REDUCTION OF FLESHED *SUS SCROFA DOMESTICUS* REMAINS USING A WOOD CHIPPER: SKELETAL TRAUMA AND DISTRIBUTION PATTERNS

THESIS

Presented to the Graduate Council of
Texas State University-San Marcos
in Partial Fulfillment
of the Requirements

for the Degree

Master of ARTS

by

Alexandria Frye

San Marcos, Texas
August 2013

REDUCTION OF FLESHED *SUS SCROFA DOMESTICUS* REMAINS USING A WOOD CHIPPER: SKELETAL TRAUMA AND DISTRIBUTION PATTERNS

Committee Members Approved:

____
Daniel J. Wescott, Chair

____
Michelle D. Hamilton

____
M. Katherine Spradley

Approved:

____
J. Michael Willoughby
Dean of the Graduate College

DEDICATION

To meu namorado, Roger Samson, for helping maintain my sanity at every step of this process and for stepping up when I needed help in a field in which you were unfamiliar. You never let me give up. I couldn’t have done this without you.

ACKNOWLEDGEMENTS

I would like to thank my mother for fostering a love of the macabre and a fascination with the unknown in my young mind and for always telling me that I can do anything I set my mind to. I would also like to thank Brianne Herrera for her photography skills and spending countless hours sorting through bones that were far more fleshy than for what she signed on. Thank you to Tina Watson for spending a long day trying to fix surge protector issues, lifting heavy smelly containers unquestioningly, format editing, and watching all those zombie movies with me when I needed a sanity break. Thank you to Matthew Elverson and Lauren Pharr for the amazing help in butchering my pig specimen and Matt's archaeological expertise in mapping and measurements, not to mention to the heavy lifting of pig remains and the fine points of wood chipper operation.

I would like to thank Duelm's farm for their porcine contribution and Sunbelt Rental Company for being strangely alright with me putting a pig through their wood chipper rental. Thank you to Dr. Steve Symes for taking the time to walk me through what I can expect with wood chipper trauma, ways to design my experiment, and introducing me to the sharp-blunt force trauma category. I would also like to thank Dr. Cheryl Johnston for helping me form the basis of this project while I was a lowly undergrad and to Dr. John Williams for encouraging me to explore skeletal trauma. A special thank you to Dr. Grady Early for contributing funding to this project. It wouldn't have been possible without your help. I would also like to thank Mary Gibson, our department secretary for always being there and guiding me through the mire of graduate paperwork. Finally, I would like to thank my committee for their advice and my advisor, Dr. Daniel Wescott for his extreme patience, understanding, and guidance through this entire process.

This manuscript was submitted on May 17, 2013.

TABLE OF CONTENTS

Page

ACKNOWLEDGEMENTS vi

LIST OF TABLES xi

LIST OF FIGURES xii

ABSTRACT xiv

CHAPTER

I. INTRODUCTION 1

Statement of Problem 1

Statement of Purpose 2

Literature Review 2

Known Wood Chipper Cases 2

Previous Experimental Studies Examining the Reduction of Remains with a Wood Chipper 5

Bone Trauma Literature 6

Sharp Force Trauma 6

Blunt Force Trauma 8

Sharp-Blunt Force Trauma 9

Biomechanical Properties of Bone and Skin 12

II. MATERIALS AND METHODS..16
Wood Chipper..16
Porcine Remains..17
Mapping and Measurements...18
Maceration Techniques...19
Macroscopic Examination..20
Microscopic Examination..21
Statistical Analysis..21
Examination of Distribution Pattern..22

III. RESULTS..23

Skeletal Trauma and Identification..23
Macroscopic Examination..24
Microscopic Examination..27
Associated Integument..29
Distribution Pattern..30

IV. DISCUSSION..33

Hard Tissue..33
Soft Tissue..35
Distribution Patterns and Implications for Concealment.....................36
Limitations..37
Advantages..38

V. CONCLUSION..40

REFERENCES 42

LIST OF TABLES

Title **Page**

1. Frequencies of observed microscopic trauma characteristics................................25
2. Frequencies of observed microscopic trauma characteristics................................28

LIST OF FIGURES

Figure **Page**

1. Young's modulus illustrating the relationship of loading processes to the deformation of bone. 13
2. J-shaped stress/strain curve illustrating the viscoelastic phases of skin deformation during loading....................15
3. Diagram of a disc-type wood chipper: a (external components) and b (internal workings) *(a: National Institute for Occupational Safety and Health, FACE Report 98-13; b: www.woodenergy.ie).* 16
4. Illustration of utilized remains (U/yellow= unused; B/blue=Distribution B; A/pink=Distribution A). (Modified from www.fabiobonvicini.net) 18
5. Pictographic representation of discharged remains map indicating locations of Distribution A and B. 19
6. Largest fragment from Distribution B- a rib measuring 84mm long 24
7. Grand total combined frequency of macroscopic trauma. 25
8. Rib fragment from Distribution b illustrating a hinge fracture (yellow arrow points to hinge fracture) 26
9. Rib fragment illustrating longitudinal fracture (circled in red) 26
10. Rib fragment with spur (yellow arrow points to spur)....................26

11. V-shaped kerf on clavicular fragment..27

12. Grand total combined frequency of microscopic trauma.......................................28

13. Clavicle fragment showing a through cut (yellow arrow) and a false start (circled in red)..29

14. The two largest pieces of skin associated with the remains...................................30

15. The two recovered hoof portions, a) 105 mm x 40 mm, b) 70mm x 50 mm.........30

16. Wood chipper distributing bone and associated tissue in thick clumps.................31

17. Southeast overall view of mapped distribution with wood chipper.......................32

18. Photographic representation of Distribution A (left) and Distribution B (right)...32

ABSTRACT

by

Alexandria Suzanne Frye, B.S.

Texas State University-San Marcos

August 2013

SUPERVISING PROFESSOR: DANIEL WESCOTT

Wood chippers are machines intended for the reduction of wood and brush into small chips for the purpose of disposal. Although uncommon, these machines have been used as tools of homicide concealment through mechanical reduction of human remains following dismemberment. In light of this use and limited prior research, it is important for forensic anthropologists to understand the mechanisms of skeletal trauma and distribution patterns.

In this study, *Sus scrofa domesticus* remains were utilized as a proxy for human remains and fed through a small commercial wood chipper. Observations following reduction included a large amount of associated hard and soft tissue with small bone fragments being embedded in large swatches of skin and muscle tissue. Skeletal trauma includes a wide array of macroscopic and microscopic sharp-blunt force trauma characteristics resulting from contact with the blade and the feed roller. This research provides experimental evidence of sharp-blunt trauma characteristics caused by wood

chippers, a distribution pattern expected from a disc-type wood chipper reduction, as well as natural and human-enacted methods of concealment. This study should be considered when searching for dispersed remains resulting from cases of suspected wood chipper reduction.

CHAPTER I

INTRODUCTION

Statement of Problem

Wood chippers are machines used for the disposal of large pieces of wood by reducing them to smaller pieces or wood chips. However, wood chippers can and have been used to reduce dismembered human remains to make disposal easier when trying to conceal crimes (Mudede 2003, Reuter 1993, Ravo 1988). In this study, the term reduce is used to mean the mechanical manipulation of large pieces into smaller pieces due to traumatic forces. While the use of wood chippers to aid in the disposal of human remains is uncommon, they can be rented at most equipment rental stores relatively cheaply and are easily transported behind vehicles with a standard two-inch ball hitch. Consequently, it is possible that they can be used to conceal crimes. Therefore, it is important that forensic scientists have an understanding of the array of skeletal trauma resulting from wood chipper reduction and knowledge of the distribution pattern of hard and soft tissues discharged from the machine. The aim of this study is to examine the patterns of trauma on skeletal elements and the distribution of hard and soft tissue of dismembered, fleshed remains reduced with a wood chipper.

Statement of Purpose

The purpose of this study is to determine the mechanism of skeletal trauma and the pattern of distribution of hard and soft tissues that occurs when fleshed skeletal elements are reduced with a gas-powered disc-type wood chipper. I hypothesize that a body reduced with a wood chipper will exhibit a highly fragmented skeleton with multiple types of trauma including sharp force, blunt force, and cortocontundente or sharp-blunt force (Steve Symes, personal communication, February 24, 2011). In addition to fragmentation of the bone, it is expected that there will be large pieces of skin stripped from the bone (Beers and Allen 2007). The results of this study will provide experimental evidence of the type of trauma inflicted on fleshed remains reduced with a wood chipper in a controlled study, and will aid law enforcement and medicolegal investigators in the identification of remains reduced with a wood chipper.

Literature Review

Known Wood Chipper Cases

The most famous example of a crime being concealed with a wood chipper is *State of Connecticut v. Richard B. Crafts*. Crafts was convicted in 1989 of murdering his wife Helle Crafts, concealing the crime by reducing her frozen body with a gas-powered wood chipper, and then disposing of the small remains in a nearby river (Ravo 1988). Chipped bone fragments consistent with human remains were recovered in the river near his house and hair and blood matching Helle Crafts were found on his chainsaw, which Richard Crafts used to dismember his wife. This was the first case in Connecticut history of a person convicted of murder in which the body was not found (Ravo 1988).

Another confirmed case of a wood chipper being used to conceal a murder occurred in Oviedo, Florida. Michele Roger was convicted of murdering her boyfriend, David Richmond on September 6, 1992. After stabbing him to death, Michele Roger burned his remains before putting them through one of Richmond’s own wood chippers and mixed the remains into a concrete block. Later, with the assistance of her family, the concrete was broken up and distributed along I-95 in central Florida (Reuter 1993). The Roger family members were convicted of dumping the body.

The most striking case of murder and wood chipper reduction is the serial killing of 34 prostitutes in Vancouver, Canada. This was the largest serial killer investigation in Canadian history. Between 1995 and 2001, Robert Pickton shot or strangled 34 women to death using a wire garrote. Following the murders, he put each of them through a wood chipper. Investigators found evidence of human remains in the pigpens on the Pickton farm, suggesting that he fed the reduced remains of the women to his pigs (Mudede 2003).

There have also been several cases of accidents involving humans being killed by wood chippers as a result of unsafe working environments. According the Centers for Disease Control and Prevention (2004), 32 wood chipper-related injuries and/or deaths occurred between 1992 and 2002 in companies with greater than 11 employees. Most of the injuries were crush injuries of the hand and forearm caused by the feeding mechanism. While the majority of deaths were associated with sharp and blunt force trauma caused by the feeding mechanism in combination with the blades, at least one man was strangled by a chain that was pulled into the wood chipper. Because only companies employing more than 11 employees are required to report accidents of this nature, it is reasonable to assume that the number of wood chipper related deaths may be underreported (Centers for Disease Control and Prevention 2004). This means that trauma inflicted on deceased individuals are not included in this report and that accidental deaths resulting from businesses smaller than 11 employees are also discluded, like the death of 14 year-old Frank Anthony Gornick, who was pulled into a wood chipper when his shovel became lodged in the blades in 2009 (Massachusetts Coalition for Occupational Safety and Health 2009). This also precludes accidental deaths that occurred during wood chipping for personal use such as that of six year-old Jeffrey Bourgeois. In 2012, this child pushed a tree branch into the feeding mechanism while his father's back was turned. When his sleeve became snagged on the branch, he was pulled into the feeder and died instantly (Caulfield 2012).

One of the accidental cases provides some information regarding the expected trauma and distribution pattern expected with wood chipper reduction of human remains. In an accidental death case study examined by Allen and Beers at the Larimer County Medical Examiner's Office, a worker wearing his equipment improperly was pulled into a commercial-sized Vermeer 2001 BC1250A brush chipper when his glove was caught in the feeding mechanism (Allen and Beers 2007). The feeder pulled his body, arms and head first, into the twelve-inch by twelve-inch feeding mechanism of the disc-type wood chipper before his partner could lower the cherry picker from which he was working. This accident resulted in the man being dismembered and the reduced body parts landing in the truck bed at which the wood chipper was aimed. The resulting distribution pattern on the ground measured 172.72 cm by 55.88 cm at the widest point. The distribution pattern in the truck measured approximately 279.40 cm by 55.88 cm. The largest tissue swatch present measured 20.32 cm by 35.56 cm. The largest anatomical elements intact were the penis, portions of the scalp, the right third and fifth fingers, and a portion of the foot with the three smaller toes still associated (Allen and Beers 2007).

The lack of extensive research on wood chipper trauma on bone suggests there is a gap in the medicolegal knowledge base regarding this topic. Previous use of wood chippers as tools of reduction of human remains warrants research into this topic to provide a baseline of observable characteristics that may be used in the future by forensic anthropologists to reconstruct events surrounding death.

Previous Experimental Studies Examining the Reduction of Remains with a Wood Chipper

While there is ample research on cortocontundente trauma with sharp instruments such as machetes and hatchets (Lynn and Fairgrieves 2009a, 2009b; Nadjem, Bohner, and Pollak 1999; Ong 1999), there are currently only two studies (Domenick 2012, Williams 2007) examining the effects of wood chipper reduction on dismembered, fleshed remains. Williams (2007) examined the damage to deer (*Odocoileus virginanus*) long bones discarded from a mechanical wood chipper.

His study looked at differences resulting from whether a chipping or shredding mechanism was used. He discovered that although fragments rarely exceeded 12 mm in length, some shredded fragments were over 35 mm in length and retained clearly identifiable anatomical structures. He also found a statistically significant difference between the mean weights of recovered bones from chipper versus shredder processing, suggesting that different chipping mechanisms are plausibly identifiable based on fragment size segregation and whether the fragments are identifiable as to bone type. It is noted that this wood chipper type prediction model requires complete or near complete recovery of fragments as any loss could cause the appearance of a lack of sizes present (Williams 2007).

Domenick (2012) examined the effects of a home model wood chipper on the forelimbs of pigs (*Sus scrofa domesticus*). Chip sizes varied in length from 15.6 mm to 45.44 mm. Chip widths ranged from 5.72 mm to 26.42 mm. There was also a considerable amount of bone reduced to a sand-like appearance, which could not be measured. He observed that the largest bone fragments (sizes 1 and 2) combined comprised approximately 55% of the total amount of fragments and stated that in his opinion, these were the fragment sizes most likely to be found during an investigation. Additionally, he recovered an average of 96% of the material input into the wood chipper as measured by weight (Domenick 2012).

Bone Trauma Literature

Sharp Force Trauma

Sharp force trauma is the application of an edged surface to another object, which results in a deformation of the second object (Symes et al. 2002). Sharp force injuries may be penetrating or perforating wounds and may fall into categories of stabbing, slashing, or cutting (Kimmerle and Baraybar 2008). Tools usually associated with such injuries include knives, saws, and other edged tools that may be serrated or non-serrated. Morphological characteristics of sharp force trauma include kerf walls and floor, striations, false starts, relatively smooth margins, and the breakaway spurs and notches (Symes et al. 2010).

Symes et al. (2010) listed several characteristics of sharp force trauma in regards to saw cut marks, such as striations, kerf shape, and false starts. Striations are roughly parallel lines that occur when an edged tool is used to inflict sharp force cutting or slicing damage on bone. Kerf refers to the shape of the walls of bone caused by displacement of bone, also called wastage, when a bone is sawed or cut. Kerfs come in many shapes including v-shaped and w-shaped depending on the tooth set of the saw or beveling of a knife. False starts, formerly termed “hesitation marks”, are cut marks that do not completely bisect the bone. They may be extremely shallow or may stop just short of bisecting the bone. The spur and notch phenomenon occurs when a bone is under stabilizing loading on one end (it is immobile) and the free end is cut. When this occurs, upon the final stroke, the bone may break away, resulting in a spur on one end and the associated notch on the other end (Symes et al. 2010). This is important in the study of wood chippers due to the feeding mechanism, which loads bones as it pulls them into the hopper. The loading of the bones that are simultaneously experiencing sharp force trauma inflicted by the swinging knives within the wood chipper may plausibly result in spurs and notches.

Differences in tool class (hacksaw, bandsaw, serrated knife, etc) can be seen in characteristics such as striations. Crowder et al. (2011) illustrated the diagnostic differences between serrated and non-serrated blades in sharp force trauma research. In addition, they reported error rates of classification of serration differentiation as well as edge-bevel siding. The authors determined that classification of a cut mark as being from a serrated versus a non-serrated blade was correct 96% of the time. However, edge-bevel was only correctly classified around 50% of the time on bony surfaces, suggesting that this characteristic requires improvement before use in court cases and was not recorded as a reliable observation in this study (Crowder et al. 2011).

Symes et al. (2010) suggest that a simple or compound microscope provides sufficient magnification for most trauma analyses conducted by forensic anthropologists. However, several studies (Bartelink et al. 2001, Lynn and Fairgrieves 2009b) have successfully used scanning electron microscopes to view sharp force trauma characteristics such as osteon pull outs. These pull outs are the removal of bone cells from their original arrangement as a result of the osteonal tensile strength exceeding that of the shear strength at interlamellar surfaces and can only be viewed under the advanced magnification of a scanning electron microscope (Lynn and Fairgrieves 2009b).

Blunt Force Trauma

Blunt force trauma occurs when a blunt surface comes into contact with an object with enough velocity to cause traumatic injury. It may be the result of high loading (blast injuries and high velocity vehicular impact) or low loading (a fall) (Kimmerle and Baraybar 2008). Trauma typical of blunt force includes crushing, blows, tears, shears, and various fractures. Examples of intentional infliction include stellate fractures or perforating wounds from being hit in the head with a baseball bat or the blunt end of a hammer. Blunt force trauma also includes accidental or human mediated falls, such as a person falling off of a roof and breaking their leg or someone falling and hitting their head on a coffee table or a hard floor (Kimmerle and Baraybar 2008).

Characteristics of blunt force trauma include jagged fracture margins, patterns of tension and compression, and various fracture patterns such as stellate, longitudinal, comminuted, and transverse fractures (Kimmerle and Baraybar 2008). The jagged fracture margins are very helpful in differentiating blunt force trauma from sharp force trauma, which tends to have smooth trauma margins due to the cutting or slicing of the edged tool (Kimmerle and Baraybar 2008).

Sharp-Blunt Force Trauma

Sharp-blunt force trauma, also called cortocontundente trauma, comprises hacking and chopping actions that occur when an edged object is swung or used to strike another object such as bone. Chopping and hacking injuries result in blunt crushing injuries in addition to sharp force trauma, and are therefore categorized as and differ from sharp force and blunt force trauma (Chacon et al. 2008). According to Chacon et al. (2008), sharp-blunt force trauma should be interpreted as deriving from a singular mechanism and indicate weapon class (ie: a chopping or hacking tool). Weapons that typically cause this type of trauma are axes, hatchets, cleavers, and machetes. Bones presenting this type of injury tend to exhibit bone fragmentation around the injury margins. Sharp-blunt tools applied to compact bone tend to leave a smooth margin on one side of the wound and a more jagged margin on the other side due to fragmentation caused by the large amount of force in the blow. This is important to consider in light of the swinging blades within a wood chipper (Steve Symes personal communication). As these blades rotate at speeds of 1835 rotations per minute, the force behind the blow is very large and it is reasonable to expect this type of trauma.

Chacon et al. (2008) also found that cancellous bone fragments tend to be relatively complete with straight-angled surfaces where the blade came in contact with the bone in cases of sharp-blunt force trauma. This causes unilateral flaking of the wound margins is common in sharp-blunt force trauma due to the angled strike of a blade to bone and is therefore expected in wood chipper trauma (Chacon et al. 2008). Linear fractures may also be present extending from the sharp-blunt force defect. This is due to the blunt force component, which is also caused by the large amount of force used to cause the injury. Therefore, it stands to reason that the presence of cancellous bone with surfaces that appear to have been sheared off with radiating linear fractures may be an indicator of sharp-blunt force trauma in wood chippers.

In a macroscopic study by Lynn and Fairgrieves (2009a), the authors discuss characteristics of axe and hatchet inflicted hacking trauma on bone. They found evidence of chattering- the complete fracturing of many small bone fragments during the process of hacking a bone with a sharp-blunt instrument- to be a main characteristic of sharp-blunt force trauma (Lynn and Fairgrieves 2009a). They discovered that defleshed bones appeared to have experienced higher forces of loading than the fleshed bones. This is presumably due to the shock absorbing behavior of the flesh. . Most importantly, this study revealed that different bones fracture differently when exposed to hacking trauma. While femora tend to fracture transversely and spirally, fibulae tended to fracture along the longitudinal axis (Lynn and Fairgrieves 2009a). These are important considerations when observing wood chipper trauma and may warrant the “chipping” (use of a wood chipper to reduce remains) of individual bones into separate, distinct piles for future studies to determine if bones chip differentially.

Ong (1999) discusses several cases of slash/chop homicides in Kuala Lumpur, Malaysia. He details that the wounds were inflicted with a swinging motion, with the head and upper extremities being the most common injury sites. Flesh wounds made in this way generally exhibited evidence of sharp-blunt force trauma. Characteristic damage to the underlying bone is generally notched, cut, or chipped defects, although in some cases the bone appeared to have been shaved off. Consistent with findings listed by Chacon et al. (2008) and Lynn and Fairgrieve (2009a) linear fractures were also common in this type of trauma (Ong 1999). This is important as the wood chipper contains swinging blades, which is a similar action in slash-chop homicides and could cause similar injuries as those found by Ong (1999).

One way to tell the difference between sharp force and sharp-blunt trauma on bone may be the orientation of striations in relation to the tool stroke. In a book chapter by Symes et al. (2002) the authors discuss this possibility, noting that sharp force trauma actions such as the cutting, slicing, or sawing actions of knives or saws result in striations that are oriented parallel to the sawing or slicing motion. Conversely, in sharp-blunt chopping or hacking actions, the resulting striations are oriented perpendicular to the tool and leave gaping wounds (Symes et al. 2002). Additionally, sharp-blunt force trauma can usually be differentiated from blunt force trauma by the presence of both sharp and blunt margins and characteristics on bones inflicted with sharp-blunt force (Galloway 1999; Kimmerle and Baraybar 2008).

Biomechanical Properties of Bone and Skin

Bone is a complex substance composed of 30% organic substance (collagen) and

70% inorganic substance (hydroxyapatite) (Kieser et al. 2013). The collagen component contributes elasticity and strength under tension. The hydroxyapatite component, which is largely comprised of calcium compounds, contributes rigidity and strength under compression. Bone is an anisotropic substance- meaning that it responds differently when placed under different types of stress. This property is important because it results in a material that may fracture differently depending on the type of bone (e.g., femur, sphenoid, etc) and orientation of the bone to the forces acting on it (Lynn and Fairgrieves 2009a). This is partially due to the microscopic orientation of bone cells, which largely contribute to anisotropy in bone and is part of the reason why the remains were placed through the machine in an order representative of a human being placed through head first (Sasaki et al. 1989). Additionally, this anisotropic property helps explain why the points of tension and compression occur in specific locations in trauma analysis. When traumatic observations are viewed in a biomechanical light, the context of traumatic events are more clear. This is true in the case of comminuted fractures in which the points of tension and compression are observable and can plausibly be used to reconstruct the traumatic context if the observer is well versed in biomechanics (Symes 2013).

Young's modulus is a mechanical model that illustrates the relationship of stress to strain (Symes et al. 2002). In other words, it shows how loading processes contribute to the deformation of substances such as bone (Figure 1). The elastic phase indicates a period in which the bone will revert to its original shape if the load is removed. Once it reaches the yield point, it progresses into the plastic region. At this point, if the load is removed, the bone will retain the deformed shape, but will not break unless it reaches the fracture point (Symes et al. 2002).

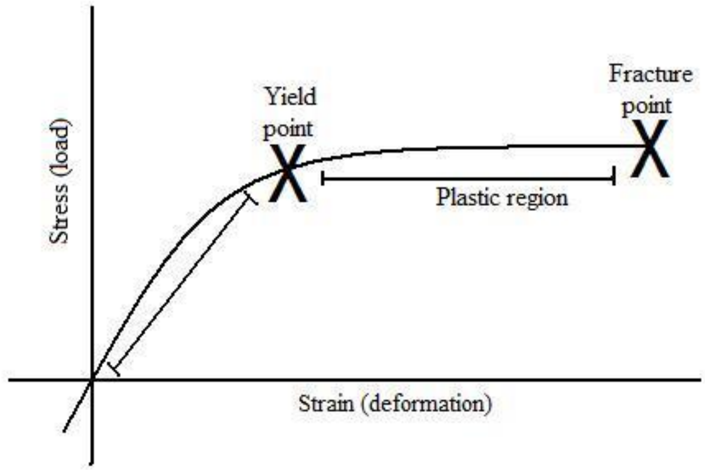

Figure 1. Young's modulus illustrating the relationship of loading processes to the deformation of bone.

Skin is the largest organ in the body and is also quite resilient and strong. It is composed of three layers: the hypodermis, the dermis, and the epidermis. The hypodermis is composed 75% adipose tissue, 20% water, and 5% protein. The dermis contributes the majority of the mechanical integrity of skin and consists around 60-70% water and 30% collagen fibers (Kieser et al. 2013). The collagen type I molecules provide structural tensile strength and stiffness to skin in addition to material integrity under high loads. Elastin fibres provide the skin with mechanical integrity under low levels of loading and allow the skin to return to its normal shape following deformation. The epidermis is the waterproof outer coating of dead keratinized cells that protects against microbial infection (Kieser et al. 2013).

As the outer defense of the body, skin must be able to compensate for stretching during body movement and is therefore under constant internal tension. While it is also anisotropic, skin has a triphasic stress/strain curve (Figure 2). During phase I, the elastin stretches while the collagen slightly straightens. In phase II the collagen aligns parallel to the applied stress and the skin stiffens to resist the stress as the fluid the collagen is suspended in redistributes throughout the material. In phase III, the skin becomes thixotropic, meaning it will respond to stress in the same manner as a solid under normal stress, but will shear-thin if squeezed (Kieser et al. 2013). Within this phase is also the viscous yield and failure points at which times the collagen fibers slip and then dissociate. This means that during the elastic phases I and II, skin that is relieved from the stress is more likely to rapidly return to its original shape. Once skin reaches the viscous yield point of phase III, the recovery and nature of deformation is dependent on the rate and magnitude of loading. At the failure point, the skin tears. This ultimately means that slow, continuous loading will result in a longer recovery period and a higher amount of creep, while rapid short loads- like that of a wood chipper- are likely to cause elastic deformation with a faster recovery and lower amount of creep. (Kieser et al. 2013).

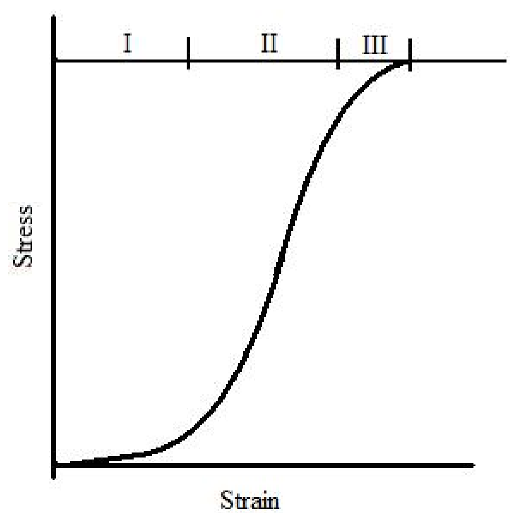

Figure 2. J-shaped stress/strain curve illustrating the viscoelastic phases of skin deformation during loading.

While the use of wood chippers to conceal crimes may be relatively uncommon, it is important to conduct experimental research so forensic anthropologists have established guidelines for recognizing the reduction of human remains using wood chippers. This study examines bony trauma patterns and the distribution of hard and soft tissue of a fleshed, disarticulated pig reduced by a gas-powered wood chipper. The information obtained from this research will be of importance to forensic anthropologists, medical examiners, and other investigators working in the medicolegal field.

CHAPTER II

MATERIALS AND METHODS

Wood Chipper

A commercial, gas-powered, disc-type brush chipper (Vermeer BC600XL) was rented for this study. This machine is capable of processing materials up to six inches or 15.2 mcm (six inches) in diameter. mmmThe chute height is 238.8 mcm (Figure 3). Material is fed into the machine in the feed tray and proceeds through the infeed hopper to the disc housing. Chipped material then exits the discharge spout. Reversible hydraulically powered wheels pull the material from the hopper towards the disk. The disk is mounted at a right angle to the incoming material and as it spins, the knives cut the material into chips. The chips are then thrown through the chute onto the ground or into a collection apparatus by flanges in the drum.

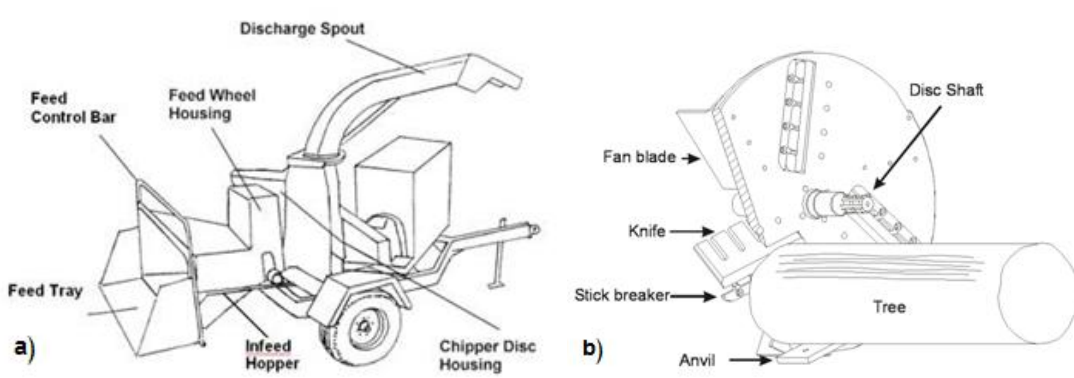

Figure 3. Diagram of a disc-type wood chipper: a (external components) and b (internal workings) *(a: National Institute for Occupational Safety and Health, FACE Report 98-13; b: www.woodenergy.ie).*

The cutting mechanisms of disc-type wood chippers are knives mounted on a spinning disk fly wheel (Figure 4). There are two swinging knives within the cutting system that are 1.6 cm thick. The knife measurements are 8.89 cm by 20.32 cm and have one usable edge each.

Porcine Remains

In this study, a single 300-pound domestic pig (*Sus scrofa domesticus*) acquired from a local farm was reduced with the Vermeer brush chipper (Figure 4). Pig size was chosen to ensure fusion of all bones in order to approximate adult human bones. The pig was euthanized the morning of the experiment at Duelm's Farms. The limbs were disarticulated from the axial portion at the joint and tissue was displaced with a standard kitchen knife to avoid confounding sharp trauma on the limbs. The head was too large to fit through the wood chipper feeder so it was not used (Figure 5). Due to difficulty separating the ribs from the vertebral column, a pair of 24-inch loppers was used to disarticulate the ribs at the articular surfaces. Due to the presence of sharp trauma on these portions, the wood chipper discharge spout was moved in between chipping of the appendicular skeleton (labeled as Distribution A) and the axial bones with lopper marks (labeled as Distribution B) in order to reduce the introduction of confounding variables to the entire sample.(Figure 4).

The appendicular skeletal portions were fed into the wood chipper proximal ends first. The vertebral column with associated os coxae was fed into the wood chipper cranial end first. The ribs were also fed cranial portions first. The overall effect was similar to a person being placed into a wood chipper head-first.

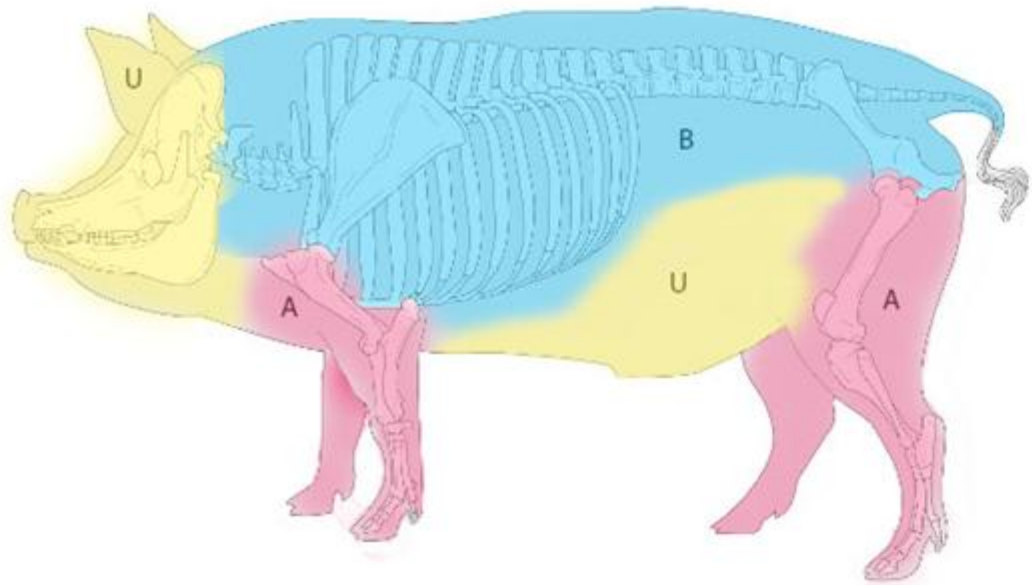

Figure 5. Illustration of utilized remains (U/yellow= unused; B/blue=Distribution B; A/pink=Distribution A). (Modified from www.fabiobonvicini.net).

Mapping and Measurements

Following completion of the remains passing through the wood chipper, the machine was shut off and a 5.5 by 4.5 square meter grid was constructed around the chipped remains using measuring tapes, chaining pins, pink , and line levels in order to define and recover the discharged remains (Figure 5). Measurements were taken from the position of the spraying chute, including maximum distance, minimum distance, and width of each distribution.

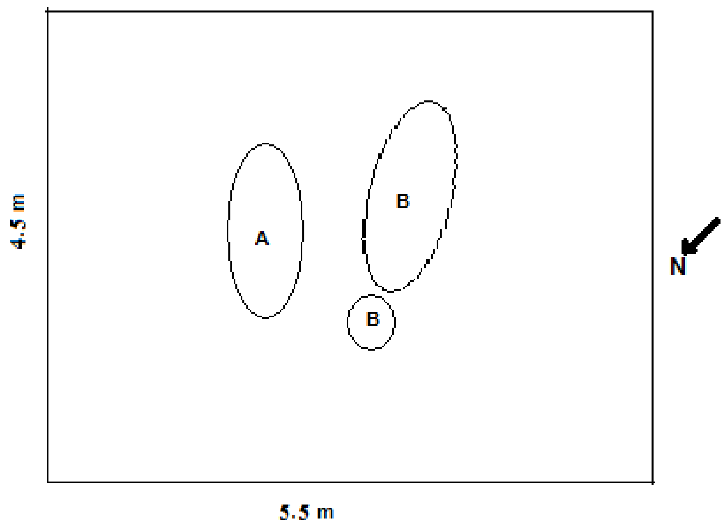

Figure 5. Pictographic representation of discharged remains map indicating locations of Distribution A and B.

Maceration Technique

After mapping, the remains were collected and deposited into two separate plastic containers labeled Distribution A (appendicular skeleton) and Distribution B (axial skeleton with the exception of the absent skull) (Figure 5). These containers remained locked behind the fence at the Forensic Anthropology Research Facility for two months time. Afterwards, they were moved to the Osteology Research and Processing Laboratory where they were filled with water and the lids were put back in place for a period of one week for additional maceration. When the week had passed, the tissue was still clinging to the bones, so they were placed in two separate labeled kettles in which the remains were covered with water and allowed to simmer at 90 degrees Celsius on a Waring brand commercial cast iron single burner for a period of 3 hours. This heat maceration technique followed that of Steadman (2006).

At this point, the remains from Distribution B were separating cleanly when submerged in water and gently prodded with gloved fingers. Distribution B material was poured into a colander within an autopsy sink containing a fine sieve to reduce the water. Tissue was deposited into a biohazard bag and bony elements were deposited into a secondary colander for further rinsing. Following the rinsing, the bones were placed on butcher paper marked with Distribution B and the date for drying.

The remains from Distribution A were poured into a colander for sifting, but were still deeply entrenched in muscle tissue. Excess tissue not containing bone was removed with scissors and disposed in the biohazard bag. Tissue containing bony elements was placed into a colander for rinsing before being deposited into a smaller pot for further maceration. After an additional two hours of macerating, the tissue cleanly separated from the bone and bones were rinsed before being deposited onto butcher paper for drying.

Macroscopic Examination

Following maceration, the 40 sample fragments from each distribution were examined for characteristics of sharp force, blunt force, and sharp-blunt force trauma. This included false starts, spurs, notches, lipping, and flaking. False starts, formerly termed “hesitation marks” are sharp trauma tool marks caused by an incomplete cut mark that does not result in separate pieces (Symes 2010). The breakaway spur and notch are observable as a projection of bone (the spur) on one side of a cut bone with a notch on the corresponding bone fragment or portion. This occurs when a bone is loaded (experiences stabilizing force) on one end and breaks off as the bone is cut on the other end. The notch occurs on the loaded side with the spur on the separated unloaded bone. In the wood chipper, this may occur while one part of the bone is loaded by pressure of the feeding mechanism and the other end is subjected to the cutting blades.

Microscopic Examination

Microscopic examination was performed using a Dino-Lite Pro Digital Microscope model AM-413ZTA. The microscope was used to observe the bone for possible striations in addition to the surfaces of bone for micro-fractures and minute flaking.

Striations are roughly parallel lines on bone caused by the cutting or sawing motions of an edged tool on bone (Crowder et al. 2011). Non-serrated blades such as those of the wood chipper knives typically cause either no striations or fine, unpatterned striae. The fine, unpatterned nature of striae represents the non-serrated, beveled edge of the blade. Conversely, a serrated blade would cause more coarse, patterned striae on the cut portions of bone. These patterned striae result from the teeth on the serrated tool (Crowder et al. 2011).

Statistical Analysis

Counts of trauma characteristics on each sampled bone were combined into grand total macroscopic and microscopic categories (n=80 each) and then converted into frequency data. This was calculated by dividing the number of each trauma characteristic by the total number of observed trauma characteristics in the macroscopic and microscopic categories separately.

Examination of Distribution Pattern

Examination of the distribution pattern entailed gridding, photographing, and mapping of the distribution area. Then location of remains in relation to the wood chipper chute and the angle of the chute were measured.

CHAPTER III

RESULTS

Skeletal Trauma and Identification

In this study, the bone samples exhibited trauma characteristics consistent with both sharp and blunt force trauma. The sharp force trauma markers were sharp, smooth edges; through cuts; false starts; lipping; flaking; striations; spurs; and notches. Observed blunt force trauma markers included jagged margins, longitudinal fractures, transverse fractures, and incomplete fractures.

Bones were grouped into two basic categories: those that could be identified as to bone type (e.g. rib or vertebra) and then separated into qualitative subcategories based on appearance and composition. Distribution A (the appendicular portion) was most easily separated into two main categories of diaphyseal and epiphyseal fragments. Unidentifiable fragments were separated into categories of cortical bone, cortical bone with associated cancellous bone, cancellous bone only, sand-like particles, and intact phalanges.

Elements from Distribution B ranged in size from sand-like grains to a rib that measured 84 mm in length by 16 mm in width (Figure 6). Some fragments were so large that anatomical identification, human versus non-human identification, and even siding was possible. Distribution B was separated into categories of rib fragments, vertebral fragments, clavicle fragments, pectoral/pelvic girdle fragments, cancellous bone, cortical bone with associated cancellous bone, sand-like particles between 5 and 10 mm, and particles less than 5 mm. The vertebral fragments were the most readily identifiable, with the majority of the centra being whole pieces. However, most of the bone present is compact bone with cancellous bone fragments being rare and when present usually attached to the associated compact bone.

Figure 6. Largest fragment from Distribution B- a rib measuring 84mm long.

Macroscopic Examination

The bones were examined macroscopically for signs of sharp or sharp blunt trauma such as flaking, lipping, peeling, spurs, notches, smooth versus jagged margins, and through cuts. Additionally, longitudinal, incomplete, hinge, and transverse fractures were observed as well as chattering (Table 1; Figures 7-11) Frequencies were calculated by dividing the count of each trauma characteristic by the total number of observed trauma characteristics.

Table.1 Frequencies of observed macroscopic trauma characteristics

	Frequency of Total Trauma by Observation Type	
Trauma Characteristic	**Distribution A**	**Distribution B**
Spur	0.004219	0.013158
Notch	0.004219	0.02193
Longitudinal fracture	0.012658	0.127193
Incomplete fracture	0.016878	0.157895
Transverse fractures	0.004219	0.030702
Through cuts	0.063291	0.065789
Blunt force margin	0.308017	0.109649
Sharp force margin	0.240506	0.241228
Lipping	0.012658	0.057018
Flaking	0.278481	0.153509
False starts	0.054852	0.008772
Kerf v shaped notch defect	0	0.013158

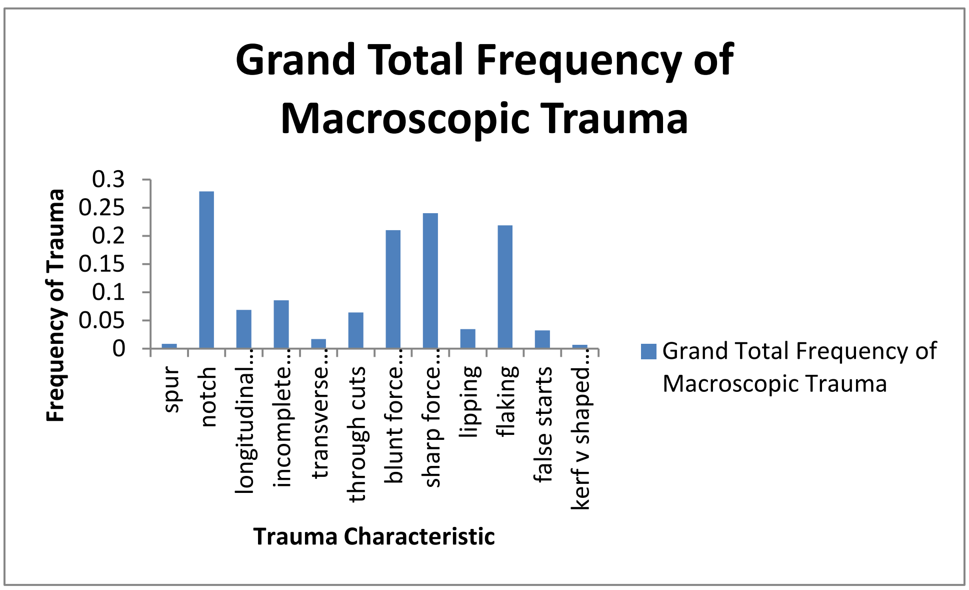

Figure 7. Grand total combined frequency of macroscopic trauma.

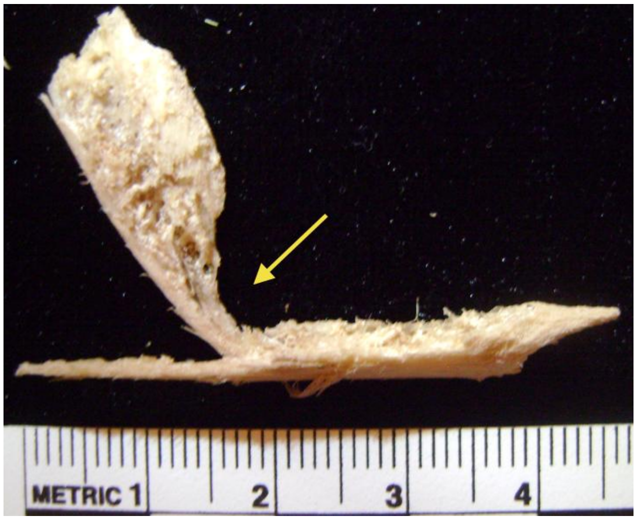

Figure 8. Rib fragment from Distribution B illustrating a hinge fracture (yellow arrow points to hinge fracture).

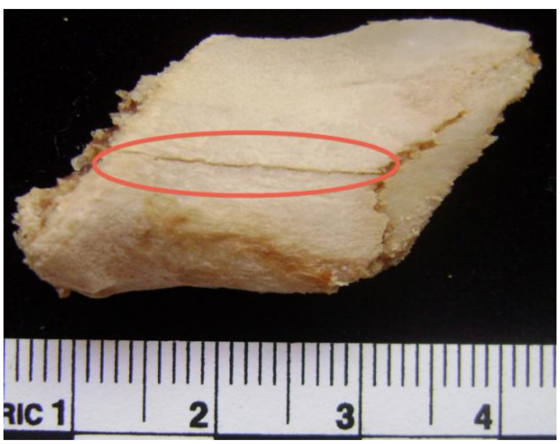

Figure 9. Rib fragment illustrating longitudinal fracture (circled in red).

Figure 10. Rib fragment with spur (yellow arrow points to spur).

Figure 11. V-shaped kerf on clavicular fragment.

Microscopic Examination

The bones were also microscopically examined for flaking, lipping, striations (Table 2; Figure 12 and 13)). The most common microscopic trauma characteristics were flaking and false starts, which comprised a total of 38.5% of the observed trauma. More than twice the amount of sharp trauma was present in comparison with blunt force trauma, but future research using a scanning electron microscope could help differentiate between the two by analyzing surface texture and the presence of osteon pull outs (Bartelink et al. 2001; Hermann and Bennett 1999).

Table 2. Frequencies of observed microscopic trauma characteristics

	Frequency of Total Trauma by Observation Type	
Trauma Characteristic	**Distribution A**	**Distribution B**
Striations	0.434783	0.336134
Flaking	0.01087	0.319328
Lipping	0.26087	0.033613
Peeling	0.130435	0.016807
Scouring	0.032609	0.042017
Longitudinal fracture	0.01087	0.109244
Incomplete fracture	0.086957	0.07563
Transverse fractures	0.01087	0.05042
Chattering	0.021739	0.016807

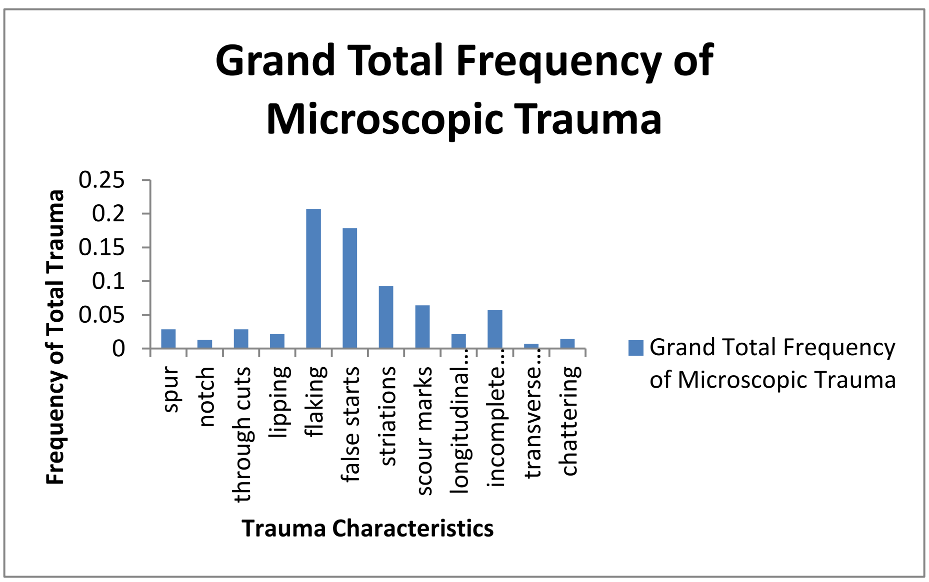

Figure 12. Grand total combined frequency of microscopic trauma.

Figure 13. Clavicle fragment showing a through cut (yellow arrow) and a false start (circled in red).

Associated Integument

As expected, several large swatches of skin were present in both A and B distributions. The largest swatch of skin was 260 mm by 170 mm wide. The smaller piece was 230 mm by 50 mm (Figure 14). In addition, there were two hoof portions present. The thinner hoof portion was 105 mm by 40 mm (Figure 15a). The thicker portion was 70 mm by 50 mm (Figure 15b).

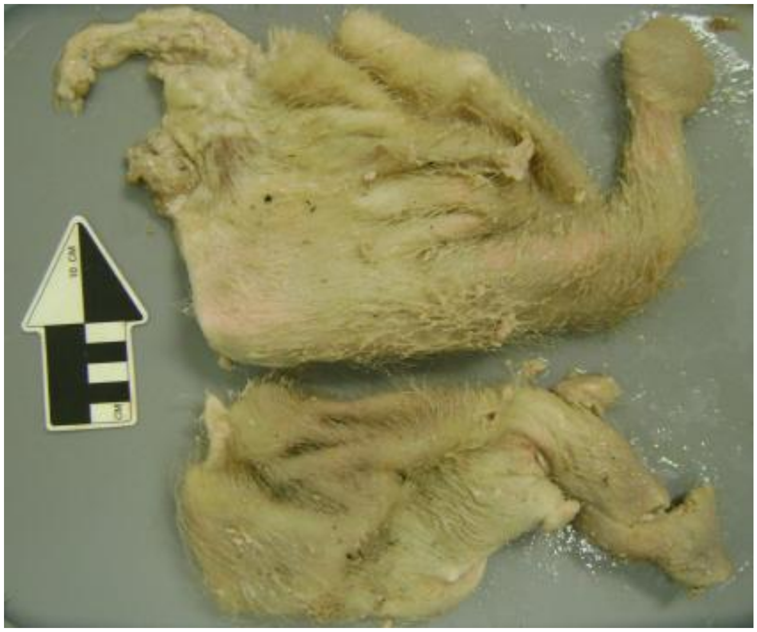

Figure 14. The two largest pieces of skin associated with the remains.

a)


b)


Figure 15 a and b. The two recovered hoof portions, a) 105 mm x 40 mm, b) 70mm x 50 mm.

Distribution Pattern

Original expectations included that the larger mass of the bone and tissue would contribute to a farther trajectory than wood chips could achieve. However, the tissue and bone distributed out of the chute in heavy wet chunks clumped together and did not project very far (Figure 16). The distribution of the remains fed through the wood chipper were measured from the base of the chute, which was even with the grid (Figure 17). The closest point was 1.8 m from the wood chipper and the farthest was 4.3 m. Distribution A, which was comprised of the limbs measured 0.9 m long by 0.5 m wide. Distribution B, which was comprised of the axial skeleton except for the head measured 1.3 m long by 0.6 m wide (Figure18). The chute angle was measured at 238 degrees and directed towards the ground

Figure 16. Wood chipper distributing bone and associated tissue in thick clumps.

Figure 17. Southeast overall view of mapped distribution with wood chipper.

Figure 18. Photographic representation of Distribution A (left) and Distribution B (right).

CHAPTER IV

DISCUSSION

Forensic scientists need to have a clear understanding of the distribution patterns and fracture morphology of bones reduced in a wood chipper since this is a known method of crime concealment (Ravo 1988; Reuter 1993; Mudede 2003). In addition, the use of wood chippers to conceal crimes may become more common because of more recent portrayals in the popular media in films and crime shows such as Fargo, CSI, CSI Miami, and Bones. Therefore, being able to differentiate wood chipper trauma from other sharp force or sharp-blunt force trauma can be an important component in medicolegal trauma analysis.

Hard Tissue

The skeletal trauma patterns observed in this study include sharp, blunt, and sharp-blunt force characteristics, but the majority of the trauma resulted from sharp force. The kerf marks present in this study were v-shaped, which is consistent with a blade beveled on one edge, such as the wood chipper knives.

In addition to scouring and false starts, radiating fractures were observed, presumably from blunt force trauma caused by tumbling within the wood chipper and loading by the feeder mechanism. A few of the bones also exhibited spurs and notches, which may have been caused by the bone being loaded by the feeding mechanism while simultaneously experiencing sharp force trauma by the swinging knives within the wood chipper. Additionally, some of the blunt force characteristics on the bones may also be due to the fast loading of the feeding mechanism as it compressed the bones while pulling them into the hopper.

Previous research has found more evidence of chattering than is present in this study (Domenick 2012). This may be attributable to occlusion of its presence by the severe fragmentation and separation of cortical bone from its cancellous component. The wood chipper in this study was much larger than the machine used in Domenick (2012). Many of the chipped remains found in this study were cancellous bone separated completely from the cortical component and were therefore difficult to associate back with the components that were originally connected.

In light of these findings, investigators should look for fragments varying in size from around 85 mm in length to bone dust with the appearance of sand-like grains. Cancellous bone stripped of its cortical component and the presence of through cuts on cortical and cancellous bone are strong indicators that remains have been through a wood chipper. Additionally, cancellous bone with surfaces that appear to have been sheared off and exhibit radiating fractures may also be an indicator of sharp-blunt force trauma resulting from wood chippers. Although some bones are large enough for a seasoned anthropologist to recognize as human or non-human upon first glance, many are not. However the majority of bones are large enough for histological sectioning and microscopic analysis. It is recommended that if in doubt of human versus non-human origins, medicolegal investigators should view sections of bone under a microscope and look for the presence of Haversian systems and plexiform arrangement of bone cells (Hillier and Bell 2007). Individual species of non-human animals have different ratios of Haversian to plexiform bone, which can also be age-dependent. When viewing these bones for histological tells of human versus non-human origins, these composition ratios should be kept in mind and may even allow species-specific identification (Aerssens et al. 1998).

Soft Tissue

A large amount of soft tissue was observed in this study. While the muscle tissue tended to be ground up, the integument presented in large swatches that were several times the size of the largest recovered bone fragments. This is plausibly due to the differential biomechanical properties of bone versus skin. As a viscoelastic material, skin behaves differently under stress than bone. Due to the high proportions of collagen and elastin fibers suspended in a fluid matrix, skin stretches until it reaches its yield point and tears (Kieser et al. 2013). It is also likely that the skin is just malleable and flat enough to fold on itself and pass through the slots under the blades.

Under brief, rapid loading like the mechanical stress of the wood chipper, the skin reaches the failure point very quickly without prolonged deformation as the skin is stripped away from the bone by the feeding mechanism and the pieces that are attached to the chipped bone that is being pulled through the discharge chute. Due to this limited rate of loading, the elastin is capable of promoting a better chance of recovering its original shape. It is reasonable to propose that the malleable skin has a better chance of fitting through the discharge chute than does the hard, nonmalleable bone.

Unlike more malleable skin, bone bends rather than stretches, and breaks instead of tears. This is due to the yield point of bone exhibiting a bending behavior rather than a stretching behavior. Because its shape cannot change to fit through the discharge chute, it must reach the failure point and be mechanically reduced to smaller pieces in order to be small enough to be discharged. In this way, the skin can exit the chipper in much larger pieces than the previously associated bone.

Distribution Pattern and Implications for Concealment

The distribution pattern portion of this study revealed that this type of wood chipper tends to discharge fleshed remains in clumps of tissue commingled with bone. These clumps did not distribute very far and tended to fall within a six meter radius from the discharge chute of the wood chipper. The distribution region is small enough that a large trashcan could ostensibly be placed under the chute to catch the majority of the remains and then be disposed of in a forest, landfill, body of water, or other remote location. It is also worth noting that a group of 7 to 10 vultures gathered in the trees near the wood chipper before the experiment was finished. The birds watched the dispersal location intently even after they were collected and moved from the site. According to Reeves' (2009) study performed in central Texas, black American vultures and turkey vultures in this area typically take around twenty-four hours to arrive at the scene of non-human remains (specifically pigs and sheep). After they arrive, they can skeletonize an intact body within three to twenty-seven hours (Reeves 2009). When the size of the remains, the carrion nature of the vulture diet, and the time it takes vultures to consume a body are taken into account, their presence could also indicate a second, natural method of disposal- scavenging. With ground human remains being as small as 84 mcm for the longest bone, it is reasonable to say that a group of vultures could consume the majority of these remains within the twenty-seven hour window of time (Martin 1996; Reeves 2009; Spradley, Hamilton, and Giordano 2012).

Limitations

This project includes several limitations. The primary limitation of this study is the use of *Sus scrofa domesticus* remains as a proxy for human remains. Although porcine remains are often used in trauma research as a proxy (Bartelink et al. 2001; Williams 2007; Lynn and Fairgrieve 2009a, 2009b; Reeves 2009; Domenick 2012), in actuality human and porcine remains are very different morphologically- both microscopically and macroscopically. These differences may affect the anisotropic properties between the two species. This study may therefore present results differing from those that may be acquired using human remains. One of the most significant differences was observed during maceration when the 300 pound, supposedly adult pig turned out to have completely un-fused epiphyses. This also means that this research is closer to approximating the reduction of a juvenile human instead of an adult in terms of bone development.

The second limitation involves the absence of fleshed cranial trauma in the data set. In a real world setting, the head would most likely be fed into the wood chipper as well. In this case, the fleshed porcine skull was too large to fit through the feeder opening, so it was not used. However, a fleshed human skull would have fit through the opening, so this wood chipper is still a practical choice for real world reduction of human remains. The researcher thought that this size wood chipper would be the most likely to be used in human remains reduction due to the smaller, but adequate size for human remains reduction in addition to the lower price.

The third limitation regards the use of loppers to separate the ribs from the vertebrae at the rib heads in order to fit all elements through the feeder mechanism. Although it is plausible that this would occur in clandestine remains reduction and disposal, it potentially presents confounding trauma. This was avoided by only analyzing rib portions of the mediolateral to anteromedial areas. Although this protected the data from confounding variables, it is plausible that the axial skeleton may have chipped differently had it been completely intact. Future research using a larger wood chipper and fully articulated human and porcine remains may help clarify if this would affect skeletal trauma patterns.

The fourth limitation regards the use of only one type of wood chipper. As Williams (2007) illustrated, the chipping and shredding mechanisms on a single home-model wood chipper varied enough for trauma differentiation between the two to be observed in the reduced bone fragments. The large variation of wood chipper types and sizes necessitates future research to determine how significant the differences are.

Advantages

There are two advantages to this study. The first advantage pertains to the use of a whole pig. While a previous study utilized pig limbs that had been sawed through the diaphyses at a butcher shop (Domenick 2012), this study used a whole pig with limbs disarticulated at the joint by the researcher, thereby avoiding the confounding trauma in

Distribution A that are often caused by butcher cleavers or saws. The use of the axial skeleton also provides a broader data set for this type of trauma, albeit cranial trauma is still lacking and should be addressed in future studies.

A second advantage of this study is the use of an inexpensive, portable wood chipper rental similar to that used by Richard Craft in the reduction of his wife's body (Ravo 1988). This results in a more real-world replication experiment. Use of a larger wood chipper would allow for whole body reduction without disarticulation, but would look very conspicuous, be more expensive, and is therefore less likely to be used in clandestine remains reduction.

CHAPTER V

CONCLUSION

The low price of $283.00 for a two day rental of large portable wood chippers makes wood chipper reduction a viable disposal method for human remains. Investigators assigned to crime scenes that possibly involve the use of wood chippers for dismemberment should be aware of several implications. One of the first things they may notice and should be aware of are large swatches of intact skin that are separated from the surrounding muscle and bone tissue. Additionally, muscle tissue that has an appearance of ground meat reflects the appearance of soft tissue discharged from a wood chipper. This is due to the wood chipper blades acting as a meat grinder by slicing up the meat into chunks small enough for discharge though the wood chipper slots and chute. Due to the immense amount of mechanical effort involved to reduce meat to that appearance, this grinding would not be expected in most other cases of sharp or sharp force trauma such as manual hatchet, machete, saw, knife, or chainsaw trauma and may be considered as a soft tissue characteristic of wood chipper trauma.

Secondly, bone fragments are likely to be embedded within this tissue and must be carefully macerated to expose the trauma characteristics underneath. Investigators should also expect to see sharp-blunt force trauma to the bone, including smooth margins where the blade struck the bones, jagged margins where the bone broke off in response to loading or being tumbled around inside the drum, v-shaped kerf walls, incomplete fractures, and marginal flaking. Also, they should keep in mind that a large portion of the bone is finely fragmented, so sieves should be used to collect the maximum amount of bone.

The small distribution pattern from this wood chipper suggests that a very small search pattern should result in the recovery of the majority of hard and soft tissue, assuming the perpetrator left the remains in a single location. It also suggests a relatively easy clean up and concealment of the crime using disposal containers such as trash bags or small plastic tubs is possible. Although upon cursory inspection the bone appears to be finely fragmented, this is due to the integration of the ground tissue, and maceration actually reveals large pieces of bone that are easily identifiable in terms of bone, siding, and even human versus non-human origins. In fact, in contrast with Domenick's study (2012) many of these bone fragments were so large that the specific element could be identified, such as the many rib and vertebrae fragments and the two hoof portions (Domenick 2012). This may be attributable to wood chipper size, pig size, or to the use of different body parts, as the majority of appendicular fragments in this study were also much smaller than those of the axial skeleton. Further research utilizing axial skeletal remains of *Sus scrofa domesticus* in a home model wood chipper is necessary to determine which of these factors is the true correlate.

REFERENCES

Aerssens J, Boonen S, Lowet G, and Dequeker J. 1998. Interspecies differences in bone composition, density, and quality: potential implications for in vivo bone research. *Endocrinology.* 139(2): 663-670.

Alunni-Perret V and Muller-Bolla M, et al. 2005. Scanning electron microscopy analysis of experimental bone hacking trauma. *Journal of Forensic Science*. 50(4):796-801.

Bartelink EJ, Wiersema JM, Demaree RS. 2001. Quantitative analysis of sharp-force trauma: an application of scanning electron microscopy in forensic anthropology. *Journal of Forensic Science*. 46(4):1288-1293.

Beers DA and Allen PC. 2007. Case Report Commercial Woodchipper Fatality. *Journal of Forensic Identification* 57(6):883-890.

Caulfield P. (2012, April 11). 6-year-old boy in Connecticut killed in wood chipper accident. *NY Daily News*.

Centers for Disease Control and Prevention. 2004. Fatal and Nonfatal Occupational Injuries Involving Wood Chippers --- United States, 1992—2002. MMWR Weekly 53(48):1130-1131.

Chacon S, Peccerelli FA, Paiz Diez L, and Rivera Fernandez C. Case Study 6.1: Disappearance, Torture, and Murder of the Individuals in a Community of Nebaj, Guatemala. In: Kimmerle EH and Baraybar JP, editors. *Skeletal Trauma: Identification of injuries resulting from human rights abuse and armed conflict.* 2008. Boca Raton: CRC Press. p. 263-300.

Crowder C, Rainwater CW, and Fridie JS. 2011. Microscopic analysis of sharp force trauma in bone and cartilage: a validation study. US Department of Justice NIJ #2009-DN-BX-K238. P 1-57.

Dirkmaat D, ed. 2012. A Companion to Forensic Anthropology. Wiley & Sons. Chapter 17. Interpreting Traumatic Injury to Bone in Medicolegal Investigations. Steve A Symes, Ericka N L'Abbe, Erin N. Chapman, Ivana Wolff, and Dennis C. Dirkmaat. P. 340-389.

Domenick K. 2012. Analysis of experiemental wood chipper trauma on bone. Diss. George Mason University, 2012.

Galloway A and Zephro L. 2005. Skeletal Trauma Analysis of the Lower Extremity In:Rich J, Dean DE, and Powers RH, editors. *Forensic Medicine of the Lower Extremity*. Totowa: The Humana Press Inc. p. 253-273.

Grodsky SM, Behr MJ, Gendler A, Drake D, Dieterle BD, Rudd RJ, and Walrath NL. 2011. Investigating the causes of death for wind turbine-associated bat fatalities. *Journal of Mammalogy.* 92(5):917-925.

Hellstrom L, Gradin P, and Torbjorn C. 2007. Strain distribution in wood during chipping. In: International Mechanical Pulping Conference.

Hillier ML and Bell LS. 2007. Differentiating human bone from animal bone: a review of histological methods. *Journal of Forensic Science.* 52(2):249-263.

Kaliszan M, Karnecki K, Akcan R, and Jankowski Z. 2011. Striated abrasions from a knife with non-serrated blade- identification of the instrument of crime on the basis of an experiment with material evidence. *International Journal of Legal Medicine.* 125(5):745-748.

Kimmerle EH and Baraybar JP. 2008. Blunt force trauma. In: Kimmerle EH and Baraybar JP, editors. *Skeletal Trauma: Identification of Injuries Resulting from Human Rights Abuse and Armed Conflict.* 2008. Boca Raton: CRC Press. p. 263-300.

Knock C and Davison M. 2007. Predicting the position of the source of blood stains for angled impacts. *Journal of Forensic Sciences.* 52(5):1044-1049.

Lasloff MA. 2000. Chipping Away at Compost. *Waste Age.* Penton Media, Inc.

Lynn KS and Fairgrieve SI. 2009a. Macroscopic analysis of axe and hatchet trauma in fleshed and defleshed mammalian long bones. *Journal of Forensic Sciences*. 54(4):786-792.

Lynn KS and Fairgrieve SI. 2009b. Microscopic indicators of axe and hatchet trauma in fleshed and defleshed mammalian long bones. *Journal of Forensic Sciences*. 54(4):793-797.

Martin D. 1996. On the cultural ecology of sky burial in the Himalayan plateau. *East and West.*46(3/4): 353-370.

Massachusetts Coalition for Occupational Safety and Health. 2009. Safety office investigating wood chipper accident.

Mudede C. 2003. Death Farm. In: Seattle News. 2003 October 30.

Nadjem H, Bohnert M, Pollak S. 1999. Appearance of injuries caused by machetes and unusually large knives. *Arch Kriminol.* 204(5-6):163-174.

Ong BB. 1999. The pattern of homicidal slash/chop injuries: a 10 year retrospective study in University Hospital Kuala Lumpur. *Journal of Clinical Forensic Medicine*. 6(1):24-29.

Randall B. 2009. Blood and tissue spatter associated with chainsaw dismemberment. *Journal of Forensic Sciences*. 54(6):1310-1314.

Ravo N. 1988. Everything but a body in murder trial. In: New York Times. 15 May 1988.

Reeves NM. 2009. Taphonomic effects of vulture scavenging. *Journal of Forensic Sciences.* 54(3):523-528.

Reuter. 1993. Evidence called concrete in dancer's murder case. In: Toledo Blade . 25 September 1993.

Sasaki N, Matsushima N, Ikawa T, Yamamura H, and Fukuda A. 1989. Orientation of bone mineral and its role in the anisotropic mechanical properties of bone -transverse anisotropy. *Journal of Biomechanics*. 22(2):157-64.

Shaw KP and Chung JH, et al. 2011. A method for studying knife tool marks on bone. *Journal of Forensic Sciences*. 56(4)967-971.

Spradley MK, Hamilton MD, & Giordano A. (2012). Spatial patterning of vulture scavenged human remains. *Forensic Science International*, *219*(1-3), 57–63.

Steadman DW, DiAntonio LL, Wilson JJ, Sheridan KE, and Tammariello SP. 2006. The effects of chemical and heat maceration techniques on the recovery of nuclear and mitochondrial DNA from bone. *Journal of Forensic Science.* 51(1):11-17.

Symes SA. 2013. A return to the basic principles of biomechanics to interpret blunt force trauma in long bones. Paper presented at the American Academy of Forensic Science. Washington, D.C.

Symes SA and Williams JA, et al. Taphonomic Context of Sharp-Force Trauma in Suspected Cases of Human Mutilation and Dismemberment. In: Haglund WD and Sorg MH, editors. *Advances in forensic taphonomy: method, theory, and archaeological perspectives*. 2002. Boca Raton: CRC Press. p. 403-434.

Symes SA, Chapman EN, Rainwater CW, Cabo LL, and Myster SMT. 2010. Knife and Saw Toolmark Analysis in Bone: A Manual Designed for the Examination of Criminal Mutilation and Dismemberment. US Department of Justice NIJ #2009-DN-BX-K238 p. 2-57.

Tucker BK, Hutchinson DL, Gilliland MF, Charles TM, Daniel HJ, and Wolfe LD. 2001. Microscopic characteristics of hacking trauma. *Journal of Forensic Science*.46(2):234-240.

Williams, JA. 2007. *Bone fragmentation created by a mechanical wood chipper*. Paper presented at the American Academy of Forensic Science, San Antonio, TX.

VITA

Alexandria Suzanne Frye was born in Asheville, North Carolina on January 13, 1989 and is the daughter of Katrina Meadows Frye. She simultaneously enrolled in high school classes and college courses at McDowell Technical Community College beginning in 2007. After completing her work at Crystal Peak Academy, Old Fort, North Carolina, in 2007, she continued on to complete her Associate's degree in Liberal Arts at McDowell Technical Community College in 2009, during which time she was student government president. Following her degree conferral, she entered Western Carolina University. During her undergraduate degree, she spent the summer of 2011 in Cullowhee, North Carolina as part of a five week forensic anthropology field school. She received the degree of Bachelor of Science in Anthropology with a concentration in Forensic Anthropology and a minor in Biology from Western Carolina University in August of 2011. In August 2011, she entered the Graduate College at Texas State University-San Marcos.

Permanent Address: alexandria.s.frye@gmail.com

This thesis was typed by Alexandria S. Frye.