The authors note some complications with their experiment, citing the inverse collection scheme as one problem as it caused the bones to all be exposed to different climactic conditions at different time periods.

Table 3: Summary Table of Materials and Methods Used (Adapted from Pal and Saha, 1984; Villa and Mahieu, 1992; Kress et al., 1995; Janjua and Rogers, 2008; Wieberg and Wescott, 2008; Wheatley, 2008; Huculak and Rogers, 2009; Shattuck, 2010; Wright, 2009; Pechnikova et al., 2011; Karr and Outram, 2012; Zephro, 2012; Coelho and Cardoso, 2013).

Study	**Species**	**Limb**	**#**	**Length of time**	**Deposition**	**Fracture method**	**Frozen?**	**Fleshed/ Defleshed**
Karr and Outram, 2012 Compare frozen to dry fracture patterns	Equine Bovine	• humerus, a radio-ulna, metacarpal, a femur, a tibia, and a metatarsal • two humeri, two radio-ulnae, two femora, and two tibiae.	6 6 (8)	• Frozen for 1, 10, 20, 40, 60 wks • 1, 3, 7, 14, 21 days Then fractured	NA	Placed on anvil, single unmodified cobble, sub-spherical diorite cobble weighing 2.45 kg, same person-diaphyseal shaft with min # blows	5 frozen -20°C 5 dried at 40°C	Defleshed Defleshed
Coelho and Cardoso, 2013 Duration of postmortem period on fx morphology	Pig Goat	Fibula, tibia metatarsals	110, 110 105	Placed 0, 28, 56, 84, 112, 140, 168 and 196 days then fractured	7 sets of 10 leg segments 3 env: ground scattered over 180m^2, buried 1m deep 1m apart,	Collected on 196th day, fractured using a custom made apparatus consisting of a drop weight (5.9kg) and a wooden frame height	No	Fleshed

					submerged 1.5m deep Inverse scheme	80cm onto wooden rod over bone Macerated after fracture		
Pal and Saha, 1984 Characterize flexural fracture behavior of whole bones as fnctn of deformation rate	Rabbit	Femora	6 groups	NA	NA	tested in three-point bending Instron servohydraulic testing machine (model 1321)	Yes -20°C	Defleshed
Wheatley, 2008 Fx patterns in deer femora-peri vs post	White tailed Deer	Femora	76 femora, 2 groups (wet (42) and dry (34))	Dry group in backyard until fx 44 days (n = 14) or 1 year (n = 20) Wet group: 21 less than 2 days old and 21 less than 4 days old.		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	NA	Defleshed
Zephro, 2012 Timing and mech of fx	Bovine	Femora humerii tibiae radioulnae	24 12 6 2 (44)		14 outdoors unprotected open rooftop to dry for 7 years	10 lb sledgehammer on asphalt Fresh bludgeoned within 1 week of procurement Frozen bludgeoned while frozen 1 month from procurement Dry individual specimens were packaged in heavyduty plastic to retain bone fragments	15 refrig 15 frozen 14 outside	Fleshed and Defleshed
Weiberg and Wescott, 2008	Pig	Ulnae Femora Tibiae	60	10 bones removed Q 28	initial sample of 10 bones was fractured	custom drop impact bone breaking apparatus, which	Frozen	Fleshed To ensure that the

Est timing of long bone fx				days, period of 141 days 5 months	immediately upon thawing and served to represent trauma occurring at the time of death. The initial sample was designated as PMI 0. The remaining bones were placed on the ground in a fenced area in central Missouri at the beginning of the summer (June 19, 2005) to decompose Ten bones were removed and fractured every 28 days for a period of 141 days	consisted of a steel strike bar and a steel base. The strike bar was made from a 10.2-kg steel pipe with a sealed end. The base consisted of plate steel with a cradle for the bones constructed of 3-inch diameter steel pipe cut in half lengthwise. When the strike bar was dropped from a height of 0.48 m, it produced a sudden dynamic force of c. 106 kg⁄cm2		fracture location was clean enough to thoroughly examine, soft tissue was removed manually and then macerated in a standard detergent and water solution
Shattuck, 2010 Thesis perimortem fx patterns	Pig	femora	50	24 weeks weathering-5 bones removed and fx immediately to simulate perimortem trauma, then 5	Surface-steel frame cage on surface-5 bones thawed and fx immediately, 5 bones removed and fx Q2 wks	Wood 2x4 upright screwed to steel plate (1cm thick), PVC pipe to guide weighted pipe-0.95m galvanized steel filled w/ #9 lead shot, sealed, 6.4kg, dropped thru pvc, height 1.48m	Frozen-wrapped in plastic bag then paper bag- thawed to 76°	Defleshed

				bones removed and fx Q2 wks				
Janjua and Rogers, 2008 Bone weathering patterns of metatarsal v femur and PMI in southern Ontario	Pig	Femora Humerus Metatarsals	24 1 25	291 days checked daily for first 10 days, then QOD 12-18d, femora and MT chkd Q3-4D for 18-35d, Q5D until 45d, weekly until 195d, biweekly until 291d	Surface- wood framed wire cages w no floor	NA	Refrigerated	Defleshed
Huculak and Rogers, 2009 Reconstructing seq of events surrounding body disposition based on color staining of bone	Pig	30 humeri + 10 for compensating scavenging 10 controls	40 10 control	8 weeks 4 wks buried 4 wks surface	• Shallow Burial 0.3m- 10 humeri divided into 2 levels of 5 w/10cm soil separating top and bottom layer • Surface- 12 bottomless cages chicken wire and lumber	Cross sectioned ea bone displaying bleaching after surface exposure	Frozen 1 week	Defleshed Controls remained fleshed
Kress et al., 1995 (psihogios) Fx patterns of human cadaver long bones	Human	Tibia Femur	253 136	?	NA	Defleshed- pin-pin set up w intact legs either pin-inertial (foot hanging freely) or pin-friction (shoed foot on	Unknown	Fleshed and defleshed

						concrete block) impacted at midshaft Pneumatic based accelerator-propels wheeled cart w 10cm steel impactor pipe toward specimen 50kg from 1.5m at 7.5m/s OR swinging pipe		
Wright, 2009 Peri and postmortem fx patterns in deer femora	Deer	Femora	87 post=46 peri=41	Old group left outside for 2 months to dry naturally New bones tested within 2 days of receipt (2 days after death) Old bones tested at least 60 days after receipt (60 days after death)	• “old” group (n=46) left outside to dry naturally for 2 months • “new” group taken to 20x30’ fenced area and defleshed day of experiment	Dynatup 8250 drop weight impact test machine 13.63kg, strike surface 3x4’’ height? Distal femur secured in vice, prox end rest on foam pad to generate shearing force for natural fx pattern Frags collected and macerated	Unknown	Defleshed
Pechnikova et al., 2011 Distinguishing btwn peri and postmortem fx: are osteons of any help?	Human	Femora Tibia Radii Fibulae	3 2 2 2	NA	NA	Fresh- Fx by BFT on transverse plane – collected from 2 autopsy cases Dry- historical 16th century bones- transverse fx of diaphysis	Unknown	Unknown

Implications

After a thorough examination of the literature, it has been determined that investigation into the timing of injury must be conducted by geographical region. The study conducted by Wieberg (2006) and Wieberg and Wescott (2008) is an acceptable framework for investigation into this phenomenon as it is already being reproduced in the literature (Shattuck 2010; Coelho and Cardoso, 2013). In order to evaluate whether the time frame of the transition from wet to dry properties is analogous, the Wieberg (2006) study was replicated in the Central Florida region.

Regional Variability

Biological and environmental factors vary depending on the geographic region in which the human remains are located and affect the decomposition processes acting on the remains (Ubelaker, 1997). Therefore, the incorporation of biological and environmental data into a model or framework will allow the forensic anthropologist to utilize a systematic approach in recovery and interpretation of human remains (Ubelaker, 1997; Sorg and Haglund, 2002). Specific taphonomic characteristics can be combined to form taphonomic suites according to macro and microenvironment, which can then be combined to form taphonomic signatures (Pokines, 2014). Regional models can be constructed, adapted for, and applied to different geographic and environmental regions in order to aid in the interpretation and evaluation of the taphonomic processes of decomposition unique to each. Knowledge of these unique taphonomic processes allows the forensic anthropologist to correctly interpret events surrounding an individual’s death (Ubelaker, 1997; Sorg and Haglund, 2002).

The Taphonomic Model

The typical scientific model encompasses a family of concepts with substantial differences, finding a relationship between them by altering one variable or another (Nordby, 2002). By creating this model, predictions are able to be made and then supported or refuted based on data gathered during observation and experimentation (Nordby, 2002). Utilization of this approach in taphonomic research allows analysis of one specific variable in a unique amalgamation of different climates, circumstances, locations, systematically developing unique models for each (Nordby, 2002). In this way, the taphonomic model provides avenues for future development of time-interval estimates and development of theory, which arises from the need to “explain explanations” (Nordby, 2002:39). Therefore, the confrontation of multifaceted variables and circumstances in death investigation during development of theory in taphonomic research is the norm, rather than the exception to the rule (Nordby, 2002).

The goals of forensic taphonomic research are five-fold: to estimate time since death, differentiate between human and nonhuman skeletal remains, understand variables affecting transportation of skeletal remains, identify taphonomic processes affecting degradation or preservation of skeletal remains, and reconstruct perimortem events (Komar and Buikstra, 2008). The building blocks of taphonomic research are rooted in the theory of uniformitarianism, which states: “similar causes produce similar effects” (Haglund, 1991:10). This theory depends on the underlying principles that processes remain unchanged over time, and natural laws remain uniform over time and through space (Haglund, 1991). Forensic taphonomy applies uniformitarian methodology to questions regarding death in order to understand certain processes, patterns and mechanisms in the reconstruction of the taphonomic history (Bristow et al. 2011). To answer these questions, research has been undertaken in a variety of manners, including actualistic, experimental, and case studies (Sorg et al., 2012).

While the experimental approach has been applied to studies of decomposition of primarily soft tissues, actualistic studies have been used to investigate real forensic cases (Sorg et al., 2012). According to Komar and Buikstra (2008), actualistic studies are used to examine taphonomic processes by observation of collected materials, either in field or laboratory settings. Sorg and Haglund (2002) note that examination of a specific taphonomic process is the basis for constructing a taphonomic model. Actualistic research provides a middle ground between traditional and forensic taphonomic research and examines a particular taphonomic process by controlling variables, thus providing a systematic approach to analysis, allowing for the construction of a taphonomic framework. These taphonomic processes can then be observed in the natural setting, allowing subsequent analysis of cases with similar processes to be combined and used to construct a model (Haglund, 1991; Sorg and Haglund, 2002). Construction of a model using similar observed processes allows for later replication of the study, as well as comparison of similar works. Sorg and Haglund (2002) note that advantages to using taphonomic models include allowance for data collection by one investigator, decreasing the chances that data will be skewed, and increasing the likelihood that a systematic approach will be applied to analysis, thereby increasing the ability to replicate the study.

Case studies also provide researchers with an avenue with which they may observe different variables in the natural setting, without undue influence from the investigator (Sorg and Haglund, 2002). In this framework, observations can be made about the variation that may occur within a particular environment, collected from real world examples (Sorg and Haglund, 2002; Sorg et al., 2012). While decomposition studies have been undertaken in an attempt to understand the processes involved, the initial models provided investigation of taphonomic processes in controlled environments, without taking into account environmental factors that vary dependent on region and climate.

Macro and Microenvironments

Historically, patterned decomposition research focused on soft tissue decomposition and entomological activity (Beary and Lyman, 2012). As it began to be understood that decomposition rates would be affected by numerous regional variables, investigation into these factors began (Beary and Lyman, 2012). Observations of regional variation can be seen in numerous actualistic studies focusing on specific region and climate (Sorg and Haglund, 2002; Beary and Lyman, 2012). Investigations into patterns of decomposition and taphonomic processes by region has become an integral part of forensic taphonomy, as it has been recognized that differences between microenvironment affect processes both intrinsic and extrinsic (Beary and Lyman, 2012). Regional environmental factors may cause a substantial deviation from normal decomposition patterns (Ubelaker, 1997; Sorg et al., 2012). Gathering data from individual ecological contexts provides a more systematic approach to analysis, allowing information about specific climate, biological, and physical processes to be applied to the remains discovered within that context. Regional variation of decomposition process can be seen in observations of natural decomposition, temperature, scavenger taxa, entomological species divergence, botanical and soil variation, as well as in a wide range of other variables (Sorg and Haglund, 2002).

According to Pokines (2014), taphonomic signatures include suites of taphonomic characteristics that can provide information regarding a unique set of circumstances, a specific taphonomic event, or a process that resulted in alteration of human remains. These suites of characteristics can be organized according to micro- or macro-environment and may be used to analyze and reconstruct specific taphonomic events. These suites of taphonomic characteristics may include naturally and artificially created alterations to the remains themselves, as well as physical characteristics of the immediate environment. These taphonomic signatures can also be used as an aid in determining post-mortem interval (PMI), while taphonomic analysis can be further used to differentiate between peri- and postmortem alterations, providing information about whether the alterations occurred as a result of human or natural intervention (Pokines, 2014).

CHAPTER 4: MATERIALS AND METHODS

Materials

One hundred and forty-five de-fleshed long bones were obtained from adult pigs (*Sus scrofa*), immediately after death, collected from Nettle's Sausage slaughterhouse in Lake City, Florida. The pigs were slaughtered for the purpose of human consumption, according to standards set by the USDA (USDAFSIS, 2003). Femora, tibiae, and humerii were obtained from adult pigs, as porcine bone is considered an acceptable proxy for human bone tissue (Sauer, 1998). The bulk of the soft tissue was removed from the bones by the slaughterhouse, leaving a small amount of muscle tissue and connective tissue at the proximal and distal ends. De-fleshed bones were chosen for this experiment to control for the factors presented by decomposition and allow for isolation of fracture patterns for analysis without the complication of decomposition. The bones were frozen (-40°C) immediately after they were collected to provide a constant environment until initiation of the experiment, wrapped first in plastic wrap and then in paper bags to prevent freezer burn (Shattuck, 2010; Wieberg, 2006; Wieberg and Wescott, 2008). According to Evans (1973), freezing bone tissue, followed by thawing, does not result in detrimental effects to the intrinsic properties of bone tissue. Prior to commencement of the experiment, the bones were allowed to thaw at room temperature.

Sample Selection and Preparation

Two experimental groups were created to test two separate microenvironments, full sun exposure and full shade exposure, in the subtropical environment of Central Florida (Tables 4 and 5). An initial sample of 5 bones, serving as a control group, (n=5) were fractured immediately upon thawing to represent perimortem trauma. The remaining long bones were placed outside in a designated area on the campus of the University of Central Florida (the deep foundations geotechnical research area at the Arboretum), half in full sun (group A, n=70), half in full shade (group B, n=70) (Figure 3 and 4).

Bones were collected each week, 5 from each group, for 14 weeks (Oct 2014-Jan 2015) from each microenvironment (n=10) and subsequently fractured (Table 4 and 5). This totals one hundred and forty long bones (n=140) between the two experimental groups, in addition to the five bones in the control group (n=145).

Table 4: Experimental Sample Groups

Sample Group	**Materials Utilized (*Sus scrofa*)**
Group 1 (full sun)	Femur Tibia Humerus (n=70)
Group 2 (full shade)	Femur Tibia Humerus (n=70)
Control	Femur Tibia Humerus (n=5)

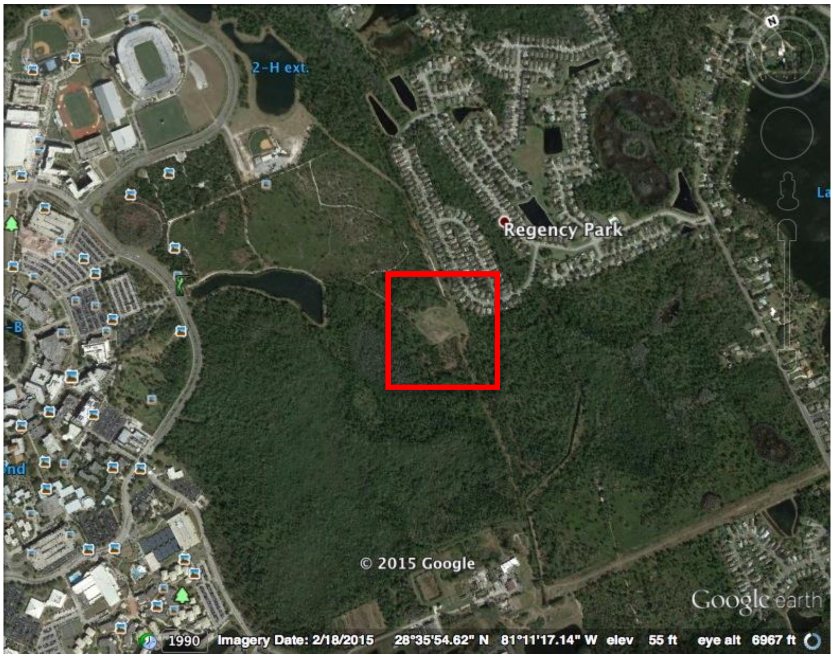


Figure 3: Aerial view of the deep foundation geotechnical research site at the Arboretum at the University of Central Florida

Figure 4: Aerial view of the research site indicating the placement of Group A and Group B.

Wieberg (2006), Shattuck (2008), Wieberg and Wescott (2008), and Coelho and Cardoso (2013) chose to collect bones at longer intervals; at four weeks and two weeks. The time interval of one week was chosen for this study because of the unique environment of Central Florida, in which there is an increased amount of rainfall, increased humidity, and high temperatures. Each bone was assigned a unique identification label and clear fishing line was used to fasten a round laminated tag, labeled with the identification number, to each before it was placed on the ground surface in the Arboretum. The bones were divided evenly and placed on the ground surface, half in an area that allowed for full sun exposure (n=70), designated group A (Figure 4 and 5), and half in a shaded area (n=70), designated group B (Figure 4 and 6). The bones were distributed evenly between the two microenvironments. The bones were covered by hardware cloth, which was staked to the ground to allow access for entomological and faunal activity, but to prevent the removal of bones by scavengers.

The bones were observed every 3-4 days to assess for scavenger activity and interference. Photographs were taken of each bone as it was collected to record subtle changes over time. Climatic data was obtained from the weather station at the Arboretum on the UCF campus and included: daily precipitation, daily temperature (minimum and maximum), average monthly temperature (minimum and maximum), and total monthly precipitation.

Table 5: Experimental Protocol Shown by Sample Group.

Group	Sample	Defleshed	Frozen	Deposition	MicroEnvironment	Weekly	Fracture	Tagged	Analysis
#1	70	Y	Y thawed before fx	Full sun Arboretum	Sub-tropical, central Florida-UCF campus Arboretum Full sun	5 per week/fx	Custom impact device	Y fishing line, tag	Gross morph-angle, surface, outline, fx morph, FFI, stats
#2	70	Y	Y thawed before fx	Full shade Arboretum	Sub-tropical, central Florida-UCF campus Arboretum Full shade	5 per week/fx	Custom impact device	Y fishing line, tag	Gross morph-angle, surface, outline, fx morph, FFI, stats
Control	5	Y	Y thawed before fx	Fx immediately Simulate peri-mortem trauma	NA	NA	Custom impact device	NA	Gross morph-angle, surface, outline, fx morph, FFI, stats

Figure 5: Group A (full sun) in the Arboretum at UCF. Bones were placed underneath a hardware cloth cage to prevent scavenging but allow for entomological access. An area was chosen that was not obscured by any tree cover and would allow for maximum sun exposure
.

Figure 6: Group B (full shade) in the Arboretum at UCF. Bones were placed underneath a hardware cloth cage to prevent scavenging but allow for entomological access. A shaded area was chosen that would allow for little penetration of direct sunlight.

Fracture Production Mechanism

The bones were fractured using a custom drop apparatus modeled on previous studies (Wieberg, 2006; Shattuck, 2010). The apparatus consisted of a wooden vertical support with an attached 3 inch PVC pipe to act as a guide for the drop weight (Figure 7). The drop weight consisted of a 1 ¼ inch diameter galvanized steel pipe with sealed ends, filled with copper B.B.s. The base of the impact device is a wooden platform to which a 3 inch steel pipe cut in half lengthwise was fixed to create a cradle in which the bones rested. The weight of the impact device totaled 9.32kg and was dropped from a height of 0.48m to create a dynamic force of 275 kg/cm$^{2.}$ The formula used to calculate the dynamic force of the impact is ghm/A where g= acceleration due to gravity (m/s^2), h=height (m), m=mass (kg), and A=surface area (cm^2) (Shattuck, 2010). According to multiple authors (Frost, 1967; Evans, 1973; Doblare and Garcia, 2003), the dynamic force required to completely fracture bone is equal to 10500kg/m^2. Therefore the dynamic force created by this apparatus was calculated as follows:

$$\mathbf{(9.8m/s^2)(48cm)(9.32kg)/15.9\ cm^2}$$

Figure 7: Custom drop apparatus modeled from Wieberg's (2006) and Shattuck's (2010) studies. A 1 ¼ -inch steel drop weight weighing 9.32kg was dropped from a height of 0.48m. A 3-inch PVC pipe acted as a guide for the drop weight. Bones were placed in the cradle at the base to ensure consistency in the point of impact

Methods of Analysis

Variables observed

The bones were photographed and analyzed upon collection from the Arboretum and immediately upon fracturing. The fracture patterns were analyzed visually, describing the fracture morphology: Fracture Outline, Fracture Surface, and Fracture Angle, as well as the degree of wet versus dry properties in order to determine at what point bone will lose its wet properties and how fractures progress through the postmortem period. Based on information provided by multiple authors (Villa and Mahieu, 1992; Outram, 1998; Wieberg, 2006; Wieberg and Wescott, 2008; Wright, 2009; Shattuck, 2010; Coelho and Cardoso, 201; Symes et al., 2014), morphological characteristics were described as follows:

1. Fracture Surface was described as rough, intermediate, or smooth.
2. Fracture Angle was described as consisting of right angles, obtuse or acute angles, or a combination of these.
3. Fracture Outline was classified as transverse/stepped (jagged), intermediate, or curved/V-shaped.
4. Postmortem interval was calculated based on number of days post-thaw, as this would simulate the period of time immediately after death.

The Fracture Freshness Index as created by Outram (1998) was used to code each bone as it was fractured (Table 6). The characteristics that were observed include: Fracture Angle, Fracture Outline, and Fracture Surface texture. A score was assigned to each bone from 0 to 2, representing the degree of involvement for each category (Table 6).

Table 6: Scores Assigned to Bones Based on FFI (Adapted from Outram, 1998; Wieberg and Wescott, 2008; Wheatley, 2008; Shattuck, 2010).

Fracture Characteristic	**Score=0**	**Score=1**	**Score=2**
Fracture Angle	Absence of right angle fractures	Fewer right angle fractures present than acute/obtuse angle fractures	Majority right angle fractures present
Fracture Outline	Presence of helical fractures only, curved	Presence of both helical fracture outlines as well as other outlines, intermediate	Absence of helical fractures, jagged
Surface Texture	Smooth texture, absence of rough texture	Primarily smooth texture, some roughness noted	Primarily rough texture

Statistical Analysis

All statistical analyses were performed using IBM SPSS Statistics 22 (IBM Corporation, 2013). To analyze the observed characteristics for each bone, a coding scheme was developed to assign a numerical value to categorical data (Table 7). For each bone, the proximal end and the distal end were examined separately to provide an overall examination of the fractures present. To analyze Fracture Angle and Fracture Surface, the anterior and posterior halves of each end of the bone were examined, with each end divided into quadrants. One fracture was marked for analysis in each quadrant of each end. For example, the proximal end of one bone had two fractures marked for analysis on the anterior half of the bone, as well as two fractures marked for analysis on the posterior half of the bone. This process was repeated for the distal portion of the bone. Each marked area was then analyzed for the Fracture Angle and assigned a value of acute, obtuse, acute and obtuse, right, right and obtuse, or right and acute. The Fracture Surface was also analyzed for each area and was scored as smooth, intermediate, or jagged.

Both ends of the bone were examined for the overall appearance of the Fracture Outline and each bone was assigned a value of curved/V shaped, intermediate, or transverse/jagged according to previous studies (Wieberg, 2006; Shattuck, 2010). Finally, the microenvironment the bones were subjected to was considered.

Table 7: Coding system used to assign a summary score to each bone for each morphological characteristic observed (Adapted from Wieberg, 2006 and Shattuck, 2010).

	0	**1**	**2**
Fracture Angle	Acute and/or obtuse angles	Both right and oblique angles	Predominantly right angles
Fracture Surface	Smooth	intermediate	Rough/jagged
Fracture Outline	Curved/V shaped	Intermediate	Jagged (stepped)/transverse

After the bones were analyzed for the presence of acute/obtuse or right angles, the surface quality, and the overall outline, all categorical data was coded for quantitative analysis. Fracture Angles that were assigned values of acute, obtuse, and acute and obtuse were assigned a score of 0. Fracture Angles that were assigned values of right and acute, or right and obtuse angles were assigned a score of 1, while Fracture Angles that were assigned a value of right, or those that exhibited a majority of right angles were assigned a score of 2. This gave the bones a summary score based on the presence of multiple types of angles, rather than an overall assessment score.

Similarly, Fracture Outlines described as curved/V shaped were assigned a score of 0, while intermediate values were assigned a score of 1 and jagged/transverse values were assigned a score of 2. Fracture Surface was similarly scored; fractures exhibiting smooth characteristics were assigned a score of 0, intermediate characteristics were assigned a score of 1, and jagged characteristics were assigned a score of 2 (Table 7).

Both Chi-Square analysis and one way analysis of variance (ANOVA) were used to investigate the relationships among the observed characteristics of the bones. Chi-square analysis and ANOVA testing were performed using the IBM SPSS Statistics program. Additionally, multiple linear regression analysis was used to assess the relationship between the variables and the postmortem interval.

Chi-Square Analysis

Chi-square analyses were performed to assess frequency and correlations between traits. The frequency of occurrence for each trait was recorded as well as how often it correlates with each other trait observed. Chi-square analyses were performed for the following analyses: Fracture Surface and Fracture Angle, Fracture Surface and Fracture Outline, and Fracture Angle and Fracture Outline were compared for the entire data set, as well as according to microenvironment.

The chi-square analysis allows for comparison for data that are categorical. The frequency of occurrence was assessed and analyzed to determine whether there is a degree of association between the morphological characteristics and whether the variables are statistically independent (Frankfort-Nachmias and Leon-Guerrero, 2015).

ANOVA

One-way analysis of variance was performed to assess the relationship between Fracture Angle, Fracture Surface, Fracture Outline, and the continuous variable of time. Each category was analyzed against the time scale of 14 weeks to determine whether there is a relationship between the frequency of a specific characteristic and the time period in which this characteristic is predominant (Frankfort-Nachmias and Leon-Guerrero, 2015).

Multivariate Linear Regression

Additionally, OLM linear regression was performed to investigate the effects of time in relation to Fracture Angle, Fracture Surface, and Fracture Outline by measuring the linear relationship between multiple variables (Frankfort-Nachmias and Leon-Guerrero, 2015). The dependent continuous variable of time was regressed on the independent variables of Fracture Angle, Fracture Surface, and Fracture Outline to determine if there was a causal relationship between these four variables. As time can be both an independent and a dependent variable, it was used as a dependent variable in this instance to determine if the Fracture Angle, Fracture Surface, and Fracture Outline could predict the time frame in which these characteristics occurred.

In this analysis, time was selected as the dependent variable. As time is a continuous variable, it was selected to compare against the variables of Fracture Angle, Fracture Surface, and Fracture Outline. Each group of bones was exposed to the elements for a period of time between 0 and 14 weeks. Bones were collected each week, arresting their exposure to the elements and the time they were exposed. The bones were immediately fractured after being removed from the outdoor enclosure and subsequently cleaned. Therefore, the dependent variable was scored from 0 to 14, indicating one week intervals of exposure.

The independent variables selected for this analysis included Fracture Angle, Fracture Surface, and Fracture Outline. Each of these variables was recoded to represent dummy variables for this analysis.

Fracture Angle

Fracture Angle was initially scored as acute, obtuse, acute and obtuse, right and acute, right and obtuse, or right. Fracture Angle was recoded to reflect either wet or dry characteristics, using the previously assigned scores of 0, 1, and 2. Bones that were assigned a value of 0, acute, obtuse, or acute and obtuse, were recoded as 0. Bones that were assigned a value of 1 or 2, right and acute, right and obtuse, or right, were recoded as 1. This was recoded to incorporate all bones that exhibited any dry characteristics.

Fracture Surface

Fracture Surface was measured initially as either smooth, intermediate, or jagged. The variable of Fracture Surface was similarly recoded to reflect either wet or dry characteristics. Bones that were assigned a value of 0, smooth, were recoded as 0, while bones assigned values of 1 or 2, intermediate or jagged, were recoded as 1. This variable was recoded to incorporate all bones that exhibited any dry characteristics.

Fracture Outline

Fracture Outline was initially measured as either curved/V shaped, intermediate, or jagged/transverse. Fracture Outline was similarly recoded to reflect either wet or dry characteristics. Bones that were assigned a score of 0, curved/V shaped, were coded as 0, while bones assigned a score of 1 or 2, intermediate or transverse, were recoded as 1. This variable was recoded to incorporate all bones that exhibited any dry characteristics.

Intraobserver Error

A separate analysis was conducted to assess intraobserver error. As the data being observed were largely categorical and subjective, an evaluation of the techniques used to analyze the bones was undertaken. The system used to mark the Fracture Angle being observed was relatively effective. Determination of Fracture Surface was decided based on examples of the best-case scenarios in the literature (Symes et al., 2014). Similarly, determination of Fracture Outline was determined based on a suite of characteristics described in the literature and best-case scenarios in the literature were used for classification (Symes et al., 2014).

After the bones were re-analyzed, the results were compared to the initial analysis to determine whether there were any major differences in the assessment and if so, where those differences lay (Appendix B, Table 2). The samples were analyzed for a second time at a different date to assess whether there was any issue with the analysis protocol (Appendix B, Table 3). After the second blind analysis, the second dataset was compared to the first and to the bone again in the lab to make a final determination regarding the characteristics observed

(Appendix B, Table 1). As intraobserver error was not addressed fully in previous studies in regards to issues related to scoring the bones, the decision was made to address it in this study.

CHAPTER 5: RESULTS

Bones were placed into two separate groups: full sun and full shade. Group A represented bones placed in full sun, while Group B represented full shade. Following collection of bones from the outdoor environments, bones were fractured using a custom drop apparatus. Each bone was cleaned and then examined for the fracture characteristics of Fracture Angle, Fracture Surface, and Fracture Outline. A control group consisting of five bones was fractured immediately after thawing to represent a postmortem interval (PMI) of 0. Gross morphological analysis, as well as statistical analyses were undertaken for each bone in the sample. One way analysis of variance (ANOVA) and Chi-square analysis were conducted to assess the relationships between and among the variables observed. Additionally, Multiple Linear Regression analysis was performed to assess the ability of fracture characteristics to predict timeframe. The results of these analyses will be presented, forthwith. Weather data and environmental considerations will be address, followed by presentation of the results obtained during Chi-square analysis, ANOVA testing, and Multiple Linear Regression analysis.

Weather Data and Environmental Considerations

Weather data was recorded daily during this study (spanning the months of October 2014 through January 2015); daily high and low temperatures, rainfall, and humidity were recorded using the HOBO link at the University of Central Florida Arboretum (Table 8). During this time period, average temperature ranged between 54° and 87° Fahrenheit (Appendix C, Figure 2).

November exhibited the most rainfall at 6.61” (Appendix C, Figure 3). Average humidity ranged from 92 to 99 percent.

Table 8: Average temperatures, total rainfall and average humidity by month.

	Average Low	**Average High**	**Total rainfall**	**Average humidity**
October 2014	65.10526	86.68421	0.17”	94%
November 2014	56.23333	74.66667	6.61”	92%
December 2014	58.06452	75.70968	2.22”	99%
January 2015	54.35294	72.88235	2.4”	94%

Some of the changes noted on the bones were related to the weather in the Central Florida region. As there is typically rain in the afternoons, many of the bones that retained soft tissue at their epiphyses exhibited softening of the tissue. Furthermore, bones in Group B (full shade) appear to have retained more moisture than those in Group A (full sun). The undersides of the bones in Group B skeletonized quickly, while the exposed side retained soft tissue. This is likely due to the increased insect activity in the shaded area. Also, the bones in Group A exhibited desiccation of the soft tissue at the epiphyses as well as the at tendon and ligament attachments. This is likely due to the dried tissues subjected to constant sun exposure.

The weather in Central Florida differs from the regions in which similar studies have been conducted. In Wieberg's (2006) study, the weather in Missouri consisted of average temperatures ranging from 36.2° to 92.4° F with a total amount of rainfall of 4.19" over the course of the study. Shattuck's (2010) study was conducted in San Marcos, Texas where average temperatures ranged from 31° to 100°F with a total amount of rainfall of 22.8" over the course of the study. The amount of rainfall received in Shattuck's study exceeded both the current study and Wieberg's (2006) study. However, average temperatures in Central Florida were higher over the months that coincided with the previous two studies (Table 8).

A significant amount of maggot activity was noted in both environments, though Group B (the shaded group) exhibited greater activity, as maggots generally prefer the dark (Gennard, 2007). Additional insect activity was noted, especially fire ants (*Solenopsis invicta*), which created ant-hills over the bones in Group A, completely covering some of the bones. Yellow jacket wasps (*Vespula maculifrons*) were also noted in abundance, as were beetles (*Choleoptera*) and flies (*Diptera*).

The bones in Group A also exhibited increased growth of what appeared to be mold and fungus (Figure 8). While the bones in Group B retained moist soft tissue (Figure 9), Group A exhibited desiccated and partially mummified soft tissue and increased fungus and mold activity. What was likely mold and fungus were noted in both groups; however, the types appeared to differ between the groups. While the presence of mold and fungus was noted during observations, analysis of the types of fungi and mold was not conducted. Colors of what appeared to be mold or fungus appeared that ranged from orange and pink to black, brown, green, white, and gray. Additionally, what appeared to be different forms of each were noted: hairy, carpet-like, soft and fuzzy.

Figure 8: A bone from Group A exhibiting what appears to be mold or fungus growth.

Figure 9: A bone from Group B exhibiting less mold and fungal growth, but retaining more moist soft tissue.

Gross Fracture Characteristics

The morphological characteristics of Fracture Angle, Fracture Surface, and Fracture Outline are typically used in analysis of trauma and determining the time frame in which the trauma has occurred (Wieberg, 2006; Shattuck, 2010). These fracture characteristics were observed in the sample and the occurrence of each was recorded accordingly (Tables 9 and 10). A coding system was created and employed to assign a summary score for each morphological characteristic observed on each bone (Table 11). The morphological characteristics observed in this study ranged from wet (or perimortem) (Figure 10) to dry (or postmortem) (Figure 11), with numerous bones exhibiting a mixture of both wet and dry characteristics (Figure 12).

The majority of samples were broken and exhibited comminuted fractures where multiple fragments were created. Of 140 bones in the sample, four did not exhibit fracture patterns consistent with the whole. These four bones exhibited incomplete or depressed fractures and were unable to be scored consistently. None of the samples in this study exhibited trauma that was associated with factors outside of this experiment.

Table 9: Fracture characteristics occurring according to week in Group A.

	Fracture Angle			**Fracture Surface**			**Fracture Outline**		
	Only Acute/ Obtuse angles	**Both right and oblique angles**	**Predominantly right angles**	**Smooth**	**Intermediate**	**Rough/ jagged**	**Curved/ V-shaped**	**Intermediate**	**Jagged(stepped)/ transverse**
Week 1	0 bones	5 bones	0 bones	2 bones	3 bones	0 bones	3 bones	2 bones	0 bones
Week 2	0 bones	4 bones	1 bone	1 bone	4 bones	0 bones	2 bones	2 bones	1 bone
Week 3	0 bones	4 bones	1 bone	0 bones	5 bones	0 bones	2 bones	1 bone	2 bones
Week 4	1 bone	4 bones	0 bones	1 bone	4 bones	0 bones	2 bones	3 bones	0 bones
Week 5	0 bones	5 bones	0 bones	2 bones	3 bones	0 bones	1 bone	4 bones	0 bones
Week 6	0 bones	5 bones	0 bones	0 bones	3 bones	2 bones	1 bone	2 bones	2 bones
Week 7	0 bones	4 bones	0 bones	0 bones	3 bones	1 bone	0 bones	2 bones	2 bones
Week 8	0 bones	3 bones	2 bones	0 bones	3 bones	2 bones	0 bones	3 bones	2 bones
Week 9	0 bones	5 bones	0 bones	1 bone	4 bones	0 bones	0 bones	5 bones	0 bones
Week 10	0 bones	4 bones	1 bone	0 bones	3 bones	2 bones	1 bone	2 bones	2 bones
Week 11	0 bones	3 bones	2 bones	1 bone	3 bones	1 bone	2 bones	1 bone	2 bones
Week 12	0 bones	3 bones	2 bones	1 bone	0 bones	4 bones	0 bones	3 bones	2 bones
Week 13	0 bones	1 bone	4 bones	0 bones	3 bones	2 bones	0 bones	2 bones	3 bones
Week 14	0 bones	3 bones	2 bones	0 bones	2 bones	3 bones	0 bones	2 bones	3 bones

Table 10: Fracture characteristics occurring according to week in Group B.

	Fracture Angle			**Fracture Surface**			**Fracture Outline**		
	Only Acute/ Obtuse angles	**Both right and oblique angles**	**Predominantly right angles**	**Smooth**	**Intermediate**	**Rough/ jagged**	**Curved/ V-shaped**	**Intermediate**	**Jagged(stepped)/ transverse**
Week 1	0 bones	4 bones	1 bone	2 bones	3 bones	0 bones	2 bones	2 bones	1 bone
Week 2	0 bones	4 bones	0 bones	0 bones	4 bones	0 bones	0 bones	3 bones	1 bone
Week 3	0 bones	5 bones	0 bones	3 bones	2 bones	0 bones	2 bones	3 bones	0 bones
Week 4	0 bones	5 bones	0 bones	3 bones	2 bones	0 bones	2 bones	3 bones	0 bones
Week 5	1 bone	4 bones	0 bones	0 bones	3 bones	2 bones	0 bones	4 bones	1 bone
Week 6	0 bones	3 bones	1 bone	2 bones	2 bones	0 bones	1 bone	2 bones	1 bone
Week 7	0 bones	5 bones	0 bones	0 bones	3 bones	2 bones	0 bones	5 bones	0 bones
Week 8	0 bones	3 bones	2 bones	0 bones	4 bones	1 bone	1 bone	4 bones	0 bones
Week 9	0 bones	3 bones	2 bones	0 bones	2 bones	3 bones	0 bones	0 bones	5 bones
Week 10	0 bones	2 bones	3 bones	0 bones	1 bone	4 bones	0 bones	2 bones	3 bones
Week 11	0 bones	3 bones	2 bones	0 bones	1 bone	4 bones	0 bones	4 bones	1 bone
Week 12	0 bones	1 bone	4 bones	0 bones	0 bones	5 bones	0 bones	3 bones	2 bones
Week 13	0 bones	4 bones	0 bones	1 bone	2 bones	1 bone	1 bone	2 bones	1 bone
Week 14	0 bones	2 bones	3 bones	0 bones	3 bones	2 bones	0 bones	2 bones	3 bones

A control group consisting of five bones was also fractured immediately after thawing to simulate perimortem trauma. These bones all exhibited characteristics expected of perimortem trauma, which are consistent with wet bone such as predominantly acute and obtuse angles, a smooth fracture surface, and curved or V shaped fracture outlines. These bones were used for comparative purposes as they exhibited characteristics consistent with perimortem trauma.

Overall, there was a shift from primarily fresh characteristics, oblique fracture angles, smooth surfaces, and curved outlines (Figure 10), toward the occurrence of predominantly jagged fracture outlines, more frequently observed right angles, and a rough surface texture as the postmortem interval increased (Figure 11). The majority of samples in both environments exhibited intermediate characteristics including a combination of right and oblique angles (acute and obtuse), an intermediate surface texture, and a combination of fracture outlines (Tables 9 and 10). For example, one half (either the proximal or distal end) of a fractured bone might exhibit a transverse outline, while the other half exhibited a V shaped fracture with extensive fragmentation (Figure 12).

Table 11: Coding system used to assign a summary score to each bone for each morphological characteristic observed (Adapted from Wieberg, 2006 and Shattuck, 2010).

	0	**1**	**2**
Fracture Angle	Acute and/or obtuse angles	Both right and oblique angles	Predominantly right angles
Fracture Surface	Smooth	intermediate	Rough/jagged
Fracture Outline	Curved/V shaped	Intermediate	Jagged (stepped)/transverse

Figure 10: Bone 1101: week 11, Group A. This bone exhibits curved fracture outlines and a smooth fracture surface.

Figure 11: Bone 1202B, week 12, Group B. This bone exhibits a transverse fracture outline.

Figure 12: Bone 201A, week 2, Group A. This bone exhibits an intermediate fracture outline. The distal end of the bone exhibits a transverse outline while the proximal end of the bone exhibits a curved/V-shaped outline and multiple fragments.

Fracture Angle was observed as an indicator the intrinsic properties of bone. Bones exhibiting exclusively oblique angles were only noted in the control group. In the first week following exposure to the elements, bones began exhibiting intermediate characteristics. The presence of right angles was noted in the first week in both Group A and Group B (Tables 9 and 10). Primarily right angles were noted in Group B as early as week one, while Group A exhibited primarily right angles as early as week two. However, aside from these early indicators of dry characteristics, primarily intermediate angles, or a combination of oblique and right angles, were seen until approximately week 10, when a shift toward more dry characteristics can be observed

(Figure 13 and 14). Completely oblique angles were observed in weeks 4 and 5, however right angles were present in almost every bone in the sample (Table 12).

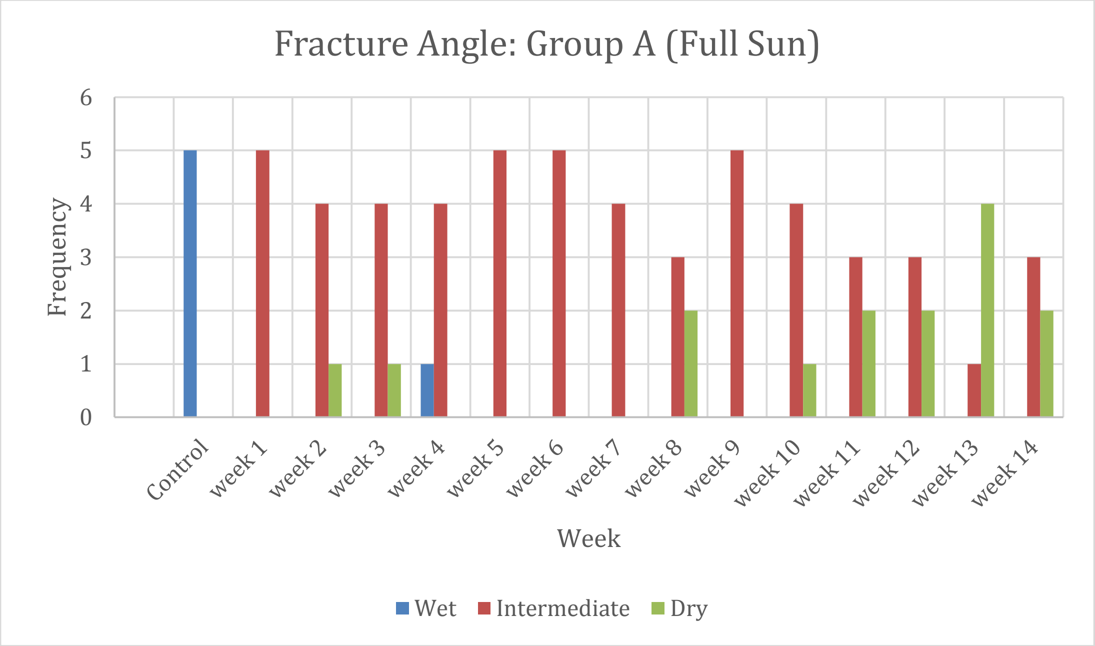


Figure 13: Bar graph representing the transition of Fracture Angles from wet to dry over 14 weeks in Group A. Note the appearance of dry characteristics as early as week two.

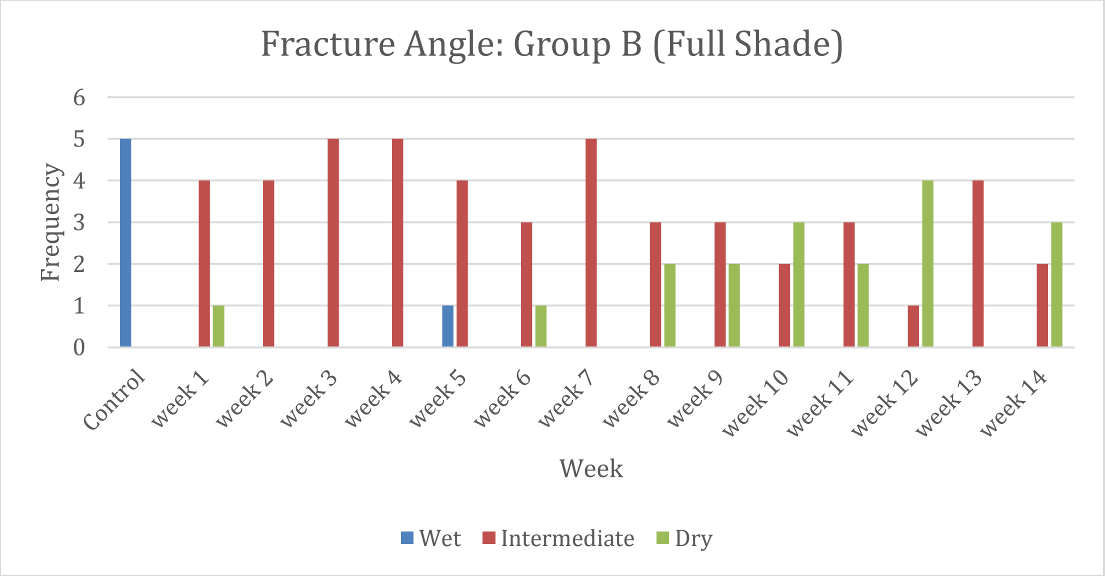


Figure 14: Bar graph representing the transition of Fracture angles from wet to dry over 14 weeks in Group B. Note the appearance of dry characteristics in the first week.

Fracture Outline was observed to shift toward a primarily dry expression of characteristics as well. Wet characteristics, curved or V shaped outlines, were observed to be dominant in the first few weeks of the study. Around week 5, a shift occurred toward more intermediate expression of characteristics (Figures 15 and 16). Dry, or transverse fracture outlines were observed as early as week 1 in Group B and Week 2 in Group A. However, there was not a transition to primarily transverse outlines until week 9. At week 9, Group B exhibited exclusively transverse outlines. Nevertheless, the majority of bones exhibited intermediate characteristics. Additionally, curved outlines were observed into week 13 (Table 12).

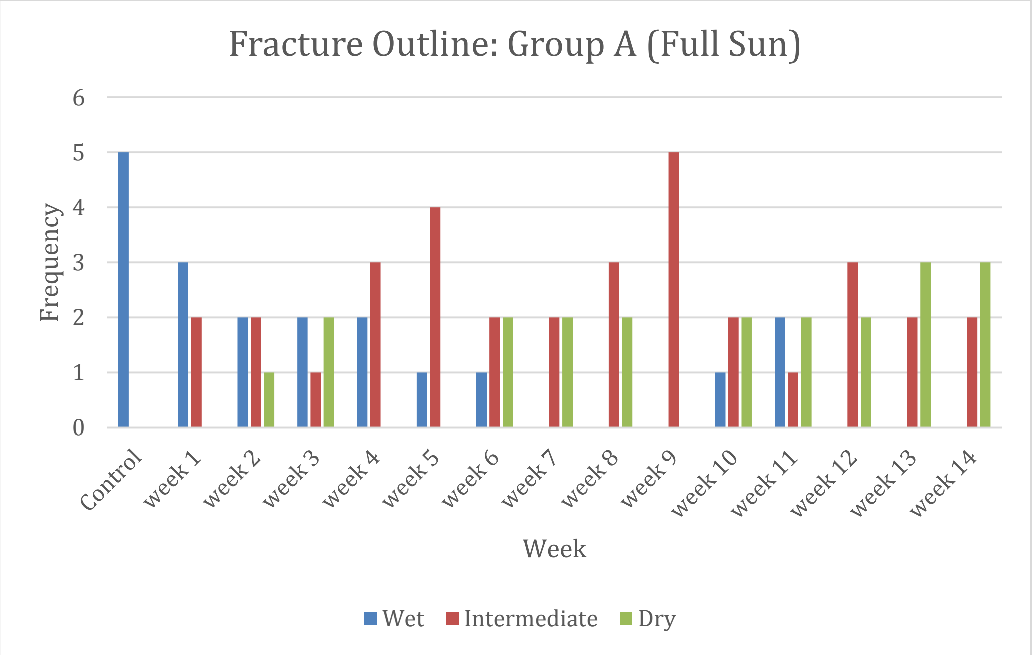


Figure 15: Bar graph representing the transition of Fracture Outline from wet to dry over 14 weeks in Group A. Note the appearance of dry characteristics in week two.

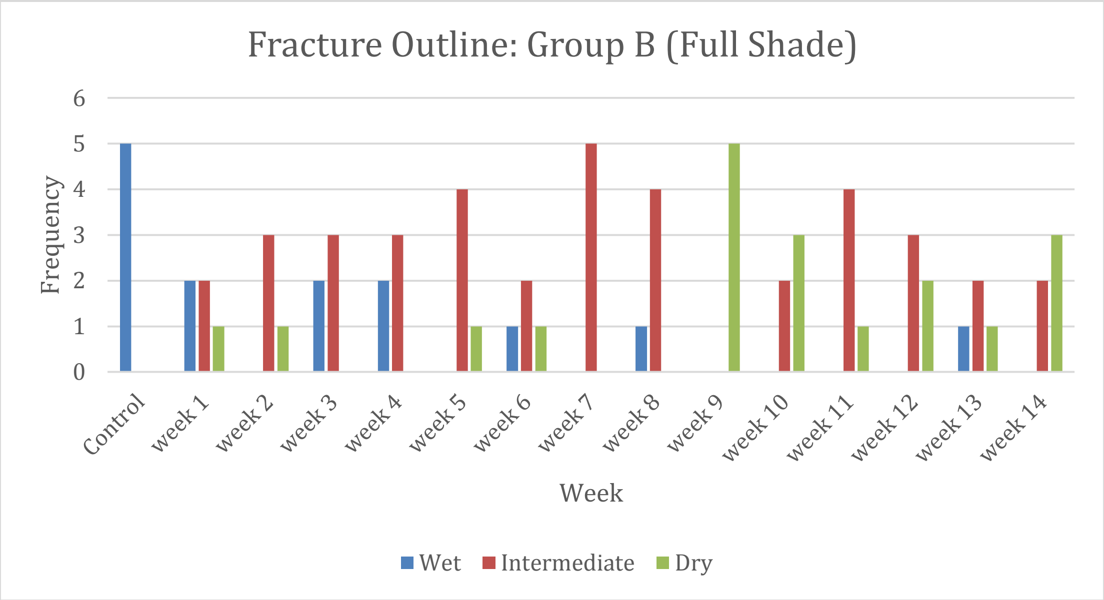


Figure 16: Bar graph representing the transition of Fracture Outline from wet to dry over 14 weeks in Group B. Note the appearance of dry characteristics in the first week.

Fracture Surface did not exhibit dry characteristics as early as angle or outline. Primarily smooth or intermediate surfaces were observed until week 5 in Group B and week 6 in Group A (Figures 17 and 18). Following the occurrence of these rough surfaces, a marked transition to rough surface texture was observed. Group B exhibited exclusively rough surface textures in week 12 and predominantly rough surface textures were seen from week 9 forward. Conversely, smooth surface textures can be seen into week 13 (Table 12).

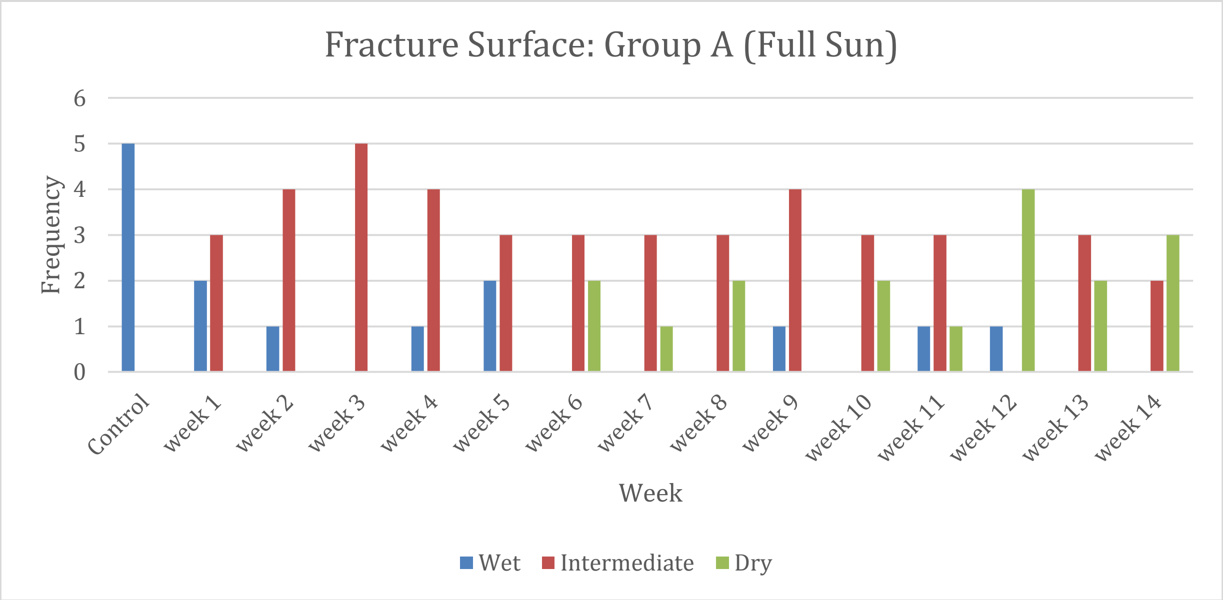


Figure 17: Bar graph representing the transition of Fracture Surface from wet to dry over 14 weeks in Group A. Note the transition to dry characteristics at week six.

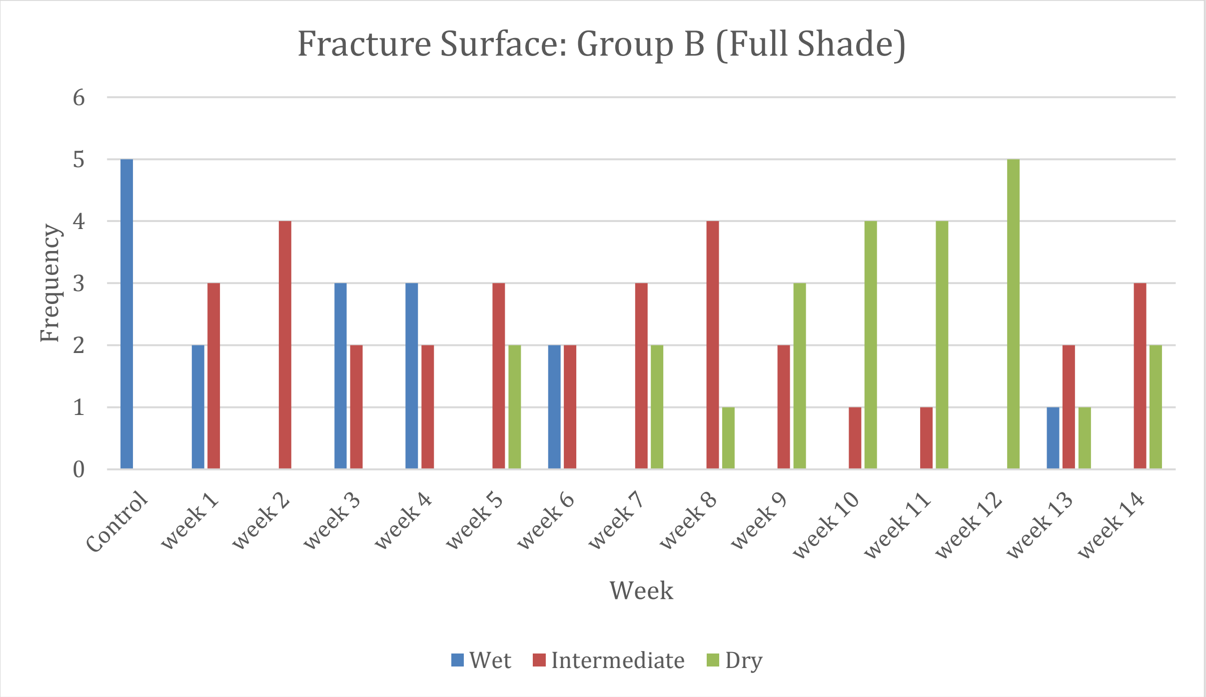


Figure 18: Bar graph representing the transition of Fracture Surface from wet to dry over 14 weeks in Group B. Note the appearance of dry characteristics in week five and the transition to dry characteristics around week 9.

Table 12: Summary table showing the frequency of occurrence of each manifestation of the observed characteristics according to week and environment.

		Fracture Angle			**Fracture Surface**			**Fracture Outline**		
		0	**1**	**2**	**0**	**1**	**2**	**0**	**1**	**2**
Week 1	**A**	0	5	0	2	3	0	3	2	0
	B	0	4	1	2	3	0	2	2	1
Week 2	**A**	0	4	1	1	4	0	2	2	1
	B	0	4	0	0	4	0	0	3	1
Week 3	**A**	0	4	1	0	5	0	2	1	2
	B	0	5	0	3	2	0	2	3	0
Week 4	**A**	1	4	0	1	4	0	2	3	0
	B	0	5	0	3	2	0	2	3	0
Week 5	**A**	0	5	0	2	3	0	1	4	0
	B	1	4	0	0	3	2	0	4	1
Week 6	**A**	0	5	0	0	3	2	1	2	2
	B	0	3	1	2	2	0	1	2	1
Week 7	**A**	0	4	0	0	3	1	0	2	2
	B	0	5	0	0	3	2	0	5	0
Week 8	**A**	0	3	2	0	3	2	0	3	2
	B	0	3	2	0	4	1	1	4	0
Week 9	**A**	0	5	0	1	4	0	0	5	0
	B	0	3	2	0	2	3	0	0	5
Week 10	**A**	0	4	1	0	3	2	1	2	2
	B	0	2	3	0	1	4	0	2	3
Week 11	**A**	0	3	2	1	3	1	2	1	2
	B	0	3	2	0	1	4	0	4	1
Week 12	**A**	0	3	2	1	0	4	0	3	2
	B	0	1	4	0	0	5	0	3	2
Week 13	**A**	0	1	4	0	3	2	0	2	3
	B	0	4	0	1	2	1	1	2	1
Week 14	**A**	0	3	2	0	2	3	0	2	3
	B	0	2	3	0	3	2	0	2	3

Statistical Analysis

The statistical analyses performed in this study include Chi-square analyses, ANOVA testing, and Multiple Linear Regression analysis. First, Chi-square results will be presented illustrating the results for the entire dataset, followed by the results for Group A and then Group B. Second, the ANOVA testing results will be presented for the entire dataset, followed by the results for Group A and then Group B. Lastly, the results for the Multiple Linear Regression analysis will be presented for the dataset.

Chi Square Analysis

Chi square analysis was performed to assess the degree of association between variables in this study. Fracture Angle, Fracture Surface, and Fracture Outline were compared to the postmortem interval, as well as to one another to determine a degree of significant association. Additionally, chi square analysis was also performed to determine whether there was a significant relationship between these variables and the environment in which they were placed. The null hypothesis is that the categories are statistically independent. The chi square analysis produces a result that will indicate whether or not the two categories are dependent upon one another (Frankfort-Nachmias and Leon-Guerrero, 2015). If the result is significant, the categories are likely dependent upon one another (Frankfort-Nachmias and Leon-Guerrero, 2015).

First, each morphological characteristic observed was compared against one another. Fracture Outline and Fracture Surface, Fracture Angle and Fracture Outline, and Fracture Angle and Fracture Surface. Significant results were obtained when comparing Fracture Outline and Fracture Surface texture (X^2=32.130, p= 0.000, DF= 4). When comparing Fracture Angle and

Fracture Outline significant results were also obtained (X^2=28.347, p= 0.000, DF=4). A significant result was also obtained when comparing Fracture Angle to Fracture Surface (X^2=16.104, p= 0.003, DF=4). These results indicate a strong degree of association among the variables observed (Table 13).

Table 13: Chi-square results for entire dataset comparing Fracture Angle, Fracture Outline, and Fracture Surface.

	Chi-square value	**Degrees of Freedom**	**Significance**
Angle vs Outline	28.347	4	0.000*
Angle vs Surface	16.104	4	0.003*
Outline vs Surface	32.130	4	0.000*

Fracture Characteristics

When discussing the frequency of Fracture Angles, it should be noted that intermediate characteristics are observed most often and are seen within the first two weeks of exposure. Group A (full sun) exhibited predominantly dry characteristics, or the presence of a majority of right angles, as early as week two. Bones in Group B (full shade) exhibited completely dry characteristics in the first week of exposure. However, it should also be noted that predominantly wet characteristics were also seen as late as week five in the shaded group.

There appears to be a point around week eight when a marked shift occurs in the prevalence of dry characteristics. A trend can be seen toward the occurrence of completely dry characteristics in the majority of the bones in each group. While some bones still exhibit intermediate characteristics, Group B in particular shows an obvious trend toward the majority of bones exhibiting dry characteristics.

Similar to both Fracture Angle and Fracture Surface characteristics, Fracture Outline exhibits a transition from predominantly wet characteristics to predominantly dry characteristics across the 14 week time period. Completely dry characteristics (transverse fracture outlines) can be seen in Group A as early as week two, while they are observed in the first week in Group B (Tables 9, 10, 12).

Intermediate characteristics are seen across the time frame of fourteen weeks, though a transition to dry characteristics can be seen around week nine. Incidentally, wet characteristics can still be seen into the 11th week in Group A and the 13th week in Group B. There exists a transition of the surface of fractures from smooth (wet) to jagged (dry) that can be seen in the 14 weeks during which this study was conducted. As with Fracture Angle, the majority of bones exhibited intermediate characteristics; however, Group A manifests completely dry characteristics as early as week six. Group B exhibits completely dry characteristics as early as week 5 (Tables 9, 10, 12).

Although dry characteristics can be seen in an early time frame, wet characteristics still persist into the 12th and 13th weeks in Groups A and B, respectively. The majority of the bones in weeks one through five exhibit a combination of wet and intermediate surface characteristics. Incidentally, the presence of intermediate characteristics persists throughout the entire fourteen week period (Tables 9, 10, 12).

These results indicate that there are significant changes in the morphology of Fracture Surface, Fracture Angle, and Fracture Outline as the postmortem interval increases. Therefore, when environment is not considered, Fracture Angle, Fracture Surface, and Fracture Outline can be used as accurate indicators of postmortem interval.

Environmental Considerations in the Timing of Injury for Group A and Group B

Additionally, the dataset was divided into separate categories and chi square analysis was performed for each group to determine whether different results would be obtained for each environment. For each group, A and B, Fracture Angle, Fracture Outline, and Fracture Surface were compared to one another. The analysis for group A produced results that were statistically significant for Fracture Angle and Fracture Outline (X^2=26.224, p=0.000, DF=4), Fracture Angle and Fracture Surface (X^2=11.663, p=0.020, DF=4), and Fracture Outline and Fracture Surface (X^2=16.972, p=0.002, DF=4) (Table 14). These results indicate a significant degree of association among all of the characteristics observed and a high degree of dependency among the variables.

Table 14: Chi-square results indicating a high degree of association between fracture characteristics for group A.

	Chi-square value	**Degrees of Freedom**	**Significance**
Angle vs Outline	26.224	4	0.000*
Angle vs Surface	11.663	4	0.020*
Outline vs Surface	16.972	4	0.002*

The analysis for group B produced results that were statistically significant for Fracture Angle and Fracture Surface (X^2=9.635, p=0.047, DF=4), as well as Fracture Outline and Fracture Surface (X^2=16.817, p=0.002, DF=4). The results for comparison of Fracture Angle and Fracture Outline were not significant, though they approached significance (X^2=8.326, p=0.080, DF=4). These results indicate a significant degree of association between the variables, signifying that the occurrence of the fracture characteristics of Fracture Angle and Fracture Surface, and Fracture Outline and Fracture Surface are likely dependent upon one another (Table 15).

Table 15: Chi-square results for Group B analysis indicating a degree of association between certain fracture characteristics.

	Chi-square value	**Degrees of Freedom**	**Significance**
Angle vs Outline	8.326	4	0.080
Angle vs Surface	9.635	4	0.047*
Outline vs Surface	16.817	4	0.002*

ANOVA testing

One way analysis of variance (ANOVA) testing was performed to assess the relationships both within and between the variables investigated (Frankfort-Nachmias and Leon-Guerrero, 2015). Time (PMI) was used as a dependent variable to compare the variables of Fracture Angle, Fracture Surface, and Fracture Outline against. The null hypothesis states that there is no difference between the occurrence of dry characteristics of Fracture Angle, Fracture Surface, and Fracture Outline across time (Frankfort-Nachmias and Leon-Guerrero, 2015). Therefore, the relationship between PMI and Fracture Surface, PMI and Fracture Angle, and PMI and Fracture Outline was investigated. As previously mentioned, a coding system was employed to transform categorical data into numerical data, allowing a quantitative comparison.

The results indicate that all three variables, Fracture Angle, Fracture Surface, and Fracture Outline were statistically significant (Table 16). This suggests that there is a significant difference between the occurrences of each characteristics as the postmortem interval increases and the variables investigated in this study are likely dependent upon one another.

Table 16: ANOVA testing reflecting the relationship between and within the variables observed of the complete dataset.

	F value	**Significance**	**R^2**	**Adjusted R^2**
Angle	2.923	0.001*	0.156	0.149
Surface	4.185	0.000*	0.227	0.221
Outline	2.432	0.006*	0.148	0.142

Environmental Considerations in the Timing of Injury for Group A and Group B

One way analysis of variance (ANOVA) testing was also performed taking environment into consideration using the postmortem interval as the dependent variable. The dataset was divided into two separate groups according to environment: Group A and Group B. The ANOVA results for group A indicate a significant relationship between Fracture Angle and the postmortem interval (F= 2.096, p=0.029), as well as between Fracture Surface and the postmortem interval (F=2.102, p=0.029) (Table 17). The relationship between Fracture Outline and PMI was not significant for group A. These results indicate that there is a significant difference in the occurrence of Fracture Angle and Fracture Surface across the postmortem interval.

Table 17: ANOVA testing for Group A indicating a significant difference in the occurrence of Fracture Angle and Fracture Surface as the PMI increases.

	F value	**Significance**
Angle	2.096	0.029*
Surface	2.102	0.029*
Outline	1.481	0.154

The ANOVA results for group B indicate significant relationships between the postmortem interval and the characteristics of Fracture Angle (F= 2.467, p=0.011), Fracture Surface (F=5.518, p=0.000), and Fracture Outline (F=2.699, p=0.005) (Table 18). As all of these results are statistically significant, this indicates that there is a significant difference in the time frame in which these characteristics occur across the postmortem interval.

Table 18: ANOVA testing for Group B indicating a significant difference in the occurrence of fracture characteristics as the PMI increases.

	F value	**Significance**
Angle	2.467	0.011*
Surface	5.518	0.000*
Outline	2.699	0.005*

Multiple Linear Regression

Additionally, multiple linear regression was performed using the postmortem interval as the dependent variable, regressing time against the variables of Fracture Angle, Fracture Surface, and Fracture Outline. This was performed in order to determine the R^2 value for each test. As linear regression also performs an ANOVA test for each variable, the results were compared.

The R^2 value provides an indicator of how the variable of time, or the postmortem interval, has an effect on the Fracture Angle, Fracture Surface and Fracture Outline (Frankfort-Nachmias and Leon-Guerrero, 2015). The R^2 values indicate a positive correlation between the variables of Fracture Angle, Fracture Surface, and Fracture Outline, and the postmortem interval (Table 19). Multiple regression analysis also indicated that Fracture Outline was statistically significant when compared to the postmortem interval (unstandardized coefficient B=2.818, standardized coefficient B= 0.276, p= 0.003, R=0.413). Additionally, Fracture Surface approached significance (unstandardized coefficient B=1.907, standardized coefficient B= 0.166, p= 0.065).

Table 19: Multiple linear regression analysis indicating a significant relationship between Fracture Outline and the postmortem interval.

	Unstandardized coefficient B	Standard Error	Standardized coefficient B	Significance
Angle	1.550	1.519	0.084	0.309
Outline	2.818	0.948	0.276	0.003*
Surface	1.907	1.023	0.166	0.065

CHAPTER 6: DISCUSSION

Distinguishing perimortem from postmortem trauma is often a task assigned to the forensic anthropologist during casework. This task is often difficult at best, and the estimation of the timing of injury can be skewed by a variety of factors. Problems in differentiating wet from dry fracture characteristics remains a challenge. The forensic anthropologist may use multiple different methods to analyze the trauma sustained by the skeletal remains, including morphological examination of the Fracture Angle, Fracture Surface, and Fracture Outline of the fractures produced, as well as determination of the Fracture Freshness Index. The difficulty lies in determining at what point bone loses its intrinsic wet properties and begins the transition to inherently dry properties.

Evidence of healing indicates antemortem trauma; however, perimortem and postmortem trauma are more difficult to determine. The difficulty in this task arises when confronted with the elastic perimortem period (Maples, 1986). It has been concluded by multiple authors (Maples, 1986; Nawrocki, 2008; Symes et al., 2014) that the definition of the perimortem period, as given by the forensic pathologist is problematic as bone may retain its “fresh” or “wet” properties long after death, complicating the estimation of the timing of skeletal trauma. Preservation of fresh properties after death lends to the exhibition of characteristics consistent with perimortem trauma for an extended period of time (Wieberg and Wescott, 2008; Shattuck, 2010). Therefore, the definition initially proposed by Nawrocki (2008), and later adopted by SWGANTH (2011), has attempted to bring clarity to problem of the perimortem period, This definition lends support to the premise that bone should be referred to as either “wet” or “dry”, rather than in terms of perimortem and postmortem (Wieberg and Wescott, 2008; Coelho and Cardoso, 2013).

Trauma can occur early in the postmortem period and can be confused with perimortem trauma as bone will retain fresh properties and exhibit wet fracture characteristics. While Fracture Angle, Fracture Surface, and Fracture Outline are the most commonly used factors when attempting to determine the timing of injury, the use of these characteristics should be undertaken with caution. As noted by Wieberg (2006) and Shattuck (2010), although there is a shift in the intrinsic properties of bone in the postmortem period, a definitive transition point does not exist. As there is no definite time period in which bone transitions from wet to dry, the purpose of this study was to investigate the time period in which bone transitions from intrinsic wet properties to dry properties in the Central Florida environment. Furthermore, the effects of different depositional microenvironments of full sun and full shade have yet to be investigated. Therefore, this study investigated the differences in fracture characteristics when bones were subjected to two separate microenvironments.

Investigating the timing of injury has proven a difficult undertaking for the forensic anthropologist. The literature has indicated that Fracture Angle, Fracture Surface, and Fracture Outline are the most useful morphological indicators for determining timing of injury (Wieberg, 2006; Wieberg and Wescott, 2008; Shattuck, 2010; Karr and Outram, 2012; LaCroix, 2013; Symes et al., 2014). Multiple authors (Wieberg, 2006; Wieberg and Wescott, 2008; Shattuck, 2010; Karr and Outram, 2012; LaCroix, 2013; Symes et al., 2014) have suggested that perimortem trauma is denoted by wet fracture characteristics such as oblique fracture angles, a smooth fracture surface, and curved or V-shaped fracture outlines. Conversely, postmortem trauma is denoted by dry fracture characteristics such as right angles, a rough fracture surface, and a transverse or jagged fracture outline. However, as indicated by this study, as well as those conducted by Wieberg (2006) and Shattuck (2010), there is a significant amount of overlap in the timing of the occurrence of these characteristics (Table 20).

The majority of the bones examined in this study exhibited intermediate fracture characteristics. This increased the difficulty in assessing the time period in which the trauma occurred. However, it appears that numerous factors are influential in the rate at which bone loses its' intrinsic wet properties. Yet, there is no definitive point at which bone stops exhibiting totally fresh characteristics and starts exhibiting completely dry characteristics (Wieberg, 2006; Shattuck, 2010). While the data collected indicates that bone may begin to exhibit dry characteristics as early as 1-2 weeks postmortem, it may also exhibit wet characteristics as late as 12-13 weeks postmortem.

The results of this study indicated that there is a shift in the intrinsic properties of bone that can be measured statistically when investigating the postmortem interval. Although there is no definitive point at which a bone will lose all intrinsic wet properties and become dry, a point at which bone begins to transition can be identified (Figures 19 and 20). Additionally, the presence of intermediate and dry characteristics can indicate that trauma did not occur during the perimortem period. In the region of Central Florida, this time period is seen sooner than the previous literature has suggested (Wieberg, 2006; Wieberg and Wescott, 2008; Shattuck, 2010). Wieberg (2006) and Shattuck (2010) have suggested that primarily dry characteristics are not seen until 141 days and 5 months in their respective environments. However, Coelho and Cardoso (2013) have suggested that by using the Fracture Freshness Index, perimortem injury can be distinguished from postmortem injury in as little as 56 days postmortem. As these characteristics are seen earlier in Central Florida, these characteristics can be used to determine whether trauma occurred in the perimortem period or in the early postmortem period. This research has significant implications for the field of forensic anthropology and supports the development of taphonomic models created according to geographic region in order to facilitate more accurate estimations of the timing of injury. Some of the findings of the current study differ from those in previous studies undertaken in different geographical regions, while others are similar in nature (Wieberg, 2006; Shattuck, 2010; Coelho and Cardoso, 2013).

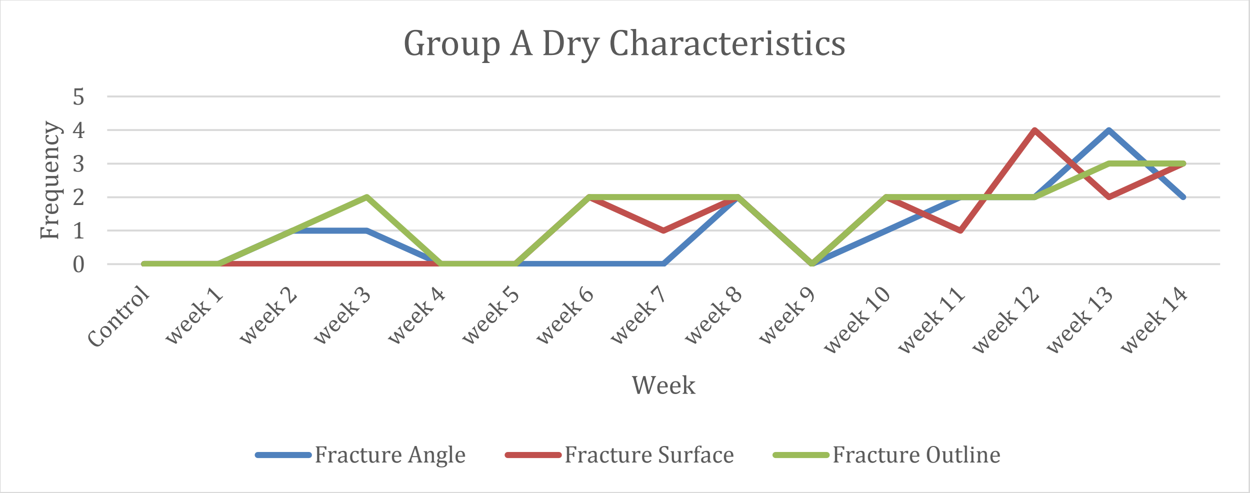


Figure 19: Line graph representing the transition of wet characteristics to dry characteristics over 14 weeks in Group A. Note the transition point around week five to nine to predominantly dry characteristics.

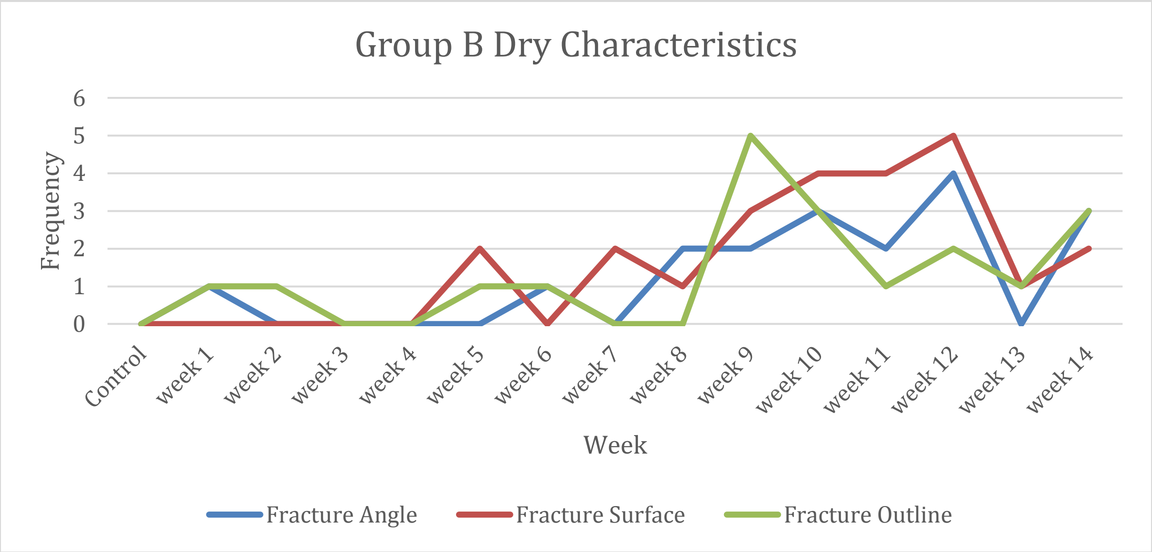


Figure 20: Line graph representing the transition of wet characteristics to dry characteristics over 14 weeks in Group B. Note the transition point around week eight to predominantly dry characteristics.

Fracture Angle

It has been suggested by multiple authors (Maples 1986; Galloway et al., 1989; Sauer, 1998; Galloway, 1999; Wieberg, 2006) that Fracture Angle can be a reliable indicator of wet or dry bone; drier bone exhibiting predominantly right angles, and wetter bone exhibiting predominantly oblique angles. However, right angles appear indiscriminately throughout the perimortem and postmortem periods. While the control group (PMI=0) exhibited singularly oblique angles (acute and obtuse), right angles were observed in the first week of the experiment and oblique angles were still present into the fourteenth week of the study. Wieberg's (2006) study indicated a statistically significant trend in the changes in Fracture Angle over the postmortem interval. The current study indicates that there is also a significant trend in the changes in Fracture Angle over time; however, this is likely due to the incorporation of a standardized protocol for examination of Fracture Angles. Because bone created angles irregularly, Fracture Angle was the most difficult characteristic to examine. Consequently, a single bone can represent multiple points in the postmortem interval. While Johnson (1985) noted acute and obtuse angles exclusively on wet bone, this is consistent with Morlan's (1984) research, which indicated that acute and obtuse angles could be seen on both wet and dry bone. The standardized protocol allowed for a summary score to be developed for each bone, incorporating eight different angles from the anterior and posterior halves of the proximal and distal ends of each bone.

Fracture Surface

Similar to the previous studies undertaken in the literature (Wieberg, 2006; Shattuck, 2010), Fracture Surface exhibited the most significant changes over the postmortem interval. Within the fourteen-week period, Fracture Surface transitioned from smooth to rough. Smooth surfaces were associated with bones that had retained fresh or wet properties and exhibited either predominantly curved or intermediate Fracture Outlines, as well as oblique or intermediate Fracture Angles. This is consistent with multiple authors' (Morlan, 1984; Villa and Mahieu, 1992; Wieberg, 2006; Wieberg and Wescott, 2008; Shattuck, 2010) interpretations of Fracture Surface exhibiting a smooth texture in wet bone and a rough texture in dry bone. As the postmortem interval increased and bones were subjected to the elements and decompositional processes, fracture surfaces became rougher and were indicative of a longer PMI (Figure 21).

Similarly, bones fractured early in the postmortem period exhibited smooth Fracture Surfaces and were indicative of an earlier PMI. However, jagged Fracture Surfaces were seen as early as the fifth week of the study and smooth surfaces still persisted into the thirteenth week of the study. Consistent with this trend, bones fractured in the intermediate period (weeks 5-9) displayed predominantly intermediate surface characteristics. Additionally, when environment was considered, Fracture Surface was one of the statistically significant results observed in this study. Change in Fracture Surface over the postmortem interval can therefore be used reliably as an indicator of postmortem injury. Because the Fracture Surface changes quickly to reflect a loss of intrinsic wet properties, it is possible to differentiate between wet and dry characteristics earlier in the postmortem interval using this morphological characteristic.

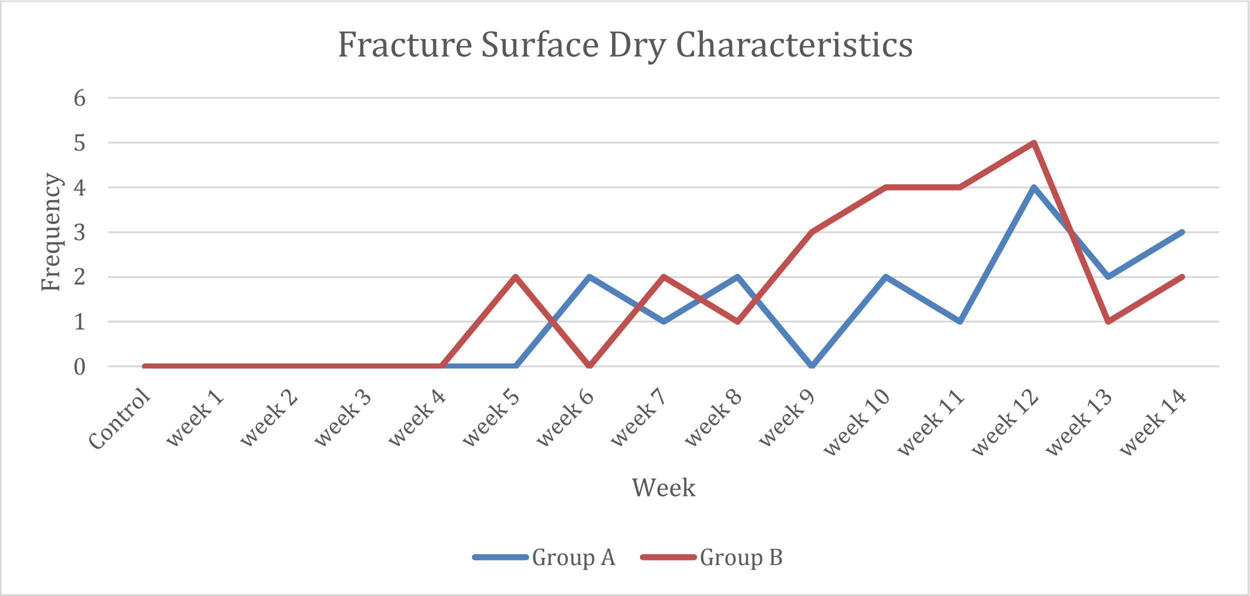


Figure 21: Line graph representing the transition of Fracture Surface from wet to dry over 14 weeks, comparing Group A and Group B. Note the difference in the frequency of dry characteristics seen between groups.

Fracture Outline

Consistent with Shattuck's (2010) results, Fracture Outline proved to be the second most statistically significant indicator of timing of injury. Transverse Fracture Outlines were seen as early as the second week of this study. Conversely, curved/V-shaped outlines persisted into the thirteenth week of this study. Consistent with the Fracture Surface results, weeks 5-9 exhibited predominantly intermediate characteristics (Figure 22). Additionally, when environment was factored into the statistical analysis, Fracture Outline was a significant indicator of timing of injury depending on environment.

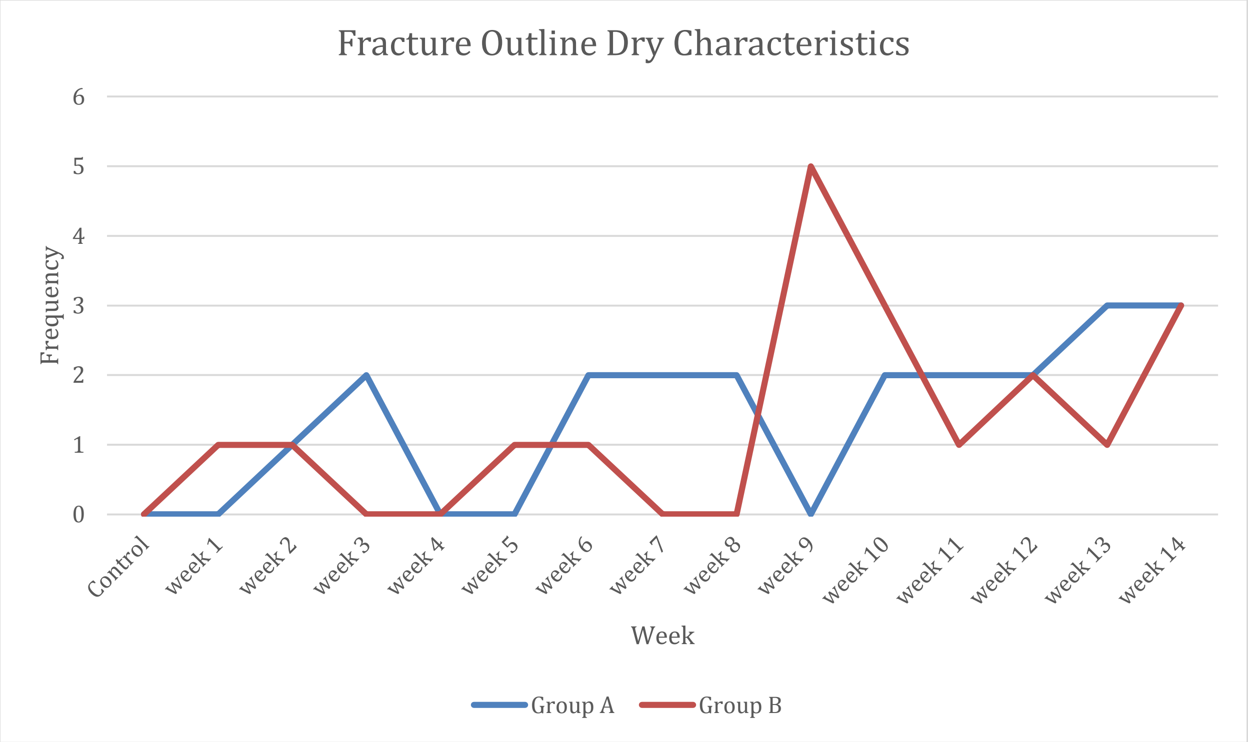


Figure 22: Line graph representing the transition of Fracture Outline from wet to dry characteristics over 14 weeks, comparing Group A and Group B. Note the difference in the frequency of dry characteristics seen between groups.

Consideration of Multiple Variables

Interestingly, for both Fracture Outline and Fracture Surface, one bone in Group B exhibited fresh characteristics in the thirteenth week. This could potentially be due to the size of the bone or the protected environment of the shaded group. Additionally, aside from the occasional bone exhibiting wet characteristics independently, predominantly wet characteristics were no longer observed after the 4th week. After 98 days in the field, bones exhibited predominantly dry fracture characteristics in all three categories. This is different from Wieberg's (2006) study in which bones exhibited predominantly dry characteristics after 141 days. Shattuck (2010) noted that even after 5 months in South-central Texas, none of the bones exhibited completely dry characteristics. The current study, however, did include bones that exhibited completely dry characteristics after 14 weeks. Additionally, similar to the current study, Coelho and Cardoso (2013) noted that a differentiation between perimortem and postmortem could be made around day 56 in their study conducted in Portugal (Table 20). Although this study attempted to incorporate numerous variables into the investigation of the timing of injury, more research is required to continue narrowing the postmortem interval. Additional avenues of research are required to aid forensic anthropologists in more accurate estimation of timing of injury in the postmortem period and differentiation of perimortem from postmortem injury.

Biomechanical Properties

The physical properties of bone must also be considered when discussing the occurrence of fracture characteristics. A fracture apparatus was created that was modeled on previous studies in order to simulate blunt force trauma to a victim lying on the ground (Wieberg, 2006; Shattuck, 2010). The custom drop-weight impact device utilizes a cradle underneath the drop weight to provide stability and consistency in creating fractures at mid-diaphysis. The impact surface of the drop weight continues through the bone at mid-diaphysis when dropped. The objective was to create a complete fracture through the diaphysis in order to examine the fracture characteristics. The use of the cradle allowed for this objective to be met. However, this stable position resulted in the creation of comminuted fractures and the subsequent fragmentation of the bones at times that obscured butterfly fractures that might have been present. The bones were not reconstructed in this study, but rather the entire fracture was considered for an overall score because of the extensive fragmentation. Symes et al. (2014) note that butterfly fractures do not aid in determining the timing of injury, but rather directionality.

While the majority of the literature investigating the timing of injury uses a cradle to stabilize bones for fracture production, Psihogios (1995) used a pin method that allowed bones to hang and to be impacted from the side. The manner in which the kinetic forces are transferred through the bone would be different in this method, as would the types of fractures produced, theoretically. However, the cradle method was selected based on multiple studies (Wieberg, 2006; Wieberg and Wescott, 2008; Shattuck, 2010; Coelho and Cardoso, 2013) in order to ensure complete fracture production through mid-diaphysis.

The cortical thickness, as well as the structure of pig (*Sus scrofa*) bone is also a factor to consider in fracture production. As the cortical bone is thicker in pigs than in humans, pig bone may retain wet properties longer than human bone, which may influence the types of fracture characteristics observed. However, deer (*Odocoileus virginianus*) bone, as used by Wheatley (2008) and Wright (2009), also exhibits cortical bone that is thicker than that of human bone and may retain wet properties for a longer period of time. The structure of pig bone may result in differences in fracture propagation due to the shape of the bone overall, as well as the organization of the microstructure.

Additional Considerations

In an effort to investigate the differences microenvironment can play in the retention or expulsion of organic properties of bone, two separate microenvironments were implemented in this study. Multiple authors have suggested that the environment and exposure to sun or shade, rainfall, and humidity can play an integral part in the retention or loss of organic material (Behrensmeyer, 1976; Galloway et al., 1989; Berryman and Lyman, 2004; Wieberg, 2006; Shattuck, 2010; Coelho and Cardoso, 2013). The current study indicates that there is a statistical difference in the changes to Fracture Surface and Fracture Outline during the decomposition process according to what type of environment the bones are exposed to in the postmortem interval. For the shaded group (Group B), the results for Fracture Angle across the postmortem interval were approaching significance, but did not indicate a strong relationship. As different results were obtained for each microenvironment investigated, it can be concluded that the depositional environment does have a significant effect on the timing of the occurrence of dry characteristics in bone. This is consistent with the results obtained by Coelho and Cardoso (2013), who determined through their investigation of different macroenvironments that environment does influence the morphological characteristics of fractures created in the postmortem period.

The changing climate over time may also have a significant effect on the presentation of specific morphological characteristics. This study was conducted between the months of October and January, which is a cooler time of year in Central Florida as compared to the summer months. Had this study been conducted during the hotter, summer months, the transition from wet to dry characteristics may have been observed earlier. Therefore, changing climates in different geographic regions reinforce the necessity for replication of this study in not only different regions, but also at different times of the year. Specific shifts in the timing of the transition of wet characteristics to dry characteristics may be influenced by the climatic shift.

Figure 23: Side by side comparison of two bones from the same week, from Group A and Group B. Both exhibit transverse fracture outlines, predominantly right angles, and a jagged fracture surface.

Furthermore, Sauer (1998) has suggested that color change of the cortical bone fracture surface can be a useful tool in determining timing of injury. Trauma occurring well into the postmortem period when bone has lost its intrinsic wet properties will supposedly exhibit a marked difference in color between the inner and outer cortical bone. However, this method can only be applied to recently fractured bones, even if the fracture was created postmortem. If the skeletal remains were left out in the environment after being fractured, the color of the fracture margins would change to reflect the color of the rest of the bone. As the bones in this study were left out in their respective environments and subsequently fractured, the use of this tool did not reflect the goals of this study and was therefore, excluded.

Limitations

Some of the limitations of this study include the types of bones used in the sample, the use of defleshed bones, the structure of pig bone as compared to human, and the differences in seasonality. First, long bones were used in this study to investigate fracture production. The bones obtained from the sausage factory consisted of femora, humerii, and tibiae. As these were the bones that were available for use, these long bones were included in the study. This is similar to what was used previously in the literature (Wieberg, 2006; Wieberg and Wescott, 2008; Shattuck, 2010; Coelho and Cardoso, 2013). Second, de-fleshed bones were used in this study as an attempt was made to control for the processes of decomposition. Additionally, when the bones were obtained from the sausage factory, the majority of the soft tissue had been removed. This is consistent with previous studies in the literature (Wheatley, 2008; Wright, 2009; Shattuck, 2010;

Karr and Outram, 2012). The structure of pig bones differs significantly from that of human bone. However, pig bone is considered to be the accepted proxy for human bone and is the best analogue available at this time (Sauer, 1998). Finally, seasonality is a factor that should be considered. While this study was undertaken between the months of October and January, different results may be obtained during a different time of the year due to climatic shifts. These climatic differences may result in varying levels of temperature, humidity, and rainfall, which may influence the retention of wet properties as well as the production of dry fracture characteristics.

Table 20: Comparison of the major studies involving timing of injury to long bones in the postmortem period (Wieberg, 2006; Shattuck, 2010; Coelho and Cardoso, 2013)

	Location	**PMI duration**	**Variables observed**	**Environment**	**Results**	**Statistically significant results**	**Appearance of Fx characteristic**
Wieberg, 2006	Central Missouri	141 days (start June 19th)	Ash weight, weathering, color difference, fx angle, outline, surface	Open field under a hickory tree	Predominantly dry characteristics after 141 days	**ANOVA:** Fx angle p=0.0002 Fx surface p=0.0001 **X^2:** fx angle v PMI p=0.0002 fx surface v PMI p=<0.0001	Right angles: 0 days Transv outline: 85 days Jagged surface: 0 days
Shattuck, 2010	Central Texas (San Marcos, TX)-arid	24 weeks (168 days)	Weathering, angle, outline, surface	Full sun	Even after 5 months, bones did not exhibit primarily dry characteristics	**ANOVA** at 2 month interval: Fx edge p=0.008 Fx outline p=001 2 week interval: Fx edge p=0.033	Right angles: 14 days Transv outline: 14 days Jagged surface: 28 days
Coelho and Cardoso, 2013	Central Portugal	196 days (April-October 2011)	FFI (angle, surface, outline)	3 macroenv: Buried, submerged, surface	Differentiation between perimortem and postmortem	**OLM: (**pig shown) *Surface:* P=<0.001	NA

					injury at 56 days using FFI		
Current study 2015	Central Florida (Orlando)	98 days (14 weeks) Oct 2014-Jan 2015	Fx angle, surface, outline	2 microenv: full sun, full shade	Primarily dry characteristics were noted within 14 week time period	**ANOVA:** *Overall*: Fx angle p=0.001 Fx surface p= 0.000 Fx outline p=0.006 *Group A:* Fx angle p=0.029 Fx surface p=0.029 *Group B:* Fx angle p=0.011 Fx surface p=0.000 Fx outline p=0.005 **OLM:** Fx outline p=0.003 **X^2:** *Overall:* Angle v Outline p=0.000 Angle v Surface P=0.003	Right angles: week 1 Transv outline: week 1 Jagged surface: week 5

						Surface v outline P=0.000 *Group A:* Angle v Outline p=0.000 Angle v surface P=0.020 Outline v surface P=0.002 *Group B:* Angle v surface p=0.047 Outline v surface P=0.002	

CHAPTER 7: FUTURE CONSIDERATIONS AND CONCLUSIONS

Future Avenues of Research

Following the conclusion of this study, it is clear that multiple avenues of research remain that should be investigated in order to continue narrowing the gap in estimating timing of injury in the postmortem period. The statistically significant results obtained regarding the Fracture Angle in the postmortem interval are most likely due to the implementation of a standardized protocol for analyzing the fracture margins. As four areas were observed on both the proximal and distal portions of the bone and used to determine a summary score, it is likely that this standardized method is the reason for a significant result being obtained. Bone fractures irregularly and therefore creates multiple angles on each bone. However, there is still a trend in the occurrence of the type of angle observed. The use of this method allowed for observation of a shift toward the occurrence of primarily right angles as the postmortem interval increased. It is therefore, the recommendation of this author that this standardized protocol be implemented to ensure that a comprehensive score is obtained, rather than attempting to assign an overall score based on observation of the bone as a whole.

Additionally, this study is the first to consider the effects microenvironment can have on the decompositional processes of bone in the Central Florida region. Central Florida is considered a subtropical environment with a high percentage of humidity and a high amount of yearly rainfall. It is typical in Florida to experience rainfall daily. Additionally, the seasonal changes in Florida are less drastic than in other geographic areas. As is such, seasonal and climatic differences according to region can influence the rate and amount of decomposition.

While Florida experiences a high average amount of rainfall and humidity, the effects of these variables on the decomposition processes in Florida has yet to be investigated. The separation of the bones into two separate microenvironments could have resulted in less exposure to rainfall in the shaded group, but more retention of moisture because of the lack of exposure to the sun and its' drying effects. When observing the bones on collection days, the side of the bones against the ground surface in the shaded group tended to be more advanced in decomposition than the group in full sun. However, it is unknown if this effect was due to increased insect activity as a result of the indirect sun exposure, or the retention of moisture in the shade. Therefore, future research should focus on a more lengthy time period and separation of samples into different depositional environments. While this study investigated the microenvironments of full sun and full shade, other environments should be taken into consideration and included in future research, as well as other geographical regions.

The use of domestic pigs (*Sus scrofa*) is an accepted proxy for human bone in the forensic anthropological literature. Similar studies have also been conducted using deer, goat, and equine bone (Wheatley, 2008; Zephro, 2012; Coelho and Cardoso, 2013). Future research may focus on expanding these studies and examining the differences in decompositional processes among faunal species considered acceptable for human proxy.

As this study investigated the taphonomic changes unique to the Central Florida environment, and the results obtained in this study differ from those obtained by both Wieberg (2006) and Shattuck (2010), it is clear that additional studies should be conducted to investigate regional variability. The creation of taphonomic models for geographic regions may help investigators in determining timing of injury in the postmortem period as bone appears to begin to lose organic components earlier in Central Florida than in other areas of the United States. According to Janjua and Rogers (2008), bone does not lose all intrinsic wet properties even after 9 months of exposure to the elements in Ontario. Therefore, taphonomic models are key in investigating injury in the postmortem interval in different geographic regions and should be considered for future implementation.

Future research should also consider implementing a larger sample size and a longer time period for observation. A larger sample would allow for analysis within each group at each time period designated. This may prove useful in investigating the differences that can be seen even within the same depositional environment and should be considered for future studies. Additionally, it may be that a more significant trend may present itself should this experiment be continued for a longer period of time.

Conclusions

Despite the best efforts of anthropologists and archaeologists alike in analyzing trauma in the perimortem and postmortem period, there still exists a period in which it cannot be determined whether a bone was broken as a result of perimortem trauma or in the early postmortem period. Although a transition from wet to dry properties can be seen and it is possible to differentiate between wet and intermediate characteristics, there still remains a period of time where bone will exhibit singularly wet characteristics after death. In the Central Florida environment, this period of time appears to be shorter than in other geographical regions, which may aid researchers in determining timing of injury. Bones fractured after five weeks postmortem begin to display predominantly dry characteristics, making it easier for observers to determine that the injury did not occur during the perimortem period. However, although dry characteristics were seen within the first few weeks, the majority of characteristics were wet or intermediate and could be considered to be perimortem injuries dependent upon the experience of the observer.

The most reliable indicator of timing of injury appears to be the Fracture Surface. A jagged Fracture Surface was seen as early as five weeks postmortem and the frequency of occurrence increased as the postmortem interval increased. Additionally, intermediate Fracture Surface characteristics were seen within the first four weeks, indicating a shift from wet to dry characteristics that can be recognized by an experienced observer. Fracture Outline appears to be the second most reliable indicator of timing of injury. Transverse Fracture Outlines were seen as early as the second week postmortem, and increased in frequency throughout the postmortem interval. However, more research should be undertaken regarding the use of Fracture Angle in estimating the timing of injury. Fracture Angle does not appear to be a reliable indicator of timing of injury in the postmortem interval as right angles were seen throughout the postmortem interval, as were oblique angles.

No standard methodology exists for interpreting fracture characteristics. An attempt was made in this study to create a standard protocol for interpreting fracture characteristics; however, unless a consensus is reached regarding the most useful characteristics, this will be of little use. Regarding this issue, more research needs to be conducted according to geographic region to assess the rate of decomposition and the rate at which bone loses its' intrinsic wet properties. Information can be compiled for geographic region and applied to similar areas. This information can also be used to train individuals in trauma analysis according to geographic region in which they are employed.

APPENDIX A: SAMPLE PHOTOGRAPHY

Appendix A, Figure 1: Bone 102A, week 1, Group A. This bone exhibits a curved fracture outline, with an intermediate fracture surface, and the presence of both right and oblique fracture angles.

Appendix A, Figure 2: Bone 102B, week 1, Group B. This bone exhibits an intermediate fracture outline, with a smooth fracture surface, and the presence of both right and oblique fracture angles.

Appendix A, Figure 3: Bone 704A, week 7, Group A. This bone exhibits an intermediate fracture outline, with both curved and stepped outlines, as well as an intermediate fracture surface and the presence of both right and oblique angles.

Appendix A, Figure 4: Bone 704B, week 7, Group B. This bone exhibits an intermediate fracture outline, with both right angles and oblique angles, a jagged surface texture and extensive fragmentation.

APPENDIX B: RAW DATA

Appendix B, Table 1: Final dataset following revision and comparison for intraobserver error.

	fx angle PA	PP	DA	DP	coded angle	surf	coded sur	outline	coded outline	time	coded time groups
101A	RA	RO	RO	RO	1	i	1	int	1	1	1
102A	A	RO	O	RO	1	i	1	curved	0	1	1
103A	A	RO	RO	RO	1	i	1	int	1	1	1
104A	RA	RO	AO	RO	1	s	0	curved	0	1	1
105A	AO	RO	RA	AO	1	s	0	curved	0	1	1
101B	R	A	RO	RA	1	i	1	int	1	1	11
102B	AO	RO	A	O	1	s	0	int	1	1	11
103B	RO	R	RO	RO	2	s	0	trans	2	1	11
104B	AO	O	AO	RO	1	i	1	curved	0	1	11
105B	A	RA	O	RA	1	i	1	curved	0	1	11
201A	AO	AO	RO	RO	1	i	1	int	1	2	2
202A	RO	RO	A	AO	1	i	1	int	1	2	2
203A	RO	R	RO	RA	2	i	1	tans	2	2	2
204A	RA	RO	RO	RA	1	i	1	curved	0	2	2
205A	RA	A	O	AO	1	s	0	curved	0	2	2
201B	RA	AO	R	AO	1	i	1	int	1	2	21
202B	RA	AO	RO	RO	1	i	1	int	1	2	21
203B	AO	R	AO	R	1	i	1	trans	2	2	21
204B										2	21
205B	RA	RA	AO	RA	1	i	1	int	1	2	21
301A	RA	RO	RA	RO	1	i	1	int	1	3	3
302A	A	RA	RO	O	1	i	1	curved	0	3	3
303A	R	O	R	RA	2	i	1	trans	2	3	3
304A	RO	O	RA	RA	1	i	1	curved	0	3	3
305A	A	RA	RO	O	1	i	1	trans	2	3	3

301B	R	O	RA	RA	1	s	0	curved	0	3	31
302B	RO	O	RA	AO	1	s	0	curved	0	3	31
303B	RA	AO	RO	AO	1	i	1	int	1	3	31
304B	RO	RA	A	RO	1	s	0	int	1	3	31
305B	O	RO	RO	RO	1	i	1	int	1	3	31
401A	RO	RO	RA	RA	1	i	1	int	1	4	4
402A	R	AO	RA	AO	1	i	1	curved	0	4	4
403A	R	RA	RA	AO	1	i	1	int	1	4	4
404A	AO	AO	AO	AO	0	s	0	curved	0	4	4
405A	A	R	RO	AO	1	i	1	int	1	4	4
401B	RO	RO	RO	RO	1	i	1	int	1	4	41
402B	R	AO	RO	RO	1	i	1	curved	0	4	41
403B	RA	RA	A	O	1	s	0	curved	0	4	41
404B	RO	RO	RO	AO	1	s	0	int	1	4	41
405B	RO	RO	O	O	1	s	0	int	1	4	41
501A	O	RO	O	RO	1	s	0	int	1	5	5
502A	RA	AO	RA	A	1	i	1	int	1	5	5
503A	RO	RO	AO	AO	1	i	1	int	1	5	5
504A	RO	O	AO	RA	1	s	0	curved	0	5	5
505A	AO	AO	RO	RA	1	i	1	int	1	5	5
501B	RA	AO	AO	AO	1	i	1	int	1	5	51
502B	A	AO	AO	RA	1	i	1	int	1	5	51
503B	AO	O	RA	AO	1	i	1	int	1	5	51
504B	A	O	AO	AO	0	j	2	int	1	5	51
505B	RO	RO	RA	RO	1	j	2	trans	2	5	51
601A	RO	RA	RO	RO	1	i	1	trans	2	6	6
602A	RO	RA	RO	RA	1	j	2	int	1	6	6
603A	AO	RA	RO	RO	1	J	2	int	1	6	6
604A	RO	RO	RA	RO	1	i	1	trans	2	6	6

605A	RO	RA	RO	AO	1	i	1	curved	0	6	6
601B	RA	RO	RA	RA	1	s	0	curved	0	6	61
602B										6	61
603B	R	RA	RA	RO	2	i	1	trans	2	6	61
604B	RA	RO	RA	RA	1	i	1	int	1	6	61
605B	RA	A	RO	RO	1	s	0	int	1	6	61
701A	RO	AO	RA	A	1	i	1	int	1	7	7
702A										7	7
703A	RA	RO	RO	RO	1	j	2	trans	2	7	7
704A	RA	A	RA	O	1	i	1	int	1	7	7
705A	RA	AO	AO	RO	1	i	1	trans	2	7	7
701B	RA	RO	RO	RO	1	i	1	int	1	7	71
702B	RO	RO	RA	RO	1	j	2	int	1	7	71
703B	RA	RO	RO	RA	1	i	1	int	1	7	71
704B	AO	AO	RO	RA	1	j	2	int	1	7	71
705B	RA	RO	RA	RO	1	i	1	int	1	7	71
801A	RA	RO	RO	RO	1	i	1	int	1	8	8
802A	RA	RO	R	RO	2	j	2	trans	2	8	8
803A	RA	RA	RO	RA	1	i	1	int	1	8	8
804A	R	RA	RA	RO	2	j	2	trans	2	8	8
805A	RO	RO	A	RA	1	i	1	int	1	8	8
801B	RA	RA	RA	RO	1	j	2	int	1	8	81
802B	RA	RA	RO	RA	1	i	1	int	1	8	81
803B	RO	RO	R	RO	2	i	1	int	1	8	81
804B	RA	R	RO	RA	2	i	1	int	1	8	81
805B	RA	RO	RO	RO	1	i	1	curved	0	8	81
901A	RA	RA	RO	AO	1	i	1	int	1	9	9
902A	RO	RO	AO	AO	1	s	0	int	1	9	9
903A	RO	RA	A	RO	1	i	1	int	1	9	9

904A	RO	AO	RA	RO	1	i	1	int	1	9	9
905A	RA	RA	O	AO	1	i	1	int	1	9	9
901B	AO	AO	RO	RA	1	j	2	trans	2	9	91
902B	R	RO	R	RO	2	i	1	trans	2	9	91
903B	RA	R	RO	RO	2	j	2	trans	2	9	91
904B	RA	RO	RO	RA	1	i	1	trans	2	9	91
905B	R	AO	RA	RO	1	j	2	trans	2	9	91
1001A	RA	RO	RA	R	2	j	2	trans	2	10	10
1002A	RA	RO	RO	RO	1	i	1	int	1	10	10
1003A	R	A	AO	RO	1	i	1	trans	2	10	10
1004A	RA	RO	RO	AO	1	j	2	int	1	10	10
1005A	A	RO	AO	O	1	i	1	curved	0	10	10
1001B	RA	AO	RO	RO	1	i	1	trans	2	10	101
1002B	R	AO	R	RA	2	j	2	int	1	10	101
1003B	RA	RO	R	RO	2	j	2	trans	2	10	101
1004B	RA	RA	AO	AO	1	j	2	trans	2	10	101
1005B	RA	R	RO	RO	2	j	2	int	1	10	101
1101A	RO	RO	R	RO	2	s	0	int	1	11	110
1102A	RO	RA	RO	AO	1	i	1	curved	0	11	110
1103A	RA	AO	AO	RA	1	j	2	trans	2	11	110
1104A	R	RO	RO	RA	2	i	1	trans	2	11	110
1105A	RO	RA	RA	RO	1	i	1	curved	0	11	110
1101B	RA	RO	RO	R	2	j	2	int	1	11	111
1102B	RA	O	R	RO	1	j	2	int	1	11	111
1103B	RA	RO	RO	RO	1	j	2	trans	2	11	111
1104B	RO	A	AO	RO	1	i	1	int	1	11	111
1105B	RO	RO	R	R	2	j	2	int	1	11	111
1201A	RA	R	RO	R	2	j	2	trans	2	12	12
1202A	RA	RO	RA	RO	1	j	2	int	1	12	12

1203A	RA	AO	R	O	1	s	0	int	1	12	12
1204A	RA	RA	R	RA	2	j	2	trans	2	12	12
1205A	RO	RO	RO	RO	1	j	2	int	1	12	12
1201B	R	RO	RO	RO	2	j	2	int	1	12	121
1202B	R	RO	R	R	2	j	2	trans	2	12	121
1203B	R	RO	AO	RO	1	j	2	int	1	12	121
1204B	RA	R	RO	RO	2	j	2	trans	2	12	121
1205B	RA	R	RO	RO	2	j	2	int	1	12	121
1301A	R	RA	R	RO	2	i	1	trans	2	13	13
1302A	RO	R	RO	R	2	j	2	trans	2	13	13
1303A	RA	RO	R	R	2	i	1	int	1	13	13
1304A	R	RO	AO	RO	1	j	2	int	1	13	13
1305A	RA	RO	RO	R	2	i	1	trans	2	13	13
1301B	RO	O	AO	A	1	s	0	curved	0	13	131
1302B	RO	RO	RO	AO	1	i	1	int	1	13	131
1303B	RO	RO	RO	AO	1	i	1	int	1	13	131
1304B										13	131
1305B	RO	RA	RO	RA	1	j	2	trans	2	13	131
1401A	RA	RA	RA	RO	1	i	1	trans	2	14	14
1402A	R	RA	AO	RA	1	j	2	trans	2	14	14
1403A	RA	O	R	O	1	j	2	int	1	14	14
1404A	R	RO	RO	RA	2	j	2	trans	2	14	14
1405A	R	RO	RA	RO	2	i	1	int	1	14	14
1401B	RO	RA	RA	RA	1	i	1	trans	2	14	141
1402B	RA	RA	R	RO	2	i	1	trans	2	14	141
1403B	RA	RA	R	RA	2	i	1	int	1	14	141
1404B	RA	R	AO	RO	1	j	2	int	1	14	141
1405B	R	RO	RO	RO	2	j	2	trans	2	14	141

Appendix B, Table 2: Initial dataset before intraobserver error was calculated.

	PA fx angle	PP	DA	DP	PA fx surface	PP	DA	DP	outline	FFI
101A	RA	RO	RO	RO	I	I	I	I	int	3
102A	A	RA	O	RO	i	i	i	i	curved	2
103A	A	RO	RO	R	i	i	i	i	int	3
104A	RA	RO	AO	RO	s	s	s	s	curved	1
105A	AO	RO	RA	AO	s	s	s	s	curved	1
101B	R	A	RO	RA	i	i	i	i	int	3
102B	AO	RO	A	RO	s	s	s	s	curved	1
103B	RO	R	RO	RO	s	s	s	s	trans	3
104B	O	AO	AO	RO	i	i	i	i	curved	0
105B	A	RA	O	RA	i	i	i	i	curved	1
201A	AO	AO	RO	RO	i	i	i	i	trans	4
202A	RO	RO	A	AO	i	i	i	i	curved	2
203A	RO	RA	RO	RA	i	i	i	i	trans	4
204A	RA	RO	RO	RA	i	i	i	i	int	3
205A	R	A	O	AO	s	s	s	s	curved	o
201B	RA	AO	RA	AO	i	i	i	i	int	3
202B	RA	AO	RO	RO	i	i	i	i	int	3
203B	AO	R	AO	R	i	i	i	i	int	3
204B										
205B	RA	RA	AO	RA	i	i	i	i	curved	2
301A	RA	RO	RA	RO	i	i	i	i	int	3
302	A	A	RO	O	i	i	i	i	curved	2
303	R	O	R	RA	i	i	i	i	trans	5
304	RO	O	RA	RA	i	i	i	i	curved	2
305	A	RA	RO	O	i	i	i	i	trans	4
301B	R	O	RA	RA	s	s	s	s	curved	1
302	RO	AO	RA	AO	s	s	s	s	curved	1

303	RA	AO	RO	AO	i	i	i	i	int	3
304	RO	RA	A	RO	s	s	s	s	curved	1
305	O	RO	RO	RO	s	s	i	i	int	3
401A	RO	O	RA	RA	i	i	i	i	int	3
402	R	AO	RA	AO	i	i	i	i	curved	2
403	R	RA	RA	AO	i	i	i	i	int	3
404	AO	AO	AO	AO	s	s	s	s	curved	0
405	A	R	RO	AO	i	i	i	i	int	3
401B	RO	RO	RO	RO	s	s	s	s	int	2
402	R	AO	RO	RO	i	i	i	i	curved	2
403	RA	RA	A	OA	s	s	s	s	curved	1
404	RO	RO	RO	AO	s	s	s	s	int	2
405	RO	RO	AO	O	s	s	s	s	int	2
501A	O	RO	RO	RO	s	s	s	s	curved	1
502	AO	RO	RA	A	i	i	i	i	int	3
503	RO	RO	AO	AO	i	i	i	i	int	3
504	RO	AO	AO	RA	s	s	s	s	curved	1
505	AO	AO	RO	RA	i	i	i	i	int	3
501B	RA	AO	AO	AO	i	i	i	i	int	2
502	A	AO	AO	RA	i	i	i	i	int	3
503	AO	RO	A	AO	i	i	i	i	int	2
504	A	O	AO	AO	j	j	j	j	int	3
505	RO	RO	RA	RO	j	j	j	j	trans	5
601A	RO	RA	RO	RO	j	j	j	j	trans	5
602	RO	RA	RA	RO	j	j	j	j	int	4
603	AO	RA	RO	RO	j	j	j	j	int	4
604	RO	RO	RA	RO	i	i	i	i	trans	4
605	RO	RA	RO	AO	i	i	i	i	curved	2
601B	RA	RO	A	RA	s	s	s	s	curved	1

602										
603	R	RA	RA	RO	j	j	j	j	trans	5
604	RO	RA	RA	RA	i	i	i	i	int	3
605	RA	RA	RO	RO	s	s	s	s	int	2
701A	RO	AO	RA	RA	i	i	i	i	int	3
702										
703	RA	RO	RO	RO	j	j	j	j	trans	5
704	RA	RA	RA	O	i	i	i	i	int	3
705	RA	AO	AO	RO	i	i	i	i	trans	4
701B	RA	RO	RO	RO	i	i	i	i	int	3
702	R	RO	RA	RO	j	j	j	j	trans	6
703	RA	RO	RO	RA	i	i	i	i	int	3
704	AO	AO	RO	RA	j	j	j	j	trans	5
705	RA	RA	RA	RO	i	i	i	i	int	3
801A	RA	RO	RO	RO	j	j	j	j	trans	5
802	RA	RO	R	RO	j	j	j	j	trans	6
803	RA	RA	RO	RA	i	i	i	i	int	3
804	R	RA	RA	RO	j	j	j	j	trans	6
805	RO	RO	RA	RA	j	j	j	j	trans	5
801B	RA	RA	RA	RO	j	j	j	j	int	4
802	RA	RA	RO	RA	i	i	i	i	int	3
803	RO	RO	R	RO	i	i	i	i	int	3
804	RA	R	RO	RA	i	i	i	i	int	4
805	RA	RA	RO	RO	i	i	i	i	curved	2
901A	RA	RA	RO	AO	i	i	i	i	int	3
902	RO	RO	AO	AO	s	s	s	s	int	2
903	RO	RA	A	RO	i	i	i	i	int	3
904	RO	AO	RA	RO	i	i	i	i	int	3
905	RA	RA	RO	AO	i	i	i	i	int	3

901B	AO	RA	RO	RA	j	j	j	j	trans	5
902	R	RO	R	RO	i	i	i	i	trans	5
903	RA	R	RO	RO	j	j	j	j	trans	6
904	RA	RO	RO	RA	i	i	i	i	trans	4
905	R	AO	RA	RO	j	j	j	j	trans	5
1001A	RA	RO	R	R	j	j	j	j	trans	6
1002	RA	RO	RO	RO	j	j	j	j	int	4
1003	R	A	AO	RO	j	j	j	j	trans	5
1004	RA	RO	RO	AO	i	i	i	i	int	3
1005	A	RO	AO	O	i	i	i	i	curved	2
1001B	RA	AO	RO	RO	i	i	i	i	trans	4
1002	R	AO	R	RA	j	j	j	j	int	5
1003	RA	RO	R	RO	j	j	j	j	trans	6
1004	R	RA	AO	AO	j	j	j	j	trans	5
1005	RA	R	RO	RO	j	j	j	j	int	5
1101A	RO	RO	R	RO	s	s	s	s	int	3
1102	RO	RA	RO	AO	i	i	i	i	curved	2
1103	RA	AO	RA	RA	j	j	j	j	trans	5
1104	R	RO	RO	RA	j	j	j	j	trans	6
1105	RO	RA	RA	RO	i	i	i	i	curved	2
1101B	RA	RO	RO	R	j	j	j	j	int	5
1102	RA	O	R	RO	j	j	j	j	int	5
1103	RA	RO	RO	RO	j	j	j	j	trans	5
1104	RO	A	AO	RO	i	i	i	i	int	3
1105	R	R	RO	RO	j	j	j	j	int	5
1201A	RA	R	RO	R	j	j	j	j	trans	6
1202	RA	RO	RA	RO	j	j	j	j	int	4
1203	RA	O	R	O	i	i	i	i	int	3
1204	RA	RA	RO	R	j	j	j	j	trans	6

1205	RO	RO	RO	RO	j	j	j	j	int	4
1201B	R	RO	RO	RO	j	j	i	i	trans	5
1202	R	RO	R	RA	j	j	j	j	trans	6
1203	R	RO	AO	RO	j	j	j	j	int	4
1204	RA	R	RO	RO	j	j	j	j	trans	6
1205	RA	R	RO	RO	j	j	j	j	int	5
1301A	R	RA	R	RO	i	i	i	i	trans	5
1302	RO	R	RO	R	j	j	j	j	trans	6
1303	RA	RO	R	R	i	i	i	i	int	4
1304	R	RO	AO	RO	j	j	j	j	int	5
1305	RA	RO	RO	R	i	i	i	i	trans	5
1301B	RO	O	AO	A	s	s	s	s	curved	0
1302	RO	RO	RO	AO	i	i	i	i	int	3
1303	RO	RO	RO	AO	i	i	i	i	int	3
1304										
1305	RO	RA	RO	RA	j	j	j	j	trans	5
1401A	RA	RA	RA	RO	i	i	i	i	trans	4
1402	R	RA	A	RA	j	j	j	j	trans	5
1403	RA	O	RA	O	j	j	j	j	int	4
1404	R	RO	RO	RA	j	j	j	j	trans	6
1405	R	RO	RA	RO	i	i	i	i	int	4
1401B	RO	RA	RA	RA	j	j	j	j	trans	5
1402	R	RA	R	RO	i	i	i	i	trans	5
1403	R	RA	R	RO	i	i	i	i	int	4
1404	RA	R	AO	RO	j	j	j	j	int	4
1405	R	RO	RO	RO	j	j	j	j	trans	6

Appendix B, Table 3: Second dataset analyzed to calculate intraobserver error.

	PA fx angle	PP	DA	DP	PA surface	PP	DA	DP	outline	FFI
101A	RA	R	RO	RA	i	i	i	i	trans	4
102	A	RO	O	RO	i	i	i	i	curved	2
103	A	R	RO	R	i	i	i	i	trans	4
104	RA	RO	AO	RO	s	s	s	s	curved	1
105	AO	RO	RA	AO	s	s	s	s	curved	0
101B	R	A	RO	RA	i	i	i	i	int	3
102	AO	RO	A	O	s	s	s	s	int	2
103	RO	R	O	RO	s	s	s	s	trans	3
104	AO	O	RO	RO	i	i	i	i	curved	2
105	A	RA	RO	RA	i	i	i	i	curved	2
201A	AO	AO	RO	RO	i	i	i	i	int	3
202	RO	RO	RA	RO	i	i	i	i	int	3
203	RO	R	RO	RA	i	i	i	i	trans	5
204	RA	RO	RO	RA	i	i	i	i	curved	2
205	R	RA	O	AO	s	s	s	s	curved	1
201B	RA	RO	R	RO	i	i	i	i	trans	5
202	RA	RA	RO	RO	i	i	i	i	int	3
203	AO	R	AO	R	i	i	i	i	trans	4
204									x	
205	RA	RA	AO	RA	i	i	i	i	int	3
301A	RA	R	RA	RO	i	i	i	i	int	4
302	RA	RA	RO	RO	i	i	i	i	int	3
303	R	RO	R	R	i	i	i	i	trans	6
304	R	O	RA	RA	i	i	i	i	trans	4
305	A	R	RO	O	j	j	j	j	trans	5

301B	R	O	RA	RA	s	s	s	s	curved	1
302	RO	O	RA	AO	s	s	s	s	curved	1
303	RA	AO	RO	AO	i	i	i	i	int	3
304	RO	RA	RA	RO	s	s	s	s	int	2
305	O	RO	RO	RO	i	i	i	i	int	3
401A	R	RO	RA	RA	i	i	i	i	int	3
402	R	AO	RA	RA	i	i	i	i	int	3
403	R	RA	RA	AO	i	i	i	i	int	3
404	AO	AO	AO	AO	s	s	s	s	int	1
405	R	R	RO	AO	i	i	i	i	int	4
401B	R	RO	RO	RO	i	i	i	i	int	4
402	R	AO	RO	RO	i	i	i	i	curved	2
403	RA	RA	A	O	i	i	i	i	int	3
404	RO	RO	RO	RA	i	i	i	i	int	3
405	RO	RO	O	RO	s	s	s	s	int	2
501A	O	RO	O	RO	i	i	i	i	int	3
502	RA	AO	R	A	j	j	i	i	trans	4
503	RO	RO	AO	AO	j	j	j	j	int	4
504	RO	RO	AO	RA	s	s	s	s	curved	1
505	AO	AO	RO	RA	i	i	i	i	int	3
501B	R	AO	RO	AO	i	i	i	i	int	3
502	RA	AO	AO	RA	i	i	i	i	int	3
503	RO	O	RA	AO	i	i	i	i	int	3
504	A	RO	AO	RO	j	j	j	j	int	4
505	RO	RO	RA	R	j	j	j	j	trans	6
601A	RO	RA	RO	RO	i	i	i	i	trans	4
602	RO	RA	RO	RA	i	i	i	i	int	3

604	RO	RO	RA	RO	i	i	i	i	trans	4
605	RO	RA	RO	AO	i	i	i	i	curved	2
601B	RA	RO	RA	RA	s	s	s	s	int	2
602									x	
603	R	RA	RA	RO	i	i	i	i	trans	5
604	RA	RO	RA	RA	i	i	i	i	trans	4
605	RA	A	RO	RO	s	s	s	s	int	2
701A	RO	AO	R	A	i	i	i	i	int	3
702									x	
703	RA	RO	RO	RO	j	j	j	j	trans	5
704	RA	A	RA	O	i	i	i	i	int	3
705	RA	AO	RA	RO	i	i	i	i	trans	4
701B	RA	RO	RO	RO	i	i	i	i	int	3
702	RO	RO	RA	RO	j	j	j	j	int	4
703	RA	RO	RO	RA	i	i	i	i	int	3
704	AO	RO	RO	RA	j	j	j	j	int	4
705	R	RO	RA	RO	i	i	i	i	int	4
801A	RA	RO	RO	RO	i	i	i	i	int	3
802	RA	RO	R	AO	i	i	i	i	trans	4
803	RA	RA	RO	RA	i	i	i	i	int	3
804	R	RA	RA	RO	i	i	i	i	trans	5
805	RO	RO	A	RA	i	i	i	i	int	3
801B	A	RA	RA	RO	j	j	j	j	int	4
802	RA	RA	RO	RA	i	i	i	i	trans	4
803	RO	RO	R	RO	i	i	i	i	int	4
804	RA	R	RO	RA	i	i	i	i	trans	5
805	RA	RO	RO	RO	i	i	i	i	int	3

901A	RA	RA	RO	AO	i	i	i	i	trans	4
902	RO	RO	AO	AO	s	s	s	s	curved	0
903	RO	RA	A	RO	i	i	i	i	curved	2
904	RO	AO	RA	RO	s	s	s	s	int	2
905	RA	RA	O	AO	i	i	i	i	int	3
901B	AO	AO	RO	RA	j	j	j	j	trans	5
902	R	RO	R	RO	i	i	i	i	trans	5
903	RA	RA	RO	A	j	j	j	j	trans	5
904	RA	RO	RO	RA	i	i	i	i	trans	4
905	R	AO	RA	RO	j	j	j	j	trans	5
1001A	RA	RO	RA	R	j	j	j	j	trans	6
1002	RA	AO	RO	RO	i	i	i	i	int	3
1003	R	A	AO	RO	i	i	i	i	trans	4
1004	RA	RO	RO	AO	i	i	j	j	int	4
1005	A	RO	AO	O	i	i	i	i	curved	2
1001B	RA	AO	RO	RO	i	i	i	i	trans	4
1002	RA	AO	RA	RA	j	j	j	j	int	4
1003	RA	RO	R	RO	j	j	j	j	trans	6
1004	RA	RA	AO	AO	j	j	j	j	trans	5
1005	RA	R	RO	RO	j	j	j	j	int	5
1101A	RO	RO	R	RO	s	s	s	s	int	3
1102	RO	RA	RO	AO	i	i	i	i	int	3
1103	RA	AO	AO	RA	j	j	j	j	trans	5
1104	R	RO	RO	AO	i	i	i	i	trans	4
1105	RO	RA	RA	RO	i	i	i	i	int	3
1101B	RA	RO	RO	R	i	i	i	i	int	3
1102	RA	O	R	O	j	j	j	j	trans	5

1103	RA	RO	RO	RO	j	j	j	j	trans	5
1104	RO	A	AO	RO	i	i	i	i	int	3
1105	RO	RO	R	R	j	j	j	j	int	5
1201A	RA	R	RO	RA	j	j	j	j	trans	6
1202	RA	RO	RA	RO	j	j	j	j	int	4
1203	RA	AO	RO	O	s	s	s	s	curved	1
1204	RA	RA	R	RA	j	j	j	j	trans	5
1205	RO	RO	RO	RO	j	j	j	j	int	4
1201B	R	RO	RO	RO	j	j	j	j	int	5
1202	R	RO	R	R	j	j	j	j	trans	6
1203	R	RO	AO	RO	j	j	j	j	int	5
1204	RA	R	RO	RO	j	j	j	j	trans	6
1205	RA	R	RO	RO	j	j	j	j	int	5
1301A	R	RA	R	RO	i	i	i	i	trans	5
1302	RO	R	RO	R	j	j	j	j	trans	6
1303	RA	RO	R	R	i	i	i	i	trans	5
1304	R	RO	AO	RO	j	j	j	j	int	4
1305	RA	RO	RO	RO	j	j	j	j	trans	5
1301B	RO	O	AO	A	i	i	i	i	int	2 or 3
1302	RO	RO	RO	AO	j	j	j	j	int	4
1303	RO	RO	RO	AO	i	i	i	i	int	3
1304									x	
1305	RO	RA	RO	RA	j	j	j	j	trans	5
1401A	RA	RA	AO	RO	i	i	i	i	trans	4
1402	R	RA	AO	RA	j	j	j	j	trans	5
1403	RA	O	R	O	j	j	j	j	int	4
1404	R	RO	R	RA	j	j	j	j	trans	6

1405	R	RO	RA	RO	i	i	i	i	int	4
1401B	RO	RA	RA	RA	i	i	i	i	trans	4
1402	R	RA	R	RO	i	i	i	i	trans	5
1403	R	RA	R	RA	i	i	i	i	int	4
1404	RA	R	AO	RO	j	j	j	j	int	4
1405	R	RO	RO	RO	j	j	j	j	trans	6

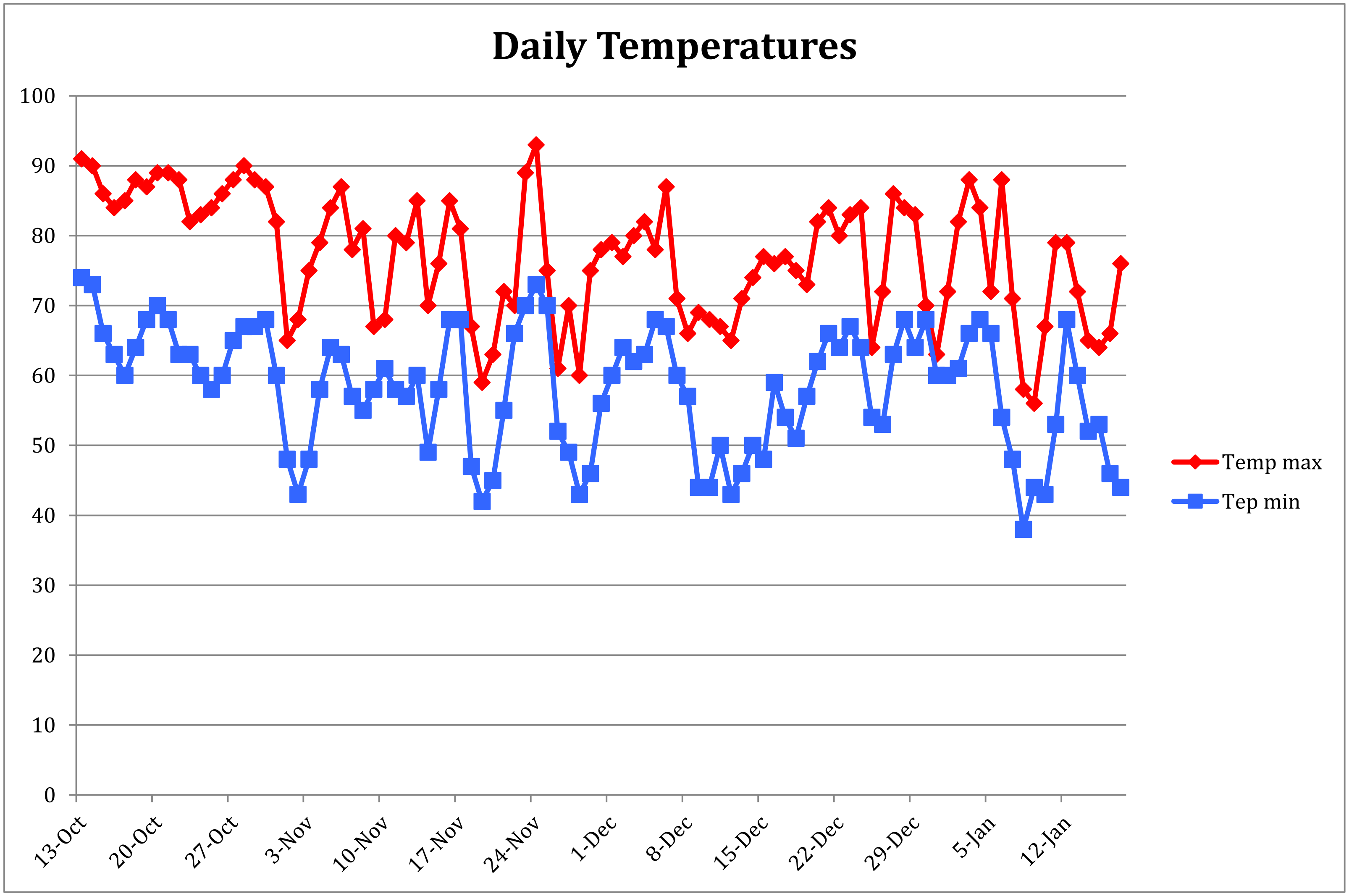
APPENDIX C: RAW WEATHER DATA

Appendix C, Table 1: Raw weather data collected from the HOBO link at the UCF Arboretum.

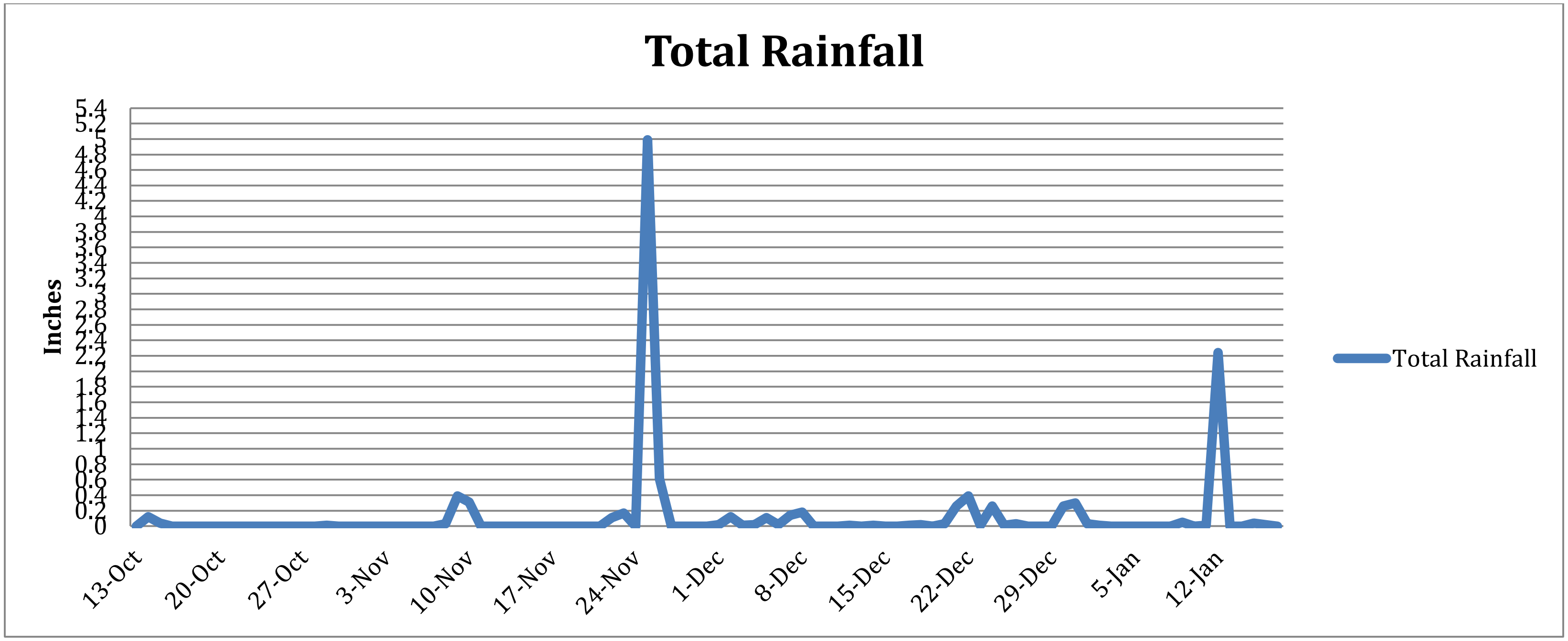
	Temp max	**Temp min**	**Temp mean**	**Rainfall**	**Humidity**
1A 10/13	91˚	74˚	82.5˚	0''	94%
1B 10/14	90°	73°	81.5	0.12"	95%
1C 10/15	86°	66°	76	0.04"	98%
1D 10/16	84°	63°	73.5	0"	95%
1E 10/17	85°	60°	72.5	0"	90%
1F 10/18	88°	64°	76	0"	85%
1 G 10/19	87°	68°	77.5	0"	97%
2A 10/20	89˚	70˚	79.5	0"	97%
2B 10/21	89˚	68˚	78.5	0"	92%
2C 10/22	88°	63°	75.5	0"	100%
2D 10/23	82˚	63°	72.5	0''	90%
2E 10/24	83˚	60°	71.5	0''	88%
2F 10/25	84°	58˚	71	0''	88%
2G 10/26	86°	60°	73	0"	91%
3A 10/27	88°	65˚	74	0"	94%
3B 10/28	90°	67˚	73	0"	98%
3C 10/29	88°	67˚	73	0.01"	99%
3D 10/30	87°	68°	83	0''	93%
3E 10/31	82˚	60˚	71	0''	95%
3F 11/1	65˚	48˚	58	0"	80%
3G 11/2	68˚	43˚	56	0"	89%
4A 11/3	75˚	48˚	52	0"	88%
4B 11/4	79˚	58˚	59	0"	95%
4C 11/5	84˚	64˚	71	0''	96%
4D 11/6	87°	63°	58	0''	98%
4E 11/7	78°	57°	66	0''	98%
4F 11/8	81°	55°	68	0.03''	95%
4G 11/9	67°	58°	63	0.39''	100%
5A 11/10	68˚	61°	64	0.31"	97%
5B 11/11	80	58	68	0”	60%
5C 11/12	79	57	58	0”	83%
5D 11/13	85	60	68	0”	92%
5E 11/14	70	49	62	0”	98%
5F 11/15	76	58	62	0"	97%
5G 11/16	85	68	68	0"	100%
6A 11/17	81	68	71	0"	99%
6B 11/18	67	47	52	0"	100%
6C 11/19	59	42	50	0"	62%

6D 11/20	63	45	54	0"	75%
6E 11/21	72	55˚	59	0"	80%
6F 11/22	70	66	65	0.11"	100%
6G 11/23	89	70˚	75	0.17"	100%
7A 11/24	93	73	78	0"	98%
7B 11/25	75˚	70˚	71	4.99"	100%
7C 11/26	61	52	58	0.61"	100%
7D 11/27	70	49	56	0"	98%
7E 11/28	60	43	52	0"	75%
7F 11/29	75˚	46	57	0"	97%
7G 11/30	78°	56	63	0"	95%
8A 12/1	79˚	60	66	0.02"	96%
8B 12/2	77	64	68	0.12"	98%
8C 12/3	80	62	68	0.01"	98%
8D 12/4	82˚	63	71	0.02"	100%
8E 12/5	78°	68	70	0.11"	97%
8F 12/6	87°	67	71	0.02"	99%
8G 12/7	71	60	65	0.14"	100%
9A 12/8	66	57	62	0.18"	100%
9B 12/9	69	44	56	0"	100%
9C 12/10	68˚	44	51	0"	97%
9D 12/11	67°	50	42	0"	100%
9E 12/12	65˚	43	48	0.01"	99%
9F 12/13	71	46	51	0"	100%
9G 12/14	74	50	52	0.01"	100%
10A 12/15	77	48	52	0"	100%
10B 12/16	76	59	56	0"	100%
10C 12/17	77	54	60	0.01"	100%
10D 12/18	75˚	51	56	0.02"	100%
10E 12/19	73	57	58	0"	100%
10F 12/20	82˚	62	64	0.03"	100%
11A 12/21	84˚	66	69	0.26"	98%
11B 12/22	80	64	70	0.39"	100%
11C 12/23	83˚	67	73	0.01"	100%
11D 12/24	84˚	64	76	0.26"	95%
11E 12/25	64	54	60	0.01"	97%
11F 12/26	72	53	61	0.03"	94%
11G 12/27	86°	63	71	0"	97%
12A 12/28	84˚	68	74	0"	100%
12B 12/29	83˚	64	70	0"	99%

12C 12/30	70	68	66	0.26"	100%
12D 12/31	63	60	62	0.3"	100%
12E 1/1	72	60	65	0.03"	100%
12F 1/2	82˚	61	68	0.01"	100%
12G 1/3	88°	66	74	0"	100%
13A 1/4	84˚	68	75	0"	100%
13B 1/5	72	66	65	0"	97%
13C 1/6	88°	54	64	0"	97%
13D 1/7	71	48	57	0"	97%
13E 1/8	58	38	50	0"	71%
13F 1/9	56	44	50	0.05"	98%
13G 1/10	67°	43	55	0"	98%
14A 1/11	79˚	53	60	0.01"	98%
14B 1/12	79˚	68	68	2.24"	100%
14C 1/13	72	60	66	0"	100%
14D 1/14	65	52	60	0"	92%
14E 1/15	64	53	56	0.04"	90%
14F 1/16	66	46	55	0.02"	83%
14G 1/17	76	44	58	0"	79%



Appendix C, Figure 1: Daily maximum and minimum temperatures for the months of October 2014-January 2015.



Appendix C, Figure 2: Total rainfall in Orlando FL for the months October 2014-January 2015.

APPENDIX D: STANDARDIZED PROTOCOL FOR GROSS OBSERVATION

Protocol for Analysis of Long Bones
Determining Wet and Dry Fracture Characteristics (Developed based on: Behrensmeyer, 1976; Outram, 1998; Wieberg, 2006; Shattuck, 2010)

Group:	A	B

Identification Number:____

Collection Date:____

Duration of Exposure:____

Bone type (circle):	Femur	Humerus	Tibia	Radio-ulna

Environment (circle):	Full sun (A)	Full shade (B)

General Observations:

Mold	Fungus	Bio erosion	Insect damage
Animal damage	Soil staining	Adherent tissue	

Fracture Angle (cross sectional, based on 4 fractures):

1. Location:

Acute Obtuse Acute and Obtuse Right

Right and Acute Right and Obtuse

2. Location:

Acute Obtuse Acute and Obtuse Right

Right and Acute Right and Obtuse

3. Location:

Acute Obtuse Acute and Obtuse Right

Right and Acute Right and Obtuse

4. Location:

Acute Obtuse Acute and Obtuse Right

Right and Acute Right and Obtuse

Fracture Surface (circle, based on same 4 sites as angle) (from **:**

1. Smooth Jagged Intermediate
2. Smooth Jagged Intermediate
3. Smooth Jagged Intermediate
4. Smooth Jagged Intermediate

Fracture Outline (circle, based on all fractures) (from Wheatley, 2008; Symes et al., 2014):

Transverse/jagged Curved/V-shaped

FFI score (total score) (from Outram, 1998):

Fracture Characteristic	**Score=0**	**Score=1**	**Score=2**
Gross Morphology	Fresh break	Combination of fresh and dry features	Majority dry features
Fracture Angle	Absence of right angle fractures	Fewer right angle fractures present than acute/obtuse angle fractures	Majority right angle fractures present
Fracture Outline	Presence of helical fractures only, curved	Presence of both helical fracture outlines as well as other outlines, intermediate	Absence of helical fractures, jagged
Surface Texture	Smooth texture, absence of rough texture	Primarily smooth texture, some roughness noted	Primarily rough texture

Behrensmeyer's Stages of Weathering (adapted from Behrensmeyer, 1976)**:**

Stage 0 Stage 1 Stage 2 Stage 3 Stage 4 Stage 5

Behrensmeyer's Stages of Weathering	
Stage 0	The surface of bone exhibits no flaking or cracking of external layer. Bone exhibits greasy quality, soft tissue may cover part/all of bone surface, and medullary cavity contains marrow.
Stage 1	Surface of bone exhibits longitudinal cracking, with mosaic cracking of soft tissue and bone at articular surfaces. Soft tissue or fat may be present.
Stage 2	Flaking of outer layer of bone along with cracking (edges of cracks exhibit flaking first). Initially, long thin flakes may still be attached at multiple sites. This is followed by more extensive flaking, resulting in loss of most of the outer layer. Soft tissue may still be present.
Stage 3	Rough areas of weathered cortical bone are exhibited by bone surface with complete removal of concentrically layered bone. This eventually will extend to the entire bone surface, however weathering is less than 1-1.5mm deep and bone fibers are attached. Cross sections of crack edges are rounded. Little to no soft tissue remains.
Stage 4	The bone exhibits rough surface texture with splinters of varying sizes. Splinters may be large enough to become detached when bone is disturbed. Inner cavity has been penetrated by weathering. Bone exhibits cracks with rounded edges that have splintered and are open.
Stage 5	Large splinters of bone have become detached and bone is disintegrating in situ. Original shape of the bone is obscured and trabecular bone is exposed. Cancellous bone may remain longer than compact bone.

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