A COMPARATIVE ANALYSIS OF SERRATED AND NON-SERRATED SHARP FORCE TRAUMA TO BONE

THESIS

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A COMPARATIVE ANALYSIS OF SERRATED AND NON-SERRATED

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ABSTRACT

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Understanding patterns of trauma is important in order to assist in identifying and distinguishing between different weapon classes. Sharp force trauma is the second most common form of armed violence in the United States, however, research into establishing class characteristics that may help distinguish serrated from non-serrated blades in sparse in the forensic literature. This study addresses this gap in the literature.

Using two sets of 4.5 inch steak knives, one serrated and one non-serrated, 200 cuts were made to 100 porcine ribs. Subsequent examination of the trauma left behind in the bone was examined at several levels: macroscopic examination of the bone, microscopic examination of the bone, and microscopic examination of casts made of each cut. This study set out to answer whether or not it was possible to distinguish between these two classes of knives by examining the trauma that they left behind in the bone. In addition, it examines the unique nature of width, kerf shape, and presence or absence of striations.

Results indicate that it is possible to distinguish between serrated and non-serrated knives based on the characteristics of trauma left behind in bone. Descriptive statistics, as well as an ANOVA statistic were run on the width measurements, showing a highly significant difference between the two knife classes. Serrated widths all fell above .60mm (average width .910mm), while those cuts made from non-serrated blades falling below .50mm (average width .306). A Y-shaped kerf occurred in approximately 78% of serrated cut marks viewed macroscopically, and 82% when viewed microscopically. A Funnel-shaped kerf occurred in approximately 86% of all non-serrated cut marks when viewed macroscopically, and 87% when viewed microscopically. Striations appeared in 72% of serrated cut marks when viewed microscopically, and 76% when viewed from the casts of the cut mark. Additionally, striations only appeared 4% of the time in non-serrated cut marks when viewed from casts, but not at all when viewed microscopically.

Results of this study indicate that the identification of width, kerf shape, and presence of striations are useful for distinguishing between serrated and non-serrated knife classes. As such, these characteristics may be useful for assisting in the exclusion or inclusion of suspects and weapons in a forensic context.

CHAPTER I

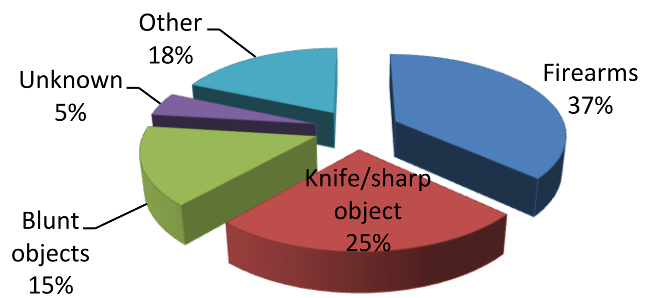
INTRODUCTION

Research into the effects of sharp force trauma on bone is important to forensic anthropology and forensic science, in general, because understanding the patterns of trauma that are left behind by knives (and other bladed weapons) can help investigators narrow down possible weapons and suspects involved in a crime. The prevalence of knife crime in the United States has maintained its position as the second most common form of armed violence (after gun crime) for almost 20 years (DOJ 2010; Truman and Rand 2010; Perkins 2003), making studies looking into the characteristics of knife trauma both important and relevant to today's scientific investigations.

Statistics on Knife Crime

Older statistics released by the National Crime Victim's Survey (NCVS) in 2003 show that crimes involving knives or other sharp objects made up 25% annually of all armed crimes between 1993 and 2001 (Perkins 2003) (see Figure 1). Further statistics released by the Department of Justice in 2011 through the Uniform Crime Report (UCR) confirms a similar trend, with knife crime comprising 13% of crime between 2002 and 2008 (DOJ 2010) (see Figure 2). Finally, statistics released by the NCVS for the year of 2009 show that crimes using guns and knives occurred in relatively equal frequency (Truman and Rand 2010) (see Figure 3). These statistics show that knife crime is a prevalent part of armed trauma related to crimes in the United States, and that it is important to be able to identify characteristics related to knife crime in order to narrow down possible weapons and suspects.

It is interesting to note the difference in the figures reported through the NCVS and those reported through the UCR. These two crime measures act in different ways to gather information on crime in the United States. The UCR gathers crime information that has been reported to law enforcement. This information is compiled once a month and sent to the Federal Bureau of Investigation for analysis. The NCVS is conducted by the US Census Bureau. They gather crime and victimization information by going house to house twice a year and talking with individuals about instances in which they experienced crime, whether or not it was reported to the police (Federal Bureau of Investigation N.d.). The larger numbers gained from the NCVS suggests that knife crime is more common that what is actually reported to law enforcement. While the percentages vary, these statistics show that the position of knife crime and the second most common form of armed violence has remained the same despite the varying survey methods.



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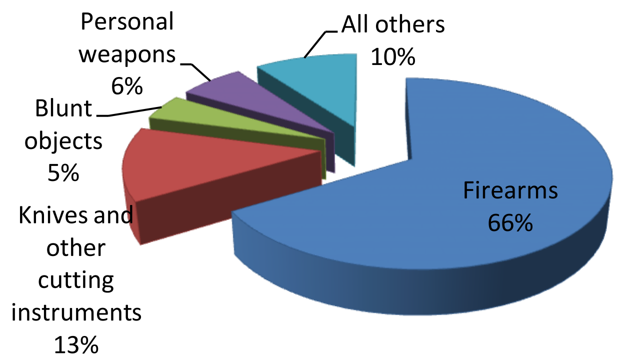

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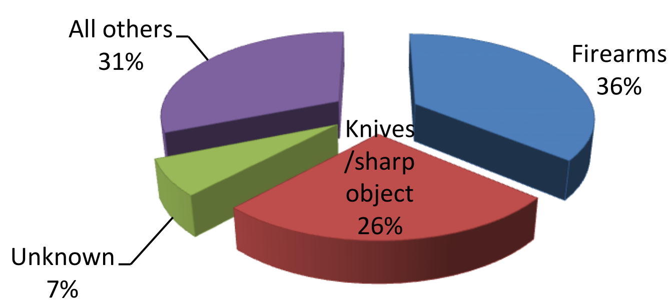

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Figure 1: Weapon crime in the United States from 1993-2001 (A), 2000-2008 (B), and 2009 (C). Note that (A) and (C) come from statistics taken as part of the NCVS, while (B) comes from statistics taken from the UCR. These surveys collect data on crime in different ways, causing the differences in the percentages. The NCVS records crime directly from door to door surveys with victims, while the UCR records only those crimes which have been reported to law enforcement

The Current Study

Despite the fact that sharp force trauma research has been increasing in scholarly journals recently (e.g., Love et al. 2011; Rainwater and Crowder 2011; Thompson and Inglis 2009; see CHAPTER II for additional discussion on previous research), very little work has focused on the unique characteristics left behind by serrated and non-serrated knives. Some of the current literature that has focused specifically on knife trauma have been case studies which discuss what trauma is seen in these isolated situations (e.g., Ciallella et al. 2002; Rao and Hart 1983) but few studies have looked at creating a trauma profile for what you would expect to see in the event knife trauma, and what this trauma might look like on bone or cartilage. In addition, few studies have ventured to attempt to examine the differences between classes of knives, specifically between serrated and non-serrated knives.

This study attempts to address this gap in the literature by examining the characteristics left behind on bone by both serrated and non-serrated knives. There have been some characteristics identified by previous research that are thought to be unique to knife class. These characteristics include kerf shape (e.g., Thompson and Inglis 2009) and the presence of striations (e.g., Bonte 1975). This current research combines these characteristics, and also examines whether or not width and length of the cut mark have a significant distinguishing relationship to knife class.

Specifically, this study asks the question of whether or not it is possible to distinguish between serrated and non-serrated knives by looking at the trauma that they leave behind in bone through the examination of cut mark morphology. This research will also examine three additional questions including:

- Are width and length of a cut mark indicative of knife class?
- Is kerf morphology (shape) indicative of knife class?
- Is the presence or absence of striations in the cut indicative of knife class?

In addition, if it is possible to distinguish between these two knife classes, a trauma profile will be compiled consisting of the most useful characteristics that can be used to assist in identifying and distinguishing between serrated and non-serrated blades.

Functional Terminology

There are a few terms that need to be clarified and defined for the purposes of the current study. The following terms and definitions will be used:

- The **kerf** of the cut refers to the floor and the walls of the cut mark (see Figure 2).
- The **width** of the cut mark refers to the distance between the widest borders of the kerf wall (see CHAPTER III for example).
- The **length** of the cut mark refers to the two points of greatest distance of the kerf floor (see CHAPTER III for example).
- **Kerf morphology/shape** refers to the shape of the kerf walls in relation to the kerf floor after the blade has cut through the bone.
- Presence or absence of **striations** refers to grooves left in the kerf walls by the blade as it transects the bone.

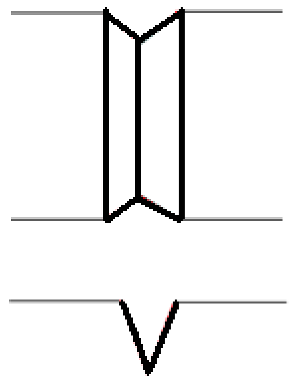


Figure 2: Example of a kerf. Kerf is outline in bold; superior (top), cross-section (bottom)

Current Study

To answer the questions outlined above, this study uses 4.5 inch serrated and non-serrated kitchen steak knives to cause sharp force trauma to ribs from domestic pigs (*Sus scrofa*). The rationale behind choosing these materials is two-fold: 4.5 inch steak knives were chosen to mimic the kind of knife that is common in household settings. This is a standard size steak knife that comes in most knife blocks, or that can be purchased on its own in nearly any store selling kitchenware. Ribs were chosen for this study because, consistently, the chest and the back are the most common sites for knife trauma on the human body (Schmidt and Pollak 2006, Ormstad et al. 1986).

Knives were newly purchased for this study in order to create a baseline trauma profile for serrated and non-serrated blades and to eliminate possible variation caused by use wear. The knives were switched out after creating 20 cut marks to the bones to prevent pseudo-striations that may occur due to chips or nicks on the blade of non-serrated knives. Once the cuts were made to the bones, they were placed into several containers (keeping those bones with trauma from the serrated blade separate from those with non-serrated trauma) and were placed out in the sun to be water macerated for two weeks. Once the bones were cleaned of any remaining tissue and fat and dried, the data collection began.

Data collection consisted of gathering measurements of width and length, both a macroscopic and microscopic examination of kerf shape, a microscopic examination of the cut for presence or absence of striations, and a microscopic examination of a cast made from each cut mark for the presence or absence of striations. The analysis that followed consisted of running descriptive statistics, chi-square tests of independence and goodness of fit, and an ANOVA.

CHAPTER II

LITERATURE REVIEW

Previous research into the area of sharp force trauma can be separated into four categories. The first area of previous research includes those studies which have focused on the identification and analysis of tool marks (those tools specifically related to sharp force trauma implements) in bone and cartilage. These studies provide a baseline for additional studies to identify characteristics that are related specifically to one class of sharp force weapon or comparisons between weapon classes. The second area relates to studies of sharp force trauma and implements, but does not include knife trauma. The third area includes those studies that have focused on knives, both serrated and non-serrated. The final area, validations studies, is one that is relatively new in the forensic literature and focuses on the outcomes and implications related to the admissibility of forensic evidence in court. These studies have seen an increase in the literature since the 1993 court ruling of *Daubert v. Merrell Dow Pharmaceuticals, Inc*. This ruling increased the importance of examining the methods currently used by forensic scientists, and as such, there have been several validation studies released in the last few years dealing with the ability of forensic anthropologists to identify characteristics of trauma.

Tool Mark Analysis

Perhaps the first examinations of tool mark characteristics as it relates to sharp force trauma weapons in American literature was conducted by Wolfgang Bonte in 1975 and Valerie Rao and Robert Hart in 1983. The study conducted by Bonte looked at the characteristics related to the identification of general knife classes based on the morphology of the weapon, and the characteristics that they leave behind during a traumatic episode. For example, he referred to the way that certain knives move through bone and cartilage, based on the shape of their blade. In addition, he identified the usefulness of striations (referred to here as rills) in cuts made from serrated blades (Bonte 1975). Bonte also examined the characteristics left by saw blades, and states that the tool marks left by the serrated teeth of a saw are not destroyed during the back and forth motion of sawing something, thus making the striations useful for identification of saw type (Bonte 1975). He stated that in both cases (knife use or saw use) the characteristics left by the weapon are often times enough to identify weapon class, and may allow scientists to link cut marks to a specific tool (Bonte 1975). Because of the ability to identify weapon type, the author also discussed the importance of examining cut and saw marks when looking into violent deaths to identify a possible murder weapon, or tool used in dismembering remains (Bonte 1975).

Rao and Hart conducted an examination of the trauma left behind during a stabbing incident. Trauma was caused to the costal cartilage, and there were visible striae left in the wound. To compare the damage on the cartilage to the suspect’s knife, the researchers took casts of both the cuts and a comparison sample made with the suspected weapon (Rao and Hart 1973). The actual cuts and the comparison cuts were examined and compared using a firearms comparison microscope, and the researchers were able to confirm that the cuts to the costal cartilage of the victim came from the suspect's knife, based on the 100% match of the characteristics of the striae present in both the injuries to the victim and the cuts made by the researchers. The authors used this case study to emphasize the importance both of finding and preserving identifying patterns in a stabbing incident, and the necessity to identify and record class and individualizing characteristics to increase the likelihood and ability to make a positive identification of a suspect weapon (Rao and Hart 1983).

Houck (1998) stressed the importance of identifying both class and individualizing characteristics for being able to distinguish between particular tools (knives) and for associating a specific cut mark with specific weapons. He stated that the use of comparison tests is the most common way in which investigators can examine and identify tool marks with specific tools (Houck 1998). By use of three knives, the researcher used a standardization device to deliver trauma to bovine tibia, and examined the cut marks for class and individualizing characteristics. Class characteristics refer to the commonalities which exist between all members of a specific group (e.g., Converse high top sneakers (Houck 1998:412)). Individualizing characteristics refer to those characteristics that are unique to a specific item (e.g., a striation that is the result of a knick in a blade, or a defect in the sole of a shoe that affects the shoe print that is left behind) (Houck 1998). Houck found that several of the cut marks could be tied to a specific type of weapon using class characteristics alone, and that several cut marks had identifiable striations, allowing for the identification of individualizing characteristics (Houck 1998).

General Sharp Force Trauma Studies

Overall, there have been a number of studies relating to the characteristics seen by an array of sharp force trauma weapons. The study of these different weapons is important in order to assist investigators in being able to distinguish between weapon classes, for example, identifying trauma made by a saw versus trauma made by an axe.

Saws and Dismemberment

One area of sharp force trauma that has appeared frequently in the forensic literature in the last 20 years is studies focusing on the unique characteristics left behind by saw blades. This area is important for recognizing possible weapons that may have been involved in dismemberment activities. A study by Symes et al. (1998) discussed the likely trauma profile created in the event that a saw has been used to cut bones and how you may see different characteristics as a saw cuts through bone (Symes et al. 1998). In addition, the author identified the kerf of the cut mark to describe the morphological features of a cut, such as the kerf wall and the kerf floor.

Saville et al. (2007) conducted a study introducing a new approach to the study of saw marks in bone though the use of an environmental scanning electron microscope (ESEM), and find that additional characteristics (such as a third kind of striae that cannot be seen at lower magnification) (Saville et al. 2007). The authors of this study reported that by using the ESEM, they are able to successfully identify several saw types based on a comparison of this new striation discovered. The study suggests that being able to identify saw type could help in matching a particular saw to marks made in the instance of dismemberment (Saville et al. 2007).

Reichs (1998) discussed the importance of retaining samples at autopsy in cases of dismemberment in order to examine the trauma to the bone to assist in identifying weapon type. She identified that most postmortem dismemberment activities are conducted using axes, saws, or knives (or combination thereof) (Reichs 1998). She also discussed the importance of knowing the difference between the kind of trauma and characteristics that are caused by different weapon (such as the fact that knives tend to produce a narrower cut rather than the wider cuts seen in saws and axes) (Reichs 1998). She also suggested that casting cut marks for additional examination can assist investigators and researchers in identifying characteristics of trauma that may not be able to be seen by examining the bone alone (Reichs 1998).

Axe and Hatchet/Hacking Trauma

Another area of sharp force trauma which has been popular in the forensic literature in recent years is those studies which focus on weapons such as axes and hatchets. These weapons can be classified under “hacking trauma.” These weapons have a sharp blade that gets wider as it extends from the incised edge (in a wedge shape).

Humphrey and Hutchinson (2001) conducted a study examining the macroscopic characteristics of trauma caused by several hacking weapons (machete, axe, and cleaver) to several pig bones (Humphrey and Hutchinson 2001). This study found that these three weapons have several different characteristics that may allow investigators to distinguish between them (for example, the cleaver produces a narrow cut with no fracturing, while the machete produces a medium cut with fractures present) (Humphrey and Hutchinson 2001).

Tucker et al. (2001) conducted a study looking at the microscopic characteristics of trauma caused by a machete, axe, and cleaver to several pig bones (Tucker et al. 2001). The authors used a scanning electron microscope (SEM) in order to examine the characteristics of trauma left behind on the bone that may not be seen at the macroscopic level. This study found that it is possible to create class characteristics for each of these weapons by examining the cut surface on bone (Tucker at al 2001). They also identified that while both cleavers and machetes display striations within the cuts, the striations vary between the three weapons is a predictable way, making them useful for distinguishing weapons (axes displayed no such striations) (Tucker et al. 2001). The authors also stressed the importance of a microscopic examination to supplement a macroscopic examination to assist in weapon identification (Tucker et al. 2001).

Alunni-Perret et al. (2005) used a scanning electron microscope to examine the differences between trauma caused by a knife and trauma caused by a hatchet on human bone. This study found that at the macroscopic level the cut marks resulting from trauma caused by both weapons was almost identical (Alunni-Perret et al. 2005). However, at the microscopic level, the authors identified clear differences. For example, the cuts made from the knife displayed very even walls and a uniform breadth across the entire length of the cut, while cuts made from the hatched displayed very uneven edges and a width that was the same across the entire lesion (Alunni-Perret et al. 2005). The authors stressed the importance of conducting a microscopic examination, especially when a macroscopic examination may not yield much useful information or may not be useful in distinguishing between cut marks made by two weapon classes (Alunni-Perret et al. 2005).

Lynn and Fairgrieve conducted both a macroscopic (2009a) and microscopic (2009b) examination of trauma caused to pig limbs using both used and unused axes and hatchets. Macroscopically, the authors found that while bisection occurred in a significant number of both the fleshed and defleshed specimens (but more likely to be seen in the defleshed specimens), the bisection of bones was dependent upon the amount of forced used (Lynn and Fairgrieve 2009a). In addition, the macroscopic examination of the bones showed that chattering occurs only in approximately half of the cases. Flaking also occurred in the trauma, and proved to be useful for determining the angle of impact of the weapon (Lynn and Fairgrieve 2009a). The study also found that a range in the length of 14-33mm might be useful for determining blade length, and that curve transverse and spiral fractures were most commonly seen in the femora, while longitudinal fractures were seen in the fleshed fibulae (Lynn and Fairgrieve 2009a).

Microscopically, Lynn and Fairgrieve found that in the fleshed bones, the fracture surface displayed a rough surface morphology, with osteon pullout and lamellar separation in the majority of cases (Lynn and Fairgrieve 2009b). In the defleshed specimens, osteon pullout was uncommon, and lamellar separation at the fracture surface occurred in only one half of the cases, and in 8 of 10 cases at the impact site (Lynn and Fairgrieve 2009b). Striations were also seen in the smooth impact sites of both fleshed and defleshed specimens. The study suggests that the smooth impact sites and the rough fracture surfaces can be used to identify trauma caused by axes and hatchets (Lynn and Fairgrieve 2009b).

Miscellaneous Weapons

Croft and Ferllini (2007) examined the characteristics of trauma caused by a screwdriver to porcine bones. The study found that the likelihood of causing skeletal trauma to bone using a screwdriver was increased when the perpetrator was a younger adult (Croft and Ferllini 2007). The trauma caused by both a flat-tip and cross-tipped screwdriver varied, suggesting that it may be possible to distinguish between the two by examining the trauma profile left behind in bone. The authors found that it is possible that the identification of a longitudinal fracture may be suggesting of a cross-tip screwdriver, as they occur almost exclusively in trauma caused by this class of weapon (Croft and Ferllini 2007). The shape of the puncture wound cause by each type of screwdriver was variable and may also be useful in identifying the weapon. The cross-tip screwdriver displayed a cruciform impression in bone, while the flat-tip screwdriver displays a rectangular impression (Croft and Ferllini 2007). Wastage was most likely to occur in trauma from both screwdrivers at the oblique angle, suggesting a scraping effect across the bone. Grazing was also a characteristic noted in the trauma profile from both screwdrivers, suggesting that the tip of the screwdriver scraped across the bone. These variations in characteristics from the cross-tip and flat-tip shows that it is possible to distinguish between these tools based on the trauma they leave in the bone (Croft and Ferllini 2007).

Lewis (2008) examined the characteristics of several different weapons including swords and how they vary from each other and from knife trauma. The study found a relatively consistent pattern in the width patterns of swords as they vary from knives. For example, swords produce longer cut marks than knives do. However, while useful for distinguishing between swords and knives, it was not useful for distinguishing between sword types (Lewis 2008). The author also identified that sword marks are typically wider, deep, and caused a large amount of damage to the walls of the cut, while having a straight kerf. Swords tend to display one smooth wall and one roughened wall. Some less-sharp swords create a square-U shaped cut, while knives tend to produce V-shaped cuts. Knives tend to display long, narrow cuts with a meandering kerf, and little damage to the walls, as well as feathering damage (Lewis 2008). The study showed that it is possible to distinguish between cuts made to bone by knives and swords. In addition, the author identified that it is possible to identify different classes of swords based on the characteristics of trauma they leave behind (Lewis 2008).

Knife-related Sharp Force Trauma Studies

Weapon Studies

Bartelink et al. (2001) examined the characteristics of cut marks caused by several types of non-serrated blades (scalpel, paring knife and utility knife) under a scanning electron microscope. The results of this study showed that there are variable width measurements between knife types, with the widest measurement coming from the cuts by the utility knife and the smallest caused by the scalpel (Bartelink et al. 2001). Despite this, the authors caution against attempting to associate a particular knife with a cut mark, however, the authors suggest that using the quantitative and qualitative difference displayed by knife type, when taken together may be useful in identifying knife type (Bartelink 2001).

In their study Thompson and Inglis (2009) examined the differential patterns caused by serrated and non-serrated stabbing events in bone. The study looked at the morphological characteristics of sharp force knife trauma both macroscopically microscopically (low-powered and scanning electron microscope). The authors found that while recorded measures of length and width did not vary when examined at each level, the measure of damage to the kerf did, likely do to a stronger magnification of the trauma (Thompson and Inglis 2009). The study also found that the shape of the kerf varies between serrated and non-serrated knife trauma. The cuts from the serrated blade produced a Y-shaped kerf, while the non-serrated blade produced a T-shaped kerf. The results of this study suggest that it is possible to distinguish between serrated and non-serrated blades (Thompson and Inglis 2009).

In 2012, Ferllini conducted a study looking at the characteristics of knife stab wounds on clothed and unclothed ribs (Ferllini 2012). Using three different kinds of kitchen knives and six halved buttered porcine torsos, the study had an individual, other than the researcher, stab at the torsos and then a macroscopic and microscopic examination was conducted to record the damage to the ribs. The stabbings were conducted using two different methods, a straight forward thrust and a downward thrust. The study found that of the 72 stab marks inflicted on the porcine torsos, 26 of them did not hit the bone. 25 (of 36) of the straight thrust stabs hit bone, and 21 (of 36) of the downward thrust stabs hit bone (Ferllini 2012). During the macroscopic analysis, the study found that there was a lack of consistency in the patterning of the wounds. The authors identified several V-shaped cut marks, however, they noted that those wounds which did not display this shape were lighter cuts, or nicks, rather than deep cut marks

(Ferllini 2012). The study also showed variation in the wound pattern at the microscopic level, however, they noted that the downward thrust stabbing motion could be characterized by a cone shape associated with the point of impact (Ferllini 2012). The authors suggest that caution must be used when examining and assessing instance of sharp force trauma due to the variability in the cut marks noted in this study. They also stress that while a macroscopic analysis is useful for the examination of wound pattern, a microscopic analysis of the trauma can further assist in analysis (Ferllini 2012).

Biomechanics Studies

There have been several studies in the field of forensic science regarding the biomechanics and kinematics of knife trauma during stabbing events. Knight (1979) discovered that a knife can stab through the skin and subcutaneous fat of the abdomen with a half and three kilograms of pressure (Knight 1979). The sharpness of the knife is identified as the overwhelming variable in the ability of a knife to cut through skin and fat, suggesting that the sharper the implement, the less pressure needed to penetrate the skin. Velocity of the stabbing motion also had an effect on ease of cutting; however, sharpness of the blade still has the greatest effect. For example, a blunt knife could not penetrate tissue even with a fast moving blade (Knight 1979). Knight also found that other factors, such as the age of the victim, area of the body stabbed, are often have no effect on the ability of a knife to transect skin and fat (Knight 1979).

Jones et al. (1994) examined the difference between the ability of blunt and sharp knives to penetrate tissue. The study found that only the sharp knife was capable of cutting through tissue (Jones et al. 1994). In addition, the study found that while a significant force is required to penetrate overlying skin, substantial force is also required to cut through the underlying tissue (Jones et al. 1994).

Miller and Jones (1996) examined the kinematics of four stabbing methods, including: long over, which is an overarm attack from a distance of 1.25m with the blade originating from the ulnar aspect of the hand; the long under, which is an underarm attack from a distance of 1.25m with the blade originating from the radial aspect of the hand; short over, which is the same as long over but from a distance of .5m; and short under, which is the same as the long under but from a distance of .5m (Miller and Jones 1996). The results of this study showed that a greater speed was reach during the 'over' attacks rather than the 'under' attacks. Angular displacement at the shoulder joint was greater in 'long' attacks than in the 'under' attacks, as well as greater in the 'over' motions rather than the 'under' motions. Angular displacement at the elbow joint was greater in the 'long' attacks and 'under' attacks. Shoulder joint velocities were greater for the 'under' rather than the 'over' and elbow joint velocities were greater for the 'over' rather than the 'under'. Greater linear speeds at the shoulder joint were present in the 'over' attacks and 'long' attacks (Miller and Jones 1996). The study found that overall the way in which a knife is held effects the speed which is obtained during a stabbing event.

O'Callaghan et al. (1999) examined the force that was required to penetrate human tissue in the event of a stabbing. The authors discovered that the greatest barrier during a stabbing event is the skin; however, there is significant secondary resistance from the underlying tissue that was not previously identified by previous research (O'Callaghan et al. 1999). The study suggested that the greatest resistance is provided by the skin, followed by a lower resistance, before increasing again as the blade hits underlying muscle, showing a secondary resistance (O'Callaghan et al. 1996).

Chadwick et al. (1999) examine the biomechanics of stabbing events examining the amount of energy and the momentum produced during an attack. The authors found that an overhand stab creates the greatest force, while a thrust generates the smallest values. Cutting force and lateral force motions also generated large values in some cases, with the greatest cutting force occurring from an overhand stabbing. Lateral forces were highest in sweeping motions but were lower than the cutting forces. Torque was also highest with this stabbing style (Chadwick et al. 1999). The study also examined if there were differences in the patterns of force between using human volunteers and a drop tower to standardize the stabbing motions. The authors found that while it is possible to replicate the amount of force using the drop tower, the force-time profile varies (Chadwick et al. 1999). This suggests that while the drop tower can be used to simulate a human stab attack, it is not the ideal method for study (Chadwick et al. 1999).

Validation Studies

Validation studies have been recently begun to appear in the forensic literature for forensic anthropology as well as other forensic science disciplines. With the ruling of *Daubert v. Merrell Dow Pharmaceuticals Inc.* (1993) and the recent report entitled "Strengthening Forensic Science in the United States: A Path Forward" released by Congress and the National Academy of Sciences on the state of forensic science in the United States, the ability to prove that the current methods are valid and thoroughly tested has become extremely important, especially where it related to providing expert testimony in courts. The results of Daubert outlined several guidelines for the admissibility of expert testimony in court. According to Grivas and Kumar (2008:772), these guidelines state that the content of the testimony must:

- Be testable and have been tested through the scientific method
- Have been subject to peer review
- Have established standards
- Have a known or potential error rate
- Have widespread acceptance by the relevant scientific community

Because of these new standards for expert testimony in court, the validations studies in forensic science have become detrimental to the field. These studies examine commonly used and accepted methods for gathering and analyzing evidence to determine the associated error rates and feasibility of use. Such validation studies related to the identification of sharp force trauma to bone include a study of the error rates associated with identifying knife class as it related to specific trauma characteristics in casting wax (Rainwater and Crowder 2011), as well as a study of the error rates associated with identifying knife class based on striations in pig cartilage (Love et al. 2011).

In their study, Rainwater and Crowder looked at the ability of the forensic anthropologist to distinguish knife class based on their identification of two main characteristics left behind after a knife was used to cut into casting wax. The characteristics that the authors used for their study include serration of the blade (serrated, non-serrated and partially serrated blades) and the direction of blade bevel (left, right, or both) (Rainwater and Crowder 2011). This study found that the identification of partially serrated blades was somewhat problematic, but when serrated and non-serrated blades were examined alone that the error rate for misclassification was very low. The preliminary results of their study showed that an individual with enough experience could identify knife class with a fairly good accuracy rate based on their identifying characteristics (Rainwater and Crowder 2011).

Love et al. conducted a similar validation study by examining knife class (serrated, non-serrated, and micro-serrated) as it relates to characteristic striations as they appear in porcine costal cartilage. Specifically, they were looking at the presence of striations, regularity of striations, and the presence of a primary and secondary striation pattern (Love et al. 2011). What the authors found was that there is a significant error rate associated with using the presence of striations as a method for identifying a serrated-edged knife and that striations appeared in the majority of cuts, even those that were from the micro- or non-serrated blades which led to a significant misclassification of knife class (Love et al. 2011).

Love et al. also conducted a validation study examining the trauma left behind by saw marks to bone, using the current macroscopic methods of analysis employed by scientists today (Love et al. 2012). The saw marks were made on the bone using three hand saws and one power saw. The researchers examined a total of 14 variables, 8 of which were quantitative and 6 of which were categorical (see Love et al. 2012 for a list of included variables). This pilot study was conducted on 10 samples. The three analysts in this study agreed on several characteristics varying from 6 out of 10 times (kerf wall shape and exit chipping) to 10 out of 10 times (harmonics) (Love et al. 2012). This research is ongoing and further and more comprehensive examination will look at the discriminant value and the interobserver error rate associated with each variable, as well as the potential error rate associated with the overall analysis (Love et at 2012).

Summary

While a significant amount of research has been done in the area of sharp force trauma, studies in examining the characteristics left behind by serrated and non-serrated knives is limited, and there is a lack of studies which examine the multitude of characteristics in conjunction with each other to distinguish between knife classes. It is the purpose of this study to determine if there are enough distinguishable characteristics between serrated and non-serrated left behind on bone to identify knife class based on the trauma they leave behind.

CHAPTER III

MATERIALS AND METHODS

Materials

Skeletal Materials

This study utilized 100 ribs from domestic pigs (*Sus scrofa*). Porcine bones and cartilage are often used as a proxy for human bones, and have been used in a number of sharp force trauma studies (e.g., Ferllini 2012; Love 2011; Thompson and Inglis 2009; Croft and Ferllini 2007). The ribs of *Sus scrofa* are similar in "dimension, weight, and structure" (Croft and Ferllini 2007) to their human counterparts, and thus, make a good substitution in the absence of available human cadavers. The ribs were purchased as part of a rack from Granzin's Butcher Shop in New Braunfels, TX. Because the ribs were previously approved for human consumption, IACUC regulations do not apply.

Exact age and weight of the pigs used for this study were unknown. The ribs were received articulated with a significant amount of flesh, and had to be defleshed prior to use in this study. The ribs were first disarticulated and the majority of flesh was removed, leaving a thin layer intact to prevent any damage to the bone by the scalpel during the defleshing. The purpose of defleshing the ribs is to remove the variable of having to cut through flesh before hitting the bone, as to set up a baseline for the characteristics recorded. The bones were defleshed and used immediately after purchase before being set out to macerate to remove remaining tissue and fat.

Knife Materials

A set of five serrated and five non-serrated common kitchen steak knives were employed for the purposes of this study. Serrated knives were purchased from Bed, Bath, and Beyond as part of a *Cuisine De France* 15 piece cutlery set (see Figure 3). Serrated knife blade measured approximately 11.3 cm (long), with a 10 cm handle. The serrated edge made up 10.3 cm of blade. The teeth were approximately 3 cm apart from each other on incised edge of the knife blade. Blade width was 1.5 mm (wide).

Figure 3: Picture of serrated knife, *France De Cuisine* 4.5” serrated steak knife

Non-serrated knives were purchased from Walmart as part of two 4 piece *Faberware* Steak Knife Sets (see Figure 4). Non-serrated knife blade measured approximately 11.2 cm (long), with an 11 cm handle. Incised edge made up 11 cm of blade. Blade width was 1.5 mm (wide) with a .5 mm wide incised edge.

Figure 4: Picture of non-serrated knife, *Faberware* 4.5” non-serrated steak knife

Methods

Data Collection

Immediately after defleshing, the bones were arranged into sets of 10 bones. One set of bones was used at a time. Five serrated knives were used to make 100 cut marks on 50 of the bones (one knife was used for each set of 10 bones to make 20 cut marks, two on each bone). The same method was applied to the non-serrated knives, for a total of 200 cuts between the two knife classes.

Bones were stabilized using a standard clamp-on-vice attached to a metal table before being cut with the knives. The sternal end of the rib was placed into the vice, and two cuts were made, one near the sternal end, and one near the vertebral end. Cuts were made by the researcher using as much force as possible. The knife was placed perpendicular to the superior surface of the bone, and the cut mark was made using one forward and one backward slicing motion, along the same cut path, across the surface of the rib. Cuts that did not follow the same path both forward and backwards were not used in the analysis, as it was unknown what impact this variation had on the characteristics of the cut mark. This same method was repeated across all 100 bones (200 cut marks).

Once cut, bones were placed in plastic containers filled with water, separated by knife class, and left to macerate outside at the Forensic Anthropology Research Facility (FARF) at Texas State University-San Marcos. The bones were left to water macerate for two weeks before being collected. By the end of the two weeks, the ribs were brought back to the Grady Early Forensic Anthropology Research Facility (GEFARL) at Texas State, and any remaining tissue and fat was hand-processed using water and brushes, to avoid any damage to the bone that may obscure cut characteristics. After the bones were cleaned, they were left to thoroughly dry before analysis. Once dried, bones were labeled in the following fashion: knife class (either S or N, with S=serrated, N=non-serrated), followed by bone number (1-50), followed by cut number (1 or 2), i.e. S3-2.

After labeling, data collection began (for an example of the data collection sheet, see APPENDIX A). Width and length measurements of the cut marks were taken using digital sliding calipers (Carrera Precision Calipers). Width measurements were taken and the widest points of the cut mark, from the edge of the kerf walls (see Figure 5). Length was measured at the furthest two points of the cut mark (see Figure 6).

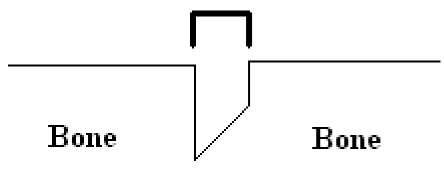


Figure 5: Diagram of width measurement. Measurement indicated by bolded lines.

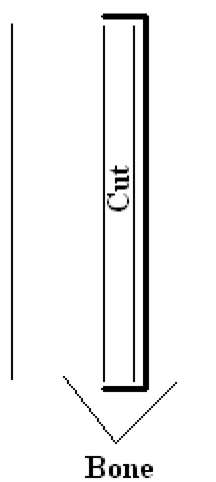


Figure 6: Diagram of length measurement. Measurement indicated by bolded lines.

Measurements of width and length were taken three times, and the average measurement was then calculated and used for the purposed of this analysis. This method was used in order to correct for any errors due to caliper measurement or readings.

After measurements were recorded, cut marks were examined for kerf shape. This occurred first at the macroscopic level, and all of the bones were examined before moving onto a microscopic examination. Kerf shapes were not established prior to experiment, but instead recorded and identified throughout the course of the data collection method based on the characteristics presented. When a kerf did not match a previously recorded shape, a new category was created. All microscopic examination was done using a Leica EZ4 Standard Light Microscope.

Following the examination of kerf shape, the presence or absence of striations was recorded. Striations are presented as grooves along the kerf wall due to the serrations of a knife and it cuts through bone. Striations were recorded at the microscopic level only, due to the fact that the cut marks created in this study were too small to be confidently identified or recorded at the macroscopic level. Striations were first recorded at the microscopic level followed by an examination of casts made from the cuts.

One the examination and collection of the data from the bone was completed, the casts of the cut marks were made using AccuTrans Red casting material, which was purchased from a forensic supply company. Casting was done in order to identify striations which may have been overlooked or gone unnoticed during data collection of the bone. The examination of casts is important because, in some cases, they can show small, detailed characteristics better than a macroscopic or microscopic examination of the bone can alone. The cases were examined at the microscopic level only, for the same reason as cited previously.

Statistical Analysis

Once data collection was completed, data analysis was conducted. Statistical analysis was done for width measurements, kerf shape (microscopically and macroscopically), and presence of striations (bone and cast). Length measurements were not used during data analysis because length was affected more by bone morphology than knife class (i.e. thinner bones made shorter cut marks, while thicker bones made longer cut marks). For width, both descriptive statistics and an Analysis of Variance (ANOVA) statistic were run on the data. A chi-square goodness of fit test was run on both the microscopic and macroscopic kerf shape data. A chi-square test of independence was run on the presence of striations in bone, while a chi-square test on independence and goodness of fit test were run on the presence of striations in the casts.

Intraobserver Error

After the initial experiment and analysis were completed, a test of intraobserver error was conducted on an additional 20 bones that had been set aside at the start of the experiment. Using the same method as the initial experiment, the bones were each cut twice resulting in a total of 40 cut marks (20 for each knife class). The bones were chosen and labeled by someone other than the researcher to assure that knife class was unknown prior to the test. Data were collected in the same fashion as the earlier experiment, and was recorded and analyzed by the researcher. Once all of the data was collected and analyzed, the original researcher recorded their opinion of which knife class (serrated or non-serrated) caused which cut marks. Afterwards, the opinion of the researcher was compared to an answer sheet compiled by the same individual who originally chose and labeled the bones for accuracy.

CHAPTER IV

RESULTS

Several statistical tests were used in order to calculate the results of this study. The results are divided by characteristic. The characteristics examined were: length, width, macroscopic kerf shape, microscopic kerf shape, microscopic (non-casted) presence or absence of striations, and microscopic (casted) presence or absence of striations. Each characteristic was examined to determine its usefulness in distinguishing between serrated and non-serrated knives. Once the analysis was completed, a test of interobserver error was run on an additional 20 bones to determine accuracy of identification.

Length

The length of the cut mark did not end up being used for this study, due to the fact that the length was affected by the width of the superior surface of the bone where the cut was made. Thinner bones had shorter cut marks, while wider bones had longer cut marks. Because of this, it was not possible to accurately see the effect of knife class to the length of the cut mark.

Width

Width is a useful measurement for assisting in determining knife class. The width of the cut mark was taken three times, and then the average score was calculated to avoid any error in taking or reading the caliper measurements. Both descriptive statistics and a standard ANOVA were run on the final width measurements, and both show a significant difference between serrated and non-serrated cuts. The descriptive statistics show that the overall average width measurement for serrated knives was .910 mm, with a measurement range of .603 mm to 1.573 mm. The overall width measurement for non-serrated knives was .306 mm, with a measurement range of .157 mm to .530. Only two non-serrated measurements fell above .50 mm. There is absolutely no overlap between serrated and non-serrated measurements, with all of the serrated measurements falling above .60 mm and all of the non-serrated measurements falling below .60 mm.

An ANOVA run on the width data showed a significant difference between the two knife classes (see Table 1). The test shows a highly significant difference between the width measurements of serrated and non-serrated knives at p=0.00. The results of these tests suggest that width is useful for assisting to determine knife class for this knife type (type referring to size and size and style of knife: 4.5" steak knife).

Table 1: ANOVA test for width measurements

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	17.38016	1	17.38016	1244.326	0.00	3.891131
Within Groups	2.639863	189	0.013968			
Total	20.02002	190				

Kerf Shape (Macroscopic)

Four kerf shapes were identified during data collection and analysis. The four shapes are: V-shaped, Y-shaped, U-shaped, and Funnel-shaped (see Figure 7 and Appendix 2 for additional examples). These kerfs can be identified by the following characteristics:

- A Y-shaped kerf is characterized by two straight, parallel kerf walls connected by an angled kerf floor, causing one of the kerf walls to be shorter than the other. It is also characterized by a wide distance between the kerf walls.
- A Funnel-shaped kerf is characterized by two parallel kerf walls, close to each other, which follow the surface of the bone. At the termination of these parallel walls is a small v-shaped kerf. This gives the impression of a funnel, where the walls represent the spout and the bottom and the v-shape at the top represents the cup part of the funnel. This kerf can also be characterized by an extremely narrow distance both between the parallel kerf walls, and the two walls of the v-shaped kerf at the top.
- A U-shaped kerf is characterized by two parallel walls connected by a curved kerf floor. It is also characterized by a wide distance between the two parallel kerf walls.
- A V-shaped kerf is characterized by two inwardly angled walls terminating at the kerf floor. It is also characterized by a wide distance between the two kerf walls at the top of the cut, but which narrows as the walls descend to the kerf floor. In addition, this kerf does not show the same narrow, parallel walls which characterize the Funnel-shaped kerf, despite mild similarities in the shape of this

kerf (V-shaped kerf) and the v-shaped funnel portion of the Funnel-shaped kerf (which also varies in the size of the v-shaped portion).

Of these four, only Funnel-shaped and Y-shaped kerfs are indicative of a specific knife class. V-shaped and U-shaped kerfs appeared in both serrated and non-serrated cuts suggesting that they are not useful in determining knife class. Funnel-shaped kerfs appeared in only cut marks made by non-serrated blades, and Y-shaped kerfs appeared only cuts made by serrated blades (see Table 2).

Several chi-square goodness of fit tests were run on the data to determine if the presence of these different kerf shapes were significant and could assist in determining knife class (see Appendix 3 for full mathematical calculations). Chi-square (p=0.01) shows that the frequency of these four kerf shapes are not equal for both serrated and non-serrated knives (see Tables 3 and 4). Additionally, chi-square (p=0.01) shows that the frequency of the Funnel-shaped kerf is not equal for both knife classes (see Table 5), and the frequency of the Y-shaped kerf is also not equal in frequency for serrated and non-serrated knives (see Table 6). This suggests that kerf shape is relatively unique to the knife class, and that the presence of the Y and Funnel-shaped kerfs may be useful in distinguishing between serrated and non-serrated knives.

Table 2: Frequency of kerf shape by knife class (macroscopic)

	Knife Class	
Kerf Shape	Serrated	Non-serrated
Y	77	0
V	19	12
Funnel	0	76
U	3	0

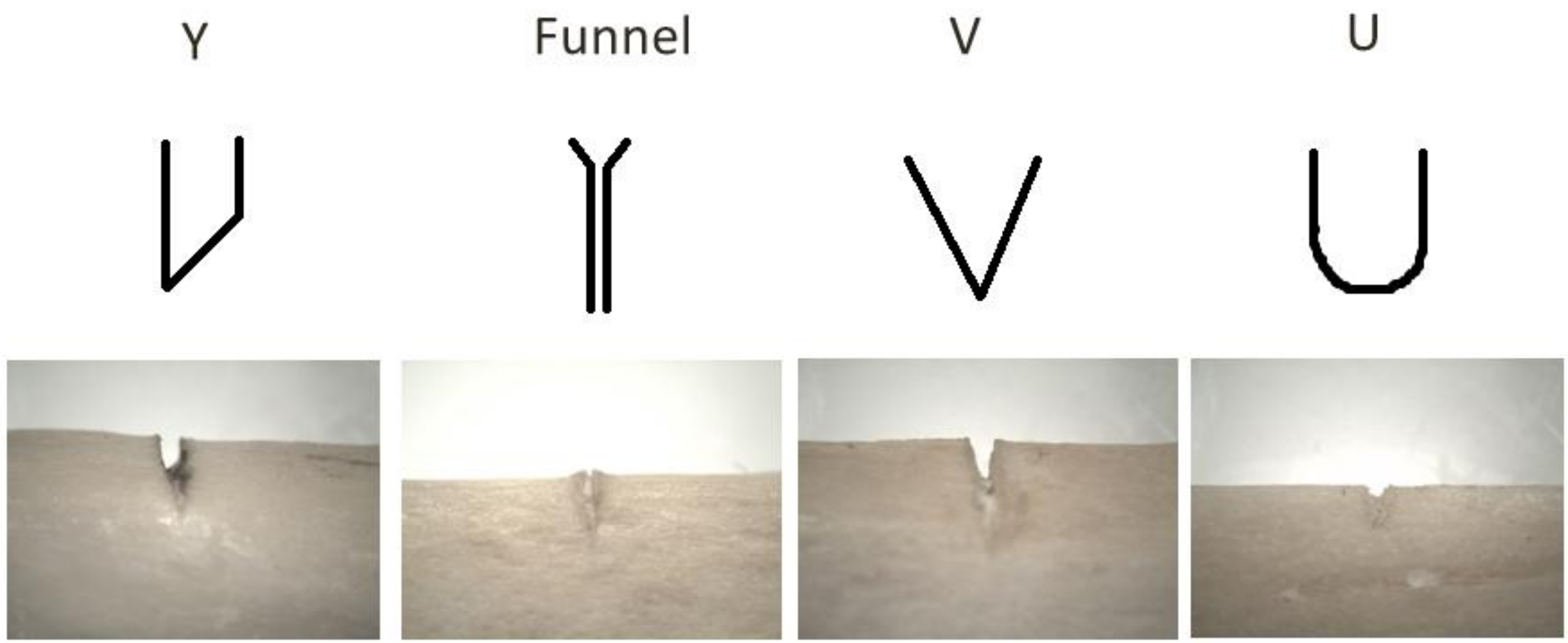


Figure 7: Examples of the kerf shapes seen in the experiment. Please see Appendix B for additional examples.

Table 3: Chi-square goodness of fit, kerf shape - serrated (macroscopic). H_0: Presence of Y, Funnel, V, and U-shaped kerfs is equal in frequency for serrated knives. H_1: Presence of Y, Funnel, V, and U-shaped kerfs is not equal in frequency for serrated knives

df	X^2	p(0.01)
3	155.505	11.341
Can reject Null Hypothesis.		

Table 4: Chi-square goodness of fit, kerf shape – non-serrated (macroscopic). H_0: Presence of Y, Funnel, V, and U-shaped kerfs is equal in frequency for non-serrated knives. H_1: Presence of Y, Funnel, V, and U-shaped kerfs is not equal in frequency for non-serrated knives

df	X^2	p(0.01)
3	181.09	11.341
Can reject Null Hypothesis.		

Table 5: Chi-square goodness of fit – Funnel-shaped kerf (macroscopic). H_0: Presence of a Funnel-shaped kerf is equal in frequency for serrated and non-serrated knives. H_1: Presence of a Funnel-shaped kerf is higher in frequency for non-serrated knives

df	X^2	p(0.01)
1	38	6.635
Can reject Null Hypothesis.		

Table 6: Chi-square goodness of fit – Y-shaped kerf (macroscopic). H_0: Presence of a Y-shaped kerf is equal in frequency for serrated and non-serrated knives. H_1: Presence of a Y-shaped kerf is higher in frequency for serrated knives

df	X^2	p(0.01)
1	77	6.635
Can reject Null Hypothesis.		

Kerf Shape (microscopic)

The same four kerf shapes were identified when the cut marks were examined microscopically (see Figure 7). Again, the presence of a V- or U-shaped cut mark does not seem to assist in identifying knife class as they appear in cuts made by both serrated and non-serrated knives. The presence of a Y- or Funnel-shaped kerf, however, is indicative of a knife class. A Funnel-shaped kerf only appeared in cuts made by the non-serrated knife, while a Y-shaped kerf only appeared in cuts made by the serrated knife (with one exception) (see Table 7). Overall, at the microscopic level, similar to the macroscopic level, kerf shape is relatively unique to knife class.

Several chi-square goodness of fit tests (p=0.01) were run for the microscopic examination level of the kerf shapes (see Appendix 3 for full mathematical calculations). These tests demonstrate that the presence of a Y, Funnel, V, or U-shaped kerf was not equal in frequency for both knife classes (see Figures 8 and 9). In addition, the tests show that the presence of a Y or Funnel-shaped kerf was not equal in frequency for serrated and non-serrated knives (see Figures 10 and 11). Thus, the presence of one of these two kerf shapes may be useful in narrowing down knife class.

Table 7: Frequency of kerf shape by knife class (microscopic)

	Microscopic	
Kerf Shape	Serrated	Non-serrated
Y	81	1
V	17	10
Funnel	0	81
U	1	1

Table 8: Chi-square goodness of fit, kerf shape - serrated (microscopic). H_0: Presence of Y, Funnel, V, and U-shaped kerfs is equal in frequency for serrated knives. H_1: Presence of Y, Funnel, V, and U-shaped kerfs is not equal in frequency for serrated knives

df	X^2	p(0.01)
3	188.179	11.341
Can reject Null Hypothesis.		

Table 9: Chi-square goodness of fit, kerf shape – non-serrated (microscopic). H_0: Presence of Y, Funnel, V, and U-shaped kerfs is equal in frequency for non-serrated knives. H_1: Presence of Y, Funnel, V, and U-shaped kerfs is not equal in frequency for non-serrated knives

df	X^2	p(0.01)
3	193.581	11.341
Can reject Null Hypothesis.		

Table10: Chi-square goodness of fit – Y-shaped kerf (microscopic). H_0: Presence of a Y-shaped kerf is equal in frequency for serrated and non-serrated knives. H_1: Presence of a Y-shaped kerf is higher in frequency for serrated knives

df	X^2	p(0.01)
1	80	6.635
Can reject Null Hypothesis.		

Table 11: Chi-square goodness of fit – Funnel-shaped kerf (microscopic). H_0: Presence of a Funnel-shaped kerf is equal in frequency for serrated and non-serrated knives. H_1: Presence of a Funnel-shaped kerf is higher in frequency for non-serrated knives

df	X^2	p(0.01)
1	81	6.635
Can reject Null Hypothesis.		

Presence of Striations (non-casted)

The presence or absence of striations was recorded at the microscopic level only, due to the fact that the resulting cut marks from both the serrated and non-serrated knives were too small to accurately examine and record whether striations were present (see Table 12 for frequencies). A chi-square test of independence (p=0.01) was run of the data to determine if the presence of striations was independent from or dependent on the class of knife responsible for making the cut mark (serrated or non-serrated). Results show (see Table 13) that the presence of striations is dependent upon the class of knife used to make the cut (see Appendix 3 for full mathematical calculations).

The presence of striations was recorded in 72 (of 100) cut marks made from the serrated blades and in 0 (of 95) cut marks made from the non-serrated blade (see Table 12). The overwhelming presence of striations in the serrated cut marks, and absence of striations in the non-serrated cut marks suggests that the presence of striations may be useful in assisting to identify knife class. The absence of striations was recorded in 28 (or 100) cut marks for the serrated blade and in 95 (of 95) cut marks from the non-serrated blade. Because the absence of striations occurred in cut marks from both serrated and non-serrated blades, it is unlikely that it will be useful in identifying knife class.

Table 12: Frequency of presence and absence of striations (non-casted)

Knife Class	Presence of Striations	Absence of Striations
Serrated	72	28
Non-Serrated	0	95

Table 13: Chi-square test of independence – presence of striations (non-casted). H_0: The presence of striations is independent of knife class. H_1: The presence of striations is dependent upon knife class

df	X^2	p(0.01)
1	108.439	6.635
Can reject Null Hypothesis.		

Presence of Striations (casted)

The cut marks were also casted using AccuTrans Red casting material, which is commonly used to cast and examine cut marks. Examining a casted version of a cut mark can sometimes reveal striations that were not seen at the macroscopic or microscopic level. As with the non-casted cut marks the presence of striations in a cut appears to be useful for assisting to identify knife class. The presence of striations (see Table 14) was recorded in 76 (of 100) cut marks made from the serrated blade and possible striations were recorded 4 (of 96) cut marks made from the non-serrated blade. Similarly to the non-casted cut marks, the overwhelming presence of striations in the serrated cut marks, and the overwhelming absence of striations in the non-serrated cut marks suggest that the presence of striations may be useful in identifying knife class. The absence of striations (see Table 4) was recorded in 24 (of 100) cut marks made from the serrated blade and in 92 (of 96) cut marks made from the non-serrated blade. Because the absence of striations occur in cut marks made from both knife classes, it is unlikely that it will be useful in distinguishing serrated and non-serrated knives.

An additional chi-square test of independence (p=0.01) was run of the data to see if the presence of striations was independent from or dependent upon the knife class for the casted cut marks as well. As before, the results (see Table 15) confirm that the presence of striations is dependent upon the knife class (see Appendix 3 for full mathematical calculations).

Table 14: Frequency of presence and absence of striations (casted)

Knife Class	Presence of Striations	Absence of Striations
Serrated	76	24
Non-Serrated	4	92

Table 15: Chi-square test of independence – presence of striations (casted). H_0: The presence of striations is independent from knife class. H_1: The presence of striations is dependent upon knife class

df	X^2	p(0.01)
1	104.624	6.635
Can reject Null Hypothesis.		

While the use of casting material is useful in the examination of cut marks, especially those cut marks which may be harder to examine by either macroscopic or microscopic means, it may not be wholly necessary. With the exception of identifying 4 cut marks from a non-serrated knife which displayed some striations (again, likely due to a use wear defect on the blade), the number of striations present or absent identifies microscopically in the bone and microscopically is not significantly different. This suggests that the researcher was able to identify striations in the bone without the implementation of casting. However, if available, casting material may be used during the collection of data to assure as much data are collected as possible.

Intraobserver Error

Using the characteristics outlined above (with the exception of length, as it was shown to have no correlation to knife class), an intraobserver error test was completed on an additional 20 bones. After the data were collected on the bones, the researcher recorded their opinion on which knife class (serrated or non-serrated) caused which cut marks. Because each bone was cut twice by the same knife, the characteristics of both cut marks were used together to reach the best possible conclusion for each bone. The researcher was able to classify 100% of the bones in the test. This suggests that the above characteristics are useful in identifying knife class for this knife type (4.5" steak knife).

CHAPTER V

DISCUSSION

The overall research question that this study set out to answer was whether or not it was possible to distinguish between serrated and non-serrated knives by examining the sharp force trauma indicators that they left behind in bone. In addition, there were three other research questions that were examined throughout the course of this study that relate to this overall question. These were: 1) are width and length indicative of knife class, 2) Is kerf morphology indicative of knife class, and 3) do striations only appear in cuts made from serrated blades?

Several of the characteristics that were examined in the course of this study to answer the questions outlined above proved useful for distinguishing serrated from non-serrated blades for the knife type examined (4.5" steak knife). As mentioned in the previous chapter, length was not used as a distinguishable characteristic, as the morphology of the pig rib affected the length of the cut mark, and obscured any relationship of length to knife class. However, the other characteristics examined (width, kerf shape, and presence of striations) are useful for identifying knife class when examined both macroscopically and microscopically, as well as when examining casts of the cut marks. While each of the characteristics, when used separately, give significant results and classifications rates, they should all be examined in conjunction with the other characteristics available in order to assure that the best and most accurate conclusion is reached for class classification.

The tendency of the cut marks made by the serrated blade to be wider, with a Y-shaped kerf and striations present within the cut could help investigators identify this knife class and assist to narrow down possible weapons or suspects. Additionally, the tendency of cut marks made by the non-serrated blade to be thinner, with a Funnel-shaped kerf and a lack of striations can identify this knife class.

It is important to note that, while the presence of these characteristics may help to identify a cut as made from a serrated or non-serrated blade, the absence of these characteristics does not necessarily assist to identify one class or the other. As mentioned earlier, two additional kerf shapes (V and U) were identified throughout the course of this study, and were not useful in identifying either knife class as they appeared in both. Thus absence of a Y-shaped kerf, for example, does not necessarily mean that the blade was non-serrated, and the same can be said of a cut without a Funnel-shaped kerf. In addition, while the presence of striations proves useful in identifying cut marks made from serrated blades, the absence of striations does not necessarily prove that the cut mark was made by a non-serrated blade, as absence of striations appeared in cuts made from the serrated knife as well. This highlights the point made above that, when available, all characteristics outlined by this study should be used in conjunction with each other to reach the best possible conclusion, and to avoid confusion or misclassification in the absence of any characteristics.

Depending on the materials available to use, both a macroscopic and microscopic analysis should assist in identifying the characteristics unique to knife class. The microscopic analysis did not necessarily add much more to the analysis than the macroscopic analysis as far as recording kerf shape or width, however, it was useful in identifying other characteristics. For example, because the cut marks were so small the presence or absence of striations was not able to be recorded at the macroscopic level, and thus, a microscopic examination was necessary to identify striations within the cut. To not conduct this examination would limit the amount of useful data collected.

In addition, the microscopic analysis revealed several other characteristics that while alone may not be useful in identifying knife class, when coupled with width, kerf shape and presence of striations may assist in distinguishing between serrated and non-serrated blades. Cut marks made from the serrated blade, for example, had a greater tendency to have a roughened, or torn up, kerf floor and in several cases, at least one of the kerf walls was also roughened. This is in opposition to the tendency of cut marks made from the non-serrated blade to have both a smooth kerf floor and smooth kerf walls. Cuts made by the serrated blades were also more likely to cause more damage to the superior surface of the bone where the cut was initially made, and were more likely to have a protrusion of bone at either one or both ends of the cut mark.

Conducting a test of intraobserver error is also useful for assuring that the characteristics outlined by this study will prove useful when examining a cut made from an unknown class of knife. The fact that the test was conducted with a 100% accuracy rate for all of the bones used suggests that the characteristics identified by the researcher for this study are significant and useful for identifying knife class.

The results of this study, when coupled with previous research shows that it is possible to distinguish between cut marks (on bone) made from serrated and non-serrated blades with fairly high accuracy rates.

Implications

There are several implications of this study for forensic anthropology and forensic science application in general. The most important, perhaps, is that it is possible to distinguish between serrated and non-serrated blades when trying to narrow down or identify a possible weapon or suspect in the instance of a stabbing event or crime. Because knife crime is such a prevalent occurrence in the United States, being able to distinguish between and identify knife classes is important. It can also be stated that the prevalence of knife crime is not limited to the United States. In the United Kingdom, for example, a significant amount of knife related research has been conducted (e.g., Jones et al. 1994; Knight 1975; etc.; see CHAPTER II for additional studies). Because of the current gun laws in the United Kingdom, knife crime often outnumbers gun crime, making it the most common form of weapon used in homicides and other crimes (Berman 2011). The prevalence of knife crime in other parts of the world suggest that this study, and other studies related to sharp force trauma, are applicable to a wide range of forensic applications and settings.

The implications of this study are not necessary limited to forensic anthropology alone. In addition to deaths related to knife crime in which the evidence may be seen on the bone, a significant amount of knife crime results in the wounding of, but not death of an individual. If the characteristics in this study, or other characteristics identified by the examination of incised wounds (e.g., Ciallella et al. 2002) are applicable, or can be made to be applicable, in such a context, it could result in being able to identify knife class from wounds in living individuals. This could assist in narrowing down possible weapons, or identifying suspects in instances of attacks or deaths where the remains are not skeletonized.

Investigations into sharp force trauma and knife class characteristics are also applicable to archaeology and bioarchaeology. Several studies have examined the effects of sharp force trauma in this context (e.g., Boschin and Crezzini 2011; Bello and Soligo 2008; Bromage and Boyde 1984) and the ability to differentiate between serrated and non-serrated blades, while applicable to metal instruments such as knives, may also be relevant to the examination of serrated and non-serrated metal instruments and edged stone tools in these situations. This may help bioarchaeologists reconstruct instances of violence if found on human bone, or archaeologists reconstruct subsistence patterns and butchering practices on animal remains.

Limitations and Further Research

It is important to remember that these characteristics have only been identified and tested for one particular type of knife (4.5" steak knife). In order to assure that these characteristics can be applied to all types of serrated and non-serrated knives (i.e. pocket knives, utility knives, chef's knives) this experiment should be repeated using different knives. In addition, there are several classes of knives which were not included in this study, such as the microserrated knife (Figure 8) or the partially serrated knife (see Figure 9). Because these knives do not fall under the standard serrated or non-serrated, it is would be useful to examine the trauma signatures left behind by these knives as well, to assure that they can also be identified and that a cut mark caused by these knives would not be confused with classically serrated or non-serrated knives.

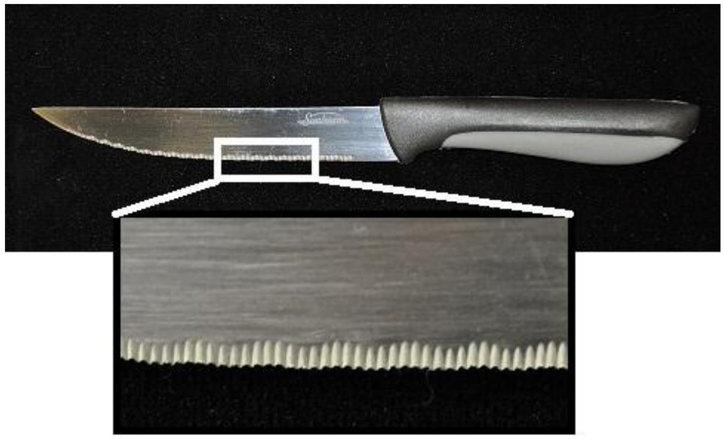


Figure 8: Microserrated blade

Figure 9: Partially serrated blade

Other limitations that have to be considered are the fact that in order to establish a baseline of trauma signatures, the cuts were made directly to bone, without flesh, skin, or subcutaneous fat as a buffer. It is necessary to see how the presence of these would affect the trauma signatures left behind on the bone. Additionally, while the force with which the cuts were made was maintained as much as possible by the researcher during the experiment, it is possible that the force was not truly standardized from bone to bone. While this is likely more realistic in mimicking true stabbing events, it may affect the expression of the characteristics identified throughout the course of this experiment. If a standardization device was employed, the experiment would also be able to examine whether or not the depth of a cut mark is a viable characteristics for distinguishing between serrated and non-serrated blades.

The knives used for this study were newly purchased and used solely for cutting the pig ribs. Additionally, they were only used to make 20 cuts in the bones each, before a new knife was used. This was to limit the confounding variable of use wear patterns on the blades of the knives. It is possible that use wear, such a chipping, on the blade may mimic striation within the cut, so it was necessary to assure that use wear was absent when doing a baseline study. However, because it is possible that in several instances of stabbing, the weapon that is used is one that is on hand, rather than newly purchased, use wear patterns need to be considered when looking at trauma signatures, so that how they may affect cut marks made from serrated and non-serrated blades can be identified.

Finally, it is important to emphasize that this experiment was conducted on ribs only. Ribs were chosen because the chest is the most common area for an individual to have been stabbed (Schmidt and Pollak 2006; Ormstad et a 1986). It is necessary to see if the characteristics identified in this study are applicable to other bones in the body that are also common areas for stabbing incidents, such as the vertebrae and the scapulae (Schmidt and Pollak 2006; Ormstad et a 1986).

Recommendations for Practicing Forensic Anthropologists

In summary, this study suggests the following methodology for the recording and identification of sharp force trauma in bone:

- The bone should be cleaned of adhering tissue and fat so that direct examination of the cut mark is possible.

- Measurements of the width of the cut mark should be recorded. This measurement should be taken from the edges of the kerf wall at the widest point of the cut.
- Kerf shape should be recorded at both a macroscopic and microscopic level if possible. Kerf shapes identified as Y-shaped or Funnel-shaped (based on the characteristics described in this study: see pages 33-34) are significant for the identification of knife class.
- Presence or absence of striations should be recorded at the macroscopic and microscopic levels if possible, as well as examined from a cast made of the cut mark. If a macroscopic examination is not possible, both a microscopic and casted examination needs to be conducted.

Overall, the following characteristics and trauma profiles best represent knife class, and should be used in the determination of a cut mark as coming from a serrated or non-serrated blade:

- Cut marks which have a wide, Y-shaped kerf and have striations recorded as being present are most likely from a serrated blade.
- Cut marks which have a narrow, Funnel-shaped kerf and lack striations are most likely from a non-serrated blade.

CHAPTER VI

CONCLUSION

Overall, the examination of sharp force trauma and specifically trauma caused by knives, whether serrated or non-serrated is a necessary and applicable field of study. Given the prevalence of knife crime and the number of deaths that result from knife attacks, it is necessary to conduct studies to establish trauma profiles for these weapons. In recent years, there have been several studies published related to the identification of several different kinds of sharp force trauma, but the literature of the differentiation of serrated and non-serrated knives is limited. This study attempts to fill that gap by examining the difference between these two knife classes in order to establish the characteristics available to distinguish these blades. This study succeeds in identifying three main characteristics which can be used to identify trauma caused by serrated and non-serrated blades. These characteristics are:

- The width of the cut mark, as measured at the widest point of the cut mark, on the kerf walls; the presence of a Y-shaped or Funnel-shaped kerf; and the presence or absence of striations.
- Cut marks made from the serrated blade in this study suggest the following trauma profile: a width above .60 mm, a Y-shaped kerf, and the presence of striations.

- While the Y-shaped kerf or striations may not always be present within the cut, the width was shown to never fall below .60 mm for all cut marks. In addition, a Y-shaped kerf appeared only once in those cuts made from the non-serrated blade, and possible striations occurred 4 (of 96) times when casted, the overwhelming prevalence of these characteristics suggest that if they are present in a cut mark it was likely caused by a serrated blade.
- Those cut marks made from the non-serrated blade suggest the following trauma profile: a width below .50 mm, a Funnel-shaped kerf, and the absence of striations.
- While the absence of striations occurred in the majority of cut marks made from this blade, they also occurred in cuts made from serrated knives (28 of 100 at the microscopic level, and 24 of 100 times when casted). This suggests that absence of striations alone may not necessarily assist investigators in identifying non-serrated trauma; however, when coupled with the additional characteristics, it is a useful measure. A Funnel-shaped kerf did not appear in any cuts from the serrated blade, and only in 2 instances did a cut from a non-serrated blade have a width greater than .50 mm (however, both fell below .55mm).

This study proves that it is possible for investigators to accurately identify knife class as either serrated of non-serrated, for this knife type, based on the trauma that they leave behind on the bone. In addition, the characteristics identified by this study (width, kerf morphology, presence of striations) has the potential to help identify knife class for additional knife types if further research is done in this area to test if they maintain the same patterns when the weapon changes (i.e. using a larger knife). This research is applicable to the field of forensics because it may be able to help investigators narrow down suspects or possible weapons in the instances of knife crime and trauma.

APPENDIX A

DATA COLLECTION FORM

Date: __________ Bone Designation:___________ Knife Class:____________

Initial Examination:

Kerf Length:__________ Kerf Width:________

Presence of striations:_____________________ Kerf Shape ______________________

Notes:____
____

Microscopic Examination:

Presence of striations:_____________________ Kerf Shape ______________________

Notes:____
____

AccuTrans Initial Examination:

Presence of striations:_____________________

Notes:____
____

AccuTrans Microscopic Examination:

Presence of striation:______________________

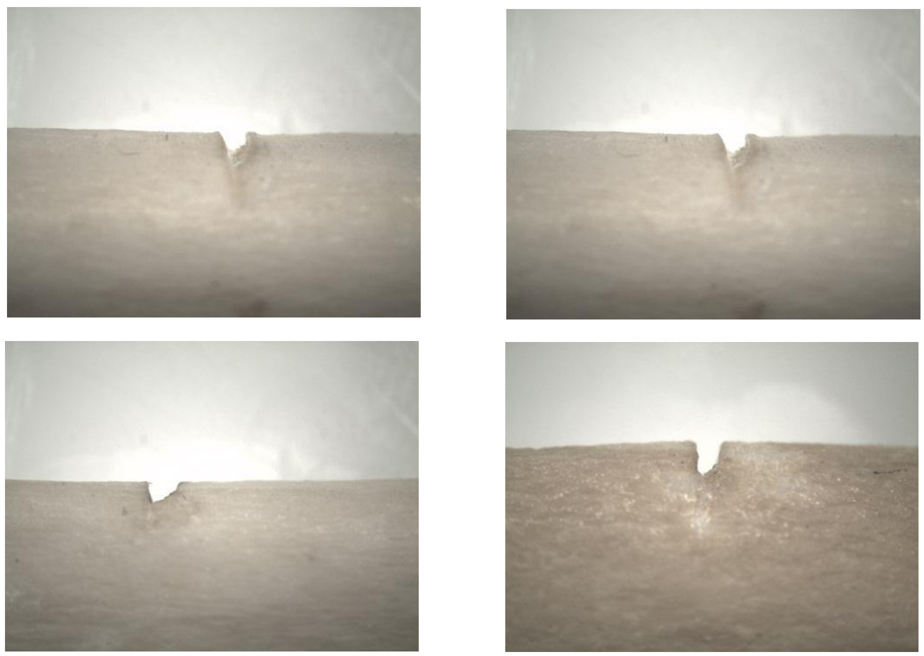
Notes:____
____

Additional Notes or Comments:

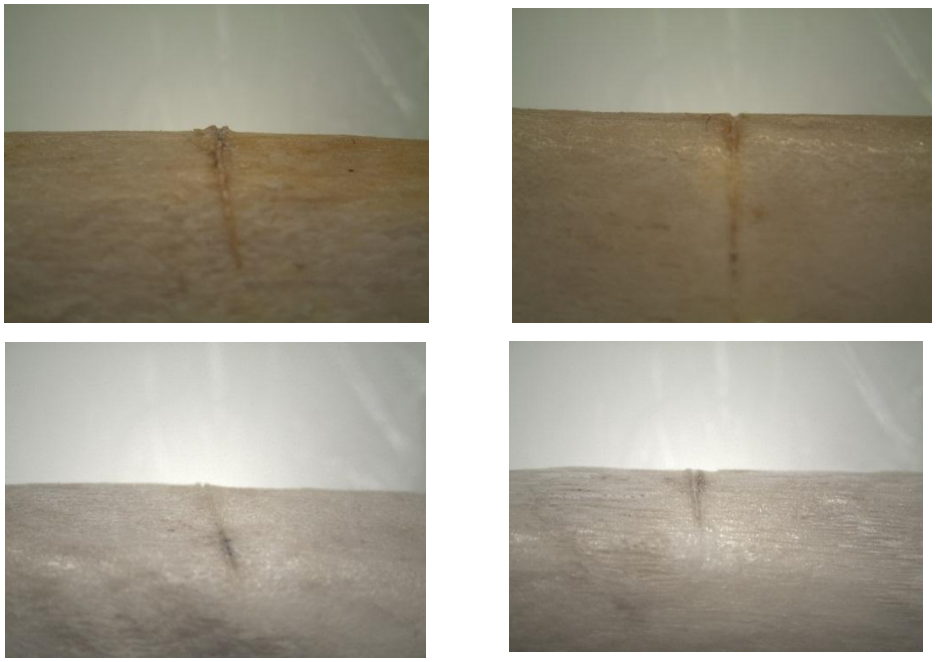
APPENDIX B

EXAMPLES OF KERF SHAPES

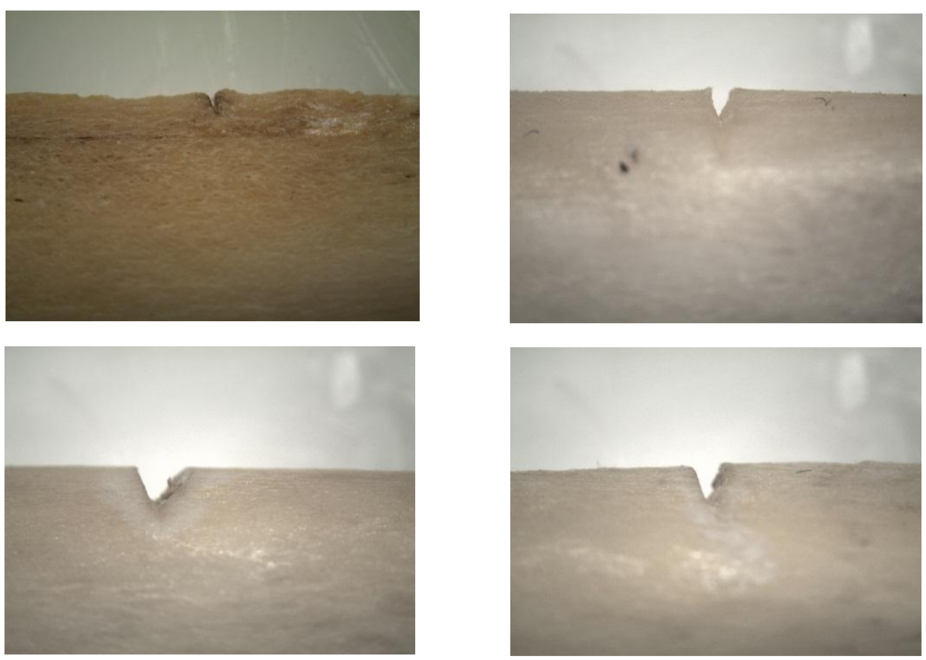
Y-shaped kerf:



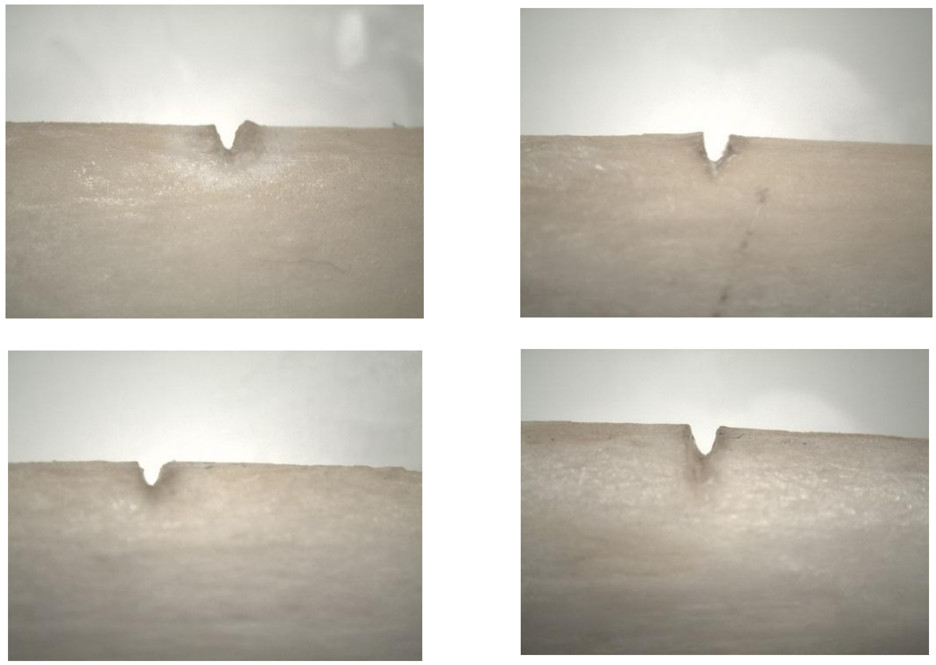
Funnel-shaped kerf:



V-shaped kerf:



U-shaped kerf:



APPENDIX C

CHI-SQUARE MATHEMATICAL CALCULATIONS

Kerf Shape	Observed	Expected	O-E	$(O-E)^2$	$(O-E)^2/E$
Y	77	24.75	52.25	2730.0625	110.3056
Funnel	0	24.75	-24.75	612.5625	24.75
U	3	24.75	-21.75	473.0625	19.1136
V	19	24.75	-5.75	33.0625	1.3359

Chi-square: Goodness of Fit Test, kerf shape, serrated – macroscopic

Kerf Shape	Observed	Expected	O-E	$(O-E)^2$	$(O-E)^2/E$
Y	0	22	-22	484	22
Funnel	76	22	54	2916	132.545
U	0	22	-22	484	22
V	12	22	-10	100	4.545

Chi-square: Goodness of Fit Test, kerf shape, non-serrated – macroscopic

Knife Class	Observed	Expected	O-E	$(O-E)^2$	$(O-E)^2/E$
Serrated	77	38.5	38.5	1482.25	38.5
Non-serrated	0	38.5	-38.5	1482.25	38.5

Chi-square: Goodness of Fit Test, Y-shape frequency – macroscopic

Knife Class	Observed	Expected	O-E	$(O-E)^2$	$(O-E)^2/E$
Serrated	0	38	-38	1444	38
Non-serrated	76	38	38	1444	38

Chi-square: Goodness of Fit Test, Funnel-shape frequency – macroscopic

Kerf Shape	Observed	Expected	O-E	$(O-E)^2$	$(O-E)^2/E$
Y	81	24.75	56.25	3164.063	127.841
Funnel	0	24.75	-24.75	612.5625	24.75
U	1	24.75	-23.75	564.0625	22.79
V	17	24.75	-17.75	315.0625	12.798

Chi-square: Goodness of Fit Test, kerf shape, serrated – microscopic

Kerf Shape	Observed	Expected	O-E	$(O-E)^2$	$(O-E)^2/E$
Y	1	23.25	-22.25	495.0625	21.293
Funnel	81	23.25	57.75	3335.063	143.444
U	1	23.25	-22.25	495.0625	21.293
V	10	23.25	-13.25	175.5625	7.551

Chi-square: Goodness of Fit Test, kerf shape, non-serrated – microscopic

Knife Class	Observed	Expected	O-E	$(O-E)^2$	$(O-E)^2/E$
Serrated	81	41	40	1600	40
Non-serrated	1	41	-40	1600	40

Chi-square: Goodness of Fit Test, Y-shape frequency – microscopic

Knife Class	Observed	Expected	O-E	$(O-E)^2$	$(O-E)^2/E$
Serrated	0	40.5	-40.5	1640.25	40.5
Non-serrated	81	40.5	40.5	1640.25	40.5

Chi-square: Goodness of Fit Test, Funnel-shape frequency – microscopic

	Observed	Expected	(O-E)	$(O-E)^2$	$(O-E)^2/E$
Serrated (Presence)	72	36.9231	35.0769	1230.3889	33.3231
Serrated (Absence)	28	63.0769	-35.0769	1230.3889	19.5062
Non-Serrated (Presence)	0	35.0769	-35.0769	1230.3389	35.0769
Non-Serrated (Absence)	95	59.9231	35.0769	1230.3889	20.5328

Chi-square: Test of Independence, presence of striations – microscopic

	Observed	Expected	(O-E)	$(O-E)^2$	$(O-E)^2/E$
Serrated (Presence)	76	40.8163	35.1837	1237.8927	30.3283
Serrated (Absence)	24	59.1837	-35.1837	1237.8927	20.9161
Non-Serrated (Presence)	4	39.1837	-35.1837	1237.8927	31.5920
Non-Serrated (Absence)	92	56.8163	35.1837	1237.8927	21.7876

Chi-square: Test of Independence, presence of striations - casted

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