Document Title: Knife and Saw Toolmark Analysis in Bone: A Manual Designed for the Examination of Criminal Mutilation and Dismemberment

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Document No.: 232864

Date Received: December 2010

Award Number: 2005-IJ-CX-K016

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Knife and Saw Toolmark Analysis in Bone: A Manual Designed for the Examination of Criminal Mutilation and Dismemberment

PART III: PRODUCTS OF NIJ FUNDING
[In original proposal: NIJ Research Milestones
Sawmark Analysis Website
Comparative Collection and Database]

Section 1: Introduction and Background

Introduction

While toolmark and toolmark examination techniques have had a long-standing history in the literature, saw mark examination and interpretation in bone has received little more than a cursory consideration in the forensic sciences. With financial assistance from the National Institute of Justice and the National Forensic Academy, the primary aim was to develop and disseminate a saw mark manual. While saw mark class characteristics have been available to the public in the form of dissertations, theses, some articles and a few book chapters (Alunni-Perret 2005, Bonte 1975, Andahl 1978, Freas 2006, Guilbeau 1989, Guilbeau 1991, Symes 1992, Symes et al. 1998, Symes et al. 2002), utilization of saw mark analysis is primarily accomplished by the first author (SAS) and dissemination of saw mark descriptions and details has not been overly successful.

The author's first attempt to produce a manual for untrained observers was at an AFTE (*Association of Firearm and Toolmark Examiners*) workshop. The abbreviated manual has become rather popular and is a handy device to use in explaining the relevance of saw mark research. (The original manual has been duplicated in Appendix A.) However, even with its early success, it quickly became evident that a more comprehensive manual on misconceptions regarding saw mark analysis, information on terminology, saw design, class characteristics and the principle cutting action was necessary.

History of Saw mark Analysis

Two enlightened researchers in the 1970s fought to introduce the topic of saw marks and to make toolmark analysis in bone more useful to forensic scientists. Wolfgang Bonte's pioneering research in 1975 represents the first concentrated effort by a researcher to closely examine saw mark striae in human bone (Bonte 1975). Bonte's research and casework, while the first to recognize features of saw cutting strokes, suffered from several limitations. Among these limitations was a lack of understanding of saw cutting action. In 1978, R. O. Andahl described numerous saw cut characteristics in metal and animal bone (Andahl 1978). His work illustrated how medicolegal cases of human dismemberment could benefit through the analysis of these characteristics. However, his proposed characteristics were at times overly simplified and thus resulted in less than accurate results for the untrained observer. While Bonte's research expanded the area of toolmark analysis, there was still a need for improvement in the understanding of the tool creating the characteristics, the principles of tool action in a cut, and the value of residual characteristics remaining after a cut. These areas were not addressed in subsequent research following Bonte's and Andahl's studies in the 1970s. Several recent articles and reports published in the *Association of Firearm and Toolmark Examiners Journal* that present case studies on the subject of saw mark analysis generally fail to offer detailed descriptions or comprehensive standards of analysis on the subject.

Symes (1992) was the first researcher to publish a doctoral dissertation on the topic of saw mark analyses of cut bone. Since that time, he has provided analysis of saw marks in nearly 200 dismemberment cases and approximately 700 to 1000 knife cut wound cases. Symes' methodology is based on his evaluation of the diagnostic potential of several features of saw marks on bones, the ability of these features to indicate saw dimensions and the potential of these characteristics to discriminate between different classes of saws and knives. Research conducted by Symes and associates (Symes et al 1988, Symes et al. 1989 a & b, Symes et al. 1990; Symes et al. 1996, Symes et al. 1998; Symes et al. 2002) provide an excellent foundation from which to continue efforts to standardize an accurate and reliable methodology for the analysis of saw and knife marks to bone. While occasional book chapters briefly describe this work (Symes, Berryman et al. 1998, and Symes et al. 2002), each represents a minor aspect of the overall scope of toolmark analysis.

Knife wound analysis has also received little attention in forensic investigation (Symes et al. 1999). Although knife stab wounds are second only to ballistic injuries as the major cause of violent death in this country, the widespread use of meaningless and misleading descriptors such as "sharp", "single-edged blade" and “hesitation mark" (which erroneously implies behavior) are common and may result in serious misinterpretation by attorneys, judges and juries.

Sharp force trauma can involve a variety of weapons and tools. Any tool with a sharp edge can produce incised wounds or kerfs (Figure 1). Most of the incised wounds are created by some class of knife and are recognized as sharp force trauma. The wound is commonly termed a knife stab wound (KSW). The term KSW is often misused, particularly by anthropologists, since most wounds they examine are without soft tissue. Many of the wounds to bone are knife cut (incised) wounds, but are not necessarily due to stabbing. Using the term knife cut wound (KCW) instead of knife stab wound is more accurate and inclusive of many actions. A KCW in bone is indicated when a sharp edged tool superficially incises bone while traversing over the surface of the bone. While a non-stabbing KCW often follows the contour of a bone, a stab may puncture, nick, or gouge a bone as it enters the body and proceeds externally to internally.

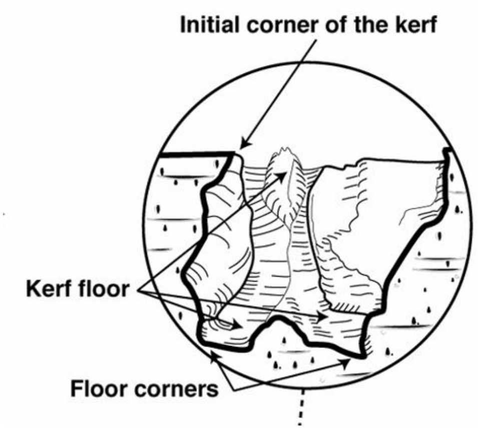


Figure 1. Kerf illustrated.

In addition, stereotypical adages are commonly taught to forensic students. For example, claims that the lack of features in knife cut wounds would '*never* rule out serrated knives,' again deters the analysis of sharp trauma. While the analysis of knife cuts to bone is not the primary focus of this research, a straight edged or serrated knife used in a 'sawing' motion has been examined in this project. However, if cut marks follow the contour of a bone onto different surfaces or if a knife is used in a reciprocating motion, the resulting features most likely indicate postmortem dismemberment rather than perimortem trauma to the victim (Symes et al. 2002). The misconceptions regarding knife and saw cuts, along with the lack of tested and validated standards demonstrate the need for a published practical guidebook on knife and saw marks in bone.

The proper documentation and analysis of saw marks can significantly contribute to the interpretation of a criminal act. However, frustration and confusion often arises with regard to proper analysis and examination of saw injuries as well as the retention of bone. The purpose of this research is to address common misconceptions regarding analysis procedures and, at the same time, develop a standardized protocol for analysis of saw marks in bone so as to meet current Daubert evidentiary standards. Likewise, the aim of this manual is to give forensic anthropologists and toolmark examiners a working knowledge of saw mark analysis in bone. The manual is not meant to be a comprehensive volume detailing every element and minutiae regarding saw marks in bone, but rather a guide and resource that will help facilitate, and hopefully improve the accuracy, of saw mark analysis.

Current Status of Toolmark Analysis in Bone

Despite a rise in interest and a need for saw mark analysis, the attempt at analysis, has become a dismal scientific endeavor. While anthropologists and pathologists conduct numerous saw and knife mark analyses on dry and fresh bone, most professionals are reluctant to examine this bone within the soft tissue. Reasons for this avoidance include, but are perhaps not limited to: 1) difficulties in examining and transporting decomposed tissues, 2) a lack of equipment or training to process the remains after soft tissue examination, and 3) a general avoidance, 4) a lack of interest in the soft tissues in general, or finally 5) it's just too damn difficult. Unfortunately, the situation often applies to forensic anthropologists and occasionally to medical examiners and coroners.

The first author, with others, has continuously campaigned for the preservation of context of human remains in any medicolegal situation (Dirkmaat et al. 2008). Part of this contextual integrity involves the preservation, exposure, and complete examination of soft and osseous tissues. If law enforcement recovers the tissues and an anthropologist is merely brought in to process the soft tissues from the bone, then the tool mark expert only receives a pair of cut elements, without context, in the crime laboratory. In this instance, the anatomical orientation (for direction of cut) as well as any injuries to the soft tissue are lost.

The first author (SAS) has demonstrated that class characteristics contribute significantly to criminal investigations. Investigators need to know the type of saw to look for and be able to demonstrate dismemberment behavior to a jury or judge. While many toolmark examiners attempt to make individual tool mark assessments, class characteristics must be emphasized when analyzing saw marks.

Even though criminalistics have shown that there is limited potential for positive identification of a saw from comparisons of saw marks on bone, the value of class characteristics of saw marks has been recognized.

Saw mark research is focused on collecting data on variation found in microscopic features of cut bone. Data are then applied to saw blade and tooth characteristics of size, set, shape, and power. This information is used to indicate saw class, subclass, or type. The narrowing of the field of possible tools that could have potentially been used in a crime makes saw mark characteristics a valuable "tool" for the forensic examiner. (Symes 1992:6). Unfortunately, a standard methodology for saw mark analysis is lacking, and the field is hindered by numerous misconceptions.

Misconceptions Regarding Saw Mark Trauma Analysis

The authors have identified eight (eight) common misconceptions which plague the field of bone and tool mark trauma analysis.

1. First and foremost, there is a belief that saws - by the action of sawing - destroys any diagnostic features that could be used to identify a class of, or a specific, saw (See Symes 1992). Not only is this incorrect, but it has greatly diminished saw mark analysis in a forensic setting and has led to its abandonment as a source of potential evidence. Tool mark examiners confronted with analysis problems regarding saw marks, often comment that there is a lack research in the field.

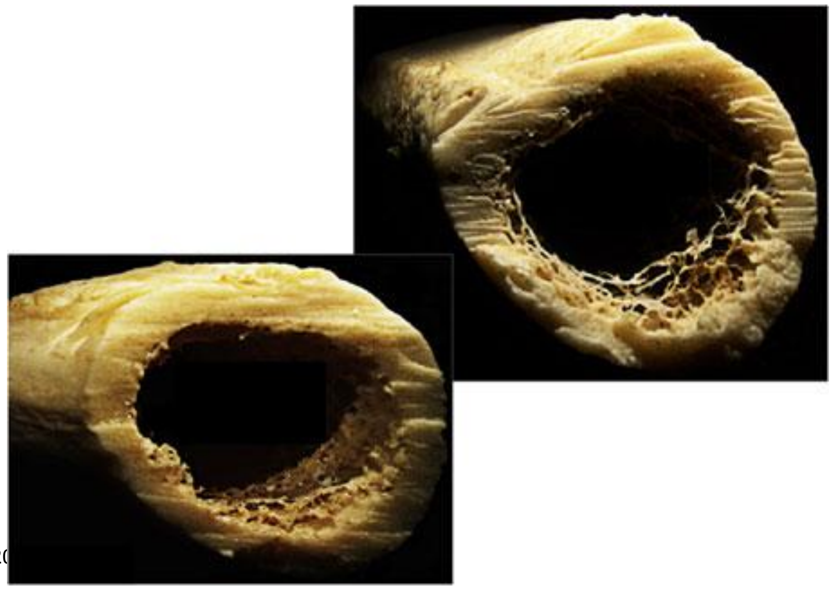
2. The second misconception is that diagnostic marks on bone are created only when the blade is worn or damaged; thereby resulting in unique individualizing characteristics. While the focus upon these “defects” is common, all blades leave diagnostic marks as they cut, regardless of wear. The correct interpretation of these characteristics can lead to a valuable identification of classes of saws and knives. In addition, correctly identifying the class of tool used (i.e., hacksaw, serrated knife, etc.) is useful for narrowing down the search for the suspected weapon or tool. Therefore, the assumption that a comparison is only necessary once the individual tool is found is incorrect, as an accurate identification of a class of tool – as indicated by tool mark features - can direct the investigator to sub-classifications, such as wavy set hacksaw, large toothed serrated knife.

3. The lack of proper equipment used to analyze saw toolmarks, whether it is too little or too much magnification has prompted another common misconception amongst

anthropologists. The problem is that low grade dissecting microscopes, commonly found in anthropology departments, are inadequate for toolmark examination. Most often, these microscopes do not permit the entire bone to be examined at one time. Additionally, many anthropologists are inexperienced in using microscopes, which often leads them to latch on to sophisticated technology, such as a scanning electron microscopy (SEM), before evaluating more appropriate means of analysis. Often it appears that anthropologists expect high magnification SEM to train them in identifying and describing features observed in saw mark analysis. SEM is unnecessary for accurate saw mark analysis in bone and in most cases has been shown to hinder the examination (Freas 2006). With that said, there has been excellent SEM work research performed on cut marks characteristics, namely Bush et al 2009; Saville et al. 2006 and Shipman 1981, to name a few.

4. The fourth misconception is that a *naked eye* examination of a cut bone surface can accurately indicate tool class. Many anthropologists are misled by the erroneous concept that all one has to do is to compare the cut surface of bone with the residual kerfs in order to classify the tool responsible for creating the defect. Unfortunately, the overall pattern one observes on the cut surfaces of bone is of little use in saw mark analysis. This is due to the fact that saw teeth change or wear when cutting hard material. In a series of cuts, the bone surface changes and indicates that the saws are continually changing. In Figure III-3, handsaw dismemberment to a proximal humerus is shown. The lack of similarities between the two bones from the same dismemberment created by the same saw is astonishing.

Figure III-2. This represents two sides of a dismembering cut in a humerus, created by a handsaw. While the same saw make these cuts, the cut surfaces look dissimilar.



5. Bones cut during the process of dismemberment commonly exhibit smooth cut surfaces and straight edges. A common fallacy is that a straight cut surface must have been produced by a power saw. Saws are designed to cut hard materials in a straight manner which results in a straight edge and relatively smooth surfaces. Thus, these characteristics are common to most saws, not specifically mechanically powered tools.

6. The term “hesitation marks” was originally used for suicidal knife cut marks to skin, where inexperience and reluctance to continue the cutting action may have been related to pain and the resistance of soft tissue to the knife slashes (Di Maio and Di Maio 1993: 183-4; Spitz 1993:271). For some reason “hesitation marks” has been attached to any shallow cut marks associated with soft tissue. The author’ suggests that a ‘hesitation mark’ is misleading (Symes et al 1999); even more ridiculous, is when this terminology is applied to saw marks on bone. Repeated false starts in bone are not the result of the victim’s hesitant, last dying act or the perpetrator’s hesitation to decapitate the victim (Figure III-4).

   Hand saws use a reciprocating motion to cut, similar to the use of a knife to cut soft tissue. A reciprocating motion should not be termed hesitation; rather, it reveals more *persistence* from the perpetrator than *hesitation*. In this manner of logic, one could consider false starts to be “persistence marks”; a determination more emotionally intuitive to the criminal intent of dismemberment.

Figure III-3. Numerous cuts on a proximal femur from saw dismemberment. Despite the number of cuts and the reciprocating motion, it would be in error to call these hesitation marks.

7. Measuring striations and features of a saw cut surface in an attempt to produce diagnostic information about the cutting tool is largely misguided and erroneous. Anthropologists are often the first to resort to measurements of observable characteristics in human remains. However without knowledge of the principles of cutting action of saws and knives and of the response of bone to this reciprocating and continuous motion, the data from these measurements may misrepresent the facts.

   Measurements are necessary in saw mark analysis in bone, but caution must be emphasized for metric analyses of a mechanism or motion that is not completely understood and where essentially, many styles of blades (teeth), can exit. Problems arise when the measurer does not recognize the difference between force (human intervention) and saw design.

   A simple way to demonstrate this principle is to examine a knife stab (KSW) wound, from a serrated knife, into costal cartilage or a material that mimics. A KSW can create a variety of patterns, which are often dependent on the orientation of the knife. In Figure III-4, a stab and chop wound are demonstrated. A chop wound, as opposed to a KSW, may create striae that accurately mimic dimensions of the tool, while a typical KSW, which strikes perpendicular to the surface, creates a changing – rather than a continuous - striae pattern. While the patterns of continuous striae are associated with chop wounds, measurements of these patterned striae have a utility if the repercussions are understood. In figure

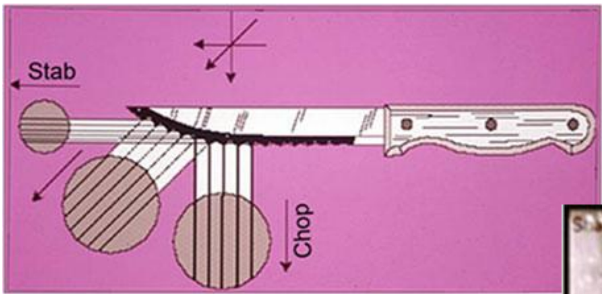


Figure III-4. A knife with demonstrated serrated pattern of cuts, depending on the direction of blade motion.

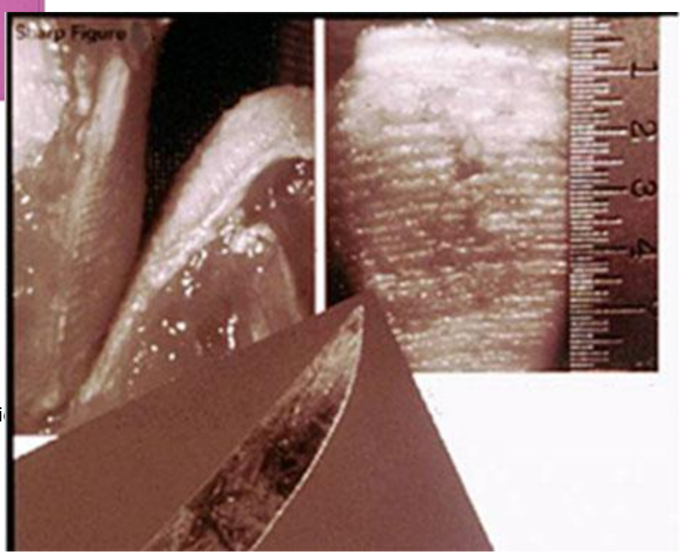
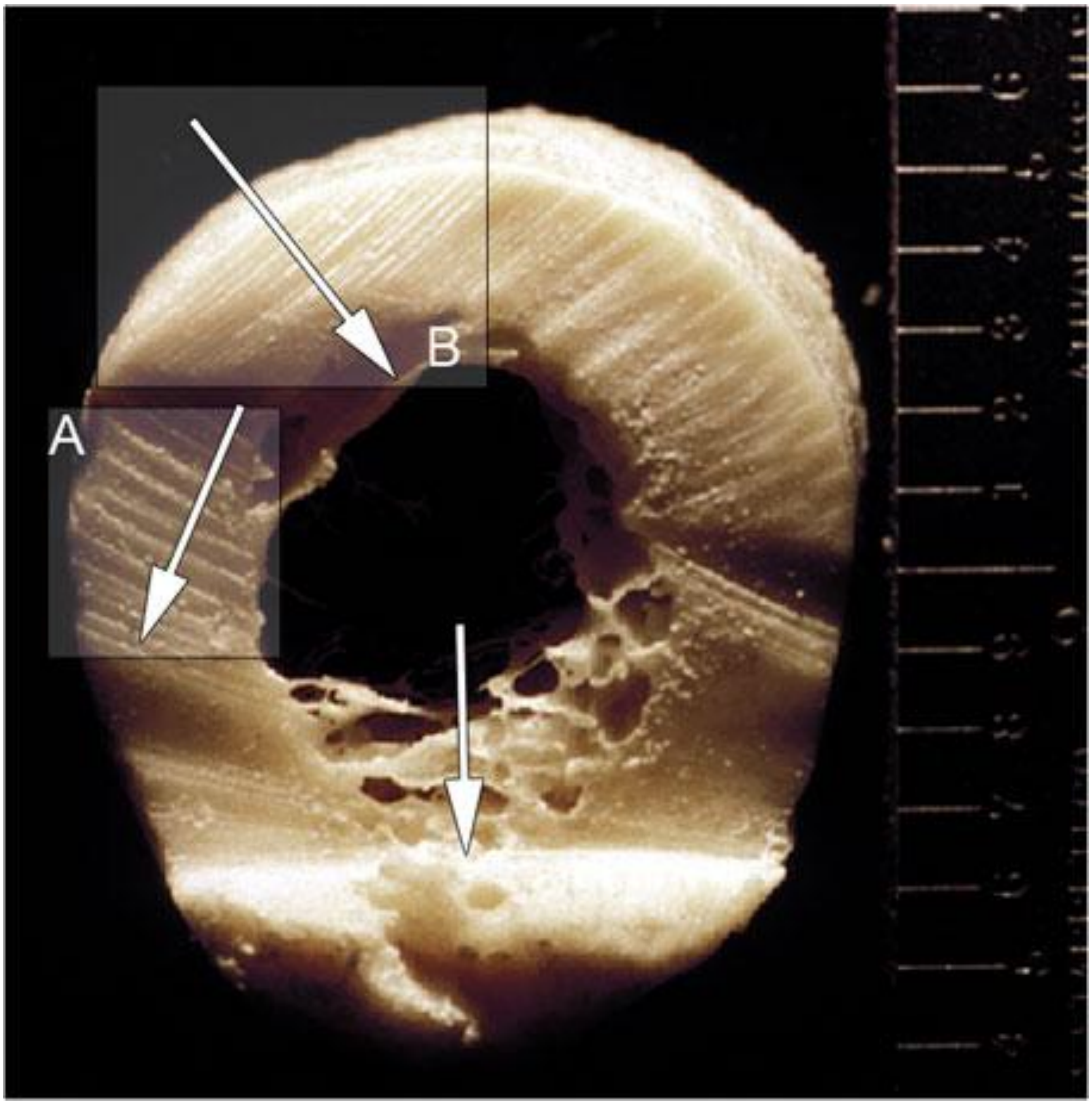


Figure III-5. Knife stab wound through costal cartilage. Notice the pattern resembles a knife stab wound in Figure III-4.

In Figure III-6, a dismembered femur is shown. One cut surface shows many different directions of cut, with the large arrows indicating direction of saw progress-perpendicular to saw stroke. The cut surfaces also show a large range of striae frequency. Area A illustrates extremely uniform and broad striations, whereas Area B demonstrates extremely fine striae. Does this indicate two saws?

Figure III-6. Dismembered femur. Three directions of saw progress (white arrows) and at least two striation density patterns.



Interestingly enough, each of these areas were created with a power saw. The saw left a fixed radius bending striae that curve into the bone, which is a characteristic feature of a power circular saw. In this case, the distance between the striae was caused by each saw tooth being forced to cut a deep swath in the bone Figure III-6 Area A, whereas in Figure III-6 Area B, where less force was applied, the teeth cut shallow swaths through the bone (Area B). Despite the fact that researchers have suggested that the metric difference between striae indicates the frequency of teeth on a circular blade (Haig 2006), it is the author's opinion that in this case, this is the same saw; this is the same blade; the differences between the striae are simply a demonstration of heavy verses light force applied (Figure III-6).

8. A common misconception is that saws and knives are similar in appearance, due to the fact that both are considered to be sharp force trauma. However, knives and saws are used for different purposes and are distinctly different in their morphological and microscopic appearance.

Confusion often occurs when trying to identify weapon class associated with blade and knife wounds. Knives can be differentiated from other blades in that knives are tools with a thin blade that sometimes terminate in a point. Knives also commonly have blade bevel (blade tapering) and always have at least one area of edge bevel (sharpened edge) on the blade. Tools such as box cutters, razor blades or machetes can be classified as knives while blades like propellers, augers, and tree chippers are not (Symes et al. 2002).

Saw marks to bone are classified as sharp trauma since there is always some portion of a saw tooth that is incising bone. The cuts created by a saw can be seen on the kerf wall striations. Saw cuts can be distinguished from knife cuts since saws leave a squared, cross section kerf floor. Filed crosscut (sharpened) saw blades create a kerf floor that when viewed in cross-section resembles a "W." In contrast, bevel-edged knife blades create a "V"-shaped kerf floor when viewed in cross-section, regardless of whether there are teeth manufactured in the blade or not (Symes et al. 2002).

Saws can easily be separated from knives, because knives, unlike saws, have an edged bevel. Saws are generally designed to cut a wider swath than a knife blade. The wider cut is possible due to the lateral bending of every other tooth (tooth set) of the saw blade. True crosscut saws have consecutive teeth that are filed at opposing angles (usually 70 degrees). The filing creates a tooth that terminates in a point and essentially takes on the shape of a sharpened blade that cuts (like a series of knives) rather than chiselling the material. Classic rip saws do not have filed teeth and create a flat bottomed kerf.

Recognizing the differences between cut marks to bone caused by knife blades and those caused by a saw are essential in toolmark identification, especially since both classes of tools may be involved. Knowledge of the types of tools available and how they are manufactured can only be beneficial to assessing the forensic significance of toolmarks in bone (Blumenschine et al. 1996, Burd et al. 1942, Burd et al. 1957, Burd et al. 1968). Since knife cuts are not the main focus of this chapter, we consider knives only when they are used in a sawing motion.

Only when the above-mentioned misconceptions are overcome and the evidentiary and forensic potential of saw marks in bones are recognized, can the value of saw mark analysis be realized. And finally, it is essential that the value of toolmarks on bone is recognized to the extent that the bone is retained as evidence. While soft tissue is routinely retained as evidence, the tissue that is unchanging, "a moment frozen in time," is often not (Smith 1996).

Diagnostic features of a saw

Tool mark examiners typically look for "unique" features that can be used to produce a positive match between the bone and the tool in question. Conversely, saw mark analysis does not necessarily identify a specific weapon, but rather a class of tool; these features are referred to as "class characteristics."

A vast range of saws are available on the market and can be categorized into approximately 15 classes of tools. The object of saw mark analysis is to recognize characteristics on kerf walls and floors in bone that may accurately reveal size, shape, set, power and direction of a saw.

Saws are defined as blades with teeth. When analyzing saw features, one must consider the way in which the teeth are "set." The set produces distinctive marks in the cut surface. For example, if teeth are bent (set) right and left, the teeth carve out a wider kerf (the actual saw trough) than the blade width. This design allows a blade to deeply penetrate a hard material without binding. Other design features usually revolve around the teeth, particularly with regard to shape and size.

A few basic concepts about saws and saw blade actions are necessary to know before attempting to interpret saw marks in bone. All saws blades have teeth which leave cut patterns in an object. As the saw teeth cut into bone, a groove or kerf is formed (Symes 1992; Symes, Berryman et al. 1998). Saw mark analysis involves examination of saw cut kerf floors and walls. Floor contour includes false starts and, occasionally, breakaway spurs. Kerf floors offer the most information about saw class by revealing the relationship of saw teeth to each other. The information includes set and number of teeth per inch (TPI) (Table 3).

Kerf walls provide evidence about teeth per inch, saw power, and the direction of cut. Knives, when used in a reciprocating/sawing motion, can also be considered saws. However, serrated knives lack saw set (lateral bending), so they create a visibly narrow, ‘V’-shaped kerf walls and floors.

Set is defined by the teeth that are bent laterally to a particular side of the blade and set is represented by striations in the kerf wall. Tooth set creates a kerf wider than the saw blade with a floor that has a squared off ‘U’– or ‘W’-shape (Figure III-7). The profile, depth and frequency of these striae may represent the shape of the blade, the amount of energy transferred to material and the motion in which the blade travels to cut through bone. Both the floor and walls contribute to interpretations of direction of cut. The object of saw mark analysis is to recognize characteristics in kerf walls and floors that may accurately reveal size, set, shape, power and direction of cut (Symes et al. 2002).

The breakaway spur is the projection of the bone at the floor of the terminal cut, where the bone fractures. This spur has a mirror image in the form of a notch, which forms on the other side of the cut bone (Figure 7). The breakaway spur is often as diagnostic as the kerf floor. The size of the spur often depends on the amount of force applied across the bone. For instance, the weight of a handheld circular power saw or chain saw (offering leverage) often produces a large breakaway spur than a saw which does not provide leverage.   Simply, the pound of weight and/or leverage in front of the saw grip greatly increases the force applied to the bone.

Handsaws are classified into two basic types: rip and crosscut. The rip saw is designed to "rip" wood with chisel-shaped teeth. The crosscut saw is designed to "cut" wood fibers across the wood grain. Almost all saws are measured by the frequency of their teeth, i.e., points per inch (PPI) or teeth per inch (TPI). There is generally one more point per inch (PPI) than tooth per inch (TPI). In forensics, TPI, or distance of the teeth from each other, is measured in inches. TPI is considered a description of saw size (Table 1), and TPI distances are listed in Table 2.

Differences between crosscut and rip teeth are illustrated in Figure III-7. Rip saws have a flat chiseling tooth, whereas crosscut saws have consecutive teeth filed at opposing angles (usually

70 degrees). This filing creates a tooth that terminates in a point, or wedge, essentially taking on the shape of a sharpened blade that cuts rather than chisels material. The teeth of a rip saw are not angled or filed. The teeth are simply notched out of the blade. As such, these saws essentially chisel out material rather than cut it.

These differences in design are used to establish saw classes. In most saws, teeth have a front and a back. The front of the tooth is designed to do the majority of the cutting as it bites into the material. Generally, reciprocating saws are designed to saw with a cutting stroke and a passive stroke. In order to distinguish a cutting stroke from a passive stroke, run a saw blade over the back of your hand. The passive stoke is easily distinguished from the cutting stroke. When the cutting stroke is forces, it is likely to cut the skin; while the passive direction slides over the skin without cutting it.

The front side of the tooth bites (steeper angle) during the cutting stroke, while the back side of the tooth slides on the passive stroke. Enlarged sections of two saw blades are shown in Figure III-7. Each diagram has arrows that indicate one of two possible directions of motion. The push stroke in these illustrations is a cutting stroke. Both these rip and crosscut saws designated in Figure III-5 are considered common 'Western" saws. The Western-style rip and crosscut saws are shown to cut in a forward motion manifesting a push stroke.

Most saw blades are designed to cut hard material and thus have teeth that are set, or are laterally bent. The most common, or typical, is the alternating set which means that adjacent teeth are bent in opposite directions (see Figure III-8). However, more complicated designs such as raker, which has every other tooth bent in an opposite direction, or wavy sets, which have a series of teeth pointed in one direction or the other, can be found.

Table III-2. Saw characteristics found in cut bone that assist in the diagnosis of saw class. Characteristics are categorized by where they are found on a cut bone.

Kerf Floor (False Starts-Breakaway Spurs)

Size
- Minimum Kerf width
- Tooth Trough Width
- Floor Dip
  - Tooth Imprints
- Blade Drift
  - Bone Islands

Set
- -Alternating: Blade Drift
  - Bone Islands
- -Raker: Parallel Striae
- -Wavy: Complicated Floor Striae
  - Drift is Subtle in Shallow Kerf

Shape Striae Contour
- Straight
- Curved
  - Rigid (Round)
    - Fixed Radius
  - Flexible
    - Wrap Around

Power
- Energy Transfer
- Consistency of Cut
- Material Waste
- Polish

Direction
- Blade Progress
  - False Start to
    - Breakaway
    - Notch/Spur
- Blade Cutting Stroke
  - Kerf Flair (Handle)
  - Exit chipping

Kerf Wall (Cross Sections)

Size
- Tooth Hop
- Pull Out Striae
  - (Tooth Scratch)
- Harmonics

Set
- -Alternating: Harmonics
- -Raker: Little Cut Surface Drift
- -Wavy: Complicated

Shape
- Striae Contour
  - Straight
  - Curved
- Tooth Orientation
  - Push (Western)
  - Pull (Japanese)
- Tooth Angle
  - Rip
  - Crosscut (Filed)
- Exit Chipping

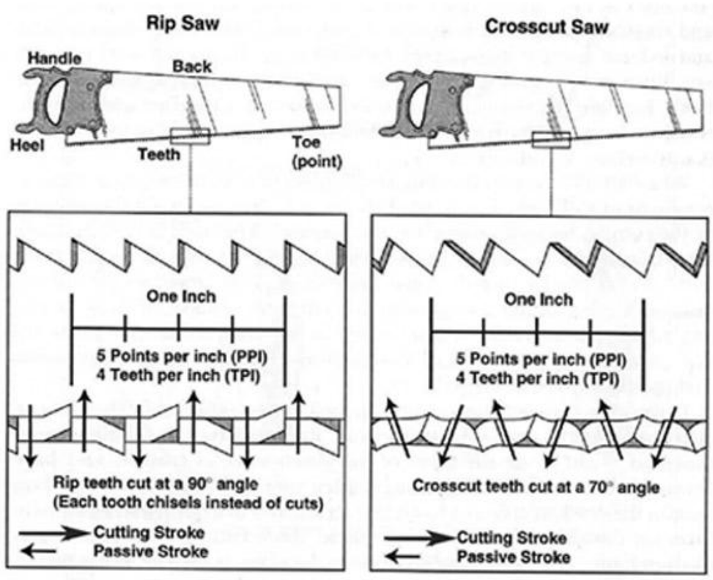
Power Energy Transfer
- Consistency of Cut
- Material Waste
- Polish
- Cut Surface Drift

Direction
- Blade Progress
- Blade Cutting Stroke
- Entrance Shaving
  - Exit Chipping
  - Kerf Flair (Handle)

Table III-3. Teeth Per Inch

Saw Tooth Distance In	cm	TPI
0.01	0.03	100
0.02	0.05	50.0
0.03	0.08	33.3
0.04	0.10	25.0
0.05	0.13	20.0
0.06	0.15	16.7
0.07	0.18	14.3
0.08	0.20	12.5
0.09	0.23	11.1
0.10	0.25	10.0
0.11	0.28	9.10
0.12	0.33	8.30
0.13	0.33	7.70
0.14	0.36	7.10
0.15	0.38	6.67
0.16	0.41	6.25
0.17	0.43	5.88
0.18	0.46	5.55
0.19	0.48	5.26
0.20	0.51	5.00

Figure III-7. Rip verses crosscut saws, with typical alternative set.

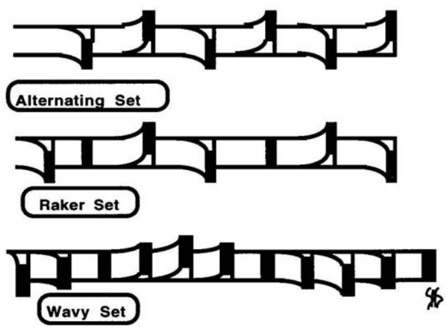


Test

Examine a blade and teeth on end. A simple crosscut saw is a blade with teeth cut out, usually with set. If you see a more complicated design, where the leading edge of the saw tooth appears as a series of small knife edges, a crosscut saw (filed teeth) is probably indicated. Examine. Typically you see alternating set, but some saws, like hacksaws, commonly have raker or wavy set. (Figure III-8.)

Saw Kerf

Figure III-8. Saw Tooth Set



The kerf is defined as the area cut, or the walls and floor of a cut. Floors are expressed in false-starts and occasionally in breakaway spurs. Kerf floors, when present, offer the most information about each tooth in terms of the relationship of the tooth points to each other or the set (lateral bending), and number of teeth per inch (TPI) (Table III-2). Kerf walls can also offer information about teeth per inch, saw power, and direction of cut. Knives, when used in a reciprocating/sawing motion, are also considered saws. However, serrated knives lack set, so they create a narrow, 'V'-shaped kerf, whether used in a reciprocating or chopping motion (Figure III-9). Most saw blades designed to cut hard material have teeth that are set. Tooth set creates a kerf wider than the saw blade (Figure III-9) with a floor that is a squared off ‘U’-shape or is ‘W’-shaped.

Break Away Spur and Notch

The breakaway spur is the projection of bone at the floor of the terminal cut, where the bone finally fails in a fracture. This spur has a mirror image in the form of a notch, which forms on the other side of the cut bone (Figure III-9).

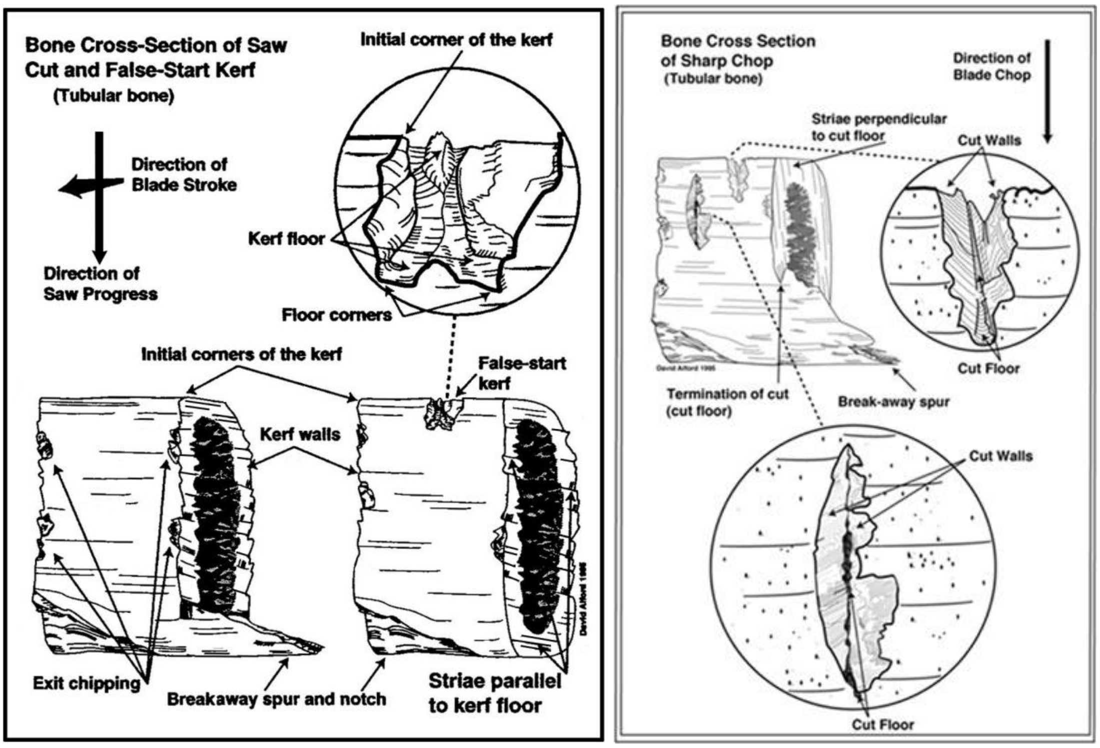


Figure III-9. Saw and knife kerf showing walls and floor of a false start and complete cut.

Break away spur is a projection of uncut bone at the terminal end of the cut after the force breaks the remaining tissue. The breakaway spur is often as diagnostic as the kerf floor. The size of the spur often depends on the amount of force applied across the bone resulting in a fracture. For instance, the weight of a handheld circular power saw or chain saw (offering leverage) often produces a large breakaway spur.

Principles of Cutting Action

The act of sawing is essentially pushing, pulling or rotating the teeth of a saw blade in such a manner as to cut (needle point teeth designed like a knife) or chisel (teeth designed similar to a flat bottomed wedge) through material. To understand residual characteristics of saw cuts, it is necessary to examine the action of the saw blade. Saw action includes the slicing or shaving of a knife blade or chisel tooth through material, as well as the actions of the banks of teeth working in unison or opposition to the blade. Since the saw teeth perform the cutting, actions of each tooth and the combinations of these teeth on a blade must be examined. Saw actions need to be examined in terms of size, set, shape, power, and direction of cut as well as how these various actions influence the cut material (Symes et al. 1998; Symes et al. 2002).

Blade and Tooth Size

Saw size is simply represented by the size of the cut made by individual saw teeth and by the combined action of saw teeth. The cut represents the minimum width of a saw tooth impression and kerf. Most importantly, size reflects the number of saw teeth per inch which is a common classification for all saws. Features are classified into characteristics of saw motion and saw tooth residual evidence, or the residual characteristics that occur when the saw stroke is interrupted. When the blade reacts to the introduction of each tooth point on an object with an up-and-down motion, or when the saw blade responds to set teeth through a rhythmic side-to-side drift, the cuts can often be interpreted in relation to teeth per inch. Obvious residual evidence is also diagnostic of TPI when a saw is stopped in mid-stroke or pulled from the kerf, leaving telltale striae

Blade and tooth size are other factors of saw design. Universally, tooth size is classified by the number of teeth per inch on a blade (Figure III-10). There are two ways to classify a blade: 1) points per inch (PPI) or 2) teeth per inch (TPI) (Self 2005, Rae 2002, Wilson 1994, Nagyszalanczy 2003). The number of points per inch is generally one value greater than the number of teeth per inch (Figure III-10). Important to note is that the quantifiable characteristics of saw cuts observed within a kerf floor and wall are more easily reflected in the number of TPI than the number of PPI. All references to the size of teeth will universally be in terms of teeth per inch or TPI.

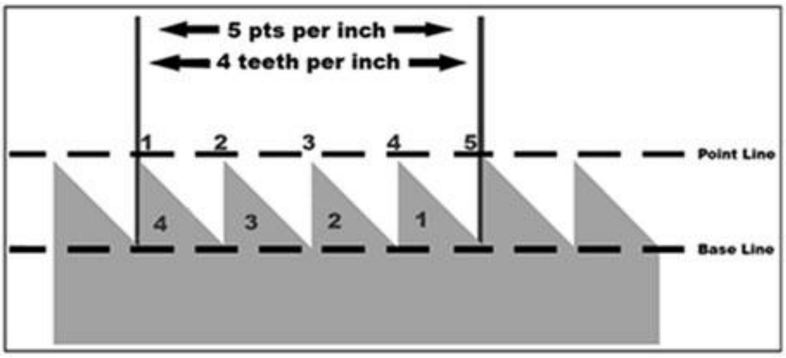


Figure III-10. Difference between teeth and points per inch. Teeth per inch (TIP): emphasis of the research.

More TPI on a saw increases the smoothness of cutting, while slowing down the speed of the cut. Conversely, fewer and larger teeth are designed to more efficiently saw softer materials. A wide, alternating set with narrow width teeth is commonly found in larger toothed saws. If this combination of features produces a cut that is similar in width as two side by side teeth, then islands of uncut material may be visible in the middle of the kerf. Therefore, the combination of tooth width, set, and distance between teeth, essentially dictates the speed and amount of material cut with each stroke or rotation of the blade.

Some saw blades are not classified by TPI or PPI. Included in these blades are power circular saw blades and flexible saws, such as the Gigli (wire) and rod (grit imbedded). Masonry circular saws and flexible saws do not have blades with teeth like other saws; rather the teeth are formed by grit impregnated blades, or by wrapped wire.

Blade and Tooth Set

Even though the above definition of a saw, i.e. blade with teeth, implies nothing of set, the altering or bending of teeth to reduce binding is an integral and tested part of saw design that has existed for close to 2000 years (Disston 1922). While saw blade tooth set is essential to the effectiveness of most saws, it is not required. Four saws, which had no definable set, include a serrated knife, the metacarpal saw (no bending, but a set is carved into the blade) and both flexible saws.

Teeth are generally set according to their size. The amount of tooth set in saws that fall into 4 to 16 points per inch is generally 0.003 to 0.005 of an inch. As a rule, the kerf does not exceed 1.5 times the thickness of the blade (Cunningham and Holtrop 1974:84; Jackson and Day

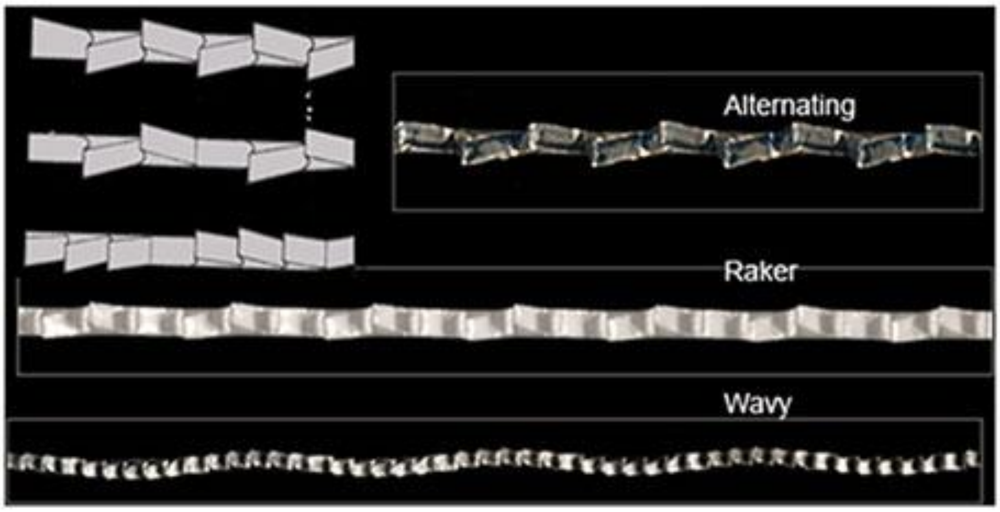
1978:75-76). If the set is greater, the teeth bend laterally to the extent that the material will be untouched in the midline as the tooth reaches its greatest flare. A ranker set is defined as a greater bending of the tooth and is designed for softer material, such a soft wood as opposed to a hard wood (Salaman 1975:405). The ranker the tooth set, the more lateral bending of the teeth which creates a wider kerf.

Alternating Set

As mentioned previously, there are three types of set most commonly used for spacing and arranging saw teeth, these include: alternating, raker, and wavy (Figure III-11). Alternating set design is applied to many shapes and sizes of teeth. Certain actions occur in blades which necessitates that every other tooth be set in a different direction. , even though.

In order to understand the cutting action of a blade with an alternating tooth set, it is important to first examine the actions of a single tooth, then to combine these with actions of the consecutive teeth. Saw teeth are set so that the cut produced is wider than the saw blade. As a single set tooth first enters the material, the tooth seeks an orientation parallel to the direction of the blade and to midline of the material. The midline orientation is compromised as the next tooth enters this material. The second tooth is alternately set. Therefore, it enters the material from a position opposite the previous tooth. In doing so, it seeks a different midline from the first tooth, while also attempting to cross the cut path of the original tooth. This pattern is further explained under 'Blade Drift.'

Figure III-11. Illustrations of the three major types of saw blade set.



The pull to the midline of the second tooth sends the first tooth in a direction parallel to the second tooth, until a compromise between the two teeth is reached. The parallel drift reverses each time a new tooth enters the material. Essentially, the new teeth enter the same two patterns of the first two teeth and approximate the same grooves. Since there are two rows of teeth set in an alternating pattern, a predictable pattern can be established. Tooth drift is defined as the pattern of teeth drifting across the kerf floor. Drift pattern is most noticeable at the beginning or end of a cut in a tubular bone, as there is little material to offer resistance or to trap the blade's motion. Once the blade is immersed in the material, much of the tooth drift is suppressed.

Raker Set

An intricate design in the cutting edge of a saw may create a more complex picture in the residual kerfs. As the term implies, rakers are specialized teeth designed to rake sawdust or imperfections from the kerf floor rather than to consistently cut or chisel. Blade teeth ‘clean up’ after the previous teeth and thus modify the kerf. Raker sets complicate saw striation examination, due to the fact that they are not symmetrically placed between every tooth. Rakers appear in a series of teeth, most commonly every third, fourth, or fifth tooth (Figure III-11). The raker design alters the kerf floor shape, the harmonics of the cut (peak and valley patterning on the bone cross section), and the predictable drift of an otherwise alternating set blade.

Raker sets are generally seen in two major types of saws, pruning and fine toothed bow saws (FTBS). Saws with raker teeth analyzed in this study include buck saws and hacksaws. Pruning saws, by design, use large teeth combined with rakers and gullets (large space between large teeth) to clear the soft wood debris cut with the teeth. Rakers are generally shorter than the regular teeth since they are designed to rake out debris in the kerf, to smooth the kerf floor and to clean the kerf. Jackson and Day (1978:77) describe the lance tooth set that has four teeth bordered by rakers with a large gullet on each side of the raker; this raker is designed for cutting unseasoned wood. Variations of this type of raker set are found in common hand pruning saws. Fine toothed bow saws are designed to cut through harder materials, such as metal. The rakers associated with these saws are identical to the other teeth, only they have no lateral bending (set).

Raker teeth also inhibit blade drift. Since it is not set to one side or the other, a raker tooth enters the material on the central path of the cut. As the raker teeth traverse through the midline, they inhibit the set teeth from diverting into a rhythmic side to side movement, especially in FTBS. Saw blades with shorter raker teeth (like pruning saws) could also be diverted from their central path by falling into a deeper groove created by a previous alternating tooth; therefore a unique kerf floor or an unsymmetrical floor contour could be created. However, one must keep in mind that the rakers of pruning saws generally occur at a rate of one out of five teeth or less and tend to be shorter than the cutting, or chipping, teeth. With this design, the raker's influence on blade drift is likely minimal.

Wavy Set

Wavy set teeth are distinct from both the alternating and raker tooth sets. A wavy blade set cuts on the same principle as an alternating blade set however, wavy set blades generally have a cluster of minuet teeth which makes setting each tooth difficult. Rather than a set for each tooth, groups of teeth are alternately bent side to side (Figure III-11). When examined on edge, the blade forms a wavy pattern with each wave, or cluster of teeth, functioning as a single alternately set tooth.

Saw blade set has numerous potential features that can be used to diagnose a saw cut. For example, mass production or poor craftsmanship may produce a tooth set that is not equal when bending to the right as opposed to bending to the left. If alternating saw blade sets do not set each tooth equally, the saw cut may produce walls that are dissimilar to each other. In Figure II-12, the clavicle has been cut with a saw. The saw consistently produced a striated wall and a smooth wall in each cut (kerf), but it had an asymmetrical set, which makes the two halves appear different (e.g., see reconstructed clavicle shaft in photograph insert).

In Figure II-13, the proximal cut wall of the right and left femora are shown. One wall is relatively smooth, while the other has visible residual striations. In this case the suspected tool had been a meat saw. This pattern - coupled with indicators of power stroke - confirmed that the direction of the saw blade had been reversed in each leg amputation.

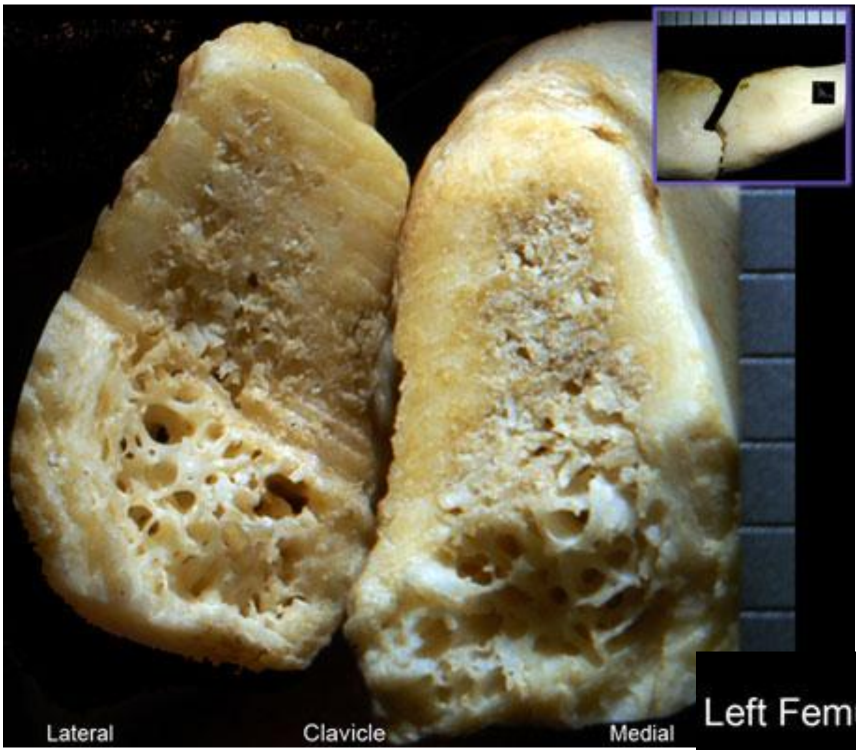


Figure II-12. Clavicle: right and left kerf walls are dissimilar due to asymmetrical saw blade sets.

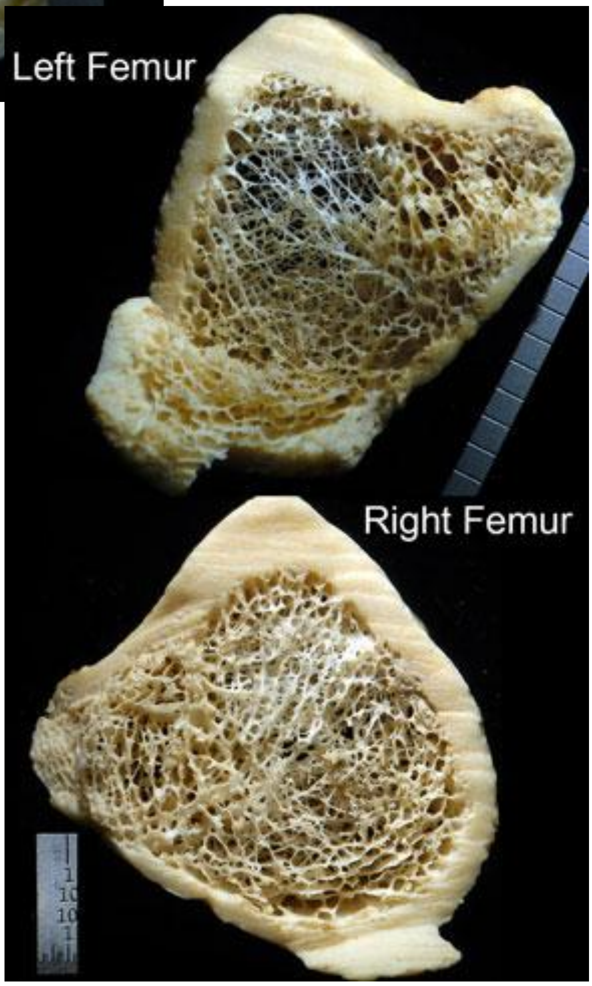


Figure III-13. This illustrates how right and left femora proximal cut walls have dissimilar appearances. This could be diagnosed as two saws or a saw blade with side differences. In this case it was a blade with pronounced set to the left, and essentially no set to the right.

Blade and Tooth Shape

Saws are further described by their shape. Shape refers to the angle in which the teeth are filed; the tooth shape as it was designed in the saw blade; and the contour or flexibility of the blade.

Rip or Crosscut Saws

The most common classification of saws in terms of tooth shape is the rip and crosscut saw (Figure III-7). These styles are important in that each function in a different manner to effectively cut different types of material.

Rip saws are designed to cut in a chiseling fashion, where each tooth chisels a bite and ejects it at the end of the stroke (Figure III-14). Rip saw teeth are filed at a flat angle to form a flat chiseled face. Large toothed saws with rip teeth are designed for cutting with the grain of wood (Cunningham and Holtrop 1974:82, Lanz 1985). The front of rip teeth project from the blade to form a raker angle of 90 degrees (perpendicular to the plane of the teeth), then trails off to the back side of the tooth and forms a gullet angle of about 60 degrees with the front of the next tooth. The rip design cuts material quickly and roughly. For a smoother rip cut, the teeth may be tilted back as much as 8 degrees, but this design cuts less material with each stroke. Most saws used in this study have rip-style teeth. As one would assume, the high the number of teeth per inch teeth, then these teeth become too small to file.

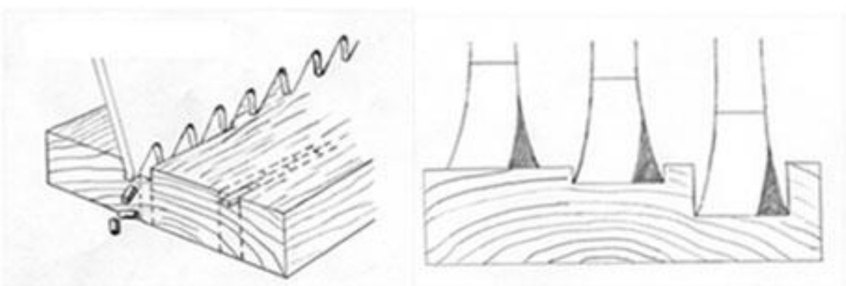


Figure II-14. Rip saws: each tooth chisels a bite with the grain. (Source: Cunningham, BM and WF Holtrop, 1974 Woodshop Tool Maintenance. Peoria: Chas. A. Bennett Co., Inc., P 74)

Crosscut saws, as the name implies, are designed for cutting across the grain of wood. Crosscut teeth are smaller and bite less material as the teeth are rotated back 15 degrees. Therefore, crosscut teeth are often the same shape as rip teeth, but the front side of the tooth is noticeably sloped back (actually rotated) on the blade, rather than aligned perpendicularly to the blade as seen with rip teeth. Crosscut teeth are filed on the cutting edge at about a 60 to 75 degree angle. The front of each tooth is similar to a knife edge and forms a needle point, rather than a chisel (Jackson and Day 1978:76, Nagyszalanczy 2003). Each tooth progresses through wood fibers with a sharp edge, and slices the instead of chiseling blocks it (Figure II-15). With recent mass production of saws, a new problem has come to light. Many saws are labeled as 'crosscut' while in fact they lack filed teeth.

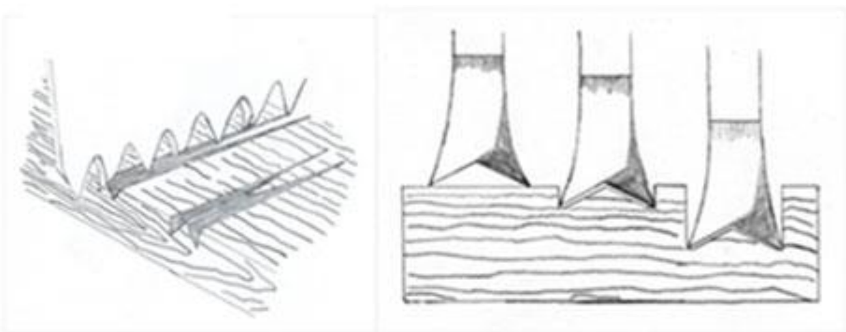


Figure II-15. Crosscut saws: cut across the grain and slice fibers of wood. (Source: Cunningham, BM and WF Holtrop, 1974 Woodshop Tool Maintenance. Peoria: Chas. A. Bennett Co., Inc., P 74)

Push/Pull Saws

Another common variation in tooth shape is the peg toothed design, where the tooth is sloped at 45 degrees . The gullet angle has to also be at 45 degrees, so that in both directions, the teeth produce an identical bite. The peg tooth design with a concurrent gullet angle (Figure III-16) has been termed a "push/pull" saw.

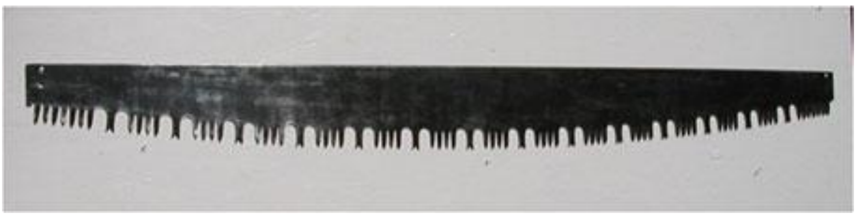


Figure 16. Push/pull, or a two person tree saw (REF)

Sometimes, different shaped teeth are placed on the same blade so as to enhance a particular type of cut. For example, pruning saws may have raker teeth inserted into a bank of crosscut teeth. Since this type of saw is designed to quickly cut soft wood logs, the teeth and gullets are often large enough to accommodate the sawdust. The crosscut teeth make the cut, while the raker teeth clean out the kerf. In large saws, raker teeth are generally rip filed and short so that they only chisel the high points of the kerf floor while the crosscut teeth are cutting.

Tooth and blade shape also determinants as to whether a saw is to cut on the push or pull stroke. Historically, the Western hand saw has a more powerful push stroke (Figure III-7). Likewise, Continuous cutting – not reciprocating - power saws have teeth designed to cut only on the front side of the tooth.

A major exception to the push designed saw is the Japanese pull saw. The Japanese have retained and perfected designs of pull saws (Figure III-17) to the point of producing a saw quite different from that of Western saws (Schwarz 2006). Because of the force being exerted on the pull, tension can be maintained even on very thin blades. Since they do not need to be ductile on the push stroke, Japanese saws utilize a more hardened metal (Rockwell Hardness Rc 54) than their Western counterparts. Thus, these saws are more brittle and are more likely to break teeth or blades. The narrower blade with a minimal set of hardened teeth creates a narrower kerf. Therefore, the pull saw wastes less wood and demands far less effort for the same job (Lanz 1985:13-17; Schwarz 2006). The push stroke is a more accurate and efficient action than the pull stroke.

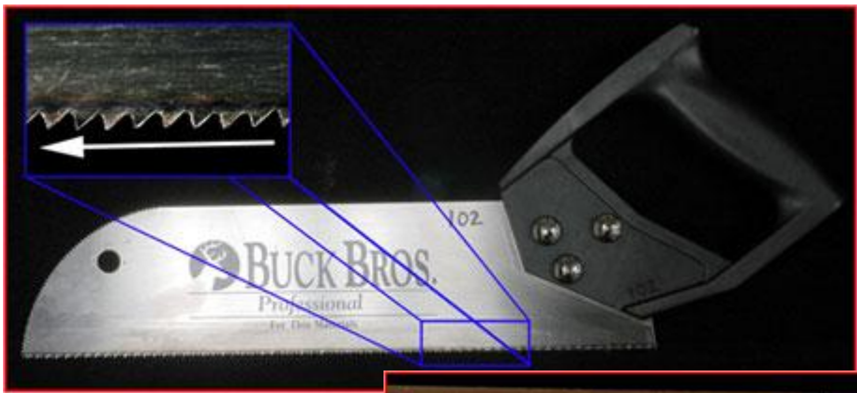


Figure III-17. Push stroke (Western) saw.

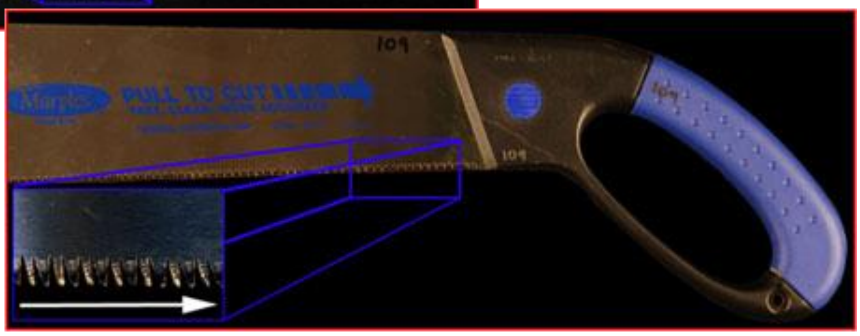


Figure III-18. Pull stroke (Japanese) saw.

Other exceptions to push stroke saws are some pruning saws – as it is easier to pull than push when in awkward positions or out on a (tree) limb; buck saws, which may have a push and pull stroke for a person on each end of the saw; (Figure III-16), and power reciprocating saw blades, which cuts on the pull stroke to avoid blade bending and binding during high speed reciprocating motions. Flexible saws generally cut in either direction as do the reciprocating (vibrating) autopsy saw.

Chain saws have a completely different type of tooth shape design. Chain saws are designed to cut soft material at high speeds. When cutting hard material like bone, these chain saws create wavy edged walls, but the teeth bite very little into the bone. Because of the hardness of bone and the basic design of the chainsaw, with a tooth in the shape of a "J" (Figure III-19), this particular saw action appears to "melt" the bone while beating it into submission (Figure III-20).

Figure III-19. Three different views of chainsaw cutting teeth. Also note raker teeth and the body of the chain. Notice the beveled cutting edge of the leading edge of the tooth, as opposed to the non-sharpened end, including the horizontal and vertical aspect of the tooth.

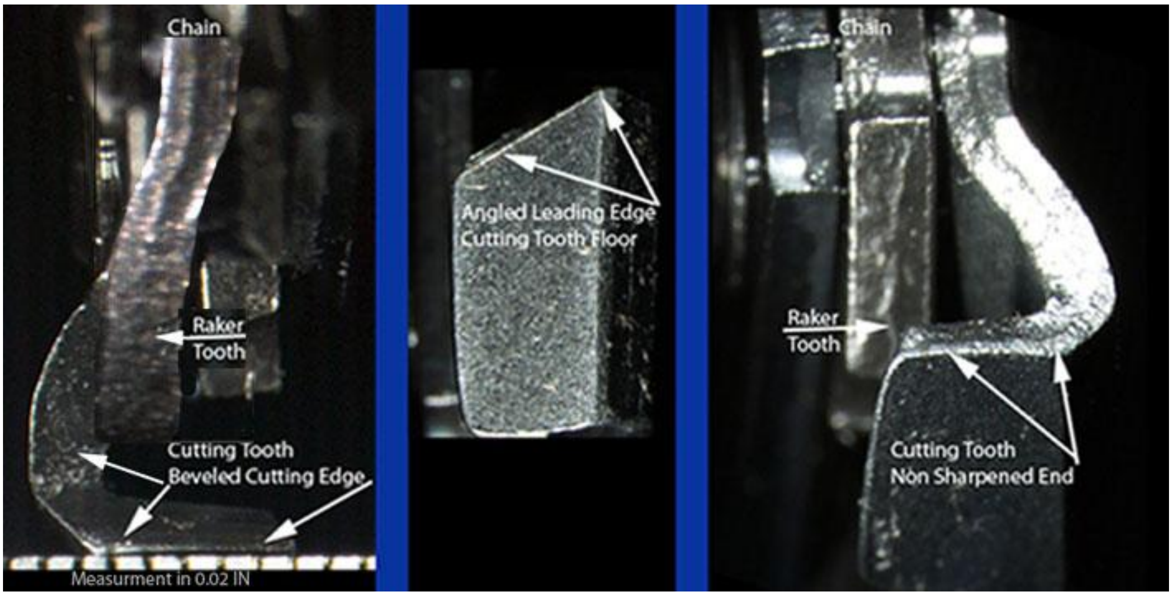
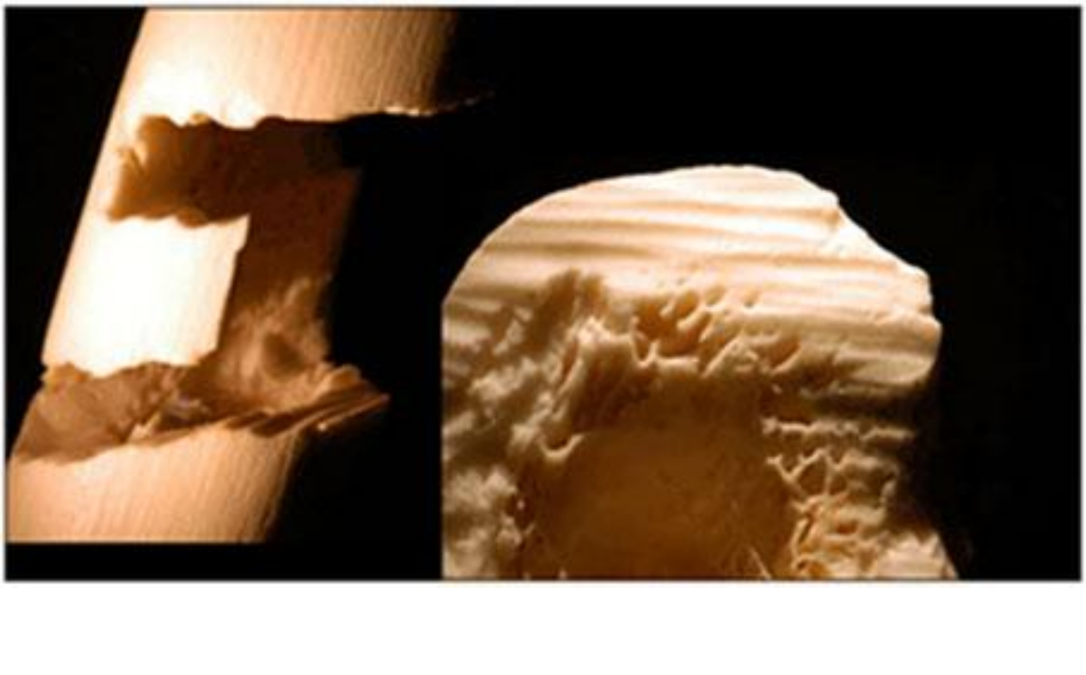
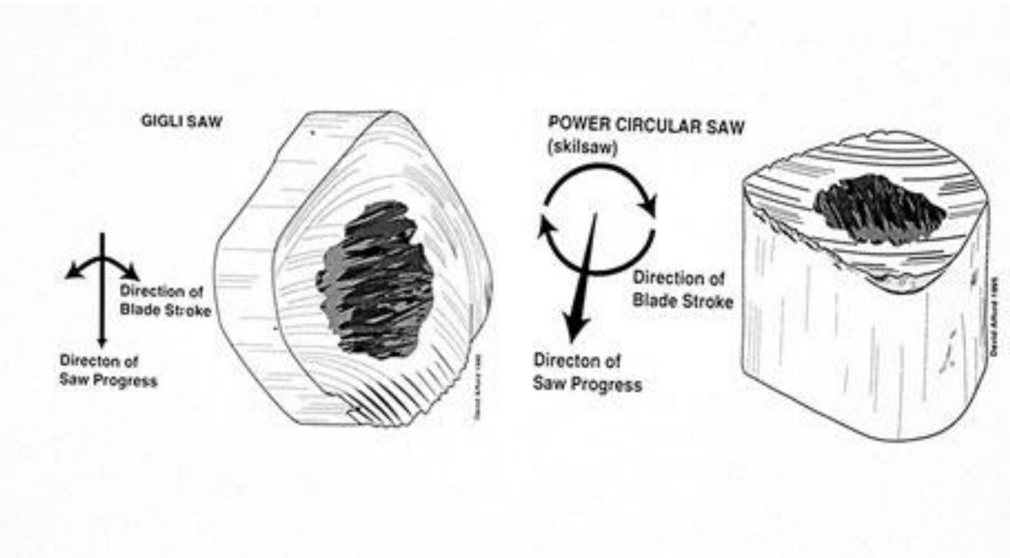


Figure III-20. This illustrates two different views of chainsaw dismemberment cuts to a femur. You see the "J"-shaped tooth "beating" the bone the blade bounces back and forth with the introduction of each tooth



Saw Blade Flexibility/Contour

Saw blade shape and the method of delivery of the teeth to a surface are also characteristics that may be used to identify saw marks. While most blades are designed to propel teeth in a straight line, some saw blades are arched or flexible (Figure III-21). How saw teeth are introduced into the material (e.g., bone, wood) may influence the residual characteristics that could leave striae which resemble blade shape or the shape of the material.



F31igure 21. Two types of „shaped' saw cuts. The Gigli saw is a flexible saw that wraps around the bone as it cuts, with striae mimicking the convex bone shape. The power circular saw bends into the bone, creating fixed radius concave striae.

Saw Power

Obvious differences exist with regard to the power mechanism of a saw. Throughout history, saws have been physically powered by the person(s) utilizing the machine. Human power varies in speed and strength, as well as in handedness and skill. Mechanically powered saws refer mainly to gas, electric, or pneumatic powered tools that reduce human variation from the sawed byproduct, while adding speed and uniformity. Power saws are designed to cut in a reciprocating or continuous motion and may be supported by a frame or hand held. In the forensic setting, power saws have recently become more common than in the past due to mass production of lower quality and lower priced power saws that are designed for private use. Many dismemberment and mutilation cases are routinely misinterpreted to have been result of a mechanically powered saw, when in fact, a hand powered saws had been used. (Symes et al. 2007).

Since a mechanically powered saw cuts with more force and speed, the blades are manufactured to withstand a higher amount of stress. Exceptions are found when the blade is supported in a frame like a band saw, or the blade has little movement like a cast/autopsy saw. Saw power is generally indicated by uniformity of cut (Figure III-22 left image), transfer of energy, and material waste (Figure III-23). A mechanical power source has a greater influence on the saw and the sawed by-product. Principles of sawing rely on blade and tooth design, and also the manner in which energy is transferred to the blade and the material. Increased speed and torque of power saws dictate their tooth design. High cutting speed combined with the potential pressure applied by the operator, requires the design of short, wide teeth, and/or a robustly supported blade. Power saws commonly cut faster but, unless heavily supported, tend to waste more material. In a high energy situation, there is an increased demand on the saw teeth. Therefore, power saws rarely utilize filed tooth saw blades (crosscut), as the needle tipped saw teeth associated with these blades would distort under pressure. However, with a new design of hardened tooth tips, examples of crosscut power saw blades are available.

Circular saws commonly have carbide tipped teeth with a design that may leave kerf floors resembling a filed toothed saw (‘W’ shaped Kerf floor). A final characteristic that may be visible in power saws is the tendency for the operator to start a new kerf instead of placing the saw back into the former kerf. In Figure III-24, the top image has three deep false starts that are regular and straight edged. This image represents the same power reciprocating saw that was used in both Figure III-22 (left image) and Figure III-23. Repeated deep false starts are closer to each other and are more indicative of a power saw. Figure III-25 illustrates more examples of false starts in a femur and a lumbar dismemberment. It would appear the saw was limited in gutting ability for deep cuts. This likely indicates a short blade or a blade not designed of deep cuts. In this case it was a 7-1/4 inch circular saw blade designed for little more than two inch cutting penetration. Figure III-25 has an unusual pattern of five parallel deep false starts. While the environment has all but obliterated the saw cut striations, these deep, uniform cuts, some within 1-2 millimeters of completion, could not have been made with a hand powered saw without fractures the shaft.

Hand powered saws are characterized by the inverse of what is visible in mechanically power saws. High energy is not visible, there is a lack of uniformity, thinner blades are used, and there are often indications of the perpetrators arm movement. Arm movement creates nonparallel striations that frequently change direction with rocking motions (Figure II-22 right image). A hand saw discourages deep false starts, as it is too much to start another deep cut over. Deep false starts are likely to be products of a powered saw.

Figure II-22. A cut fibula where the striations demonstrate a uniformity of cut on the bone and visible also in the embossed enlargement. The femur shows irregular striations from a hand saw.

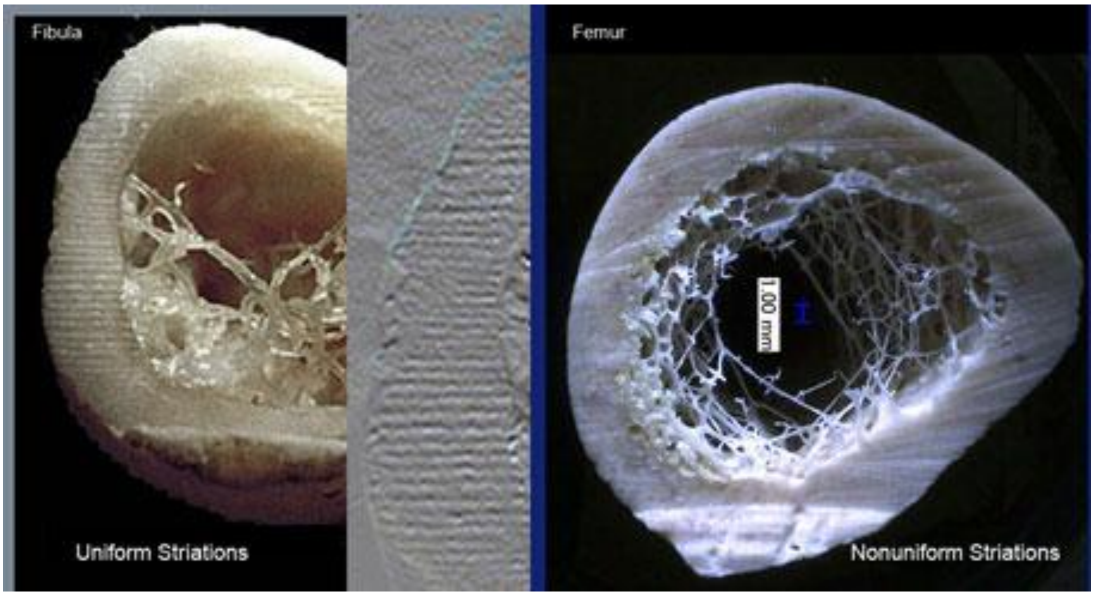
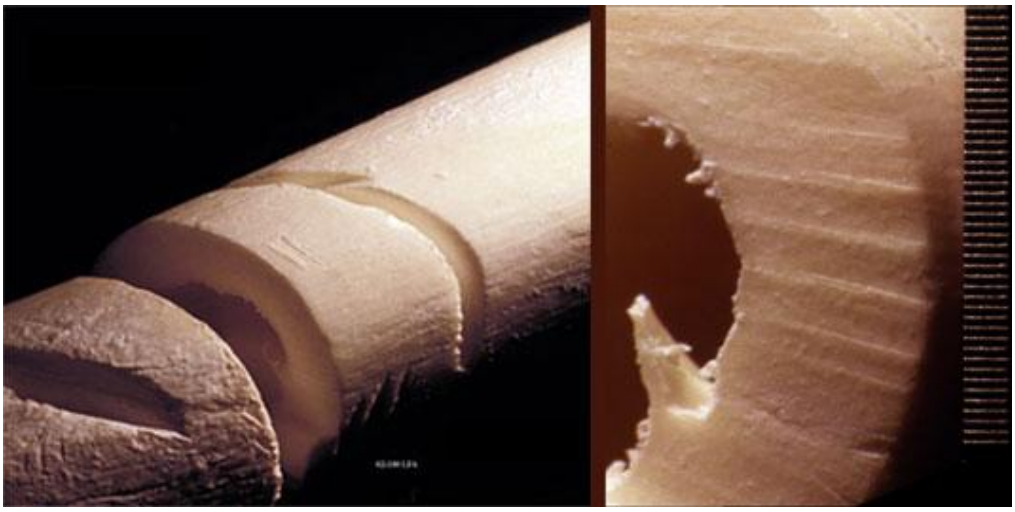


Figure II-23. Numerous false starts cuts and a kerf wall on the femur. The kerf width is wide and all cuts are extremely uniform and smooth. The smooth walls make it difficult to see each tooth striation; rather only passive stroke striations are visible (right Image). These defects are classified as reciprocating cuts from a power saw.



Direction of Saw Motion

Establishing saw cut direction from cuts on bone is feasible and contributes to crime scene investigation. However, "direction" may be misleading, unless it is clearly defined. Direction of cut indicates two separate saw actions; the direction of blade progress, and the direction of blade stroke (Figures III-9 and III-26). Indicators of direction of saw progress can be determined from the false start and breakaway spur. False starts, where individual teeth strike and chisel material, or where actual kerfs are abandoned for another cut, commonly produce initial cuts. The plane formed between the false start and the breakaway spur or notch usually gives the precise direction of saw progress.

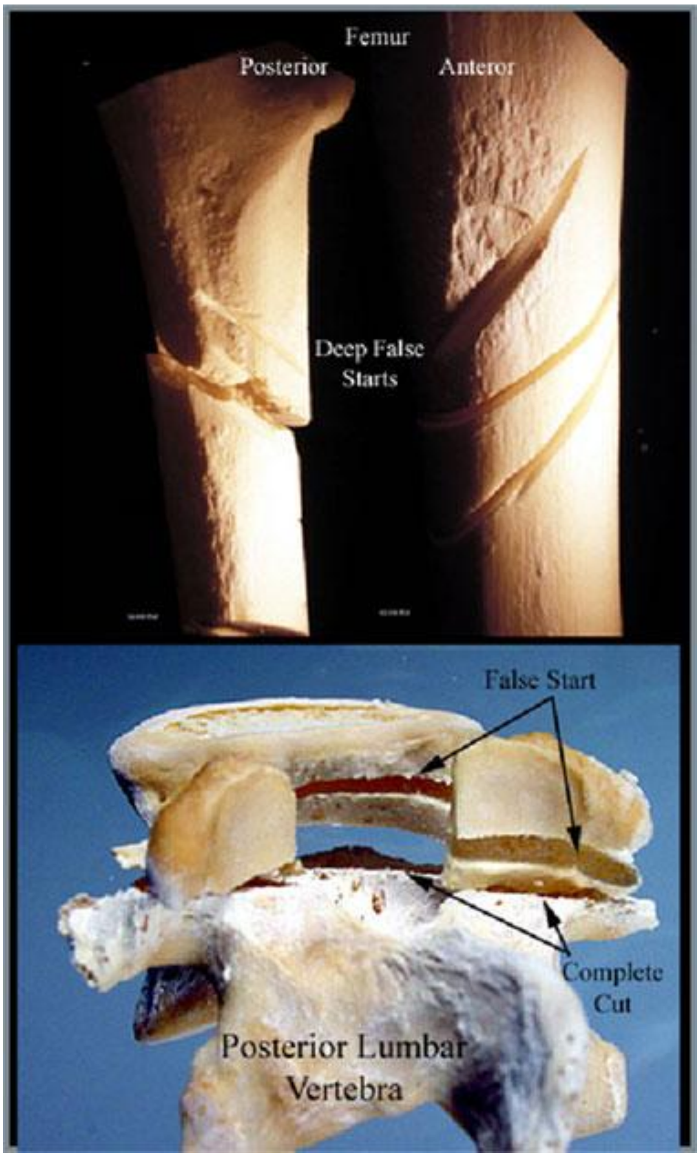


Figure III-24. Numerous false start cuts are present on both femoral shafts. Deep false starts on the 5th lumbar vertebrae are a common place for dismemberment. The kerf width is somewhat wide and all cuts are extremely uniform and smooth, such that it is difficult to see the striae.

Figure III-25. Two views of numerous identical false starts, which are too uniform for a hand saw.

Direction of saw stroke is simply the direction of the tooth as it cuts or shaves the bone, or essentially the direction of the residual striations. As mentioned above, many saws are designed to cut in one direction. If the saw is used in a reciprocating motion, there is a cutting stroke and a passive stroke. Teeth exiting the bone on the power stroke generally produce exit chipping (Figures III-9 and III-26), while passive strokes generally leave no exit chipping. The direction of the cutting and passive strokes is essentially the direction of the residual striations in the bone. Direction of blade stroke (tooth striae) is essentially perpendicular to blade progress.

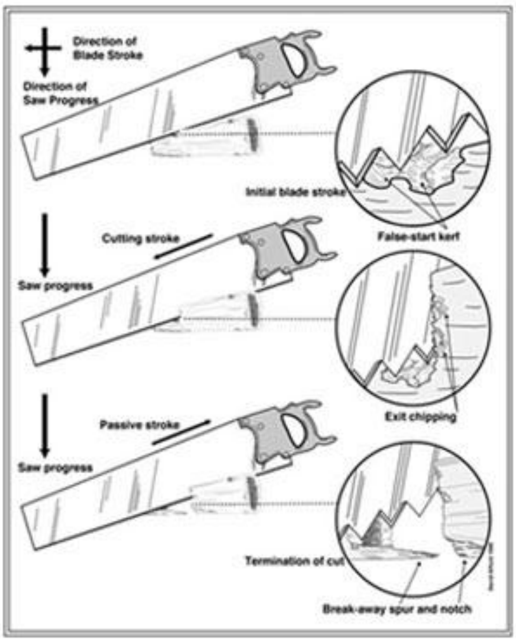


Figure III-26. Forming a kerf with the cutting stroke and passive strokes demonstrated and exit chipping highlighted.

Figure III-27 illustrates a proper documentation of the cut surface of bone. Analysis has indicated direction of saw progress and stroke.

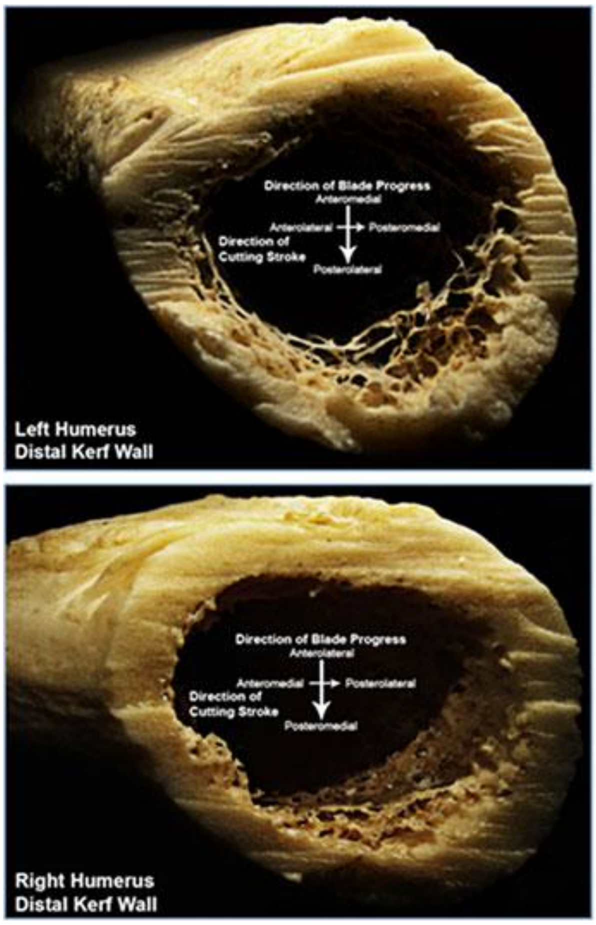


Figure III-27. Humeral cuts as in Figure III-2, but now labeled with small arrow showing the direction of saw stroke (striae) and large arrow showing saw progress (false start to break-away).

Introduction to Saw Mark Analysis Characteristics

Each definition is provided with the location in which to observe this feature(s) on a saw cut. Locations include, kerf floor (KF), kerf wall (KW), break-away spur (BA), or false start (FS).

Kerf

The kerf is described as the walls and floor of a cut (Figures III-9 and III-26). Floors are expressed in false-starts and occasionally in break-away spurs. Kerf floors (KF), when present, offer the most information about the points of each tooth, the relationship of the points to each other or the set (lateral bending) and number of teeth per inch (TPI). Kerf walls (KW) can also offer information about teeth per inch, saw power, and direction of cut.

<u>Break-Away Spur</u>

The break-away spur (BS) is a projection of uncut bone at the terminal end of the cut after the force breaks the remaining tissue. This commonly occurs on the stable end of the bone (Figures III-9 and III-26). The break-away spur is often diagnostic for residual kerf floors. The size of the spur often depends on the amount force applied across the bone, which also results in a fracture of that bone. For instance, the weight of a handheld circular power saw or chain saw often produces a large break-away spur if any additional force is applied to the bone when cutting.

<u>False Starts</u>

False start (FS) kerfs are cuts that did not completely separate bone into two halves. A false start is composed of two initial corners, two walls, two floor corners, and a floor (Figure III-9). False start cuts are not considered 'hesitation' marks and are not termed as such (see below).

Traits and Characteristics Associated with Saw Size, Set, Shape

<u>Minimum Kerf Width -</u> is a measurement of the width of the kerf. Minimum kerf width is directly related to the width of the set of the blade (Figure III-28).

<u>Teeth Per Inch (TPI) -</u> is a measure of the number of complete (not just points) teeth per inch. There is one more point per inch (PPI) than there are teeth per inch (Figure III-7 and III-10).

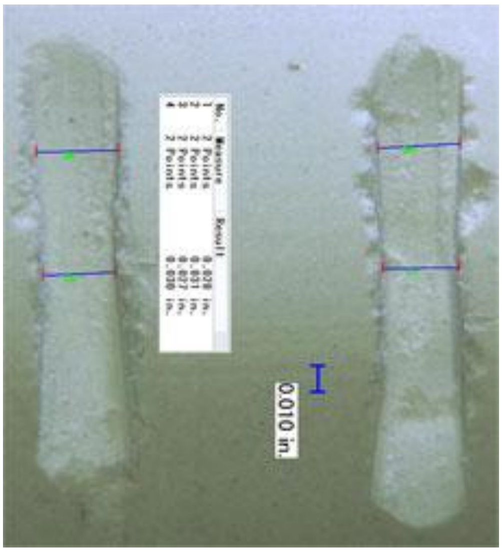


Figure III-28. Minimum kerf width measurement of saw mark in chalk.

Tooth Hop–refers to striae across the face of the bone which generally progress in a straight pattern. With close observation, the residual kerfs (striations) occasionally show patterned hopping or predictable waves. Blade hopping is created as teeth begin to enter the kerf and each successive tooth strikes bone, which produces movement of the whole blade. Measuring from peak to peak or dip to dip of each wave indicates the distance between teeth on the saw. It has been demonstrated that tooth hop can occur with a variety of saws and accurately indicates spacing of saw teeth (Andahl 1978; Symes 1992) (Figure III-29). (KW)

Pull Out Striae-(Tooth Scratch) - involves the presence of perpendicular striae on the cut surface of the bone. When the saw is withdrawn from the kerf in mid-stroke, the blade creates striations on the cut surface. Bonte (1975:319) recognized pull out striae as appearing "vertical to the sawing level which extend[s] over several saw marks . . . [and] corresponds, with normally set saws, to twice the distance between the teeth." Unfortunately, the phrase "normally set saws" is a misleading one. Alternating set saws can leave this type of pattern, but a saw with a raker set (See Saw Set below) may leave striae that represent the distance of three rather than two teeth. Occasionally, all the teeth may leave residual marks when the blade is removed. Pull out striae are characteristics that do not easily stand alone and are most useful when used to corroborate other - more reliable - estimations of tooth distance. (Figure III-30). (KW)

Tooth Imprint and Floor Dip - are the result of combined saw tooth actions which cut a kerf floor in bone. When the floor of the kerf is examined on end, the seemingly flat-bottomed kerf may actually be notched or wavy. Tooth imprints and floor dip are residual imprints from tooth points in the kerf floor created after a saw is interrupted in the cutting stroke. Consecutive tooth imprint features can be measured in false starts and break-away spurs to represent the distance between teeth, indicate the set (shape) of the blade and indicate the shape of the individual tooth. (Andahl 1978:36-37; Symes 1992) (Figure III-31). (KF)

Saw Tooth Width- is calculated in two ways: 1. measurement of floor patterns and 2. measurement of residual tooth trough. Floor patterns give an average estimation of saw tooth width while the residual tooth image, if properly interpreted, produces an accurate image of an the tooth. (KF)

Saw tooth set is used to describe the lateral bend of teeth. Three major types exist namely, alternating, raker, and wavy (Figure III-11). A cheaper blade may have no set, especially if there is no lateral bend to the teeth. (this is also mentioned in section 1, in detail, do you want to mention it again?).

Figure III-29. Tooth hop: peak to peak or valley to valley represent distance between 2 teeth.

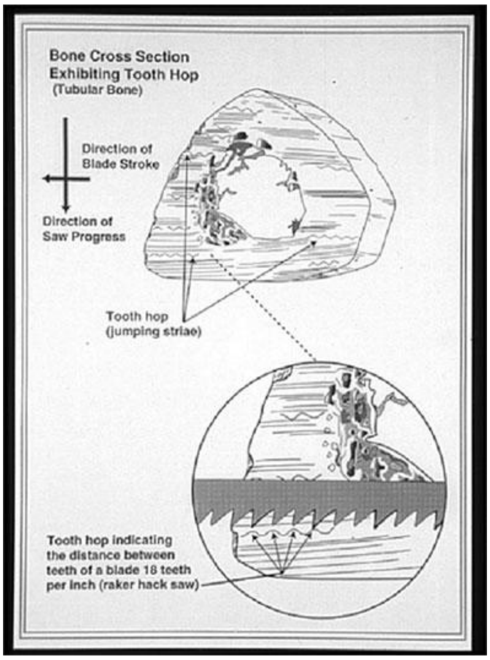


Figure III-30. Pull out striae. Where in the plane of the cut may indicate two or three teeth distance.

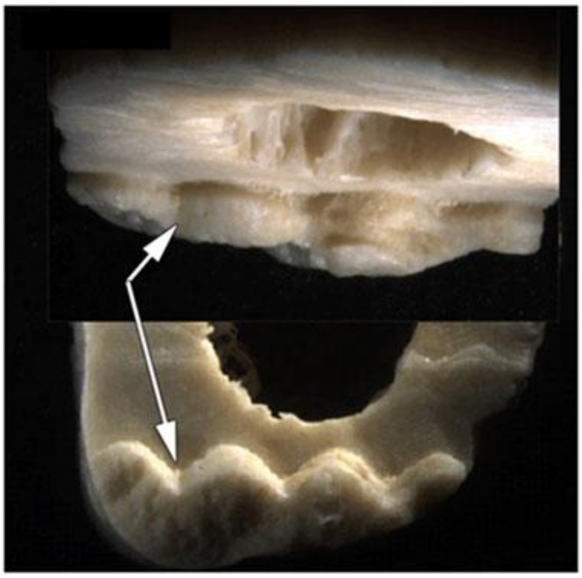


Figure III-31. Floor (top) and wall (bottom) views of tooth imprints (arrows) and floor dip, represent residual imprints from tooth points in the kerf floor created after a saw is interrupted in the cutting stroke. Each is important for indications of TPI. This was a 5 TIP(TPI) toothed saw with large gullets, so the features are accentuated.

Blade Drift refers to the pattern of teeth drifting across a kerf floor; where every tooth that enters the material creates a directional change in the blade. Blade drift is most evident in shallow cuts produced by alternating set saws (Figures III-32 and III-33).

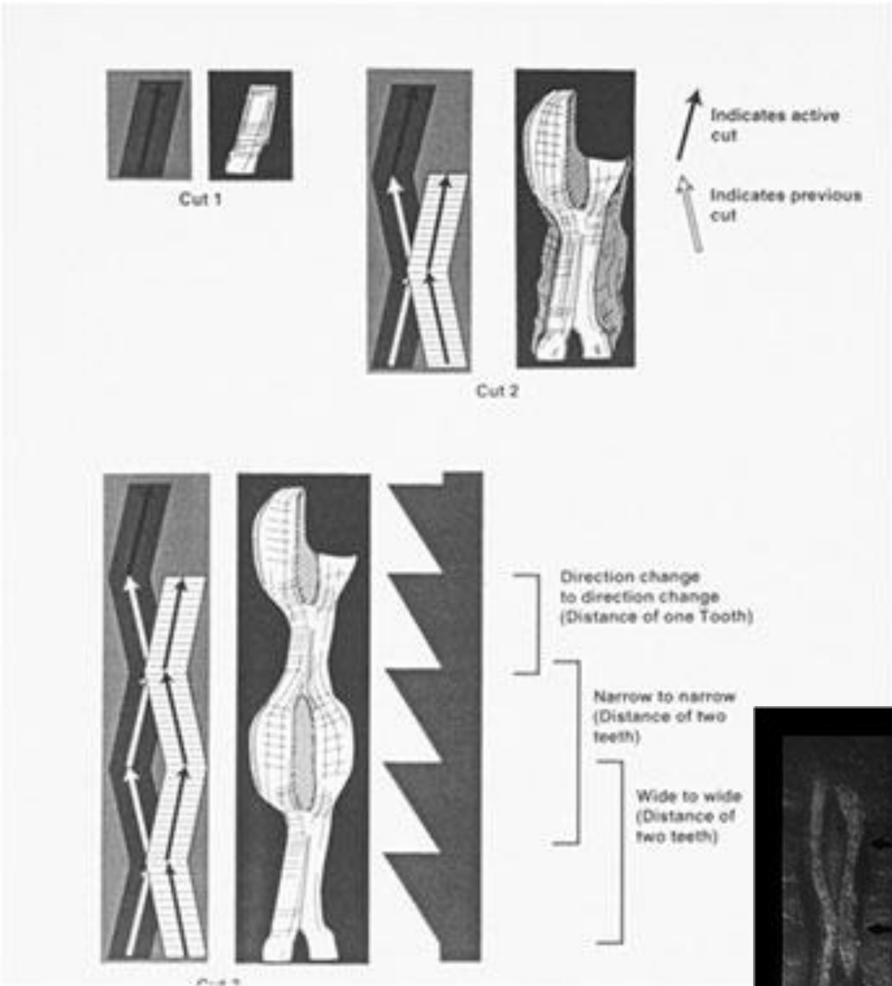
In order to understand this motion, one needs to examine the action of a single tooth, and then combine this action with the actions of consecutive teeth. As a single set tooth enters the material, the tooth seeks an orientation parallel to the direction of the blade and to the midline of the material. This midline orientation is compromised as the next tooth enters the material. The second tooth is alternately set to the first tooth and therefore enters the material from a position opposite the previous tooth and seeks a different midline from the first tooth. Therefore, the second tooth actually attempts to cross the path left by the first tooth (Figures III-32 and III-33).

While the second tooth is pulled to the midline, the first tooth is sent in a direction parallel to the second tooth; this continues until a compromise is reached between the two teeth. Parallel drift is reversed each time a new tooth enters the material, with new teeth essentially entering the same two patterns and approximately the same grooves. This continual seeking of midline with intermittent introduction of opposite set teeth creates a fluctuating pattern in superficial cuts, resembling a chain of 'figure 8s.' Thus a very predictable pattern is established since there are essentially two rows of teeth set in an alternating pattern.

Once the blade is immersed in the material, much of the drift is suppressed. Drift patterns are most noticeable at the beginning or end of a cut in a tubular bone since there is little material to offer resistance or trap the blade's motion.

Harmonics- are described as peaks and valleys that are exhibited three-dimensionally in bone cross sections (Symes 1992). Harmonic oscillations are found to exist in nearly all blades with alternating set teeth, and are the direct result of normal cutting action in hand and mechanically powered saws. *Harmonics are simply the side view expression of blade drift* and are good indicative characteristics of blade set and TPI (Figures III-34). (KW)

Figure III-32. Pattern of teeth drifting across the kerf floor. Every tooth entering the material creates a direction change an important characteristic for indications of TPI.



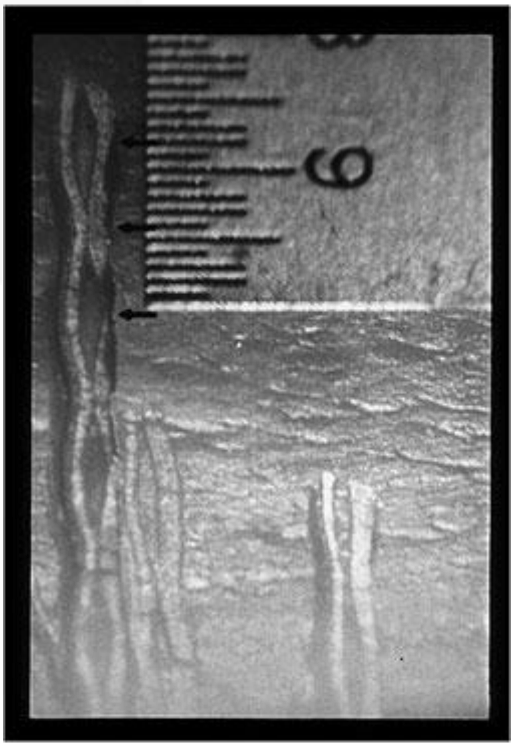


Figure III-33. Kerf demonstrating blade drift (in this case, direction change to direction change). Distance (arrows) is about 0.11 in making TPI in the blade about 0.09 in (see Table 2).

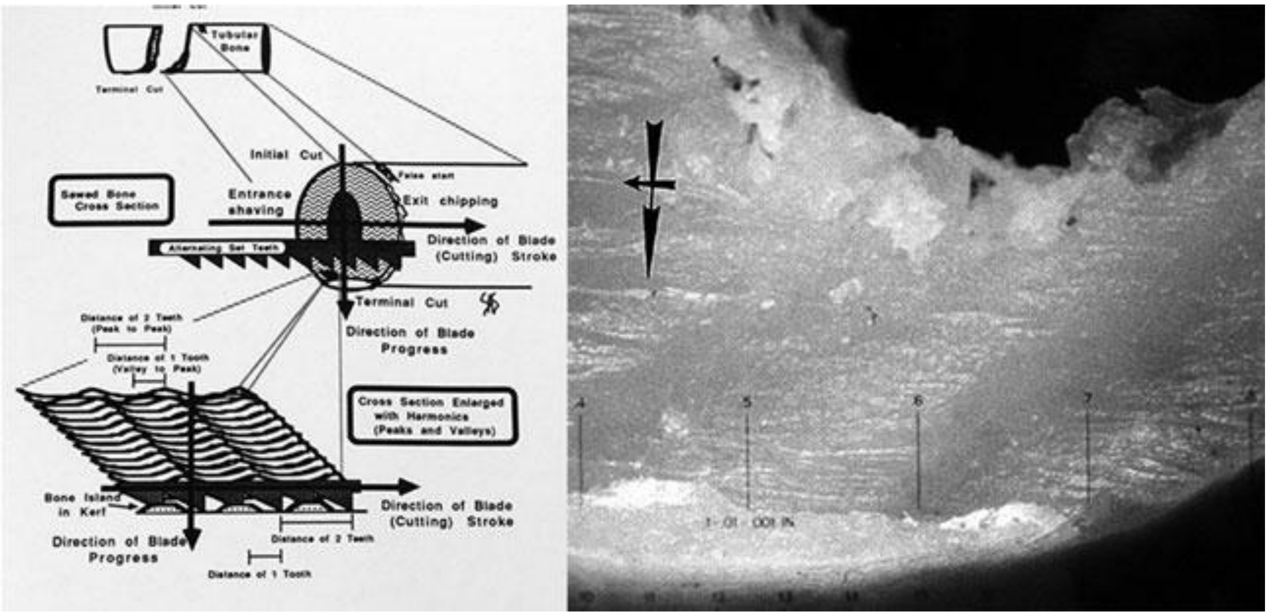


Figure III-34. Actual kerf demonstrating harmonics of an alternating set saw blade, Harmonics are essentially blade drift observed from the side, where the introduction of each tooth forces lateral movement of the saw blade. This lateral movement is indicated by peaks and valleys on the wall of the cut. Harmonics are indicative of blade set and TPI where peak to peak, or valley to valley, is the distance between two teeth. (Original Figures from Symes 1992.)

<u>Bone Islands </u>- are characteristic of alternating set blades and blade drift. A wider set increases blade drift and leaves material in the midline of the kerf, or an island at the wide part of the 'figure 8.' (KF) (Figure III-33).

Shape applies to the contour of the blade, the tooth as it is cut out of the saw blade, and whether or not the teeth are filed at an angle. The most common classifications are rip and crosscut saws (Figure III-7). These styles are important in that each functions differently so as to effectively cut a desired material.

Contour

<u>Flat</u>-Typical straight blades, inclusive of both hand and mechanically powered saws; produces a flat-bottomed kerf. (KF)

<u>Curved</u>-Curved blades (such as circular saws, autopsy blades, and curved pruning saws) and flexible blades (such as gigli saws) leave a residual curved kerf floor. (KF)

Tooth Orientation

Tooth orientation is diagnosed with the direction of sawing motion. The confluence of features visible in analyzing saw direction allows for the determination as to whether a blade's power stroke is occurring on the push or the pull.

<u>Push Saw</u>-A typical "Western" saw cuts on the push stroke (Schwartz 2006). It has a wider

blade and produces more material waste which, in turn, creates a wider kerf. In general, push saws have larger teeth and the push stroke is more powerful, which gives the cuts a more accurate and efficient action than with a pull saw (Figure III-17).

Pull Saw- A Japanese pull saw cuts on the pull stroke. Blade design is thin with aggressive teeth. Despite the awkward pull stroke, this saw is very efficient as the thin teeth cut less material and create less waste (Figure III-18).

Rip-Rip saw teeth are not angled or filed. The teeth are simply notched out of the blade. As such, these saws essentially chisel material, rather than cut it. Rip saws are designed to cut with the grain of wood (Figure III-7).

Crosscut-A crosscut saw has teeth that have been filed to an angle, usually producing a point. The filing allows each tooth to act as a tiny blade, which cuts through material. Crosscut saws are designed to cut across (or through) the grain of wood. (Figure III-7).

Traits and Characteristics Associated with Saw Power (Hand vs. Mechanical)

Separating hand powered from mechanically powered saws is approached in the examination of three characteristics; consistency of cut, energy transfer, and material waste. These characteristics are greater with mechanically powered saws (Figures III-21, III-22, and III-23).

Consistency of Cut

Consistency of cut is anticipated in continuous cutting power saws; where the blade continuously cuts material at high speeds. However, this consistency is evident in all power saws, even those with reciprocating actions. Consistency refers to recognizable patterning, with a gradual change in patterns. Hand powered saws typically exhibit an inconsistency in cut that is evident on the kerf wall. (KW)

Energy Transfer

Mechanically powered saws increase energy transfer to cut bone and usually create more polish on the cut surface. Increased tooth speed, saw weight, and torque lead to a tendency to inadvertently discontinue a cut. Because of the ease of the cut, it is not important to reinsert the blade in the kerf that was initially started. The opposite tendency is true in hand powered saws as it is more efficient to reinsert the blade in the false start to continue the cut. (FS)

Material Waste

Power saws are generally characterized as wasteful of material. This may be credited to the stout blade design or the “ease” of producing a cut (Figure 21, 22, and 23).Since power saw cuts are produced with little expansion of human energy; it is likely that more cuts are produced and more material is wasted. Power saws which lack large teeth or thick blades must be supported, i.e. band saw. (FS)

Traits and Characteristics Associated with the Saw Direction

Cutting/Passive Stroke

Cutting stroke is either a continuous action in a single direction or a reciprocating action which produces the majority of the cut. If an equal force is applied to a reciprocating blade, the direction of stroke cutting or chiseling of bone is also the direction of the cutting stroke. This is usually due to the design (slant) of the teeth.

A passive stroke occurs in reciprocating saws where the lack of an aggressive tilt in the saw teeth allows them to slide across the bone without leaving more that a single striation (Figure III-I-22 and III-27).

Blade Progress
Indicators of direction of saw progress center on the false start and break away spur. Initial cuts are commonly accompanied by false starts, where individual teeth strike and incise material or where actual kerfs are abandoned for another cut. The plane formed between the false start and the break-away spur or notch gives the precise direction of saw progress. Direction of blade progress is perpendicular to stroke and tooth striae (Figures III-9 and III-26).

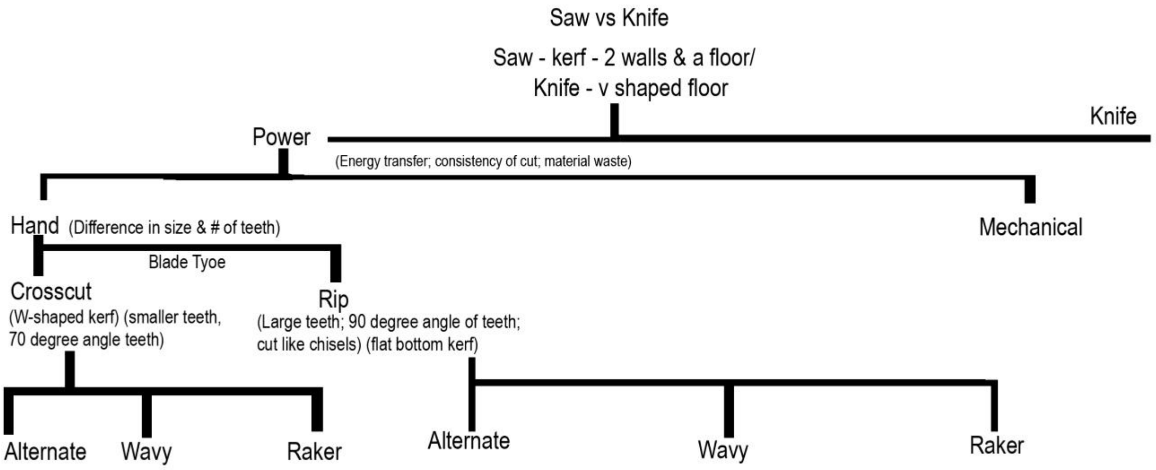
Entrance Shaving-As the saw enters the side of the bone, the blade can shave the bone entrance and give it a polished and scalloped appearance. Shaving can be a consequence of twisting of the saw such that the blade is not allowed a direct path into the kerf. More often it is simply due to the tooth set being wider than the blade, which forces each tooth to cut a kerf. Seldom is there chipping as the tooth enters the bone, and if present, it is difficult to observe. (KW)

Exit Chipping-Exit chipping is present with few exceptions. Exit chipping occurs at the end of the cutting stroke or on the side of the stroke emphasized by the individual sawing. As a rule, the largest chips of bone are removed on the cutting stroke as the blade exits the bone (Figures III-9 and III-26). (KW)

Kerf Flare - If kerf flaring occurs on one end of the kerf floor, it indicates the 'handle-end' of the blade. It is expresses the increased movement of the flexible blade as it continually enters the kerf. The opposite end of the kerf floor does not exhibit a flare (Figure III-35).

Figure III-35. False start: flare at one end. This suggests the end of the kerf where flexible saw blade is flared due to lateral movement of the handle, while the blade supported by the kerf does not flare.

Saw Mark Analysis Flow Chart



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