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From Trauma to Trial: Proposing New Methods for Examining the Variability of Sharp Force Trauma on Bone

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FROM TRAUMA TO TRIAL: PROPOSING NEW METHODS FOR EXAMINING THE VARIABILITY OF SHARP FORCE TRAUMA ON BONE

A Thesis

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In Partial Fulfillment

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Master of Arts

by

Amanda D. Feldman

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FROM TRAUMA TO TRIAL:
PROPOSING NEW METHODS FOR EXAMINING THE VARIABILITY OF SHARP FORCE TRAUMA ON BONE

by

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APPROVED FOR THE DEPARTMENT OF ANTHROPOLOGY

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ABSTRACT

FROM TRAUMA TO TRIAL: PROPOSING NEW METHODS FOR EXAMINING THE VARIABILITY OF SHARP FORCE TRAUMA ON BONE

By Amanda D. Feldman

Although sharp force trauma is not the most common form of homicide in the United States, it accounts for the majority of violent crimes committed in the United Kingdom, and the frequency of knife related crimes has been increasing over several decades. Despite the prevalence of sharp force trauma in forensic literature, there is still a large gap linking weapons to skeletal injuries. Although there have been forensic studies on the effects of fabric during decomposition, very little data exist on the effects of fabric and bodily coverings on wounds during stabbing events. In a significant number of homicide cases, victims are clothed. Therefore, understanding the effects of bodily coverings is crucial to better understanding a number of forensic contexts. In this thesis, a preliminary pilot study and a skeletal cut mark analysis study with a guided-drop impacting device were used to address this issue by analyzing the effects of fabric resistance during stabbing events. The results indicated that weapon type and fabric type significantly altered kerf mark appearance ($p<0.05$). Weapon type had a significant effect on kerf wall gradients, marginal distortion, width, and depth ($p<0.05$). Fabric type significantly altered wall gradients, width, and depth ($p<0.05$). Finally, low powered standard light microscopy was shown to be an accurate and inexpensive method for examining cut marks on bone.

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CHAPTER 1: INTRODUCTION

1.1 Problem Statement

Although sharp force trauma is the second most common cause of violent deaths just under ballistic injuries in the United States and the most common form of homicide in the United Kingdom, there is a dearth of studies examining the effects of fabric and flesh during stabbing events (Symes, Kroman, Myster, Rainwater, & Matia, 2006). Statistics released by the National Crime Victim's Survey (NCVS) reveal that crimes involving knives or other sharp objects accounted for 25% of annual crimes between 1993 and 2001 in the United States (Perkins, 2003). The NCVS reported in 2009 that crimes using guns and crimes using knives occurred in relatively equal frequency (Truman & Rand, 2010). According to the Department of Justice report, knife crime comprised 13% of crimes between the years of 2002 and 2008 (DOJ, 2010). It is important to note that the variation in frequencies of knife crime reported to the NCVS and the Department of Justice differ due to different methods of gathering information. The Department of Justice gathers information based on reports made to law enforcement whereas the NCVS reports crime based on the UC Census Bureau by talking with individuals and instances in which they experienced crime, whether or not it was reported to the police. The higher percentage of knife related crimes reported by the NCVS suggests that knife crimes may not be reported as frequently to law enforcement, and they may be more common than the statistics indicate. Due to the prevalence of sharp force trauma in crime, it is crucial to be able to identify characteristics of sharp force trauma to narrow down possible weapons and suspects during investigation.

Sharp force trauma homicides resulting from domestic violence are a common occurrence in forensic cases, and such scenarios need to be addressed in current research. Data collected from the FBI's Homicide Report in 2011 indicated that 94 percent of female victims (1,509 out of 1,601) were murdered by a male they knew. Sixteen times as many females were murdered by a male they knew (1,509 victims) than were killed by male strangers (92 victims). For victims who knew their offenders, 61 percent (926) of female homicide victims were wives or intimate acquaintances of their killers. According to an analysis of 2011 homicide data, women are far more likely to be killed at home than in any other locale. The study also reports that knives and other cutting instruments accounted for 20 percent of all female murders. Stabbing incidents occur in a variety of locations and circumstances, but access to knives and other cutting instruments is likely in most homes. Regardless of locale, knives are used in a variety of circumstances because they have the advantage of being easily explained and concealed (Ferllini, 2012). Because many homicides occur in homes and with common instruments found in homes, appropriate forensic analyses of these scenarios are necessary in addition to previous research in other locales (Violence Policy Center, 2013).

Research has often focused on ballistic trauma over sharp force trauma; however, the prevalence of knife trauma, especially when access to guns is limited, is an area of much needed research. There have been several diagnostic characteristics identified by previous research conducted on kerf shape, referring to the shape of walls of a cut mark in relation to the floor after blade penetration, and the presence of striations (Bonte, 1975; Tegtmeyer, 2012; Thompson & Inglis, 2009; Figure 1). This current study is a modified replication of previous studies conducted on sharp force trauma with the addition of clothing and bedding fabric and skin variables that were often unaccounted for in previous studies.

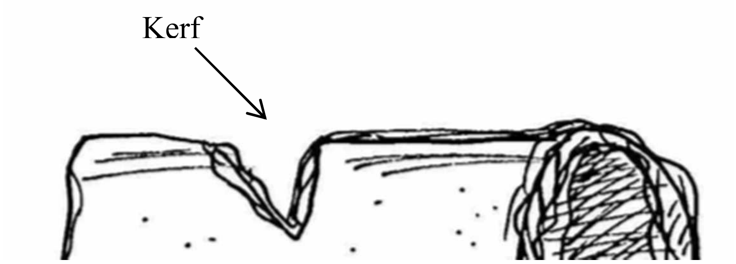


Figure 1. Example of a kerf; Superior view. © 2015 Amanda Feldman

1.2 Significance of Study

Aside from the importance of understanding sharp force trauma during homicide investigations, making sure standards are accurate is essential. The intellectual merit of this study contributes to Daubert standards of sharp force trauma analysis used in a court of law as well as academic theory on trauma. There is a lack of consistent data on cut mark analysis, and the majority of research focuses on class characteristics of weapons. Furthermore, there is an abundance of contradicting and ambiguous data, and many studies fail to adequately address significant issues in the field, such as the ability to identify and accurately link cut mark characteristics with weapons.

The broader impacts of this research extend beyond academic research and the ability to aid with forensic analyses. Understanding motives of domestic abusers can provide new dialogue on domestic violence and improve outreach and resources. Information myths about availability and access to resources is a reoccurring problem, especially since many victims do not want to be labeled as a “battered spouse” or even feel unworthy of leaving due to drug or alcohol addiction. Understanding such patterns is necessary for piecing together events that may have occurred during the homicide. While women are more likely to use knives to kill and men are more likely to use guns, women appear to be killed by knives more often. Such discrepancies between statistics and observations can alter forensic investigations on motives of murder.

This research was designed to expand upon academic research and provide educational opportunities to examine cut marks while including flesh and fabric variables and determine whether they alter the penetrative ability of weapons. By examining realistic forensic scenarios, this study applies relevant data on crime patterns to experimental methods of knife wound analysis to strengthen the expertise of analysts in the field.

1.3 Research Context

Knife wound analysis has received relatively less attention in crime scene investigations than ballistic injuries (Symes, Smith, Gardner, Francisco, & Horton, 1999; Thompson & Inglis, 2009), and widespread use of misleading descriptors, such as “sharp,” “single-edged blade,” and “hesitation mark” (which inaccurately emphasizes behavior), can result in serious misinterpretations by law enforcement officers, judges, attorneys, and juries. Due to discrepancies in standards, misleading information is often taught to forensic students, such as the claim that a lack of features in knife-injuries would never rule out serrated knives (Symes et al., 2006). This alters the accuracy of current sharp force trauma methods and leads to a lack of research into tested and validated standards. Having accurate measures and proper documentation and analysis is crucial to forensic investigation. After publication by the National Research Council addressing severe flaws in forensic research, a conference was organized and determined that more research on accuracy and error rates is needed to determine sources of potential bias (Shermer, 2015). The purpose of this research is to address current standards on sharp force trauma and examine the implications of fabric and skin variables in relation to knife-wounds on bone.

By including fabric resistance variables in this study, more accurate analyses of forensic data may be provided to forensic anthropologists. In a large proportion of homicide cases, victims are wearing or are wrapped in various types of fabrics and clothing. Most research that has been conducted on sharp force trauma wounds has not included fabric variables and this is not representative of actual forensic scenarios (Carr & Wainwright, 2011; Croft & Ferllini, 2007; Daeid, Cassidy, McHugh, 2008; Ferllini, 2012; Kemp, Carr, Kieser, Niven, & Taylor, 2009). Moreover, due to the prevalence of fatal homicides in domestic violence disputes, which often occur in the bedroom, an analysis of bedding fabric along with common clothing fabrics may provide useful forensic information which may better aid in homicide investigations and postmortem interval determination (Violence Policy Center, 2013).

In order to assess whether fabric significantly alters the mechanics of knife wounds, this research poses two main research questions:

RQ1. *Are the cut mark characteristics observed on bone in this experimental study consistent with findings in previous studies?*

This statement refers to the accuracy of commonly observed characteristics. Such features include length, width, cross-section, margins, walls, floor, projections, debris, and lateral ridging of cut marks. These characteristics were observed in previous studies. Lateral riding was described in the study by Alunni-Perret et al. (2005), differing from the "shoulder effect" characteristics observed by Shipman and Rose (1983) that refers to the presence of a secondary mark rather than raising on the sides of the kerf. Striation characteristics were categorized by Loe and Cox (2005) to describe scraping marks on the bones. Cross-section shape has been described in several studies by Potts and Shipman (1981), Blumenschine et al. (1996), Symes (1992), and Symes et al. (2010). However, much of this research has focused on nonserrated blades. Serrated cross-section profiles have not been consistently studied (Tegtmeyer, 2012; Tennick 2012). Extremities, margins, floor and kerf wall features have been described in studies by Alunni-Perret et al. (2005), Symes et al. (2010), and Wenham (1989) to distinguish between hatchet and knife trauma. Mark dimensions such as length and width were described by Lewis (2008), and a relationship was observed between blade type and kerf width. Diagnostic kerf shapes were categorized by Humphrey and Hutchinson (2001) and Lewis (2008). Finally, debris characteristics have been examined in studies by Potts and Shipman (1981), Blumenschine et al. (1996), Humphrey and Hutchinsion (2001), Alunni-Perret et al. (2005) and Lewis (2008).

It is important to know whether characteristics correspond with or deviate from specific weapon and blade types in best case scenarios before testing outside variables. If cut mark characteristics can be continuously and accurately observed on remains, it is reasonable to conclude that these characteristics will be diagnostic features, meaning that these features can be used to classify weapon and blade types. If there are differences in patterns, these patterns can be addressed in further tests.

RQ2. *Are standard cut mark characteristics observed on bone and cartilage altered in size, shape, or morphology when both fabric and flesh are present?*

This refers to the ability to classify characteristics of cut marks and ultimately observe differences in patterns between unclothed and clothed remains. Are there differences in the listed features (length, width, cross-section, margins, walls, floor, projections, debris, lateral ridging) when fabric is present? Do some fabrics cause the blade to respond differently than other fabrics?

1.4 Aims of Thesis

This study centers on the identification of cut mark features to attempt to identify and link weapons to unknown marks on bone and cartilage. Five instruments (including a serrated knife, a scalloped knife, a nonserrated knife, a screwdriver, and pocketknife) were used to inflict sharp force trauma on porcine, or pig, (*Sus scrofa*) ribs. Patterned knives/blades are specifically defined as knives or blades with teeth, such as steak knives or bread knives. Knives with a scalloped edge have a saw-toothed edge with wider teeth than a serrated blade measuring more than 1 mm wide. Knives with a serrated edge have a saw-toothed edge with individual teeth measuring 1 mm or narrower. A knife with a tapered edge or fine edge has a smooth, un-patterned edge to provide a fine cutting edge (Tennick, 2012).

The tools were purchased based on the premise that household kitchen knives, folding pocketknives, and screwdrivers are the most commonly utilized weapons in sharp force injuries (Schmidt & Pollak, 2006). The research questions of the study center on whether or not: (1) knives and other sharp instruments can be categorized through potential characteristics of cut marks, defined as incised marks created by a slicing motion of a tool where the blade travels parallel to the surface (Tennick, 2012), made on a surface medium; (2) features of cut marks on bone and cartilage can then be examined microscopically and used to devise categorization criteria; (3) kerf features, referring to the channel formed by the progression of a blade through bone which make up the walls and floors of a cut mark (Symes, 1992), can be associated with features of knives and sharp instruments; (4) skin tension has a direct effect on force and energy for knife penetration; and finally, (5) clothing and other fabric forms produce variables on degree of penetration and factors of resistance.

In the current study, five sharp force trauma instruments, five different fabrics (including cotton bedding fabric, cotton t-shirt fabric, jean drill, polyester/cotton blend fabric, and satin fabric), and a guided drop impacting device were used to make consistent cut marks on porcine ribs. The objectives of this study included: (1) the testing of various knives and sharp instruments to produce marks on bone to determine the feasibility of classification criteria; (2) the testing of fabric types on the degree of resistance of knife penetration; and (3) the determination of particular features (if feasible) that can be used to create classification criteria in order to diagnose potential weapons from the examination of unknown cut marks on bone.

This research seeks to answer the question of whether knives and screwdrivers can be categorized and identified from marks on bone through kerf feature analysis. The study focuses on three main hypotheses which center on the ability to classify cut marks on bone and the confirmation that factors such as skin and clothing affect the degree of knife penetration. The hypotheses state that:

H_1. Fabric alters the cut marks left on bone by creating marks with shallower wall gradients, increased marginal distortion, and cut marks with a decreased width and depth.

H_2. The elasticity of flesh causes cut marks on fleshed skeletal remains to be more rounded than on defleshed bone.

H_3. Single-edged blades will cause splitting, nonserrated blades will produce clean-cut incisions, serrated blades will produce striated incisions, and screwdrivers will produce wide, U-shaped incisions on fleshed and clothed remains.

The null hypotheses (H_0) of this research state that fabric does not alter the penetrative ability of weapons, the elasticity of skin does not affect cut mark shape, and incisions on fleshed and clothed remains are not affected by blade type.

Criteria used to analyze the cut marks made on bone include the analysis of kerf morphology, class weapon characteristics, individual weapon characteristics, and striation patterns. Kerf morphology or kerf shape refers to the shape of the kerf walls in relation to the kerf floor after blade penetration (Figure 2). Class characteristics can be defined as features that can be used to place subjects or objects into a particular group while individual characteristics are features that can be used to distinguish a subject or object from other subjects or objects of the same class with a high degree of certainty (Tegtmeyer, 2012; Tennick, 2012).

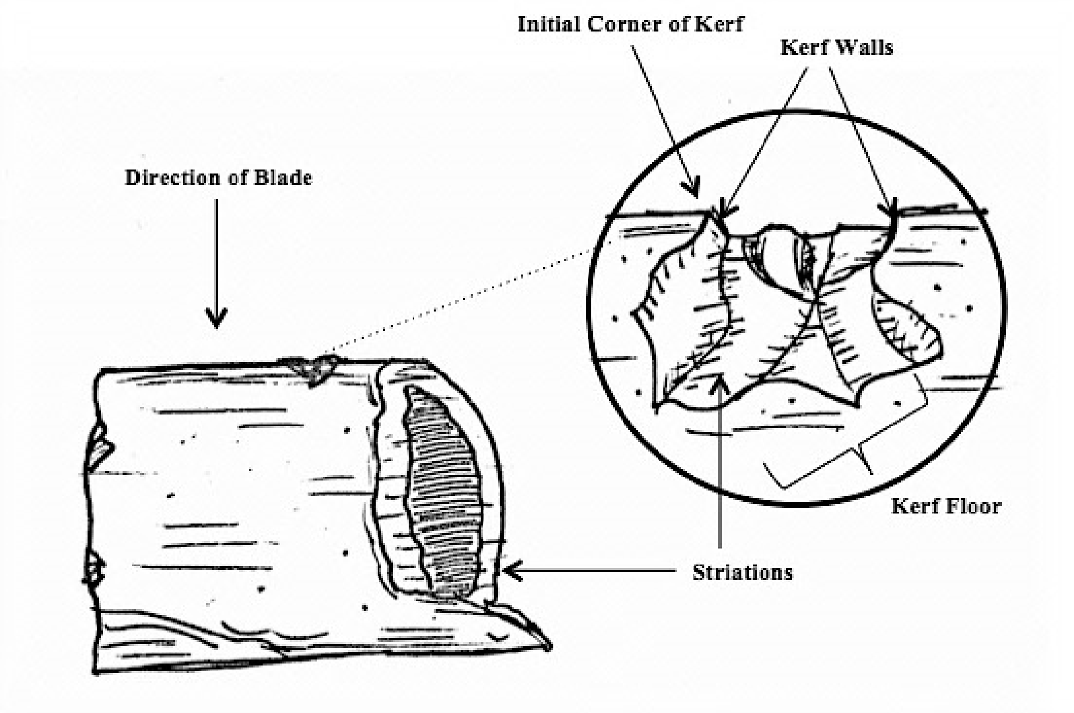


Figure 2. Kerf schematic. © 2015 Amanda Feldman

CHAPTER 2: LITERATURE REVIEW

2.1 Introduction

Research into sharp force trauma mechanisms and characteristics can be categorized into four main types of analyses. These analyses include studies focusing on identification and analysis of tool marks in bone and cartilage, research into the elements of sharp force trauma (not including knife trauma), research focusing on knives (including serrated, partially serrated, and nonserrated knives), and validation studies that focus on the implications of research related to the admissibility of forensic evidence in court following the 1993 court ruling of *Daubert v. Merrell Dow Pharmaceuticals, Inc.*, signifying the importance of releasing validation studies that examine the methods currently used in the forensic field (Tennick, 2012). In the post-Daubert era, many anthropological and decompositional assumptions have been reconsidered to make criteria more quantifiable and acceptable in court (Smith, 2014).

The examination of sharp force trauma on bone in forensic settings is generally conducted within the field of forensic anthropology. Forensic anthropology is a branch of physical anthropology that focuses on the identification of human skeleton remains, often during crime scene investigations. Physical anthropology stems from biological theory and anatomy and contains an evolutionary component to explain the complexities of human life. Though sharp force trauma studies have become monumental in aiding forensic investigations, the history of sharp force trauma research began in archaeological contexts rather than within the field of forensics. These studies largely focused on reconstruction of butchery techniques and distinguishing between marks produced through taphonomic processes and those produced by human elements. Forensic analysis of sharp force trauma is a much more recent application of this discipline.

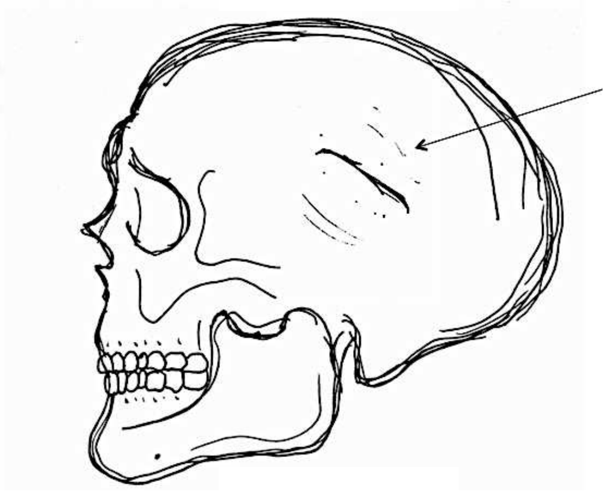
The epistemological and historical development of the anthropological field has thus led to application of specific fields of knowledge in medicolegal contexts. Forensic anthropologists are specialists in human skeletal morphology and are trained in recognizing patterns of normal or abnormal skeletal morphology, including the effects of trauma in ways that other practitioners are not. Forensic anthropologists have traditionally aided in explaining traumatic injuries due to violent deaths and often assist in cases of identification of skeletal trauma, criminal prosecution, and human rights advocacy (Tidball-Binz, 2008). Aided by the expertise of forensic anthropologists, analysis of knife marks can be applied to forensic investigation with the application of Edmund Locard's Principle (1910) that asserts that tool marks profile the shape, nature, and characteristics of weapons (Shaw et al., 2011).

2.2 Skeletal Trauma Characteristics

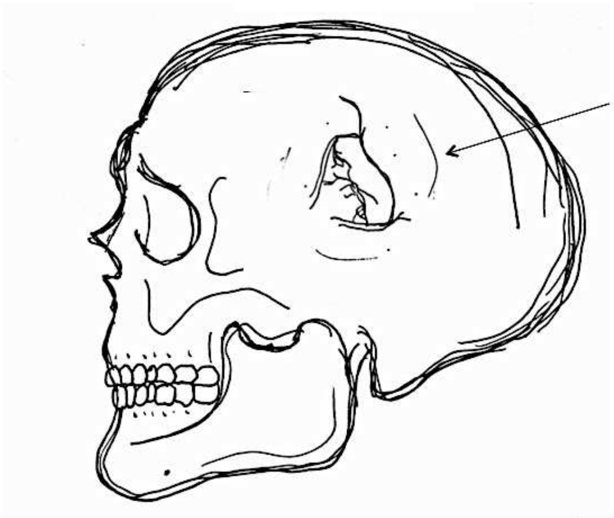
Skeletal trauma is caused by the application of energy on a continuum from high to low levels of input on the human body. Skeletal trauma tends to occur via sharp force application, differing from blunt force application, depending on factors such as directionality, velocity, and focus of impact (Table 1). The aim of the forensic anthropologist is to determine the nature of the trauma, the number and order of impacts, and the time at which injuries were sustained (antemortem, perimortem, or postmortem) (Byers, 2009). Tool marks are defined by the American Association of Firearm and Toolmark Examiners as marks produced when a tool or object is placed against another object and force is applied so that an impression is made (Puentes & Cardoso, 2013). Sharp force trauma specifically refers to injury resulting from an instrument with a sharp edge or point and involves a combination of high and low energy levels of input with force applied over a narrow focus of impact (Byers, 2009). Common mechanisms of sharp force trauma include the use of knives, machetes, axes, hatchets, ice picks, saws, and bite marks. Wounds characterized by sharp force trauma can be defined as punctures, clefts or notches, and incisions. Punctures are defined as marks indicative of instruments placed at a vertical direction to the bone surface and may exhibit a conical shape (Byers, 2002). Clefts and notches are marks caused by a vertically applied dynamic force with an instrument that has a long, sharp edge (Byers, 2002). These marks are indicative of hacking trauma created by axes, cleavers, or machetes (Byers, 2002). Incisions are wounds that are longer than they are wide resulting from force that is applied across the surface with an instrument containing a long, sharp edge (Symes, Chapman, Rainwater, Cabo, & Myster, 2010).

Table 1.

Summary of Characteristics Observed for Blunt Force and Sharp Force Trauma. © 2015 Amanda Feldman



Incised Wound: Sharp Force Trauma
Edges cleanly defined
No bruising
Uniform depth
No tissue bridging
Scoring or chipping of bone
Fine scarring



Laceration: Blunt Force Trauma
Edges jagged and irregular
Bruising and abrasions present
Varied depth
Tissue bridging
Possible fracturing
Extensive scarring

Sharp force trauma wounds on soft tissue differ from wounds and effects exhibited on bone. Sharp force trauma injuries on skin are referred to as incised wounds and can establish weapon type by wound shape, edge characteristics, and possibly by comparison of remaining fragments of the weapon within the wounds. Incised wounds have certain characteristics, such as clean-cut and well-defined edges free from contusions, the width is greater than the edge of the weapon, the length is greater than the width and depth, the cut is spindle-shaped, shows more hemorrhaging, is deeper at the head of the wound and becomes increasingly shallow, and exhibits edge bevel depending on the blade angle. Stab wound characteristics include the length of the wound being shorter than the width due to skin elasticity, the depth being greater than the dimension of the external injury, and a clean cut edge. Correlating damage to skin and clothing is often valuable in linking weapons to injuries. However, current literature indicates that characteristics of weapons can be better preserved in bone when compared to soft tissues due to the rigidity of bone and ability to preserve wound shape and dimension (Shaw et al., 2011). In most cases, weapons are identified through macroscopic and microscopic (optical and SEM) analysis of bone.

According to Thompson and Inglis (2009), characteristics of marks that are indicative of weapon type involve the classification of kerf features, wall characteristics, margin characteristics, floor characteristics, and debris characteristics that also depend on blade edge type, anatomy, and class characteristics of blade types. A weapon with two cutting edges tends to produce a wound with sharp edges and clean cuts. Single-edged blades are likely to cause splitting or fishtailing at one end as a result of the blunt back of the weapon. When considering the properties of cortical bone, certain characteristics are more prevalent when examining marks on bone compared to incised wounds. For instance, cut mark shape on bone tends to become more rounded when the weapon is withdrawn due to skin elasticity (Daeid et al., 2008). Furthermore, knife marks are usually narrower than the width because lesions on fresh cortical bone usually close following weapon withdrawal due to the elastic nature of bone (Cerutti et al., 2014).

2.3 Sharp Force Trauma Identification on Bone

Seminal works. Forensic applications of sharp force trauma research became prevalent in literature following the studies conducted by Burd and Kirk (1942) and Bonte (1975). Burd and Kirk (1942) concluded that marks left by an instrument might provide characteristics for identification on mediums, such as wood, metal, or other smooth surfaces. Significant uses of tool mark examination in relation to sharp force trauma weapons were analyzed in studies by Wolfgang Bonte (1975), Walker and Long (1977), Eickhoff and Herrmann (1985), Wenham (1989), Blumenschine et al. (1996), and Thompson and Inglis (2009) in creating diagnostic criteria, though many previous studies were conducted primarily in archaeological contexts. Bonte (1975) determined that sharp force trauma on human bone coincides with the effects implemented on inanimate objects such as wood and metal. Bonte (1975) also identified how striations can be used in weapon identification and noted characteristics left behind by saw blades. Little information is given on classification, but it is stated that features can distinguish tools. These findings were crucial to forensic research because they showed that characteristics left by a weapon are often enough to link items by weapon class. Walker and Long (1977) provided metal tool classification systems in archaeological contexts. In the study, classification criteria for marks on bone were established using experimental tool mark data made with flaked obsidian tools, a steel knife, and a small steel axe. Results indicated that steel knives, steel axes, and obsidian blades with unmodified edges produced V-shaped marks. Coarse and fine-flaked stone tools produced differed cut mark shapes. Potts and Shipman (1981) found kerf cross-section to be a distinguishable cut mark feature. V-shaped marks were found to be diagnostic of blades while tooth marks left U-shaped marks. Studies by Eickhoff and Herrmann (1985) and Blumenshine et al. (1996) were significant to sharp force trauma research in that they distinguished conclusive evidence relating cut marks on bone with scavenger tooth marks, percussion marks, and modern excavation marks. Other principle analyses of sharp force trauma on bone include studies on weapon identification from marks on skin and cartilage (Sitiene Zakaras, Pauliukevicius, & Kisielius, 2006), saw mark and dismemberment analysis (Symes, 1992; Symes et al., 1996), and weapon identification from marks on bone (Houck, 1998; Bartelink, Wiersema, & Demaree, 2001; Humphrey & Hutchinson, 2001; Tucker Hutchinson, Gilliand, Charles, Daniel, & Wolfe, 2001; Alunni-Perret et al., 2005).

Homicide studies. Banasr, de la Grandmaison, and Durigon (2003) examined 58 fatalities due to stab or incised wounds from autopsies performed in 1996-2000 in the Department of Pathology and Forensic Medicine in Garches, France to determine the frequency of the presence of bone or cartilage lesions. The researchers found that bone/cartilage lesions were present in 53% of the cases. Yet, over two-thirds (68.9%) of the fatalities were caused by knives, and thoracic injuries were the most common causes of death in the study. Sitiene et al. (2007) examined 418 homicide cases (205 of the cases included wounds to rib cartilages), in which 835 knives were submitted to identify and link specific tools. Conclusions about instruments were made for 49.7% of total number of instruments submitted, and 40.3%, probability conclusions were made, suggesting that cut mark classification criteria were able to aid in analysis. The tool could not be identified or verified in 10% of the cases. The researchers found that the analysis of dynamic traces in hard tissues supplements skin wound characteristic analysis and is useful to forensic investigation.

Instrument and material studies. Other studies on sharp force trauma also contributed greatly to forensic research. Rao and Hart (1983) examined trauma caused to costal cartilage in a stabbing incident. Casts of both the cuts and a comparison sample made from the suspect's weapon were used to examine the characteristics of the cut marks, resulting in a 100% match in the characteristics of striae found on the victim and the weapon. This research impacted sharp force trauma research by emphasizing the importance of finding and preserving patterns of sharp force trauma and identifying class and individual characteristics to link weapons to injuries. Wenham (1989) can be credited with making one of the first detailed criteria for classification of metal weapons using experimental marks made on archaeological skeletons. The criteria proposed by Wenham (1989) to classify cut marks included: (1) linearity, without the presence of large irregularities; (2) a well-defined and clean edge to the injury; (3) a cut bone surface which is flat and smooth; and (4) the presence of parallel scratch marks on cut bone surfaces.

Other studies examined the effects of sharp instruments on bone and cartilage to various simulants while using different diagnostic methods to identify patterns and characteristics of marks left behind. Gilchrist, Keenan, Curtis, Cassidy, Byrne, and

Destrade (2008) studied the effects of four knives, including a cook’s knife, carving knife, utility knife, and kitchen knife, and a skin simulant to examine the dynamics of skin penetration using two different knife speeds impacted with impact rig. The study included blades that were single-edged, double-sided, and without serrations. The results showed that the marks of each knife were distinct from the other knives. The researchers, however, noted that the study was limited in that it used synthetic skin. Skin tension was also shown to have a direct effect on the force and energy required for knife penetration. Gilchrist el al. (2008) further suggested that quality control processes fail to produce consistently uniform blade tips in knives.

Gibelli, Mazzarelli, Porta, Rizzi, and Cattaneo (2012) studied 14 lesions made on defleshed human radii with 7 sharp instruments to detect metal residues left on bone. The particle composition matched the instrument in 58% of cases. Gibelli et al. (2012) indicated that sharp force trauma frequently leaves relatively few metal residues on bone. Sharp tools often contaminate the specimen by bringing residues from materials that have been previously cut. Although this process results in the contamination of the particle composition from different tools, Gibelli et al. (2012) argue that more information is able to be obtained to link weapons, suspects, and locations to sharp force trauma injuries. Capuani et al. (2013) looked at the accuracy of using epifluorescence macroscopy in sharp force trauma studies. The researchers used human clavicles and three different kinds of lesions and analyzed the marks using light microscopy, SEM, and micro-computed tomography which were compared with epifluorescence macroscopy. Epifluorescence and SEM were shown to be accurate and useful methods, but it was further noted that the cost and degradation of remains tends to make standard light microscopy a more valuable and more commonly used method in sharp force trauma research.

Knife studies. Pounder and Reeder's study (2011) analyzed stab wounds made in porcine cartilage using 13 serrated knives (4 drop-point, 9 straight spine; 9 coarsely serrated, 3 finely serrated, 1 mixed pattern serration). The researchers concluded that all 13 knives produced striations as anticipated in previous research indicating that striations are a characteristic of knife wounds. The study also further showed standard light microscopy to be more valuable and accessible than scanning electron microscopy (SEM) and elemental analysis methods given the amount of information provided by each method. While SEM and elemental analysis can provide more detailed images, the classifying information that can be obtained is not significantly greater than that which can be observed through standard light microscopy, making such costly and degrading processes less valuable in forensic validation studies.

Tegtmeyer (2012) attempted to distinguish between serrated and nonserrated knife marks on 100 porcine ribs. Macroscopic and microscopic examination of bone and casts were used to examine the nature of width, kerf shape, and the presence or absence of striations. The study showed that it is possible to distinguish between the two blade types with a Y-shaped kerf occurring in 78% of marks made with serrated blades when viewed macroscopically and 82% when viewed microscopically and a funnel-shaped kerf present in 86% of marks made with nonserrated blades when viewed macroscopically and 87% when viewed microscopically. Results indicated that striations were present in 72%

of marks made with serrated blades when viewed macroscopically and 76% when viewed from casts of the cut mark. The study showed that it is possible to distinguish between serrated and nonserrated blades by the identification of width, kerf shape, and the presence of striations.

A study conducted by Tennick (2012) sought to propose a classification system for identifying kerfs on bone. Nine blades (including serrated, scalloped, and fine edge knives), and 23 participants were used to make marks on fleshed porcine bone under force-measured conditions. Results showed that consistent force was difficult to achieve, and therefore, marks on bone made by the same knife had wide variation in appearance and depth. Distinct classification features were not able to be obtained, but Tennick observed trends in identifying criteria including margin regularity, margin definition, floor width, and wall gradient.

In a study conducted by Crowder, Rainwater, and Fridie (2013) cuts on a wax medium, porcine cartilage, and porcine bone were examined in 504 observations by serrated and nonserrated blades, noting previous studies attempting to distinguish between marks made by the two. Serrated blades were distinguishable from nonserrated blades due to the presence of patterned striations. However, the study emphasized there was difficulty in distinguishing between some serrated and partially serrated blades, indicating a need for further research. According to Crowder et al. (2013), standard light microscopes, which are typically found in labs, yield the same results as instruments with higher technological capabilities and an increased depth of field is not necessary for determining blade characteristics. Puentes and Cardoso (2013) further examined tool class characteristics with the application of additional variables to be examined on 120 human cartilage samples using three serrated knives. Puentes and Cardoso (2013) noted that though the use of mechanically controlled devices to impact bone can eliminate sources or error, they are not realistic to real forensic scenarios. This study determined that blade penetration angle and variation affected the identification of tool class characteristics, but appeared to be related to bony features such as texture and porosity.

Other studies. The study of metrical characteristics of sharp force trauma was carried out in research by Cerutti, Magli, Porta, Gibelli, and Cattaneo (2014). In this study, the researchers looked at whether it was possible to identify metrical characteristics of a blade based off of measurements of its lesion. One hundred and ten lesions on porcine femurs and 11 blades were used in the study. Results showed that there appeared to be correlations with the width and angle of lesions and the angle of the blade as well as the angle of lesion and the height of the blade.

The correlation between impulsive force, V-shape tool mark angle, and elasticity coefficients was examined in research by Shaw et al. (2011). The researchers examined knife chop marks on porcine skulls using a digital microscope and concluded that mapping dimensions of marks can help identify the shape and type of knife. The κ value (θ/ψ) was defined as the elasticity coefficient obtained after the knife angle (θ) and the V-shape tool mark angle (ψ) were compared. Impulsive energy ($kg\text{-}m^2/s^2$) was calculated by multiplying knife's gravity force and designated height in each trial. The study found that flat-grind blades produced different shapes from those made by chisel-grind blades.

There also appeared to be positive linear correlations between the elasticity coefficients and impulsive forces calculated.

2.4 Miscellaneous Weapons

Hacking trauma. Characteristics of marks and fractures caused by axes, hatchets, and machetes are categorized as wounds caused by hacking trauma. Weapons that produce hacking trauma tend to have a sharp blade edge that increases in size as it extends to the incised edge, usually in a wedge shape (Tegtmeyer, 2012). In a study conducted by Humphrey and Hutchinson (2001) examining macroscopic characteristics of hacking trauma, it was found that different instruments display several differentiating characteristics. For instance, cleavers tend to produce narrow cuts without fracturing while machetes create medium cuts with fractures present (Humphrey & Hutchinson, 2001).

Alunni-Perret et al. (2005) reported that microscopic analyses determined that characteristics examined were indicative of sharp force injury and distinguishable from sharp-blunt injury to bone with chopping weapons. The authors also indicated three different classes of hacking trauma differentiated by size, shape, and the presence of breakage. However, this study used defleshed remains, and it is unclear how the absence of flesh may have influenced the results obtained (Lewis, 2008). In Lynn and Fairgrieve's (2009) study of hacking trauma, it was determined that hatchet wounds can be distinguished from knife wounds by the absence of unilateral elevation of the cortex, corroborating the findings of Alunni-Perret et al. (2005). The findings of Shaw et al. (2011) further suggest that axes and saws produce more damage and more morphologically different patterns than knives. Though studies conducted by Tucker et al. (2001), Alunni-Perret et al. (2005), Reichs (1998), and Wenham (1989) determined that a lack of striations appeared to be diagnostic of axe wounds, Lynn and Fairgrieve (2009) found contradicting results.

Saw mark and dismemberment analysis. Saw mark and dismemberment analysis has provided crucial information for weapon identification in forensic cases. Bonte's (1975) research on striae in bone contributed to research in saw mark analysis by recognizing features of saw cutting strokes. However, the study displayed severe limitations due to the lack of understanding of saw cutting action (Symes et al., 2006). Andahl (1978) conducted a more thorough examination of saw mark analysis and determined criteria to be examined. Such criteria included striation patterns, wave formations, and swarf lips, or the shavings removed from a cutting instrument. Striation patterns are complex and differ from single-action cut marks, appearing as parallel "rills" or grooves that correspond with the serrations of the blade (Andahl, 1978; Bonte, 1975). Wave formations occur during stopping patterns when a saw is released and then the sawing motion is resumed. The distance between the crests indicates distance between individual teeth. Finally, swarf lips can be used to determine directionality (Andahl, 1978).

Symes (1992) was the first researcher to publish extensive research on the topic of saw mark analysis. Symes, Berryman, and Smith (1998) determined the likely trauma created through use of a saw and identified characteristics present when a saw cuts through bone. Morphological features of kerf marks made by saws were also examined and defined. Reichs (1998) identified that most postmortem dismemberment is conducted using axes, saws, knives, or a combination of the three while also addressing the importance of distinguishing between characteristics resulting from different weapons. In this research, Reichs (1998) noted that knives produce narrower cuts in comparison to the wider cuts observed in saws and axes. Saville, Hainsworth, and Rutty (2007) used SEM to analyze characteristics in addition to the already established characteristics of kerf marks. In this study, the authors were successfully able to identify weapons by saw marks made in cases of dismemberment.

Other weapons. Tools other than knives and hacking weapons have been found to have been used in several forensic cases. Croft and Ferllini (2007) examined screwdriver trauma on porcine bones. According to the study, types of weapons used may vary with a perpetrator's socioeconomic and environmental status. The likelihood of using a screwdriver increased when the perpetrator was a younger individual, however, these factors have not been consistently documented (Croft & Ferllini, 2007). Screwdrivers may be used due to accessibility, the fact that they are lightweight and easy to carry, can be carried discreetly, and can be explained easily in comparison to guns and knives. Though flat-tipped screwdrivers tend to be the most commonly used, both flat-tipped and cross-tipped screwdrivers were used, and the study determined it is possible to distinguish marks made between the two. The presence of longitudinal fractures is a possible feature associated with cross-tipped screwdrivers. Cross-tipped screwdrivers also tended to leave a cruciform impression in bone while flat-tipped screwdrivers often left rectangular impressions (Croft & Ferllini, 2007).

Lewis (2008) compared marks made by swords to those made by knives and attempted to distinguish between the two. In the study, it was found that swords exhibit consistent width patterns that vary from knives. Sword marks tend to be wider, deeper, and associated with damage to the walls of the cut while having a straight kerf. Sword marks also often exhibit one smooth and one roughened wall. Swords that are less sharp create square, U-shaped cuts that differ from characteristic V-shaped cuts made by knives. These marks differ from knives in that knives often create long, narrow cuts with a kerf that is not as straight as kerfs associated with sword marks, little damage to the walls, and feathering damage on bone. This study concluded that it is possible to distinguish between knives and swords as well as different classes of swords based on characteristics left behind (Lewis, 2008).

2.5 Distinguishing Between Knives and Other Sources of Trauma

Determining whether marks on bone are a result of knives or other edged tools, such as hacking weapons and screwdrivers, has been examined by researchers in a number of forensic studies (Table 2). The findings of Tucker et al. (2001) classified weapon hacking trauma based on several criteria. Cleavers display fine, thin, distinct and parallel striations while machetes exhibit coarse, thick and more continuous striations, and axes leave behind no striations due to shattering of bone (Tucker et al., 2001; Humphrey & Hutchinson, 2001).

Table 2

Summary of Observed Characteristics for Punctures, Incisions, and Clefts

Characteristic	Punctures	Incisions	Clefts
Cross section	V-shaped	V-shaped	V-shaped
Width	Narrow/wide	Narrow/wide	Wide
Depth	Shallow/medium	Shallow/deep	Medium/deep
Length	Same as width	Short/long	Short/long
Striations	Vertical	Vertical	Horizontal
Fracturing	May be present	Absent	Present
Wastage	Minimal	Minimal	Extensive

Literature on cut mark analysis can also be seen as diagnostic criteria for identifying weapons. As Croft and Ferllini (2007) distinguished between screwdrivers and knives due to the presence of longitudinal fractures and cruciform and rectangular impressions which differed from the V-shaped marks left by knives, different knife marks can be identified and classified. Knife marks can be classified by striations that appear perpendicular to the kerf floor, minimal wastage (defined as fragments of bone which are separated from the main section), and hinge fractures (defined as the portion of bone lifted from the fractured area but still attached to the original source) (Ferllini, 2012). Lewis's (2008) study further distinguished knife marks from other weapons due to the findings that sword marks usually exhibit much more damage to the walls than knife marks.

In addition, knife properties have provided diagnostic criteria for distinguishing between weapons. Knives occasionally terminate at a point and commonly display blade bevel (blade tapering) and at least one area of edge bevel (sharpened edge) (Symes et al., 2006). Box cutters, razor blades, axes, cleavers, and machetes can be classified as types of knife blades while propellers, augers, and tree chippers are not similarly classified (Symes et al., 2006). Saws can easily be distinguished from knives due to the presence of edge bevel on knives that is absent on saws, and cuts made by saws tend to leave a squared cross-section kerf floor with sharpened saws creating W-shaped cross-sections (Symes et al., 2002). Criteria used to distinguish saw marks often include differences in grades of set, such as alternating, raker (comprising of specialized teeth designed to rake sawdust), and wavy, and are not entirely relative to knife blades. However, a few features have the potential to be applied to knife blades, including floor contour, entrance shaving, and kerf flare (Symes et al., 2010). Floor contour is often flat in straight blades, but this refers to a residual curved kerf floor that is left by flexible blades. Entrance shaving occurs as the saw enters the side of the bone, resulting in a polished and scalloped appearance. Kerf flare refers to flaring of a cut mark. Flaring at the end of the cut in the floor is indicative of the handle end of the blade, as the opposite end of the kerf does not exhibit a flare.

2.6 Forensic Analysis of Knife Cut Marks

Forensic examination of marks made by knives on bone has been discussed in terms of comparison between weapon types, such as in saw and dismemberment studies and hacking trauma studies, but there is still a lack of research primarily focusing on knife blades specifically and the following marks created on bone. There have also been several biomechanical forensic studies that have shed light on important factors of knife trauma. Knight (1979) observed that a knife could penetrate skin and subcutaneous fat of the abdomen with three and a half kilograms of pressure. Knight (1979) also found that the sharpness of the knife is the primary variable in the ability of a blade to cut through skin and fat tissues, therefore, sharpness is directly related to the pressure needed to penetrate the soft tissues. It was further determined that other variables, such as the age of victim and area of penetration, tend to affect the ability of a knife to cut through skin and fat. Jones, Nokes, and Leadbeatter (1994) further examined the biomechanics of knife stabs by analyzing the ability of blunt and sharp knives to penetrate soft tissues. The authors found that only the sharp knife was able to cut through the tissues and the ability to penetrate underlying tissues requires substantial force.

Houck (1998) utilized striation analysis to determine whether it was possible to identify specific knives from marks made on bone. One hundred and five bovine tibial shafts were impacted with three different blade types. This analysis focused solely on striation patterns, and Houck came to the conclusion that it was possible to match marks through striation analysis and establish links to weapon types. Bartelink et al. (2001) focused on cut mark width analysis to identify weapons. In this study, a utility knife, a paring knife, and a scalpel blade were used, and marks were then cast and examined. However, the study identified a relationship between blade type and mark width, but there was overlap resulting in misclassification (Bartelink et al., 2001).

In a study conducted by Thompson and Inglis (2009), the researchers examined stab marks rather than incised marks to distinguish between and develop criteria for serrated and nonserrated blades. Cut marks were made on a rib, radius, scapula, vertebrae, and carpal, all porcine bones, with serrated and nonserrated blades. The study showed that serrated blades produced longer and narrower marks with more damage on the specimens than nonserrated blades. Nonserrated blades can be classified by producing T-shaped incisions surrounded by a triangular-shaped depressed region of compact bone. Serrated blades often produce Y-shaped incisions surrounded by a triangular, depressed region while also exhibiting a right lateral curve to the incision. The authors remarked, however, that the sample size was small and marks were made on remains with little soft tissue.

Ferllini (2012) examined characteristics of knife cut marks on clothed and unclothed porcine ribs using three different kinds of kitchen knives and two different stabbing methods, a straight thrust and a downward thrust. The results showed that of the 72 marks, 26 did not hit the bone, 25 (of 36) straight thrusts hit the bone, and 21 (of 36) downward thrusts hit the bone. Several V-shaped marks were observed, but lighter cuts tended to show less of a V-shape kerf than deep cuts. It was also noted that downward thrusts could be characterized by a cone shape due to association with the point of impact.

2.7 Use of Fabric Analysis in Forensic Contexts

While fabric examination has often remained a separate field of analysis in sharp force trauma research, the study of fabric variables and properties can aid in understanding how blades penetrate bone. The forensic examination of apparel became prominent after the Azaria Chamberlain trial in 1980. The case involves the disappearance of the infant Azaria Chamberlain from the family campsite in Ayers Rock, Australia. The mother claimed that she saw a dingo exiting the tent and carrying an object in its mouth. Later, fabric was found, which was determined to have belonged to Azaria. Forensic analysts determined that the damage to the clothing was caused by the cutting action of scissors to simulate canine damage, resulting in the conviction of Lindy Chamberlain for murder with Michael Chamberlain convicted as an accessory after the fact. However, five years later, further examination indicated that dingoes were actually capable of producing the observed damage, thus leading to the release of Lindy and Michael Chamberlain (Kemp, Carr, Kieser, Niven, & Taylor, 2009).

Most research has been carried out on skeletal remains without skin or clothing, which is not representative of actual circumstances. While fabric analysis often assists in investigation surrounding the circumstances of death, fabric has seldom been analyzed in comparison to marks and stab wounds found on skin and bone. Furthermore, the structural stabilization and degradation of fabric altered through laundering has not been highly investigated (Kemp et al., 2009). Sharp force trauma injuries are often accompanied by cutting damage to clothing, therefore, corroborating research can be very useful in linking weapons through the identification of consistent characteristics and features.

Daeid et al. (2008) examined the correlation between knife damage in clothing and skin wounds. Four different types of knives were used on fabric stretched tight and loose over porcine skin, which was then stabbed with an impact rig. Results showed that when the fabric was stretched tight over the skin, significant differences in the length of the wound on skin and fabric were observed. This study demonstrated that skin elasticity significantly affects knife penetration. Because fabric affects the degree of correspondence between measurements of the study, fabrics containing natural fibers (cotton and wool) produced marks with lengths of greater variance to the width of the weapon. Results also determined that a weapon with two cutting edges produced wounds with sharp edges and clean-cut ends. Single-edged weapons caused splitting or fishtailing at one end as a result of the blunt back of the weapon. It was also observed that the shape became more rounded when a weapon was withdrawn due to skin elasticity.

Research on apparel was further carried out by Kemp et al. (2009). The research showed that analysis of damaged apparel can provide information about the cause of death and events leading up to death and after death. Since stab injuries often occur in the chest area and victims are often clothed, these variables were included. This study examined the damage to apparel in stab events by using human impact trials as well as a guided drop-testing device where a blade was dropped to simulate stabbing. Scallops, serrations, and imperfections on the blade increased fabric fraying and distortion. It was concluded that damage was much more variable in human impact trials and more consistent in guided drop trials. However, variable results are more representative of actual forensic scenarios whereas controlled force applications tend to only provide "best case scenarios."

Though Daroux, Carr, Kieser, Niven, and Taylor (2010) analyzed damage to fabric in blunt force trauma impacts, the research provided insight into the behavior of fabrics when laundered and layered before impact. Two 100% cotton fabrics (single jersey knit and bull drill) were stabbed as single and double layers using an impact rig. Fabrics varied between new, dimensionally stable (laundered 6 times), and aged (laundered approximately 30 times) specimens. Results determined that the impact energy was absorbed via several mechanisms: yarn and fiber deformation, bending, flattening, smearing, fracture, and fibrillation (friction between fabric layers). The thickness of fabric also alters the force required to damage apparel. Multiple fabric layers absorb more impact energy than single layers and damage on underlying layers is reduced. Considering whether clothes were worn as layers during trauma can provide insight on potentially missing clothing evidence. Furthermore, the impulse increased with increased laundering. Different fabrics respond differently to identical impacts. Understanding effect of laundering is significant because clothing is often laundered in attempt to remove evidence. Laundering did not destroy evidence of trauma, but rather altered appearance and was more difficult to see macroscopically (Daroux et al., 2010).

Ferllini (2012) analyzed six half porcine torsos that were fleshed and clothed to examine the affect of clothing on cut mark characteristics. Three knife types were used (two straight-bladed and one serrated) while applying both straight and downward thrusts. Pigs were selected in this study as a widely accepted medium comparable to humans due to their similar soft and hard-tissue structure and density. This study also indicated that soft tissue and clothing produce variables on the degree of penetration and factors of resistance. Varied results were obtained with a lack of consistent diagnostic features due to the wide range of patterns, though there was a consistency in patterns between flat edge and serrated knives (Ferllini, 2012).

Mitchell, Carr, Niven, Harrison, and Girvan (2012) did not analyze the behavior of fabric due to trauma, but rather analyzed fabric degradation in burial conditions. The researchers observed properties of laundered and non-laundered fabrics. The study found that the tear force required was weaker after burial regardless of soil type. Regardless, the study is applicable to forensic research when degraded clothing is found on buried remains, especially if the degradation of fabric affected the appearance and properties of sharp force trauma damage present on fabric (Mitchell et al., 2012).

2.8 Summary

Several seminal works on weapon identification and cut mark characteristics have contributed to forensic sharp force trauma research (see Table 3). Studies by Burd and Kirk (1942) and Bonte (1975) examined cut marks on different mediums. Walker and Long (1977), Houck (1998), Bartelink et al. (2001), Humphrey and Hutchinson (2001), Tucker et al. (2001), Alunni-Perret et al. (2005), and Wenham (1989) contributed to developing metal tool classification criteria. Eickhoff and Herrmann (1985) and Blumenshine et al. (1996) were able to distinguish cut marks by activity. Sitiene et al. (2006) conducted research on cut marks on skin and cartilage. Symes (1992) and Symes et al. (1996) contributed to data on saw mark analysis, and Banasr et al. (2003) and Sitiene et al. (2007) examined sharp force trauma in homicide cases. Rao and Hart (1983) analyzed cut marks on cartilage, while Gilchrist et al. (2008) examined cut marks using skin simulants. Gilchrist et al. (2012) examined metal residues left by weapons, and Capuani et al. (2013) provided data on the usefulness of epifluorescence macroscopy in cut mark analysis. Pounder and Reeder (2011), Tegtmeyer (2012), Tennick (2012), Crowder et al. (2013), and Puentes and Cardoso (2013) examined distinguishing characteristics by knife class. Cerutti et al. (2014) investigated metric characteristics of cut marks. Shaw et al. (2011) studied sharp force trauma impact force.

Studies on trauma by weapon type also provided significant contributions to forensic research. Hacking trauma has been examined in studies by Humphrey and Hutchinson (2001), Alunni-Perret et al. (2005), Lynn and Fairgrieve (2009), and Reichs (1998). Saw marks and dismemberment analysis has been studied by Symes (1992), Symes et al. (2006), Andahl (1978), Reichs (1998), and Saville et al. (2007). Croft and Ferllini (2007) analyzed screwdriver marks, and Lewis (2008) analyzed marks made by swords.

Other contributing studies include research on blade metrics and classification criteria by Knight (1979), on the biomechanics of stab marks, Houck (1998) and Bartelink et al. (2001), on cut mark width, and Thompson and Inglis (2009), on the development of cut mark criteria. Studies on fabric variables include research by Ferllini (2012), Daeid et al. (2008), Kemp et al. (2009), Daroux et al. (2010), and Mitchell et al. (2012). Table 3 shows the cut mark characteristics that were observed in several seminal studies on sharp force trauma, the types of microscopy used, and the type of tool used.

Table 3

Previous Findings on Cut Mark Characteristics

			Microscopic Analysis		Observed Cut Mark Characteristics						
Authors	Date	Tool Type	SEM	Low Power	Width	Depth	Striae	Wall and Edge Morphology	Cross-section Shape	Floor	Lateral Ridging
Potts and Shipman	1981	Stone	✓				✓		✓		
Eickhoff and Herrmann	1985	Stone			✓	✓	✓	✓	✓		
Wenham	1989	Metal		✓			✓	✓			
Blumenshine et al.	1996	Stone Metal		✓			✓		✓		
Houck	1998	Bone	✓				✓				
Bartelink et al.	2001	Metal	✓		✓	✓					
Alunni-Perret et al.	2006	Metal	✓				✓		✓	✓	✓
Lewis	2008	Metal		✓				✓	✓	✓	

Note: Check marks indicate the presence of the observed characteristic.

CHAPTER THREE: EXPERIMENTAL DESIGN

3.1 Introduction

Having established the background of previous sharp force trauma studies, certain variables must be considered in the design of the current study. While there are many types of knives, kitchen knife blades are commonly used in sharp force trauma incidents (Hunt & Cowling, 1991; Karlsson, 1998). Few studies have examined knife trauma and weapon characteristics, and many of the studies had very limited samples (Alunni-Perret et al., 2005). This chapter discusses weapon classification, soft tissue considerations, and pilot study results.

3.2 Classification of Weapons

Because kitchen knives are the most commonly used weapons, research focused on kitchen knives and their blade characteristics. A screwdriver was also used during the study as research has indicated that very limited data exist on screwdriver trauma. These weapons were chosen because they are commonly used in homicides and are readily available and easy to purchase (Tennick, 2012). Several knife blade shapes are common and blades can be categorized according to knife edge, knife anatomy, and type (Figure 3).

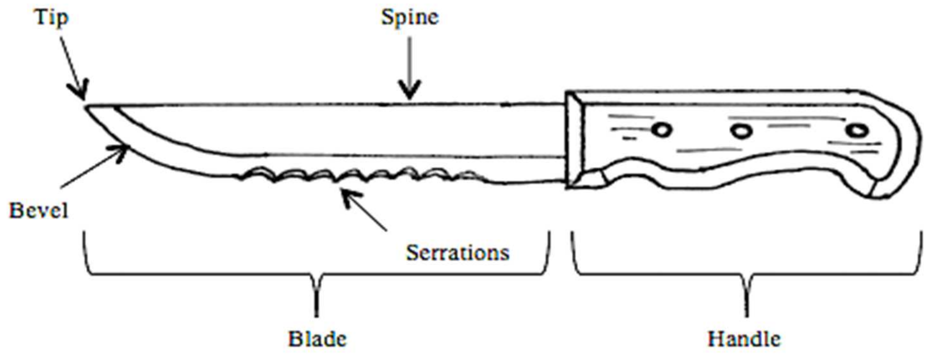


Figure 3. Knife anatomy. © 2015 Amanda Feldman

Knife anatomy. Despite variation in size, function, and edge characteristics, all knives share a similar morphology (Wareing, Hill, Trotter, & Hall, 2008). Knives consist of a point, tip, edge, heel, spine, bolster, tang, and handle. The point refers to the area of the knife used to make fine incisions. The tip of the knife consists of the first third of the blade and is used to make fine slices. The edge is located between the tip and the heel of the blade. Double-edged blades are sharp on both edges. The heel refers to the heaviest part of the knife closest to the handle, functioning to cut through hard tough materials. The top of the blade is the spine, and this may taper or narrow towards the point. The bolster is located between the handle and the blade and functions to protect the fingers when holding the knife. The tang is classified as the part of the blade that extends into the handle. The handle is the grasping edge of the knife (Tennick, 2012; Wareing et al., 2008).

Knife edge. The knife edge of a blade is the thinned cutting surface that comes after the tip and before the heel. Types of knife edges include nonserrated fine-ground (including double-ground and single-ground knives), serrated, and scalloped edges. When viewed in cross-section, fine-ground edges taper from the spine to the knife edge, and this class includes single and double-ground edges. Single-ground edges are ground on only one side of the blade whereas double-ground edges are ground on both sides. Fine-ground edges are nonserrated and leave no visible patterned striations or very fine unpatterned striations. Serrated edges are saw-toothed with smaller teeth (narrower than 1 mm) than teeth found on scalloped edges. Serrated blades generally leave striations resembling scallops or teeth in a distinct pattern. Scalloped edges are also saw-toothed, but the teeth are wider than those of serrated blades (wider than 1 mm). Partially serrated blades exhibit characteristics of both serrated and nonserrated knives (Crowder et al., 2011; Tennick, 2012; Wareing et al., 2008). The sides of beveled edges are expected to be visible and can be either on the left, right, or both sides of the cut. When the milled edge is visible on the left side, the blade has a left edge bevel and vice versa on the right side (Crowder et al, 2011).

Knife type. Common knives include utility knives, serrated knives, carving knives, chef's knives, scalloped slicing knives, and bread knives. Utility knives tend to be around 15 cm in length and have fine blades (Tennick, 2012; Wareing et al., 2008). Serrated knives are an equivalent to utility knives, but have serrated edges. Carving knives are large and range from 18-26 cm in length (Tennick, 2012; Wareing et al., 2008). Scalloped slicing knives are about 28 cm in length and scalloped with shallow bevels (Tennick, 2012; Wareing et al., 2008). Bread knives are equivalent to scalloped slicing knives but have deeper bevels (Tennick, 2012; Wareing et al., 2008).

Screwdriver anatomy. Screwdrivers consist of the handle, shank, and blade (Figure 4). Standard screwdrivers have flat tips while commonly used Philips head screwdrivers are cross-tipped. The blade is located on the tip of the screwdriver, after the shank. The shank is the long portion between the blade and the handle. The handle is the grasping portion of the screwdriver. The shank is usually made from tough steel while the blade is hardened to reduce wear. Handles can be made of plastic, wood, or metal. Screwdrivers often leave distinct marks that resemble the shape of the tip. Longitudinal fractures and cruciform impressions are generally associated with cross-tipped screwdrivers. Flat-tipped screwdrivers often leave rectangular impressions (Croft & Ferllini, 2007).

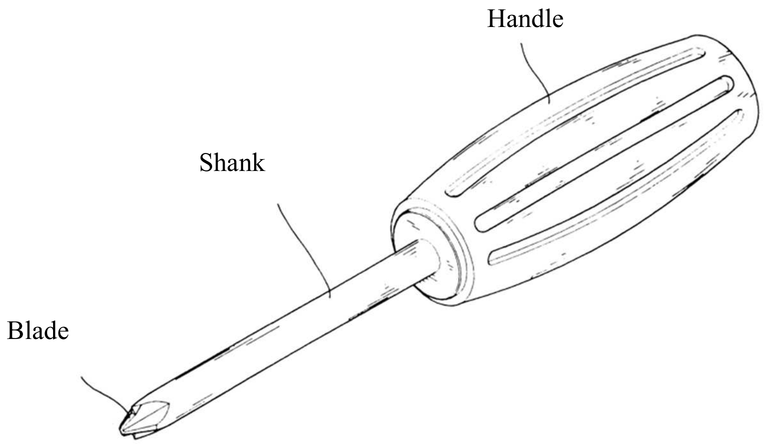


Figure 4. Screwdriver anatomy. © 2015 Amanda Feldman

3.3 Soft Tissue

Soft tissues often affect the shape and morphology of bones and often act as facilitators of bodily movement. The contraction of muscles is what causes tensile forces to be exerted and facilitates bodily movement relative to other bones. Tissues are considered "soft" if the anatomical structure attaches to bone or the periosteum, defined as the dense layer of vascular connective tissue surrounding the bone, attachment sites are visible, and tensile force is exerted on the bone (White, Black, Folkens, 2012). Skin is composed of two structural layers: the outer epidermis and the underlying dermis. The underlying dermis provides most of the mechanical strength with the outer epidermis functioning to protect underlying dermis. The dermis is a matrix of aligned collagen fibers and elastin fibers interwoven in substance of proteoglycans, water, and cells. Strength is due to the formation and mechanical properties of collagen fibers while elastin provides the dermis with elasticity. Tensile tests on skin show non-linear stress-strain relationships in a J-shape formation. When the dermis is in a normal, relaxed state, collagen and elastin fibers are not highly ordered. As skin becomes strained, elastin fibers carry the load while collagen fibers remain unorganized. Increase in strain causes collagen fibers to increasingly align in the direction of the load (Gilchrist et al., 2008).

Several studies have examined knife blade penetration on soft tissue and found skin to be the most resistive tissue (Knight, 1975). However, once force has been applied, no further force needs to be applied. Studies by Shipman and Rose (1983) and Humprey and Hutchinson (2001) have shown that the periosteum and additional tissue on bone can affect the depth of cut marks during sharp force trauma action. Gilchrist et al. (2008) found between four knives (Chef's, utility, carving, and kitchen knives), the utility knife required the least energy to break the skin while the Chef's knife required the most energy. Several studies have acknowledged that further testing needs to be done on skin resistance.

3.4 Fabric Variables

In many cases, sharp force trauma is accompanied by damage to apparel (Kemp et al., 2009). Linking damage to apparel with trauma on remains is largely dependent on analyzing severance dimensions and fiber end morphology. More fabric distortion around the point of penetration is often caused by blunt tipped instruments whereas little or no fabric distortion is generally present with sharp blades (Kemp et al., 2009). Scallops and serrations have also been reported as increasing distortion and fraying. However, due to the elasticity of fabric, severance dimensions do not accurately reflect weapon dimensions (Costello & Lawton, 1990; Kemp et al., 2009). Still, much information can be obtained on blade type and characteristics. Diagnostic characteristics of fabric damage focus on the degree of distortion, changes in yarn spacing, direction of the severance line, and the position of severed fiber ends. Generalizations that have been made about the cause of fabric damage specify that scissor cuts cause pinched ends accompanied by lateral distortion, knife cuts cause the presence of flat tops without a lip, and impact tears cause mushroom-shaped caps (Adolf & Hearle, 1998; Hearle, Lomas, Cooke, & Duerdon, 1989, 1998; Kemp et al., 2009; Pelton & Ukpabi, 1995; Stowell & Card, 1990).

Morphological features can be observed in different fabrics in different ways. Variation in fabric morphology may have an affect on penetrative ability due to the variability in tension and the structure of the fibers. Impacting fabrics containing natural fibers (such as cotton and wool) tends to produce marks with much greater lengths than the width of the blade (Daeid et al., 2008). According to Daeid et al. (2008), fabrics such as knit apparel can exhibit fiber end curling away from the impacted face and looping segments caused by unraveling. Drill fabrics also often exhibit overlapping between severed edges. Clean-cut fibers are often more commonly observed in drill specimens that are tightly woven. Cotton fabrics, on the other hand, tend to exhibit flattening and a smeared appearance with elongated and irregular fiber ends. Because guard impressions (or bubbling resulting from the handle hitting the specimen during penetration, discussed further in section 3.5) are rarely observed on skin or bone, guard impressions on fabric can be useful in determining the depth and angle of penetration. Finding prominent marks on the upper edge of the mark generally indicates that the weapon was used in a downward thrusting motion rather than penetration at a perpendicular angle (Daeid et al., 2008). Furthermore, serrations have been reported to increase fraying and distortion in fabric (Kemp et al., 2009).

Directionality can also be determined by examining different characteristics of the upper and lower edge marks. Sharp, single-ground blades (such as kitchen knives) generally have broader blunt edges than other types of knives. These types of blades often create narrower severance marks on fabric compared to severances with upper edges that taper to a point from knives with large upper edges (Carr & Wainwright, 2011; Daeid et al., 2008; Kemp et al., 2009). Blunt edges tend to result in Y-shaped damage (Kemp et al., 2009). However, directionality cannot be determined in screwdrivers due to their symmetrical shape (Kemp et al., 2009).

3.5 Application of Penetrative Force

The weapon impact on the surface can be categorized into three phases (Daroux et al., 2010; Kemp et al., 2009). The initial phase involves the penetration of the tip into the fabric. The initial phase of the impact event then causes the fabric to be driven into the underlying flesh and bone resulting in tensioning of fibers and tearing. Therefore, the tip morphology, blade thickness, and cross-sectional area of the blade tip greatly affect the penetrative ability of the weapon (Daroux et al., 2010; Kemp et al., 2009). The blunt tip of a screwdriver, by this principle, will require the most force to penetrate the specimens (Daroux et al., 2010; Kemp et al., 2009). The second phase involves the action of the blade creating a hole formed by the tip. This is referred to as the damage propagation or run through phase (Daroux et al., 2010; Kemp et al., 2009). Here, sharpness and morphology of the blade edge are the factors that affect the weapon penetrative ability the most (Daroux et al., 2010; Kemp et al., 2009). The blade edges of serrated and nonserrated knives with larger blade edge areas will generally have more influence on the creation of marks than a screwdriver's consistent diameter (Daroux et al., 2010; Kemp et al., 2009). Finally, the last phase involves the dissipation of remaining energy creating guard impressions (bubbling) in fabric materials and the impact of mass (whether through stab action or impact device action) bouncing on the specimen (Daroux et al., 2010; Kemp et al., 2009). This effect is generally present regardless of weapon type.

3.6 Pilot Study Results

An experimental pilot study was used to examine the feasibility of attempting to identify and link weapons to marks on bone by examining sharp force trauma characteristics (Tables 5-27). Three instruments (including a serrated knife, nonserrated knife, and flat-tipped screwdriver) were used to inflict sharp force trauma on porcine (*Sus scrofa*) ribs and compared with cut marks made by the same weapons on medium-grade jeweler's wax. Jeweler's wax was chosen to compare with porcine ribs because it has often been used as a suitable surface medium in forensic studies. In order to assess whether fabric altered trauma patterns, jean drill, polyester, and 100% cotton comforter fabrics were secured to the specimens and compared with unclothed control specimens. Five marks were made on each specimen with each weapon. A total of 60 marks were then analyzed using Chi square and ANOVA tests.

Table 4 displays descriptive statistics of the cut mark characteristic scores. Tables 5 and 6 display the scoring measurements and scores for cut mark characteristics observed in the pilot study, and Tables 7 through 27 show results of chi square and ANOVA tests on weapon and fabric groups. The majority of dependent variables were categorical measurements and scored on a scale. As kerf length is a metric variable, however, ANOVA tests were run on that particular variable. Because serrated and nonserrated knives produced similar results, they were grouped together and tested against screwdrivers in the chi-square tests.

In the fabric groups, unclothed and polyester fabrics also showed many similarities and were grouped together against cotton and jean drill fabrics. Chi square tests for fabric groups indicated that striations, kerf width, kerf depth, cross-section, wall gradients, wall projections, floor, and debris significantly differed between fabric types (see Tables 7-15; $p<0.05$). Margins did not significantly differ (see Table 13). Striations were significantly different in the thin/unclothed fabric group (see Table 7; $p<0.05$). It was predicted that margins would differ between weapon and fabric groups, however none of the fabric groups significantly differed in marginal distortion. Kerf width and kerf depth were predicted to differ between fabric groups, and the results support this hypothesis.

In weapon groups, kerf width, kerf depth, cross-section, wall gradients, floor, and debris differed between weapon types (see Tables 16-24; $p<0.05$). Margins did not significantly differ as predicted (see Table 22), however the results confirmed predictions that kerf width and depth would differ between weapon types.

ANOVA analysis confirmed predictions that kerf length would differ between fabric and weapon types (see Table 25; $p<0.05$). Weapon Post Hoc tests were run on length and indicated that serrated weapons differed from screwdrivers (see Table 26; $p<0.05$). Fabric Post Hoc tests revealed that the jean drill group significantly differed from the comforter, polyester, and unclothed groups (see Table 27; $p<0.05$).

Given the smaller sample size and outside variables including observer error, inconsistent application of force, and imperfections in used weapons, results of the study may be inconsistent with studies that are able to provide much more control over such variables. However, this pilot study provided data useful for the calibration of the full study.

Table 4

Descriptive Statistics of Dependent Variables in Relation to Weapon and Fabric Type

Dependent Variable	*n*	*Minimum*	*Maximum*	*Mean*	*Std. Deviation*
Striations	60	1	2	1.67	0.475
Width	60	1	2	1.58	0.497
Depth	60	1	2	1.33	0.475
Cross-Section	60	1	2	1.33	0.475
Wall Gradients	60	1	4	2.17	1.152
Wall Projections	60	1	2	1.75	0.437
Margins	60	1	5	2.83	0.905
Floor	60	1	5	2.83	1.355
Debris	60	2	4	3.08	0.766
Lateral Ridging	60	1	1	1.00	0.000
Length	60	1.44	35.03	13.230	7.906
Weapon	60	1	3	2.00	0.823
Fabric	60	1	4	2.50	1.127

Table 5

Summary of Pilot Study Scaled Scores for Dependent Variables

Weapon	Striations (1-2)	Width (1-4)	Depth (1-4)	X-Section Shape (1-4)	Wall Gradients (1-5)	Wall Projections (1-3)	Margins (1-5)	Floor (1-6)	Debris (1-5)	Lateral Ridging (1-2)	Fabric Type	Fabric Damage (1-4)
Serrated Knife	2	2	2	1	1	1	5	5	3	1	Unclothed	----------
Serrated Knife	2	2	1	1	2	2	2	2	3	1	Jeans	2
Serrated Knife	1	2	1	1	2	2	3	1	4	1	Polyester	2
Serrated Knife	2	2	2	1	1	2	3	1	4	1	Cotton Comforter	3
Nonserrated Knife	1	2	2	1	1	1	3	1	3	1	Unclothed	----------
Nonserrated Knife	2	2	1	1	2	2	3	5	3	1	Jeans	3
Nonserrated Knife	2	1	1	1	2	2	3	3	3	1	Polyester	2
Nonserrated Knife	1	2	2	1	1	2	1	4	4	1	Cotton Comforter	1
Screwdriver	2	1	1	2	2	2	3	3	2	1	Unclothed	----------
Screwdriver	2	1	1	2	4	1	2	3	2	1	Jeans	1
Screwdriver	2	1	1	2	4	2	3	3	2	1	Polyester	2
Screwdriver	1	1	1	2	4	2	3	3	4	1	Cotton Comforter	3

Table 6

Scoring Measurements and Descriptions for Pilot Study Cut Mark Characteristics

Dependent Variable	*Scoring*					
Striations	Present (1) – grooves and lines present	Absent (2) – no grooves or lines visible				
Width	Wide (1) – width greater than 25% of kerf height	Narrow (2) –width narrower than 25% of kerf height	Consistent (3) – difficult to classify whether greater or narrower than 25% of kerf height	Varied (4) – width varied		
Depth	Shallow (1) –depth less than 25% of kerf height	Deep (2) – depth greater than 25% of kerf height	Consistent (3) – difficult to classify whether greater or narrower than 25% of kerf height	Varied (4) – depth varied		
Cross-Section	V-shape (1) – in profile-view, walls come to a point	U-shape (2) – in profile-view, walls do not come to a point	Unobservable (3) – unable to classify cross-section	Other (4) – cross-section shape differs from V and U		
Wall Gradients	Very Steep (1) – walls at a near 90° angle	Steep (2) – walls between 45° and 90° angle	None (3) – no walls	Shallow (4) – walls less than 45° angle	Very Shallow (5) – walls present but close to 0° angle	
Wall Projections	Many (1) – 5 or more bony projections on wall	Few (2) – fewer than 5 bony projections on wall	None (3) – no wall projections visible			
Margins	Regular (1) – margins are linear	Irregular (2) – margins are somewhat linear, but deviate from linear form	Defined (3) – margins are distinct (nonlinear shape)	Undefined (4) – margins are unclear	Splitting (5) – margins split into separate channels	
Floor*	Defined (1) – floor clearly outlined	Undefined (2) – difficult to distinguish floor	Wide (3) – floor linear and greater than 25% of kerf height	Narrow (4) – floor linear and narrower than 25% of kerf height	Splitting (5) – cracks on floor	Debris (6) – indistinguishable due to debris on floor
Debris	Absent (1) – no debris	Crushing (2) – debris granular in appearance	Flaking (3) – large, flaked debris	Fine (4) – debris powdery and small	Other (5) – distinct debris pattern	
Lateral Ridging	Present (1)- 1 or both edges of kerf raised	Absent (2) – no visibly raised edge				
Length	Measured from the two furthest edges on kerf					

Note: Score was determined from the description that best suited the mark.
* If floor was nonlinear with no cracks, it was marked as defined or undefined. If floor was linear, it was marked as wide or narrow. If splitting was present, floor splitting was recorded regardless of clarity of floor definition

Table 7

Chi-Square Tests for Striations in Relation to Fabric Type

Fabric		*Value*	*df*	*Significance*
Comforter	Pearson Chi-Square	3.750	1	0.053
	Continuity Correction[b]	1.838	1	0.175
	Likelihood Ratio	5.232	1	0.022
Drill*	Pearson Chi-Square			
	N of Valid Cases	15		
Thin/Unclothed	Pearson Chi-Square	7.500	1	0.006
	Continuity Correction[b]	5.419	1	0.020
	Likelihood Ratio	10.465	1	0.001
Total	Pearson Chi-Square	0.938	1	0.333
	Continuity Correction[b]	0.459	1	0.498
	Likelihood Ratio	0.963	1	0.326

*Note: Striations were constant in drill/jean fabric samples.

Table 8

Chi-Square Tests for Kerf Width in Relation to Fabric Type

Fabric		*Value*	*df*	*Significance*
Comforter	Pearson Chi-Square	15.000	1	0.001
	Continuity Correction[b]	10.838	1	0.001
	Likelihood Ratio	19.095	1	0.001
Drill	Pearson Chi-Square	15.000	1	0.001
	Continuity Correction[b]	10.838	1	0.001
	Likelihood Ratio	19.095	1	0.001
Thin/Unclothed	Pearson Chi-Square	15.000	1	0.001
	Continuity Correction[b]	12.150	1	0.001
	Likelihood Ratio	19.095	1	0.001
Total	Pearson Chi-Square	42.000	1	0.001
	Continuity Correction[b]	38.477	1	0.001
	Likelihood Ratio	51.362	1	0.001

Table 9

Chi-Square Tests for Kerf Depth in Relation to Fabric Type

Fabric		*Value*	*df*	*Significance*
Comforter	Pearson Chi-Square	15.000	1	0.001
	Continuity Correction[b]	10.838	1	0.001
	Likelihood Ratio	19.095	1	0.001
Drill*	Pearson Chi-Square			
	N of Valid Cases	15		
Thin/Unclothed	Pearson Chi-Square	7.500	1	0.006
	Continuity Correction[b]	5.419	1	0.020
	Likelihood Ratio	10.465	1	0.001
Total	Pearson Chi-Square	15.000	1	0.001
	Continuity Correction[b]	12.834	1	0.001
	Likelihood Ratio	20.930	1	0.001

*Note: Striations were constant in drill/jean fabric samples.

Table 10

Chi-Square Tests for Cross-Section in Relation to Fabric Type

Fabric		*Value*	*df*	*Significance*
Comforter	Pearson Chi-Square	15.000	1	0.001
	Continuity Correction[b]	10.838	1	0.001
	Likelihood Ratio	19.095	1	0.001
Drill	Pearson Chi-Square	15.000	1	0.001
	Continuity Correction[b]	10.838	1	0.001
	Likelihood Ratio	19.095	1	0.001
Thin/Unclothed	Pearson Chi-Square	30.000	1	0.001
	Continuity Correction[b]	25.669	1	0.001
	Likelihood Ratio	38.191	1	0.001
Total	Pearson Chi-Square	60.000	1	0.001
	Continuity Correction[b]	55.584	1	0.001
	Likelihood Ratio	76.382	1	0.001

Table 11

Chi-Square Tests for Wall Gradients in Relation to Fabric Type

Fabric		*Value*	*df*	*Significance*
Comforter	Pearson Chi-Square	15.000	1	0.001
	Continuity Correction[c]	10.838	1	0.001
	Likelihood Ratio	19.095	1	0.001
Drill	Pearson Chi-Square	15.000	1	0.001
	Continuity Correction[c]	10.838	1	0.001
	Likelihood Ratio	19.095	1	0.001
Thin/Unclothed	Pearson Chi-Square	15.000	2	0.001
	Likelihood Ratio	19.095	2	0.001
Total	Pearson Chi-Square	42.000	2	0.001
	Likelihood Ratio	51.362	2	0.001

Table 12

Chi-Square Tests for Wall Projections in Relation to Fabric Type

Fabric		*Value*	*df*	*Significance*
Comforter*	Pearson Chi-Square			
	N of Valid Cases	15		
Drill	Pearson Chi-Square	15.000	1	0.001
	Continuity Correction[b]	10.838	1	0.001
	Likelihood Ratio	19.095	1	0.001
Thin/Unclothed	Pearson Chi-Square	7.500	1	0.006
	Continuity Correction[b]	5.419	1	0.020
	Likelihood Ratio	10.465	1	0.001
Total	Pearson Chi-Square	0.000	1	1.000
	Continuity Correction[b]	0.000	1	1.000
	Likelihood Ratio	0.000	1	1.000

*Note: Wall projections were constant in comforter fabrics.

Table 13

Chi-Square Tests for Margins in Relation to Fabric Type

Fabric		*Value*	*df*	*Significance*
Comforter	Pearson Chi-Square	3.750	1	0.053
	Continuity Correction[c]	1.838	1	0.175
	Likelihood Ratio	5.232	1	0.022
Drill	Pearson Chi-Square	3.750	1	0.053
	Continuity Correction[c]	1.838	1	0.175
	Likelihood Ratio	5.232	1	0.022
Thin/Unclothed	Pearson Chi-Square	3.000	1	0.083
	Continuity Correction[c]	1.470	1	0.225
	Likelihood Ratio	4.540	1	0.033
Total	Pearson Chi-Square	6.563	3	0.087
	Likelihood Ratio	9.594	3	0.022

Table 14

Chi-Square Tests for Kerf Floor in Relation to Fabric Type

Fabric		*Value*	*df*	*Significance*
Comforter	Pearson Chi-Square	15.000	2	0.001
	Likelihood Ratio	19.095	2	0.001
Drill	Pearson Chi-Square	15.000	2	0.001
	Likelihood Ratio	19.095	2	0.001
Thin/Unclothed	Pearson Chi-Square	15.000	2	0.001
	Likelihood Ratio	19.095	2	0.001
Total	Pearson Chi-Square	42.000	4	0.001
	Likelihood Ratio	51.362	4	0.001

Table 15

Chi-Square Tests for Debris in Relation to Fabric Type

Fabric		*Value*	*df*	*Significance*
Comforter*	Pearson Chi-Square			
	N of Valid Cases	15		
Drill	Pearson Chi-Square	15.000	1	0.001
	Continuity Correction[d]	10.838	1	0.001
	Likelihood Ratio	19.095	1	0.001
Thin/Unclothed	Pearson Chi-Square	30.000	2	0.001
	Likelihood Ratio	38.191	2	0.001
Total	Pearson Chi-Square	43.125	2	0.001
	Likelihood Ratio	53.888	2	0.001

*Note: Debris was constant in comforter fabrics.

Table 16

Chi-Square Tests for Striations in Relation to Weapon Type

	Value	*df*	*Significance*
Pearson Chi-Square	0.938	1	0.333
Continuity Correction[b]	0.459	1	0.498
Likelihood Ratio	0.963	1	0.326

Table 17

Chi-Square Tests for Kerf Width in Relation to Weapon Type

	Value	*df*	*Significance*
Pearson Chi-Square	42.000	1	0.001
Continuity Correction[b]	38.477	1	0.001
Likelihood Ratio	51.362	1	0.001

Table 18

Chi-Square Tests for Kerf Depth in Relation to Weapon Type

	Value	*df*	*Significance*
Pearson Chi-Square	15.000	1	0.001
Continuity Correction[b]	12.834	1	0.001
Likelihood Ratio	20.930	1	0.001

Table 19

Chi-Square Tests for Cross-Section in Relation to Weapon Type

	Value	*df*	*Significance*
Pearson Chi-Square	60.000	1	0.001
Continuity Correction[b]	55.584	1	0.001
Likelihood Ratio	76.382	1	0.001

Table 20

Chi-Square Tests for Wall Gradients in Relation to Weapon Type

	Value	*df*	*Significance*
Pearson Chi-Square	42.000	2	0.001
Likelihood Ratio	51.362	2	0.001

Table 21

Chi-Square Tests for Wall Projections in Relation to Weapon Type

	Value	*df*	*Significance*
Pearson Chi-Square	0.000	1	1.000
Continuity Correction[b]	0.000	1	1.000
Likelihood Ratio	0.000	1	1.000

Table 22

Chi-Square Tests for Margins in Relation to Weapon Type

	Value	*df*	*Significance*
Pearson Chi-Square	6.563	3	0.087
Likelihood Ratio	9.594	3	0.022

Table 23

Chi-Square Tests for Kerf Floor in Relation to Weapon Type

	Value	*df*	*Significance*
Pearson Chi-Square	42.000	4	0.001
Likelihood Ratio	51.362	4	0.001

Table 24

Chi-Square Tests for Debris in Relation to Weapon Type

	Value	*df*	*Significance*
Pearson Chi-Square	43.125	2	0.001
Likelihood Ratio	53.888	2	0.001

Table 25

Tests of Between-Subjects Effects for Kerf Length by Weapon and Fabric Type

Source	*Type III Sum of Squares*	*df*	*Mean Square*	*F*	*Significance*	*Partial Eta Squared*	*Noncent. Parameter*	*Observed Power*
Corrected Model	1726.975	11	156.998	3.843	0.001	0.468	42.268	0.993
Intercept	10501.445	1	10501.445	257.024	0.001	0.843	257.024	1.000
Blade	395.729	2	197.864	4.843	0.012	0.168	9.686	0.775
Fabric	877.119	3	292.373	7.156	0.001	0.309	21.468	0.974
Blade * Fabric	454.127	6	75.688	1.852	0.109	0.188	11.115	0.632
Error	1961.176	48	40.858					

Table 26

Post Hoc Tests for Kerf Length by Weapon Type

					95% Confidence Interval	
(I) Blade	(J) Blade	*Mean Difference (I-J)*	*Std. Error*	*Sig.*	*Lower Bound*	*Upper Bound*
Serrated	Nonserrated	2.122	2.0213	0.550	-2.767	7.010
	Screwdriver	6.190	2.0213	0.010	1.301	11.078
Nonserrated	Serrated	-2.122	2.0213	0.550	-7.010	2.767
	Screwdriver	4.068	2.0213	0.120	-0.821	8.957
Screwdriver	Serrated	-6.190	2.0213	0.010	-11.078	-1.301
	Nonserrated	-4.068	2.0213	0.120	-8.957	0.821

Table 27

Post Hoc Tests for Kerf Length by Fabric Type

(I) Fabric	(J) Fabric	*Mean Difference (I-J)*	*Std. Error*	*Sig.*	*95% Confidence Interval*	
					Lower Bound	*Upper Bound*
Comforter	Drill	9.130	2.334	0.002	2.918	15.342
	Polyester	-0.448	2.334	0.997	-6.660	5.764
	Unclothed	2.655	2.334	0.668	-3.556	8.867
Drill	Comforter	-9.130	2.334	0.002	-15.342	-2.918
	Polyester	-9.578	2.334	0.001	-15.790	-3.366
	Unclothed	-6.475	2.334	0.038	-12.686	-0.263
Polyester	Comforter	0.448	2.334	0.997	-5.764	6.660
	Drill	9.578	2.334	0.001	3.366	15.790
	Unclothed	3.103	2.334	0.549	-3.108	9.315
Unclothed	Comforter	-2.655	2.334	0.668	-8.867	3.556
	Drill	6.475	2.334	0.038	0.263	12.686
	Polyester	-3.103	2.334	0.549	-9.315	3.108

CHAPTER FOUR: MATERIALS AND METHODS

4.1 Introduction

The sample was obtained from six domestic porcine carcasses purchased from a local butcher. Porcine ribs were primarily examined macroscopically and microscopically using a standard light microscope. Environmental conditions were recorded during tests and ranged between 75° and 90° Fahrenheit. Five instruments were used to inflict stab wounds, including a serrated knife, a scalloped knife, a nonserrated knife, a pocketknife, and a flat-tipped screwdriver. Five fabrics, including cotton, polyester, jean drill, cotton comforter, and satin materials, were secured to the specimens and compared with unclothed samples. Porcine remains were used as they are often used as a suitable medium to replicate trauma on human remains. Since existing research indicates that kitchen knives are most commonly used in homicides, used kitchen knives were obtained. A screwdriver was included due to the lack of data on marks made by screwdrivers in forensic studies. The chest cavity is most likely to be impacted during homicides and stabbing injuries, so ribs were chosen to more closely resemble real-life scenarios. The specimens were impacted with guided drop impact tests in order to attempt to produce consistent kerf marks on bone. A sliding caliper and tape measure were used for data collection. Marks were examined both macroscopically and microscopically.

4.2 Weapon Samples

Weapons were purchased used in order to account for wear patterns. Characteristics of the knife blades and the screwdriver tip were measured using digital sliding calipers. The number of teeth per inch (TPI) and the total number of teeth in the exposed blade were recorded (Symes, 1992). The cutting edge tooth height was also measured from one tooth located at the blade tip, midpoint, and handle. The total blade length from the tip to the handle was recorded. The width of the spine at the blade handle and the blade tip were recorded. The presence or absence of beveled edges was recorded as well as whether the blade was sharpened on one or both edges. The length and width of the blade tip, shank, and handle of the screwdriver were also documented.

4.3 Specimen Preparation

The porcine samples were purchased from a local butcher and examined for any marks. Because remains were declared fit for consumption, the overall sample was fairly homogenous in terms of factors such as illness and disease due to industry standards. The samples were secured to a specimen plate with fabric coverings secured onto the specimens (unless unclothed) for impact testing. After examining marks made on the fabric and flesh, soft tissue was removed from the ribs by macerating the specimens using a biological detergent solution. The contained solution simmered on a hot plate for approximately three hours. The bones were removed, rinsed with distilled water, and the flesh was carefully removed.

4.4 Bone Surface Features

Bone surface features were examined in each rib specimen as the bone surface has been shown to affect kerf morphology and depth (Eickhoff & Herrman, 1985). Porosity was analyzed by observing the presence of pores in the bone in numerous areas. Texture was recorded as smooth in samples with little variation in texture and recorded as textured where great variation in the topography was observed. The gradient was determined by analyzing the slope of the area surrounding the kerf mark. Level surfaces were categorized as having no gradient, slopes greater than 45° were classified as steep, and slopes below 45° were classified as shallow (Tennick, 2012).

4.5 Classification of Marks

Characteristics of blades and kerf marks were examined and scored based on pre-selected criteria from previous studies. Kerf features, profile and wall characteristics, margin characteristics, floor characteristics, and debris characteristics were examined in this study.

Kerf features. The shape of kerf marks was examined according to specifications on tip shape. Rounded tip shapes exhibited rounded margins. Tapered tip shapes showed narrowing at one or both margins. Square tip shapes had symmetrical, square-shaped margins. Any other shapes were categorized as other (Alunni-Perret et al., 2006; Figure 5).

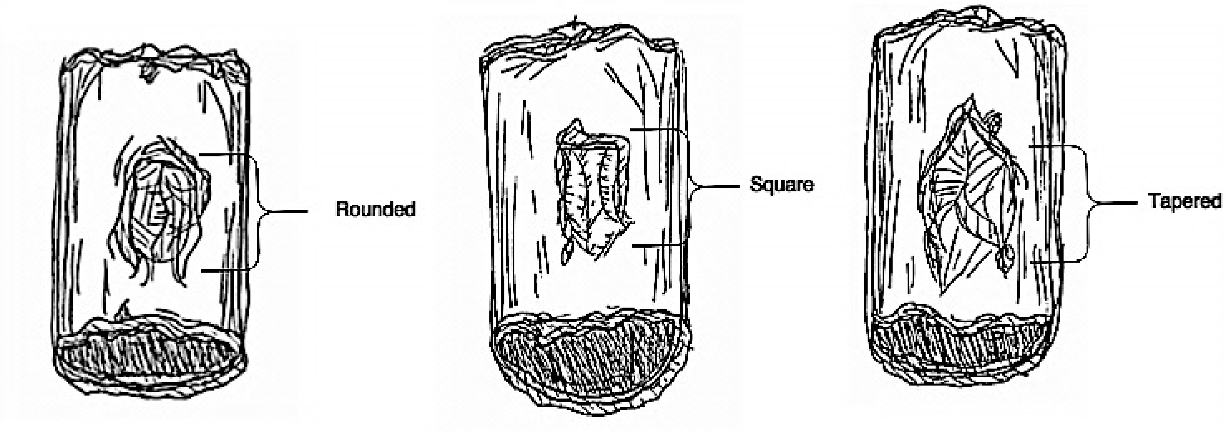


Figure 5. Kerf features. © 2015 Amanda Feldman

Bifurcation. Bifurcation or "splitting" occurs when the kerf splits into multiple channels. This was recorded as present or absent (Eickhoff & Hermann, 1985; Figure 6).

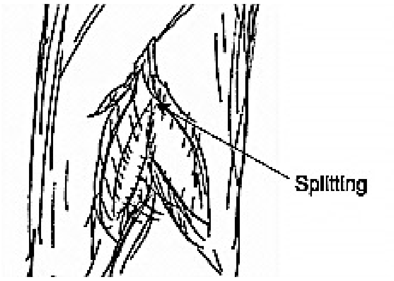


Figure 6. Bifurcation. © 2015 Amanda Feldman

Profile and wall characteristics. Profile and wall characteristics included the cross-section shape, wall gradient, and wall projection features. The cross-section exhibited the profile view of the kerf shape. The cross-section shape was recorded as V-shaped, U-shaped, unobservable, or other (such as very wide |_|-shaped marks) (Shipman, 1983; Figure 7).

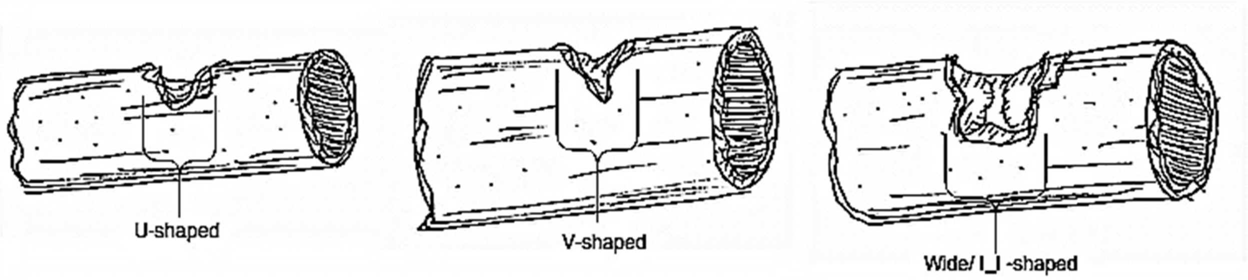


Figure 7. Cross-section profile. © 2015 Amanda Feldman

The wall gradient refers to the slope of the kerf wall. The wall gradient was recorded as very steep if it had a wall angle approximately 90°, steep if it had a wall angle between 45° and 90°, shallow if it had a wall angle less than 45°, very shallow if it had a wall angle close to 0°, and no wall gradient if it was not present (Tennick, 2012; Figure 8).

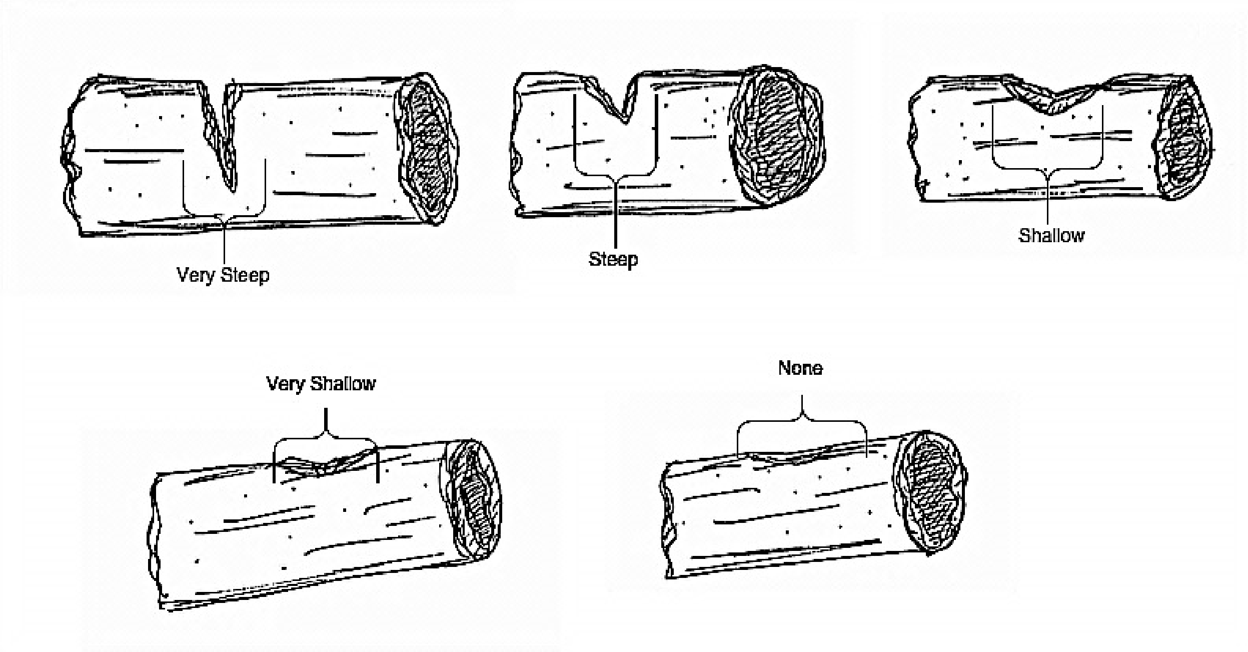


Figure 8. Wall gradient. © 2015 Amanda Feldman

Wall projections are protrusions of various sizes that are attached to the wall of the kerf. Many projections were recorded if five or more were found and few were recorded if there were less than five wall projections.

Margin characteristics. Margin regularity, margin definition, margin splitting, and lateral ridging of kerf marks were recorded. Margin regularity refers to the linear nature of the kerf edges. Linear edges were recorded as regular and edges that deviated from a linear form were recorded as irregular (Alunni-Perret et al., 2005; Figure 9). Margin splitting was also recorded as present or absent.

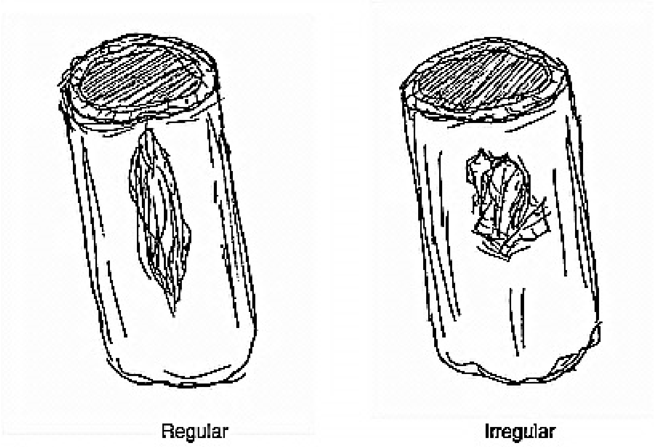


Figure 9. Margin regularity. © 2015 Amanda Feldman

Lateral ridging, also known as unilateral rising, refers to the formation of a ridge on one or both margins of a kerf. Lateral ridging was recorded as present or absent (Alunni-Perret et al., 2005; Figure 10).

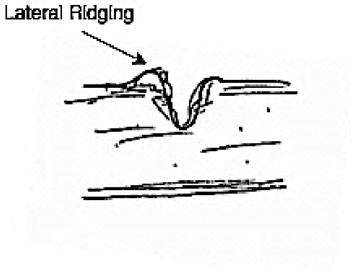


Figure 10. Lateral ridging. © 2015 Amanda Feldman

Floor characteristics. The floor of a kerf is defined as the area connecting the walls of a kerf. Features recorded included floor definition, splitting, and width. Floor definition is characterized based on the clarity of the floor margins. Defined floors show clear boundaries between the floor and walls of the kerf. Boundaries that were ambiguous or unclear were recorded as undefined (Tennick, 2012; Figure 11).

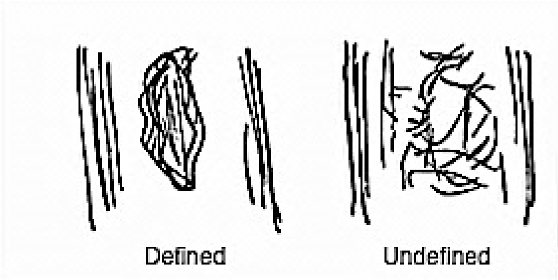


Figure 11. Floor definition. © 2015 Amanda Feldman

The size of the floor was recorded as the floor width. The floor width was categorized as either wide or narrow. Wide floors were greater than 25% of the height of the kerf and narrow floors were less than 25% of the height of the kerf. The presence or absence of cracks on the floor (floor splitting) was also recorded (Tennick, 2012; Figure 12, 13).

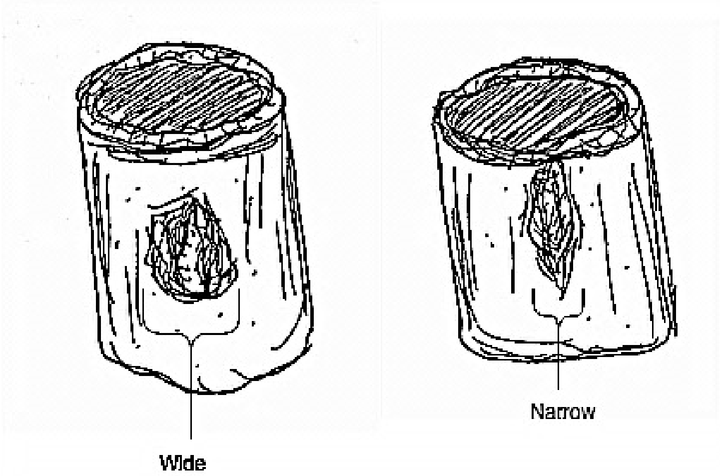


Figure 12. Floor width. © 2015 Amanda Feldman

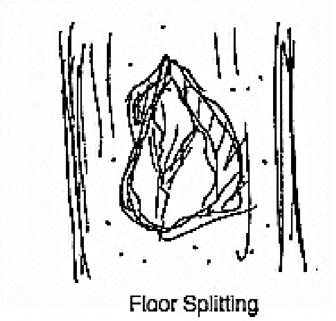


Figure 13. Floor splitting. © 2015 Amanda Feldman

Debris characteristics. Debris was categorized by crushing and flaking characteristics. Crushing occurs when the debris has a granular appearance. Crushing was recorded as present or absent. Flaking is commonly associated with hacking trauma and the debris has a flat appearance. Flaking was recorded as present or absent.

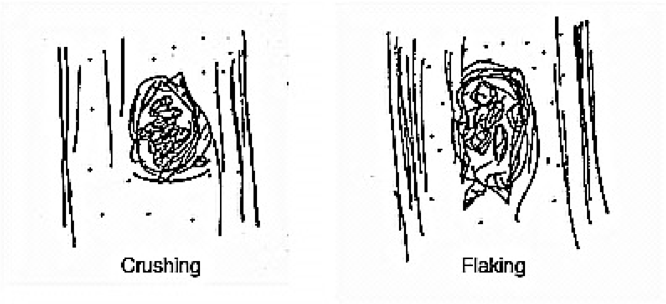


Figure 14. Debris characteristics. © 2015 Amanda Feldman

Scoring measurements. Kerf mark characteristics were measured categorically according to the observance of specific characteristics. Characteristics were scored by the best description of observed features. Table 28, also used in the pilot study (Table 6), displays descriptions of kerf characteristic measurement scores. Length was measured metrically and not included in the categorical measurements.

Table 28

Scoring Measurements and Descriptions for Cut Mark Characteristics

Dependent Variable	*Scoring*					
Striations	Present (1) – grooves and lines present	Absent (2) – no grooves or lines visible				
Width	Wide (1) – width greater than 25% of kerf height	Narrow (2) –width narrower than 25% of kerf height	Consistent (3) – difficult to classify whether greater or narrower than 25% of kerf height	Varied (4) – width varied		
Depth	Shallow (1) –depth less than 25% of kerf height	Deep (2) – depth greater than 25% of kerf height	Consistent (3) – difficult to classify whether greater or narrower than 25% of kerf height	Varied (4) – depth varied		
Cross-Section	V-shape (1) – in profile-view, walls come to a point	U-shape (2) – in profile-view, walls do not come to a point	Unobservable (3) – unable to classify cross-section	Other (4) – cross-section shape differs from V and U		
Wall Gradients	Very Steep (1) – walls at a near 90° angle	Steep (2) – walls between 45° and 90° angle	None (3) – no walls	Shallow (4) – walls less than 45° angle	Very Shallow (5) – walls present but close to 0° angle	
Wall Projections	Many (1) – 5 or more bony projections on wall	Few (2) – fewer than 5 bony projections on wall	None (3) – no wall projections visible			
Margins	Regular (1) – margins are linear	Irregular (2) – margins are somewhat linear, but deviate from linear form	Defined (3) – margins are distinct (nonlinear shape)	Undefined (4) – margins are unclear	Splitting (5) – margins split into separate channels	
Floor*	Defined (1) – floor clearly outlined	Undefined (2) – difficult to distinguish floor	Wide (3) – floor linear and greater than 25% of kerf height	Narrow (4) – floor linear and narrower than 25% of kerf height	Splitting (5) – cracks on floor	Debris (6) – indistinguishable due to debris on floor
Debris	Absent (1) – no debris	Crushing (2) – debris granular in appearance	Flaking (3) – large, flaked debris	Fine (4) – debris powdery and small	Other (5) – distinct debris pattern	
Lateral Ridging	Present (1)- 1 or both edges of kerf raised	Absent (2) – no visibly raised edge				
Length	Measured from the two furthest edges on kerf					

Note: Score was determined from the description that best suited the mark.
* If floor was nonlinear with no cracks, it was marked as defined or undefined. If floor was linear, it was marked as wide or narrow. If splitting was present, floor splitting was recorded regardless of clarity of floor definition

4.6 Fabric Analysis

Fabric type and damage can be examined in addition to kerf mark features. However, in the current study, fabric damage from drop-impact tests was extensive in the vast majority of the specimens, therefore damage was only recorded in the pilot study and not the current study. Five fabrics were used in the main study including jean drill, polyester, satin, cotton, and a cotton comforter. Fabric used in the pilot study included jean drill, polyester, and a cotton comforter. Features from unclothed specimens were also noted in both studies. In the pilot study, fabric damage was categorized as either extensive, moderate, minimal, or absent. Extensive fabric damage was recorded in the presence of severed fibers, tearing, and a frayed and disorganized appearance. Moderate damage showed disorganization and some fraying of fiber ends. Minimal damage was recorded when the cut mark margins were mostly organized with little fraying of the fiber ends. Damage was recorded as absent if cut marks were absent or linear with no severed fibers, tearing, or fraying (Daeid et al., 2008; Daroux et al., 2010; Ferllini, 2012; Kemp et al., 2009).

4.7 Impacting Device

A guided-drop impacting device was used to control force of impact and minimize error by creating cut marks as consistently as possible. Each specimen was placed onto a flat wooden block secured on to a NEULOG 225 force plate sensor. Weapon blades were attached to a 1” x 10” metal pipe that impacted the specimen by guided free fall through a 1.5” wide PVC pipe placed over the specimen (Figure 15, 16). The average force of three drop-impacts per weapon was logged using the NEULOG 225 force plate sensor (Figure 17, 18). The drop height of 0.6 meters was determined by examining the impact from various heights. 15 cuts were made in approximately 8 locations corresponding with the ribcage of the porcine specimen.

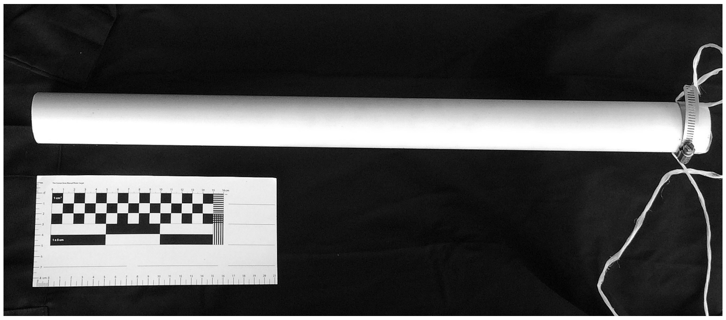


Figure 15. Drop-impact pipe. © 2015 Amanda Feldman

Figure 16. Impact blades. © 2015 Amanda Feldman

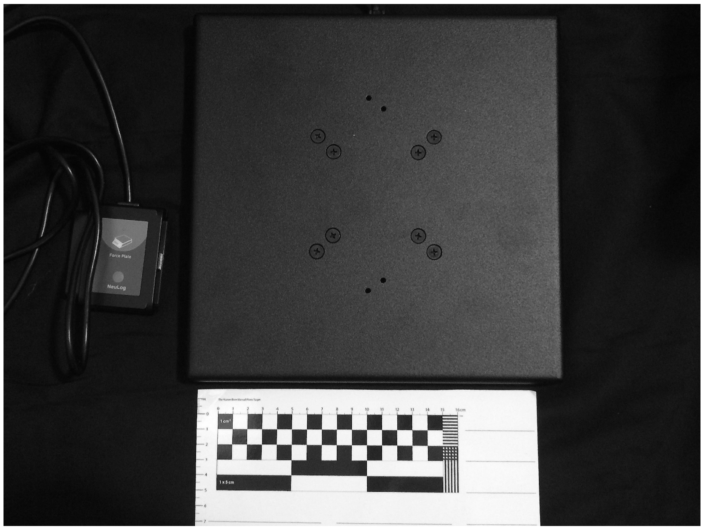


Figure 17. NEULOG 225 force plate sensor. © 2015 Amanda Feldman

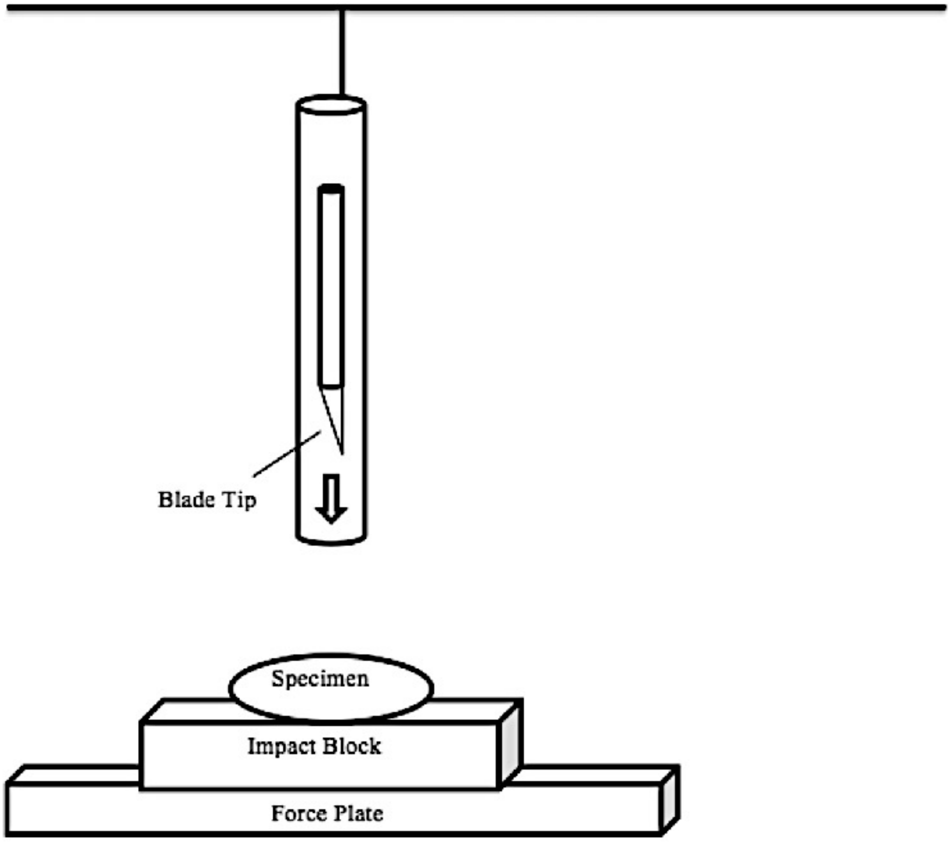


Figure 18. Impact test design. © 2015 Amanda Feldman

To calculate the impact force, the potential energy (PE) was first calculated using mass (m), gravity (g), and height (h) in the formulas below:

$$PE = mgh$$
$$KE = 0$$
$$V = \sqrt{2gh}$$
$$KE = \frac{1}{2} mv^2$$
$$PE = 0$$

Kinetic energy (KE) just before the impact is equal to the potential energy at the drop height. The impact velocity (V) and the impact force were then calculated according to the work-energy principle.

4.8 Intraobserver Error

To account for measurement error when measuring cut marks, measurements on each bone were taken, and the best estimates of the dimensions were calculated using the following form:

$$X = x_{best} \pm \sigma_M$$

In the formula, X is the dimension being measured, x_{best} is the best estimate of that dimension (the average of all measurements taken of the dimension), and σ_M is the standard error of x_{best}. σ_M was obtained by squaring the deviations of each measurement from x_{best}, adding the squared deviations together, dividing the sum by the number of individual measurements minus one, and taking the square root of the result to obtain the standard deviation, σ. The standard deviation was then divided by the square root of the number of individual measurements used to calculate σ_M. To determine the standard error, σ, the deviation from each measurement and the mean was calculated, squared, and added to together to calculate the sum of squares. The sum of squares was divided by (n-1) and the square root was taken (White, Black, & Folkens, 2012).

CHAPTER FIVE: RESULTS

5.1 Introduction

The results were analyzed using several statistical tests. A total of 450 marks were examined, and all data were converted to z-scores to allow analysis using SPSS 22 statistical software. The variables analyzed included the length, width, depth, margins, wall gradients, wall projections, striations, cross-section, debris and floor of the kerf marks with weapon type and fabric type as covariates. Multivariate tests were run to examine the relationship between weapon type, fabric type, and kerf mark characteristics. The null hypotheses assume that there is no difference between specimens with fabric and flesh and defleshed, unclothed specimens with respect to kerf mark wall gradients, marginal distortion, width, depth, striations, and cross-section. The null hypotheses can be rejected if the p-value is less than or equal to 0.05.

Table 29 shows descriptive statistics for the dependent variables. Spearmen's rank order correlations were first run to see if any variables had a strong correlation with one another and could be grouped together. Striations and cross-section were highly correlated with weapon type (see Table 30; $r=0.796$, $p<0.01$; $r=0.722$, $p<0.01$). As found in the pilot study, weapons could be grouped together and were categorized into serrated, nonserrated, and screwdriver groups. Striations and wall projections, cross-section and wall gradients, and margins and floor were positively correlated and therefore grouped together (see Table 31).

Once weapon types were grouped together, weapon type (serrated, nonserrated, and screwdriver) showed strong, positive correlations with cross section and striation patterns (see Table 31; r=0.454, p<0.01; r=0.459, p<0.01). Table 5 displays descriptive statistics for each of the dependent variables.

Multivariate tests were run on the z-scores to examine weapon and fabric groups with kerf mark characteristics. Weapons and fabrics were shown to significantly alter kerf marks (see Table 32; p<0.01). Post Hoc tests showed that weapons differed from one another in kerf striations and wall projections, width, depth, kerf shape, margins and floor, and debris (see Table 58; p<0.01). As lateral ridging was a constant, data on lateral ridging were not included in the analysis. Post Hoc tests showed that fabric also differed on a statistically significant level in terms of striations and wall projections, width, depth, kerf shape, debris, and length (see Tables 59-64; p<0.05).

Table 29

Descriptive Statistics of Dependent Variables

	n	*Min*	*Max*	*Mean*	*Standard Deviation*
Striations	450	1	2	1.656	0.476
Width	450	1	4	1.782	0.691
Depth	450	1	4	1.544	0.615
Cross-Section	450	1	5	1.222	0.467
Wall Gradients	450	1	5	2.338	1.512
Wall Projections	450	1	3	1.478	0.513
Margins	450	1	5	2.102	1.269
Floor	450	1	6	2.504	1.519
Debris	450	1	5	3.067	0.949
Weapon	450	1	5	3.000	1.416
Fabric	450	1	6	3.500	1.710

Note: Dependent variables are scaled.

Table 30

Correlations of Dependent Variables (Striations and Cross-Section) with Weapon and Fabric Type

Spearman	*Striations*	*Cross-Section*
Correlation Coefficient	0.796	0.722
Sig. (2-Tailed)	0.001	0.001
n	450	450

Table 31

Wall Projection, Wall Gradient, and Floor Correlations with Weapon and Fabric Type

Striations	*Spearman*	*Wall Projections*
	Correlation Coefficient	0.459
	Significance (2-Tailed)	0.001
	n	450
Cross-Section	*Spearman*	*Wall Gradients*
	Correlation Coefficient	0.454
	Significance (2-Tailed)	0.001
	n	450
Margins	*Spearman*	*Floor*
	Correlation Coefficient	0.333
	Significance (2-Tailed)	0.001
	n	450

Table 32

Multivariate Tests of Weapon (Serrated, Nonserrated, and Screwdriver) and Fabric (Comforter, Satin, Cotton, Drill, Polyester, and Unclothed) Groups Compared to Kerf Characteristic Patterns

Effect		*Value*	*F*	*Hypothesis df*	*Error df*	*Significance*	*Partial Eta Squared*	*Noncent. Parameter*	*Observed Power*
Intercept	Wilks' Lambda	0.782	19.790	6.000	427.000	0.001	0.218	118.737	1.000
Fabric	Wilks' Lambda	0.757	4.098	30.000	1710.000	0.001	0.054	97.673	1.000
Weapon	Wilks' Lambda	0.100	154.298	12.000	854.000	0.001	0.684	1851.571	1.000

5.2 Striations and Wall Projections

Table 33 displays the descriptive statistics for dependent variable striations and wall projections divided by weapon and fabric types. The majority of striations were produced by serrated weapons (n=153). Striations are considered a diagnostic characteristic of serrated blades, and the results showed that serrated knives differed greatly from nonserrated knives and screwdrivers, as predicted.

Wall projections commonly occurred in serrated knives (50%), with the most occurring in cotton fabric (22%). Striations and wall projections differed significantly by weapon and fabric type (see Table 34; p<0.01). Striations and wall projections made by serrated knives differed significantly from nonserrated knives and screwdrivers (see Table 35; p<0.01). The cotton fabric significantly differed the most from the other fabrics in terms of striations and wall projections (see Table 36; p<0.01).

Table 33

Descriptive Statistics of Striation and Wall Projection Kerf Patterns by Weapon and Fabric Type

Variable	*Fabric*	*Weapon Group*	*Mean*	*Standard Deviation*	*n*
Striations and Wall Projections	Comforter	Serrated	-2.309	0.000	30
		Nonserrated	1.677	0.036	30
		Screwdriver	1.742	0.000	15
	Satin	Serrated	-2.244	0.356	30
		Nonserrated	1.612	0.494	30
		Screwdriver	1.742	0.000	15
	Cotton	Serrated	-1.774	1.048	30
		Nonserrated	-0.022	0.599	30
		Screwdriver	1.352	0.807	15
	Drill	Serrated	-0.834	1.823	30
		Nonserrated	0.962	1.097	30
		Screwdriver	1.222	0.892	15
	Polyester	Serrated	-1.919	0.793	30
		Nonserrated	0.638	0.982	30
		Screwdriver	0.962	0.988	15
	Unclothed	Serrated	-0.414	1.591	30
		Nonserrated	1.222	0.876	30
		Screwdriver	-0.207	0.000	15

Table 34

Test of Between-Subjects Effects for Weapon and Fabric Effects on Kerf Striation and Wall Projection Patterns

Dependent Variable		*F*	*Significance*
Striations and Wall Projections	Intercept	17.223	0.001
	Weapon	446.529	0.001
	Fabric	5.365	0.001

Table 35

Weapon Post Hoc Tests for Striation and Wall Projection Kerf Patterns

Dependent Variable	*Weapon (I)*	*Weapon (J)*	*Mean Difference (I-J)*	*Significance*
Striations and Wall Projections	Serrated	Nonserrated	-2.597	0.001
		Screwdriver	-2.718	0.001
	Nonserrated	Serrated	2.597	0.001
		Screwdriver	-0.121	0.565
	Screwdriver	Serrated	2.718	0.001
		Nonserrated	0.121	0.565

Table 36

Fabric Post Hoc Tests for Striation and Wall Projection Kerf Patterns

Dependent Variable	*Fabric (I)*	*Fabric (J)*	*Mean Difference (I-J)*	*Significance*
Striations and Wall Projections	Cotton	Comforter	-0.544	0.004
		Satin	-0.543	0.004
		Drill	-0.744	0.001
		Polyester	-0.128	0.957
		Unclothed	-0.730	0.001

5.3 Width

Table 37 shows descriptive statistics for kerf width patterns grouped by weapon and fabric types. Wide kerf marks occurred the most frequently in the screwdriver group (51%), and narrow kerf marks were the most frequently found in in nonserrated knives (27%). The widest marks were found in cotton (22%) and cotton comforter (23%) fabric, and the narrowest marks were found in the thinnest coverings, including the satin (19%), polyester (19%), and unclothed specimens (18%). Width significantly differed in weapon and fabric groups (see Table 38; p<0.01). Serrated knives and nonserrated knives significantly differed from the screwdriver group (see Table 39; p<0.01). Drill fabrics also differed greatly from all other fabrics at a statistically significant level (see Table 40; $p<0.01$).

Table 37

Descriptive Statistics of Kerf Width by Weapon and Fabric Type

Variable	Fabric	*Weapon Group*	*Mean*	*Standard Deviation*	*n*
Width	Comforter	Serrated	-0.312	0.729	30
		Nonserrated	-0.022	0.622	30
		Screwdriver	-0.842	0.599	15
	Satin	Serrated	0.074	0.548	30
		Nonserrated	0.026	0.588	30
		Screwdriver	-0.649	0.706	15
	Cotton	Serrated	0.219	1.197	30
		Nonserrated	-0.071	0.925	30
		Screwdriver	-1.131	0.000	15
	Drill	Serrated	0.797	1.438	30
		Nonserrated	0.845	1.395	30
		Screwdriver	-0.456	1.206	15
	Polyester	Serrated	0.219	0.753	30
		Nonserrated	0.170	0.441	30
		Screwdriver	-0.938	0.509	15
	Unclothed	Serrated	0.202	0.753	30
		Nonserrated	0.219	0.889	30
		Screwdriver	-0.842	0.373	15

Table 38

Test of Between-Subjects Effects for Weapon and Fabric Effects on Kerf Width

Dependent Variable		*F*	*Significance*
Width	Intercept	10.520	0.001
	Weapon	52.616	0.001
	Fabric	6.930	0.001

Table 39

Weapon Post Hoc Tests for Kerf Width

Dependent Variable	*Weapon (I)*	*Weapon (J)*	*Mean Difference (I-J)*	*Significance*
Width	Serrated	Nonserrated	-0.016	0.983
		Screwdriver	1.045	0.001
	Nonserrated	Serrated	0.016	0.983
		Screwdriver	1.061	0.001
	Screwdriver	Serrated	-1.045	0.001
		Nonserrated	-1.016	0.001

Table 40

Fabric Post Hoc Tests for Kerf Width

Dependent Variable	*Fabric (I)*	*Fabric (J)*	*Mean Difference (I-J)*	*Significance*
Width	Drill	Comforter	0.868	0.001
		Satin	0.656	0.001
		Cotton	0.733	0.001
		Polyester	0.598	0.001
		Unclothed	0.540	0.002

5.4 Depth

Descriptive statistics for kerf depth grouped by weapon and fabric types are displayed in Table 41. Screwdrivers produced the shallowest marks (33%) whereas scalloped knives (in the serrated knife group) produced the deepest marks (27%). The shallowest marks occurred in the drill fabric (20%) and unclothed specimens (20%), and the deepest marks occurred in the polyester fabric (23%). The interaction between depth variables differed within weapon groups and fabric groups at a statistically significant level (see Table 42; $p<0.05$). Serrated and nonserrated knives significantly differed from the screwdriver group (see Table 43; $p<0.01$).

Table 41

Descriptive Statistics of Kerf Depth by Weapon and Fabric Type

Dependent Variable	Fabric	*Weapon*	*Mean*	*Std. Deviation*	*n*
Depth	Comforter	Serrated	-0.018	0.826	30
		Nonserrated	0.090	0.811	30
		Screwdriver	-0.886	0.000	15
	Satin	Serrated	0.036	0.820	30
		Nonserrated	0.253	0.758	30
		Screwdriver	-0.343	0.794	15
	Cotton	Serrated	0.633	0.847	30
		Nonserrated	-0.235	0.811	30
		Screwdriver	-0.886	0.000	15
	Drill	Serrated	0.633	1.651	30
		Nonserrated	-0.072	1.526	30
		Screwdriver	-0.560	0.674	15
	Polyester	Serrated	0.470	0.617	30
		Nonserrated	0.090	0.811	30
		Screwdriver	-0.127	0.840	15
	Unclothed	Serrated	-0.615	0.617	30
		Nonserrated	0.579	0.891	30
		Screwdriver	-0.886	0.000	15

Table 42

Test of Between-Subjects Effects for Weapon and Fabric Effects on Kerf Depth

Dependent Variable		*F*	*Significance*
Depth	Intercept	5.236	0.023
	Weapon	26.470	0.028
	Fabric	2.540	0.001

Table 43

Weapon Post Hoc Tests for Kerf Depth

Dependent Variable	*(I) Weapon*	*(J) Weapon*	*Mean Difference (I-J)*	*Significance*
Depth	Serrated	Nonserrated	0.0723125	0.727
		Screwdriver	0.8044768	0.001
	Nonserrated	Serrated	-0.0723125	0.727
		Screwdriver	0.7321643	0.001
	Screwdriver	Serrated	-0.8044768	0.001
		Nonserrated	-0.7321643	0.001

5.5 Kerf Shape

Table 44 shows descriptive statistics for kerf shape grouped by weapon and fabric types. V-shaped cross-sections occurred the most frequently in the knives (100%), whereas U-shaped cross-sections occurred the most frequently in screwdrivers (98%). Very steep and steep wall-gradients occurred the most frequently in scalloped knives (28%). Very shallow and shallow wall-gradients occurred the most frequently in screwdrivers (51%). The steepest wall gradients occurred in the drill (19%) and polyester fabrics (19%). Kerf shape significantly differed between weapon groups and fabric type (see Table 45; $p<0.01$). The screwdriver group significantly differed in kerf shape from the serrated knife and nonserrated knife groups (see Table 46; $p<0.01$). Kerf shape of marks made on polyester fabrics also differed significantly from marks made on cotton and cotton comforter fabrics (see Table 47; $p<0.01$).

Table 44

Descriptive Statistics of Kerf Shape by Weapon and Fabric Type

Dependent Variable	Fabric	*Weapon*	*Mean*	*Std. Deviation*	*n*
Shape	Comforter	Serrated	-0.237	1.242	30
		Nonserrated	-0.413	1.121	30
		Screwdriver	2.766	0.000	15
	Satin	Serrated	-0.545	0.880	30
		Nonserrated	-0.611	1.053	30
		Screwdriver	2.193	1.057	15
	Cotton	Serrated	-0.986	0.333	30
		Nonserrated	-0.282	1.720	30
		Screwdriver	3.207	0.323	15
	Drill	Serrated	-0.755	0.730	30
		Nonserrated	-0.640	1.407	30
		Screwdriver	2.644	0.517	15
	Polyester	Serrated	-0.920	0.744	30
		Nonserrated	-1.251	0.392	30
		Screwdriver	2.678	0.824	15
	Unclothed	Serrated	-0.457	1.063	30
		Nonserrated	-1.052	0.620	30
		Screwdriver	2.810	0.465	15

Table 45

Test of Between-Subjects Effects for Weapon and Fabric Effects on Kerf Shape

Dependent Variable		*F*	*Significance*
Shape	Intercept	90.692	0.001
	Weapon	2.877	0.001
	Fabric	453.624	0.014

Table 46

Weapon Post Hoc Tests for Kerf Shape

Dependent Variable	*(I) Weapon*	*(J) Weapon*	*Mean Difference (I-J)*	*Significance*
Shape	Serrated	Nonserrated	0.058	0.833
		Screwdriver	-3.366	0.001
	Nonserrated	Serrated	-0.058	0.833
		Screwdriver	-3.424	0.001
	Screwdriver	Serrated	3.366	0.001
		Nonserrated	3.424	0.001

Table 47

Fabric Post Hoc Tests for Kerf Shape

Dependent Variable	*(I) Weapon*	*(J) Weapon*	*Mean Difference (I-J)*	*Significance*
Shape	Polyester	Comforter	-0.626	0.001
		Satin	-0.309	0.358
		Cotton	-0.467	0.035
		Drill	-0.304	0.377
		Unclothed	-0.291	0.427

5.6 Margins and Floor

Descriptive statistics are displayed in Table 48. Margin regularity occurred the most frequently in nonserrated knives. Serrated knives produced the most irregular marks (25). Margin regularity was also the most frequent in satin (43) and polyester fabrics (44) and the most irregular in cotton fabric (20). Kerf floor was the most defined in nonserrated knives (29%) and in unclothed specimens (20%). Kerf floor was the most undefined in scalloped knives (24%) and in drill fabric (27%). The widest kerf floors occurred in screwdrivers (66%) and in cotton fabric (24%). Margins and floor significantly differed between weapon groups (see Table 49; $p<0.01$). Nonserrated knives significantly differed from other weapon groups in kerf margins and floor (see Table 50; $p<0.01$).

Table 48

Descriptive Statistics of Margins and Floor by Weapon and Fabric Type

Dependent Variable	Fabric	*Weapon*	*Mean*	*Std. Deviation*	*n*
Margins and Floor	Comforter	Serrated	-0.005	1.624	30
		Nonserrated	-0.658	1.527	30
		Screwdriver	0.928	1.236	15
	Satin	Serrated	0.193	1.462	30
		Nonserrated	-0.710	1.403	30
		Screwdriver	0.306	1.508	15
	Cotton	Serrated	0.508	1.593	30
		Nonserrated	-0.855	1.069	30
		Screwdriver	0.088	1.240	15
	Drill	Serrated	0.789	1.587	30
		Nonserrated	-0.220	1.455	30
		Screwdriver	0.166	1.216	15
	Polyester	Serrated	-0.250	1.485	30
		Nonserrated	-0.306	1.094	30
		Screwdriver	0.929	0.988	15
	Unclothed	Serrated	0.613	2.327	30
		Nonserrated	-0.894	1.478	30
		Screwdriver	1.174	0.486	15

Table 49

Test of Between-Subjects Effects for Weapon and Fabric Effects on Margins and Floor

Dependent Variable		*F*	*Significance*
Margins and Floor	Intercept	1.859	0.173
	Weapon	26.703	0.001
	Fabric	0.776	0.567

Table 50

Weapon Post Hoc Tests for Margins and Floor

Dependent Variable	*(I) Weapon*	*(J) Weapon*	*Mean Difference (I-J)*	*Significance*
Margins and Floor	Serrated	Nonserrated	0.915	0.001
		Screwdriver	-0.290	0.279
	Nonserrated	Serrated	-0.915	0.001
		Screwdriver	-1.206	0.001
	Screwdriver	Serrated	0.290	0.279
		Nonserrated	1.206	0.001

5.7 Debris

Descriptive statistics are displayed in Table 51. Crushing occurred the most often in nonserrated knives (34%) and in cotton comforter fabric (26%). Flaking occurred the most in serrated knives (33%) and in unclothed specimens (21%). Fine debris occurred the most in pocketknives (33%) and in polyester fabric (20%). Debris differed significantly with both fabric type and weapon type (see Table 52; $p<0.05$). The screwdriver group significantly differed the most from serrated knives and nonserrated knives (see Table 53; $p<0.01$). Cotton, drill, polyester, and unclothed specimens significantly differed from each other, with drill fabrics differing the most from other fabrics (see Table 54; $p<0.05$).

Table 51

Descriptive Statistics of Debris by Weapon and Fabric Type

Dependent Variable	Fabric	*Weapon*	*Mean*	*Std. Deviation*	*n*
Debris	Comforter	Serrated	0.246	0.491	30
		Nonserrated	0.633	0.799	30
		Screwdriver	-1.125	0.000	15
		Total	0.127	0.879	75
	Satin	Serrated	0.000	0.267	30
		Nonserrated	0.843	0.535	30
		Screwdriver	-0.773	0.651	15
		Total	0.183	0.772	75
	Cotton	Serrated	0.105	0.879	30
		Nonserrated	-0.246	1.209	30
		Screwdriver	-0.914	1.448	15
		Total	-0.239	1.189	75
	Drill	Serrated	0.176	0.946	30
		Nonserrated	-1.230	1.249	30
		Screwdriver	-0.211	0.544	15
		Total	-0.464	1.198	75
	Polyester	Serrated	0.422	0.818	30
		Nonserrated	0.211	0.996	30
		Screwdriver	-0.070	0.976	15
		Total	0.239	0.930	75
	Unclothed	Serrated	0.422	0.535	30
		Nonserrated	0.000	1.033	30
		Screwdriver	-0.070	0.000	15
		Total	0.155	0.761	75
	Total	Serrated	0.228	0.707	180
		Nonserrated	0.035	1.196	180
		Screwdriver	-0.527	0.881	90
		Total	0.000	1.000	450

Table 52

Test of Between-Subjects Effects for Weapon and Fabric Effects on Debris

Dependent Variable		*F*	*Significance*
Debris	Intercept	4.326	0.038
	Weapon	23.959	0.001
	Fabric	5.813	0.001

Table 53

Weapon Post Hoc Tests for Debris

Dependent Variable	*(I) Weapon*	*(J) Weapon*	*Mean Difference (I-J)*	*Significacne*
Debris	Serrated	Nonserrated	0.193	0.080
		Screwdriver	0.756	0.001
	Nonserrated	Serrated	-0.193	0.080
		Screwdriver	0.562	0.001
	Screwdriver	Serrated	-0.756	0.001
		Nonserrated	-0.562	0.001

Table 54

Fabric Post Hoc Tests for Debris

Dependent Variable	*(I) Fabric*	*(J) Fabric*	*Mean Difference (I-J)*	*Significance*
Debris	Cotton	Comforter	-0.365	0.092
		Satin	-0.422	0.030
		Drill	0.225	0.586
		Polyester	-0.478	0.008
		Unclothed	-0.394	0.054
	Drill	Comforter	-0.590	0.001
		Satin	-0.647	0.001
		Cotton	-0.225	0.586
		Polyester	-0.703	0.001
		Unclothed	-0.618	0.001
	Polyester	Comforter	0.112	0.966
		Satin	0.056	0.999
		Cotton	0.478	0.008
		Drill	0.703	0.001
		Unclothed	0.084	0.990
	Unclothed	Comforter	0.028	1.000
		Satin	-0.028	1.000
		Cotton	0.394	0.054
		Drill	0.618	0.001
		Polyester	-0.084	0.990

5.8 Length

Descriptive statistics are displayed in Table 55. The longest mean lengths occurred with polyester fabric (6.97 mm) and the shortest with cotton fabric (4.85 mm).

Length differences were significant between fabric groups (see Table 56; $p<0.01$). In terms of length, the cotton fabric differed the most from all others except for the drill fabric (see Table 57; $p<0.05$).

Table 55

Descriptive Statistics of Kerf Length by Weapon and Fabric Type

Dependent Variable	Weapon	Fabric	*Mean*	*Std. Deviation*	*n*
Length	Serrated	Comforter	5.533	2.670	15
		Satin	6.280	2.196	15
		Cotton	5.231	2.396	15
		Drill	6.834	2.487	15
		Polyester	6.435	3.229	15
		Unclothed	4.289	1.678	15
		Total	5.767	2.564	90
	Nonserrated	Comforter	6.075	4.098	15
		Satin	6.395	3.041	15
		Cotton	3.483	1.260	15
		Drill	6.789	3.558	15
		Polyester	7.133	2.758	15
		Unclothed	7.298	3.125	15
		Total	6.195	3.276	90
	Scalloped	Comforter	6.357	2.881	15
		Satin	6.394	3.339	15
		Cotton	6.291	4.326	15
		Drill	7.431	2.665	15
		Polyester	6.007	2.417	15
		Unclothed	6.325	1.555	15
		Total	6.468	2.937	90
	Pocketknife	Comforter	6.273	2.594	15
		Satin	8.131	3.479	15
		Cotton	4.100	1.288	15
		Drill	4.983	3.547	15
		Polyester	7.817	3.611	15
		Unclothed	5.824	2.122	15
		Total	6.188	3.170	90
	Screwdriver	Comforter	7.019	3.180	15
		Satin	6.957	3.934	15
		Cotton	5.155	2.390	15
		Drill	4.485	1.951	15
		Polyester	7.478	3.752	15
		Unclothed	8.078	3.843	15
		Total	6.529	3.422	90
	Total	Comforter	6.252	3.085	75
		Satin	6.832	3.237	75
		Cotton	4.852	2.699	75
		Drill	6.104	3.059	75
		Polyester	6.974	3.177	75
		Unclothed	6.363	2.862	75
		Total	6.229	3.087	450

Table 56

Test of Between-Subjects Effects for Weapon and Fabric Effects on Kerf Length

Dependent Variable		*F*	*Significance*
Length	Intercept	1815.717	0.001
	Weapon	0.602	0.548
	Fabric	4.874	0.001

Table 57

Fabric Post Hoc Tests for Kerf Length

Dependent Variable	*(I) Fabric*	*(J) Fabric*	*Mean Difference (I-J)*	*Significance*
	Cotton	Comforter	-1.3996	0.046
		Satin	-1.9797	0.001
		Drill	-1.2525	0.103
		Polyester	-2.1220	0.001
		Unclothed	-1.5108	0.024

5.9 Results for Dependent Variables

Tables 58 through 64 display complete data of all of the dependent variables that were discussed previously. Table 58 shows Post Hoc tests for weapon type for all dependent variables. Tables 59 through 64 displays Post Hoc tests for fabric type for all dependent variables. Table 65 shows weapon characteristics, and Table 66 shows impact force measurements. Impact force ranged between 52.23 N and 58.60 N. Tables 67 and 68 summarize all of the observed cut mark characteristics found during the study in relation to one another by weapon and fabric type. Finally, Table 69 summarizes the significant dependent variable findings for weapon and fabric groups.

Table 58

Weapon Post Hoc Tests for Dependent Variables

						95% Confidence Interval	
Dependent Variable	*(I) Weapon*	*(J) Weapon*	*Mean Difference (I-J)*	*Std. Error*	*Significance*	*Lower Bound*	*Upper Bound*
Shape	Serrated	Nonserrated	0.058	0.101	0.833	-0.179	0.295
		Screwdriver	-3.366	0.124	0.001	-3.657	-3.076
	Nonserrated	Serrated	-0.058	0.101	0.833	-0.295	0.179
		Screwdriver	-3.424	0.124	0.001	-3.715	-3.134
	Screwdriver	Serrated	3.366	0.124	0.001	3.076	3.657
		Nonserrated	3.424	0.124	0.001	3.134	3.715
Margins and Floor	Serrated	Nonserrated	0.915	0.155	0.001	0.551	1.280
		Screwdriver	-0.290	0.190	0.279	-0.737	0.157
	Nonserrated	Serrated	-0.915	0.155	0.001	-1.280	-0.551
		Screwdriver	-1.206	0.190	0.001	-1.652	-0.759
	Screwdriver	Serrated	0.290	0.190	0.279	-0.157	0.737
		Nonserrated	1.206	0.190	0.001	0.759	1.652
Striations and Wall Projections	Serrated	Nonserrated	-2.597	0.097	0.001	-2.824	-2.369
		Screwdriver	-2.718	0.118	0.001	-2.996	-2.439
	Nonserrated	Serrated	2.597	0.097	0.001	2.369	2.824
		Screwdriver	-0.121	0.118	0.565	-0.399	0.158
	Screwdriver	Serrated	2.718	0.118	0.001	2.439	2.996
		Nonserrated	0.121	0.118	0.565	-0.158	0.399
Width	Serrated	Nonserrated	-0.016	0.092	0.983	-0.232	0.200
		Screwdriver	1.045	0.112	0.001	0.078	1.309
	Nonserrated	Serrated	0.016	0.092	0.983	-0.200	0.232
		Screwdriver	1.061	0.112	0.001	0.796	1.323
	Screwdriver	Serrated	-1.045	0.112	0.001	-1.309	-0.780
		Nonserrated	-1.061	0.112	0.001	-1.325	-0.796
Depth	Serrated	Nonserrated	0.072	0.095	0.727	-0.151	0.296
		Screwdriver	0.804	0.116	0.001	0.531	1.078
	Nonserrated	Serrated	-0.072	0.095	0.727	-0.296	0.151
		Screwdriver	0.732	0.116	0.001	0.459	1.006
	Screwdriver	Serrated	-0.804	0.116	0.001	-1.078	-0.531
		Nonserrated	-0.732	0.116	0.001	-1.006	-0.459
Debris	Serrated	Nonserrated	0.193	0.090	0.080	-0.017	0.404
		Screwdriver	0.756	0.110	0.001	0.497	1.014
	Nonserrated	Serrated	-0.193	0.090	0.080	-0.404	0.017
		Screwdriver	0.562	0.110	0.001	0.304	0.820
	Screwdriver	Serrated	-0.756	0.110	0.001	-1.014	-0.497
		Nonserrated	-0.562	0.110	0.001	-0.820	-0.304

Table 59

Fabric Post Hoc Tests for Kerf Shape

Dependent Variable	*(I) Fabric*	*(J) Fabric*	*Mean Difference (I-J)*	*Std. Error*	*Significance*	*95% Confidence Interval Lower Bound*	*95% Confidence Interval Upper Bound*
Shape	Comforter	Satin	0.317	0.156	0.326	-0.130	0.765
		Cotton	0.159	0.156	0.912	-0.288	0.606
		Drill	0.322	0.156	0.309	-0.125	0.770
		Polyester	0.626	0.156	0.001	0.179	1.073
		Unclothed	0.335	0.156	0.266	-0.112	0.782
	Satin	Comforter	-0.317	0.156	0.326	-0.765	0.130
		Cotton	-0.158	0.156	0.913	-0.606	0.289
		Drill	0.005	0.156	1.000	-0.442	0.452
		Polyester	0.309	0.156	0.358	-0.139	0.756
		Unclothed	0.017	0.156	1.000	-0.430	0.465
	Cotton	Comforter	-0.159	0.156	0.912	-0.606	0.288
		Satin	0.158	0.156	0.913	-0.289	0.606
		Drill	0.163	0.156	0.902	-0.284	0.611
		Polyester	0.467	0.156	0.035	0.020	0.914
		Unclothed	0.176	0.156	0.870	-0.271	0.623
	Drill	Comforter	-0.322	0.156	0.309	-0.770	0.125
		Satin	-0.005	0.156	1.000	-0.452	0.442
		Cotton	-0.163	0.156	0.902	-0.611	0.284
		Polyester	0.304	0.156	0.377	-0.144	0.751
		Unclothed	0.013	0.156	1.000	-0.435	0.460
	Polyester	Comforter	-0.626	0.156	0.001	-1.073	-0.179
		Satin	-0.309	0.156	0.358	-0.756	0.139
		Cotton	-0.467	0.156	0.035	-0.914	-0.020
		Drill	-0.304	0.156	0.377	-0.751	0.144
		Unclothed	-0.291	0.156	0.427	-0.738	0.156
	Unclothed	Comforter	-0.335	0.156	0.266	-0.782	0.112
		Satin	-0.018	0.156	1.000	-0.465	0.430
		Cotton	-0.176	0.156	0.870	-0.623	0.271
		Drill	-0.013	0.156	1.000	-0.460	0.435
		Polyester	0.291	0.156	0.427	-0.156	0.738

Table 60

Fabric Post Hoc Tests for Margins and Floor

Dependent Variable	*(I) Fabric*	*(J) Fabric*	*Mean Difference (I-J)*	*Std. Error*	*Significance*	*95% Confidence Interval*	
						Lower Bound	*Upper Bound*
Margins and Floor	Comforter	Satin	0.066	0.240	1.000	-0.622	0.754
		Cotton	0.042	0.240	1.000	-0.647	0.730
		Drill	-0.340	0.240	0.717	-1.028	0.348
		Polyester	-0.043	0.240	1.000	-0.731	0.645
		Unclothed	-0.202	0.240	0.960	-0.890	0.486
	Satin	Comforter	-0.066	0.240	1.000	-0.754	0.622
		Cotton	-0.025	0.240	1.000	-0.713	0.663
		Drill	-0.407	0.240	0.538	-1.095	0.282
		Polyester	-0.109	0.240	0.998	-0.797	0.579
		Unclothed	-0.268	0.240	0.875	-0.956	0.420
	Cotton	Comforter	-0.042	0.240	1.000	-0.730	0.647
		Satin	0.025	0.240	1.000	-0.663	0.713
		Drill	-0.382	0.240	0.606	-1.070	0.306
		Polyester	-0.084	0.240	0.999	-0.772	0.604
		Unclothed	-0.243	0.240	0.914	-0.931	0.445
	Drill	Comforter	0.340	0.240	0.717	-0.348	1.028
		Satin	0.407	0.240	0.538	-0.282	1.095
		Cotton	0.382	0.240	0.606	-0.306	1.070
		Polyester	0.298	0.240	0.818	-0.391	0.985
		Unclothed	0.139	0.240	0.993	-0.549	0.827
	Polyester	Comforter	0.043	0.240	1.000	-0.645	0.731
		Satin	0.109	0.240	0.998	-0.579	0.797
		Cotton	0.084	0.240	0.999	-0.604	0.772
		Drill	-0.298	0.240	0.818	-0.985	0.391
		Unclothed	-0.159	0.240	0.986	-0.847	0.529
	Unclothed	Comforter	0.202	0.240	0.960	-0.486	0.890
		Satin	0.268	0.240	0.875	-0.420	0.956
		Cotton	0.243	0.240	0.914	-0.445	0.931
		Drill	-0.139	0.240	0.993	-0.827	0.549
		Polyester	0.159	0.240	0.986	-0.529	0.847

Table 61

Fabric Post Hoc Tests for Striations and Wall Projections

Dependent Variable	*(I) Fabric*	*(J) Fabric*	*Mean Difference (I-J)*	*Std. Error*	*Significance*	*95% Confidence Interval*	
						Lower Bound	*Upper Bound*
Striations and Wall Projections	Comforter	Satin	0.000	0.150	1.000	-0.429	0.429
		Cotton	0.544	0.150	0.004	0.115	0.972
		Drill	-0.200	0.150	0.764	-0.629	0.229
		Polyester	0.416	0.150	0.064	-0.013	0.845
		Unclothed	-0.187	0.150	0.814	-0.616	0.242
	Satin	Comforter	0.000	0.150	1.000	-0.429	0.429
		Cotton	0.544	0.150	0.004	0.115	0.972
		Drill	-0.200	0.150	0.764	-0.629	0.229
		Polyester	0.416	0.150	0.064	-0.013	0.845
		Unclothed	-0.187	0.150	0.814	-0.616	0.242
	Cotton	Comforter	-0.544	0.150	0.004	-0.972	-0.115
		Satin	-0.544	0.150	0.004	-0.972	-0.115
		Drill	-0.744	0.150	0.001	-1.173	-0.315
		Polyester	-0.128	0.150	0.957	-0.557	0.301
		Unclothed	-0.730	0.150	0.001	-1.159	-0.301
	Drill	Comforter	0.200	0.150	0.764	-0.229	0.629
		Satin	0.200	0.150	0.764	-0.229	0.629
		Cotton	0.744	0.150	0.001	0.315	1.173
		Polyester	0.616	0.150	0.001	0.187	1.045
		Unclothed	0.014	0.150	1.000	-0.415	0.443
	Polyester	Comforter	-0.416	0.150	0.064	-0.845	0.013
		Satin	-0.416	0.150	0.064	-0.845	0.013
		Cotton	0.128	0.150	0.957	-0.301	0.557
		Drill	-0.616	0.150	0.001	-1.045	-0.187
		Unclothed	-0.602	0.150	0.001	-1.031	-0.173
	Unclothed	Comforter	0.187	0.150	0.814	-0.242	0.616
		Satin	0.187	0.150	0.814	-0.242	0.616
		Cotton	0.730	0.150	0.001	0.301	1.159
		Drill	-0.014	0.150	1.000	-0.443	0.415
		Polyester	0.602	0.150	0.001	0.173	1.031

Table 62

Fabric Post Hoc Tests for Kerf Width

Dependent Variable	*(I) Fabric*	*(J) Fabric*	*Mean Difference (I-J)*	*Std. Error*	*Significance*	*95% Confidence Interval*	
						Lower Bound	*Upper Bound*
Width	Comforter	Satin	-0.212	0.142	0.670	-0.619	0.195
		Cotton	-0.135	0.142	0.933	-0.542	0.272
		Drill	-0.868	0.142	0.001	-1.275	-0.461
		Polyester	-0.270	0.142	0.404	-0.677	0.137
		Unclothed	-0.328	0.142	0.194	-0.735	0.079
	Satin	Comforter	0.212	0.142	0.670	-0.195	0.619
		Cotton	0.077	0.142	0.994	-0.330	0.484
		Drill	-0.656	0.142	0.001	-1.063	-0.249
		Polyester	-0.058	0.142	0.999	-0.465	0.349
		Unclothed	-0.116	0.142	0.965	-0.523	0.291
	Cotton	Comforter	0.135	0.142	0.933	-0.272	0.542
		Satin	-0.077	0.142	0.994	-0.484	0.330
		Drill	-0.733	0.142	0.001	-1.140	-0.326
		Polyester	-0.135	0.142	0.933	-0.542	0.272
		Unclothed	-0.193	0.142	0.753	-0.600	0.214
	Drill	Comforter	0.868	0.142	0.001	0.461	1.275
		Satin	0.656	0.142	0.001	0.249	1.063
		Cotton	0.733	0.142	0.001	0.326	1.140
		Polyester	0.598	0.142	0.001	0.191	1.005
		Unclothed	0.540	0.142	0.002	0.133	0.947
	Polyester	Comforter	0.270	0.142	0.404	-0.137	0.677
		Satin	0.058	0.142	0.999	-0.349	0.465
		Cotton	0.135	0.142	0.933	-0.272	0.542
		Drill	-0.598	0.142	0.001	-1.005	-0.191
		Unclothed	-0.058	0.142	0.999	-0.465	0.349
	Unclothed	Comforter	0.328	0.142	0.194	-0.079	0.735
		Satin	0.116	0.142	0.965	-0.291	0.523
		Cotton	0.193	0.142	0.753	-0.214	0.600
		Drill	-0.540	0.142	0.002	-0.947	-0.133
		Polyester	0.058	0.142	0.999	-0.349	0.465

Table 63

Fabric Post Hoc Tests for Kerf Depth

Dependent Variable	*(I) Fabric*	*(J) Fabric*	*Mean Difference (I-J)*	*Std. Error*	*Significance*	*95% Confidence Interval*	
						Lower Bound	*Upper Bound*
Depth	Comforter	Satin	-0.195	0.147	0.770	-0.616	0.226
		Cotton	-0.130	0.147	0.950	-0.551	0.291
		Drill	-0.260	0.147	0.487	-0.681	0.161
		Polyester	-0.347	0.147	0.173	-0.768	0.074
		Unclothed	0.043	0.147	1.000	-0.378	0.465
	Satin	Comforter	0.195	0.147	0.770	-0.226	0.616
		Cotton	0.065	0.147	0.998	-0.356	0.486
		Drill	-0.065	0.147	0.998	-0.486	0.356
		Polyester	-0.152	0.147	0.907	-0.573	0.269
		Unclothed	0.239	0.147	0.584	-0.183	0.660
	Cotton	Comforter	0.130	0.147	0.950	-0.291	0.551
		Satin	-0.065	0.147	0.998	-0.486	0.356
		Drill	-0.130	0.147	0.950	-0.551	0.291
		Polyester	-0.217	0.147	0.681	-0.638	0.204
		Unclothed	0.174	0.147	0.846	-0.248	0.595
	Drill	Comforter	0.260	0.147	0.487	-0.161	0.681
		Satin	0.065	0.147	0.998	-0.356	0.486
		Cotton	0.130	0.147	0.950	-0.291	0.551
		Polyester	-0.087	0.147	0.992	-0.508	0.334
		Unclothed	0.304	0.147	0.308	-0.117	0.725
	Polyester	Comforter	0.347	0.147	0.173	-0.074	0.768
		Satin	0.152	0.147	0.907	-0.269	0.573
		Cotton	0.217	0.147	0.681	-0.204	0.638
		Drill	0.087	0.147	0.992	-0.334	0.508
		Unclothed	0.390	0.147	0.087	-0.031	0.812
	Unclothed	Comforter	-0.043	0.147	1.000	-0.465	0.378
		Satin	-0.239	0.147	0.584	-0.660	0.182
		Cotton	-0.174	0.147	0.846	-0.595	0.248
		Drill	-0.304	0.147	0.308	-0.725	0.117
		Polyester	-0.390	0.147	0.087	-0.812	0.031

Table 64

Fabric Post Hoc Tests for Debris

Dependent Variable	*(I) Fabric*	*(J) Fabric*	*Mean Difference (I-J)*	*Std. Error*	*Significance*	*95% Confidence Interval*	
						Lower Bound	*Upper Bound*
Debris	Comforter	Satin	-0.056	0.139	0.999	-0.453	0.341
		Cotton	0.365	0.139	0.092	-0.032	0.763
		Drill	0.590	0.139	0.001	0.193	0.988
		Polyester	-0.112	0.139	0.966	-0.510	0.285
		Unclothed	-0.028	0.139	1.000	-0.425	0.369
	Satin	Comforter	0.056	0.139	0.999	-0.341	0.454
		Cotton	0.422	0.139	0.030	0.024	0.819
		Drill	0.646	0.139	0.001	0.249	1.044
		Polyester	-0.056	0.139	0.999	-0.453	0.341
		Unclothed	0.028	0.139	1.000	-0.369	0.425
	Cotton	Comforter	-0.365	0.139	0.092	-0.763	0.032
		Satin	-0.422	0.139	0.030	-0.819	-0.024
		Drill	0.225	0.139	0.586	-0.172	0.622
		Polyester	-0.478	0.139	0.008	-0.875	-0.081
		Unclothed	-0.394	0.139	0.054	-0.791	0.004
	Drill	Comforter	-0.590	0.139	0.001	-0.988	-0.193
		Satin	-0.647	0.139	0.001	-1.044	-0.249
		Cotton	-0.225	0.139	0.586	-0.622	0.172
		Polyester	-0.703	0.139	0.001	-1.100	-0.305
		Unclothed	-0.618	0.139	0.001	-1.016	-0.221
	Polyester	Comforter	0.112	0.139	0.966	-0.285	0.510
		Satin	0.056	0.139	0.999	-0.341	0.454
		Cotton	0.478	0.139	0.008	0.081	0.875
		Drill	0.703	0.139	0.001	0.305	1.100
		Unclothed	0.084	0.139	0.990	-0.313	0.482
	Unclothed	Comforter	0.028	0.139	1.000	-0.369	0.425
		Satin	-0.028	0.139	1.000	-0.425	0.369
		Cotton	0.394	0.139	0.054	-0.004	0.791
		Drill	0.618	0.139	0.001	0.221	1.016
		Polyester	-0.084	0.139	0.990	-0.482	0.313

Table 65

Weapon Characteristics

	Weapon				
Characteristic	Serrated	Nonserrated	Scalloped	Pocketknife	Screwdriver
Weight (g)	860	880	820	920	900
Length cm)	30.4	30.6	30.5	30.4	30.5
Width (cm)	2.54	2.54	2.54	2.54	2.54
Blade Length (cm)	4.825	5.045	5.014	4.973	4.699
Blade Width (cm)	1.527	1.675	1.751	1.536	0.894
Number of Teeth	40	0	8	0	0
Teeth Per Inch (TPI)	29	0	6	0	0
Beveling	Yes	Yes	No	Yes	Yes
Number of Sharp Edges	1	1	1	1	1

Table 66

Impact Force Measurements

Weapon	*Impact Force (N)*
Serrated Knife	54.78
Nonserrated Knife	56.06
Scalloped Knife	52.23
Pocketknife	58.60
Screwdriver	57.33

Table 67

Summary of Cut Mark Characteristics Observed with Weapon Types (Serrated, Nonserrated, Scalloped, Pocketknife, and Screwdriver Groups)

Characteristic	*Serrated Knives*	*Nonserrated Knives*	*Scalloped Knives*	*Pocketknives*	*Screwdriver*
Striations	✓		✓		
Wall Projections	✓		✓		
Wide Width					✓
Narrow Width		✓		✓	
Shallow Depth					✓
Deep Depth			✓		
V-shaped Cross-section	✓	✓	✓	✓	
U-shaped Cross-section					✓
Steep Wall Gradients	✓	✓	✓	✓	
Shallow Wall Gradients	✓				✓
Regular Margins		✓		✓	
Irregular Margins	✓		✓	✓	
Margin Splitting			✓		
Defined Floor		✓		✓	
Undefined Floor			✓		
Floor Splitting	✓		✓		
Crushing		✓			✓
Flaking	✓		✓		
Fine Debris		✓		✓	

Note: Check marks indicate the presence of the observed characteristics in each weapon group.

Table 68

Summary of Cut Mark Characteristics Observed with Fabric Types (Comforter, Satin, Cotton, Drill, Polyester, and Unclothed Groups)

Characteristic	*Comforter*	*Satin*	*Cotton*	*Drill*	*Polyester*	*Unclothed*
Striations	✓	✓			✓	
Wall Projections			✓		✓	
Wide Width	✓		✓			
Narrow Width		✓			✓	✓
Shallow Depth	✓			✓		✓
Deep Depth		✓			✓	
V-shaped Cross-section	✓	✓	✓	✓	✓	✓
U-shaped Cross-section	✓	✓	✓	✓	✓	✓
Steep Wall Gradients				✓	✓	
Shallow Wall Gradients	✓					
Regular Margins		✓			✓	
Irregular Margins			✓	✓		
Margin Splitting						✓
Defined Floor	✓					✓
Undefined Floor				✓		
Floor Splitting		✓				✓
Crushing	✓		✓			
Flaking				✓	✓	✓
Fine Debris	✓				✓	

Note: Check marks indicate the presence of the observed characteristics in each fabric group.

Table 69

Significant Differences in Cut Mark Characteristics Observed in Weapon and Fabric Groups

Significant Differences	*Weapons*	*Fabric*	*Intercept*
Striations and Wall Projections	✓**	✓**	✓**
Width	✓**	✓**	✓**
Depth	✓**	✓*	✓*
Kerf Shape	✓**	✓*	✓**
Margins and Floor	✓**		
Debris	✓**	✓**	✓*
Length		✓**	✓**

Note: Check marks indicate significant characteristic findings in weapon and fabric groups.
** Significant at the 0.01 level
*   Significant at the 0.05 level

5.9 Intraobserver Error

After tests were completed, intraobserver error tests were conducted by reexamining 30 bones from each weapon and fabric class and comparing results with the original data. 227 out of the 300 mark characteristics examined (76%) were consistent with the original data. Due to subjectivity of cut mark characteristics, margin and floor characteristics were the most difficult to assess. However, it should be noted that some discrepancies in characteristic assessments resulted from ambiguity in determining how to best categorize particular characteristics. For instance, some marks displayed defined floor characteristics, but could also be classified as having a wide floor. Though having more categorical options accounts for variation, it also creates further ambiguity. Future research should make modifications on classification processes to include additional characteristics, simpler categorical options, or ways to metrically categorize marks. Despite the ambiguity in categorical options, the conjunction of features was useful in assessing weapon class based on kerf mark characteristics. Weapon class was correctly identified in 83% of the cases.

CHAPTER SIX: DISCUSSION

6.1 Introduction

Weapon type and fabric type were shown to significantly alter kerf mark appearance. The hypotheses of the current study stated that flesh and fabric alter cut marks on bone by creating shallower wall gradients, increased marginal distortion, and cut marks with a decreased width and depth; cut marks on fleshed skeletal remains will be rounded, and single-edged blades will cause splitting; nonserrated blades will produce clean-cut incisions; serrated blades will produce striated incisions; and screwdrivers will produce wide, U-shaped incisions on fleshed and clothed remains. The results indicated that weapon type significantly affected kerf wall gradients, marginal distortion, width, and depth, and fabric type significantly affected wall gradients, width, and depth. Marginal distortion was not significantly affected by fabric type as predicted. Marginal distortion, therefore, may not be a distinguishable characteristic between clothed and unclothed samples, or this may be a result of the difficulty in assessing marginal distortion skewed by surface debris. Cut marks exhibited rounding features with projections and debris. Splitting was observed in single-edged blades. Nonserrated blades produced clean-cut marks with fewer projections, and serrated blades produced striations. Screwdrivers produced wide, U-shaped marks. Serrated knives and nonserrated knives were distinguishable from screwdrivers, and serrated knives were distinguishable from nonserrated knives in several cases, suggesting that marks can be classified by weapon class. Fibers were present in several cut marks as well and are able to aid in the determination of fabric type in forensic cases.

The current study confirmed findings by Symes et al. (2010), Potts and Shipman (1981), Blumenschine et al. (1986), and Alunni-Perret et al. (2005) that suggested serrated blades produce V-shaped cross-sections. However, scalloped blades produced U-shaped cross-sections in a few cases in addition to commonly found V-shaped cross-sections, suggesting that the creation of U-shaped marks may not be limited to screwdrivers. Furthermore, the highest number of deep cut marks and cut marks with varied depths were found in scalloped blades. This may be a result of teeth "skipping" as the blade hits the surface, causing variation in cross-sectional shape (Tegtmeyer, 2012). Serrated blades tended to produce wider kerf marks while nonserrated blades produced narrower, clean-cut marks with less wall projections and a lack of striations. Screwdrivers tended to produce shallow, wide, U-shaped marks and crushed debris. However, it is important to note that although the characteristics examined aid in the determination of a weapon, there is some degree of variation in characteristics produced. The absence of a feature, such as striations, did not necessarily mean that the weapon came from a nonserrated knife, for instance. Therefore, all characteristics should be examined in conjunction with each other. In addition, this study showed that low powered standard light microscopy was useful in assessing cut mark characteristics and is, therefore, an accurate, practical, and less costly method for examining cut marks on bone.

6.2 Implications

This research has several significant implications in the field of forensic anthropology. First, distinguishing between serrated knives, nonserrated knives, and screwdrivers was possible using cut mark classification criteria. Second, fabric was shown to have an effect on the appearance of cut marks on bone. The prevalence of sharp force trauma crime indicates that this research and other sharp force trauma studies are applicable to research in forensic settings. In addition, this research contributes to tool mark studies in archaeological and bioarchaeological settings. Such research on sharp force trauma can assist in the determination of violent scenarios, cause of death, subsistence patterns, and butchery techniques.

6.3 Limitations

Several limitations in this study should be considered. First, though the drop-impact tests were useful in producing consistent marks, the trajectory and angle of the blade may still have been affected during drop-impact tests. More sophisticated guided drop-impact tests can be built to test the consistency of cut mark patterns on bone. Second, multiple weapons from the same class were not tested in this study. Further research should test multiple weapons in multiple classes to control for any error that may result due to fluctuations or imperfections in the blade. Third, sharp force trauma affects bone differently in living animals. However, due to the nature of the study, only post-mortem cut marks were analyzed. Still, distinguishing cut mark features can assist in dismemberment and post-mortem sharp force trauma cases.

Furthermore, this experiment was conducted using only rib specimens. Ribs were chosen because the chest cavity is most likely to be impacted during a stabbing event (Schmidt & Pollack, 2006). Still, further research should examine kerf features on other bones, such as vertebrae and scapulae, which are also common stabbing locations

(Schmidt & Pollack, 2006). Cut marks could not be adequately examined on soft tissue; therefore, future research studies should also analyze soft tissue cut marks.

Finally, the analysis of kerf mark characteristics is subjective, and intraobserver error may affect results. Due to the lack of metric characteristics, categorical measurements were used in the study, and these measurements had to be converted into z-scores. Because so many categorical options were used to analyze marks, there was more ambiguity in classifying features. However, the conjunction of characteristics made it possible to correctly determine weapon class just by examining cut mark features.

CHAPTER SEVEN: CONCLUSION

Overall, the examination of cut mark features on fleshed and clothed bone was possible and distinguishable by weapon and fabric type. This study attempts to fill the gap in sharp force trauma literature on specimens with flesh and fabric present, and distinguishable characteristics were found that could be used to classify weapons. Distinguishable weapon characteristics include kerf wall gradients, marginal distortion, width, and depth. Distinguishable fabric type characteristics were present in wall gradients, width, and depth. Rounding features, projections, and debris were found in cut marks as characteristics that were distinguishable from defleshed bone specimens. Splitting was observed in single-edged blades; nonserrated blades produced clean-cut marks with fewer projections; serrated blades produced striations; and screwdrivers produced wide, U-shaped marks. This study also found that the absence of striations is not always a distinguishable feature in nonserrated knives as striations were not always present in marks made by serrated weapons.

This research indicated that it is possible to classify cut marks by weapon and fabric type based on trauma characteristics left on bone. While there is variation and subjectivity in the classification of kerf features, analyzing all features in conjunction with each other can assist greatly in the forensic identification process. The use of a guided-drop device was necessary for this research as it allowed for consistent force and directionality when producing cut marks. This study also found standard light microscopy to be a cost-effective and accessible option for analyzing cut marks on bone. Most significantly, this study challenges current data on differentiating serrated and nonserrated knives. The inclusion of scalloped blades showed that cross-section shape, in particular, was not always consistent with current data that suggest serrated blades produce V-shaped kerf marks. Screwdriver marks have also rarely been examined during sharp force trauma studies, and this study was able to identify classifying criteria for this weapon. Furthermore, fabric has rarely been assessed in research on sharp force trauma, and fabrics were shown to have an effect on wall gradients, width, and depth. As the use of bedding fabric has not been previously analyzed in sharp force trauma studies, this research will be useful during forensic examinations.

The results of this experiment foster several recommendations and considerations for future research. Depth is a variable that has seldom been addressed in research when compared to other variables. While depth was addressed in the current study, characteristics were only superficially analyzed. Debris may also obscure depth measurements. Future research on sharp force trauma should analyze depth characteristics further and determine whether this variable can be used to develop consistent classification criteria. Such research might analyze cut marks made at a fixed depth to establish whether significant differences are found between weapon classes. Guided-drop tests were useful in this experiment; however, human stabbing behaviors in relation to cut marks can be analyzed in future research as well. Finally, the inclusion of additional bedding fabrics is suggested in future sharp force trauma studies.

This study touched on the variability of sharp force trauma on bone. By including fabric and flesh in the experiment, it was possible to provide a more accurate representation of the cutting mechanisms and resistance variables that affect blade penetration. This study was able to categorize weapons, examine kerf classification features, apply statistical testing on data to determine associations between kerf features and weapons and fabrics, and identify trends useful in weapon diagnostics. Although kerf feature trends aid in the establishment of cut mark criteria, quantification of kerf features, such as debris size, floor width, and depth, may provide more consistent and discriminatory classification criteria. Through the exploration of these variables, this study has provided a benchmark for establishing kerf classification criteria crucial to the field of forensics.

APPENDIX

Data Collection Form

Date: ________________ Specimen Number: ________________
Knife Class: ________________ Mark Number: ________________

Macroscopic Examination:

Kerf Widths: Average Kerf Width: ________________

Kerf Depths: Average Kerf Depth: ________________

Notes:
____
____
____

Data Collection Form

Date: ______________
Knife Class: ______________
Specimen Number: ______________
Number of Marks: ______________

Microscopic Examination:

Mark Characteristics:

Knife Edge (Score)

Shape	Rounded	Square	Tapered	Unobservable	
Bifurcation	Y / N				

General Characteristics

Striations	Y / N				
Width	Wide	Narrow	Consistent		Varied
Depth	Shallow	Deep	Consistent		Varied
X-Section Shape	V	U	Unobservable		Other
Wall Gradients	Very Steep Steep	None	Shallow		Very Shallow
Wall Projections	Many	Few	None		
Margins	Regular	Irregular	Defined		Undefined
	Splitting				
Floor	Defined	Undefined	Wide	Narrow	Splitting
	Debris				
Debris	Absent	Crushing	Flaking	Fine	Other
Lateral Ridging	Y / N				

Fabric

Type	Comforter	Satin	Cotton	Drill
	Polyster/Blend	Unclothed		
Damage	Extensive	Moderate	Minimal	Absent

Notes:

Weapon Characteristics

Weapon	Weight	Length	Width	Blade Length	Blade Width	Number of Teeth	Teeth Per Inch (TPI)	Beveling	Edge (Sharp)
Serrated Knife									
Nonserrated Knife									
Scalloped Knife									
Pocket Knife									
Screwdriver									

Notes:

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