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Morphology of Saw Marks in Human Bone: Identification of Class Characteristics

Steven A. Symes
University of Tennessee - Knoxville

To the Graduate Council:

I am submitting herewith a dissertation written by Steven A. Symes entitled "Morphology of Saw Marks in Human Bone: Identification of Class Characteristics." I have examined the final electronic copy of this dissertation for form and content and recommend that it be accepted in partial fulfillment of the requirements for the degree of Doctor of Philosophy, with a major in Anthropology.

William M. Bass, Major Professor

We have read this dissertation and recommend its acceptance:

Richard L. Jantz, Walter E. Klippel, Hugh E. Berryman, O'Brian Smith, Cleland Blake

Accepted for the Council:

Carolyn R. Hodges

Vice Provost and Dean of the Graduate School

(Original signatures are on file with official student records.)

To the Graduate Council:

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William M. Bass, Ph.D., Major Professor

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Accepted for the Council:

Associate Vice Chancellor
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MORPHOLOGY OF SAW MARKS IN HUMAN BONE: IDENTIFICATION OF CLASS CHARACTERISTICS

A Dissertation

Presented for the

Doctor of Philosophy

Degree

The University of Tennessee, Knoxville

Steven A. Symes

May 1992

DEDICATION

This dissertation is dedicated to my parents, Ray and Mildred.

Without their continual support and appreciation

of higher education,

this would not have been possible.

ACKNOWLEDGEMENTS

Most doctoral students have four committee members to acknowledge, I have two groups of committee members. The first group represents the core of my advanced degree training. Dr. William M. Bass has been my support and strength since the first day we met in South Dakota, in 1978. Through luck and his graces, I was able to serve Bill as his graduate assistant for 5 years. I dare say there was never a better team in the field or in the classroom. Thank you for the experiences of a lifetime. It is you who is the "good man."

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A thank you is extended to Drs. Charles and Gretel Harlan of the Nashville Medical Examiners Office for letting this anthropologist get his feet wet on the "forensics side." Charles has the distinction of having three tool mark on bone cases in rapid succession, demonstrating to this author the need for more research in this area. A fascinating power saw mark case was also sent to me by Mr. Craig Lahren and Dr. Frank King of the Hamilton County Medical Examiners Office. Thanks for the food for thought.

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I had many proof readers attempting to iron out the kinks in this project. Tami Ruth read, edited, and basically continues to make my job easier on a daily basis; thanks Tami. Ken Hawkes and Jeff Moore also edited or contributed ideas to the project, I thank you both.

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Although I have dedicated this dissertation to Ray and Mildred Symes, I must also thank my brothers, Merle and Lennie, their families, and my Uncle Carroll. Their continual and rather persistent encouragement was essential to my success. Thank you for your confidence and assurances!

On more of a Blues note, let me thank the talented Jeff Chaz. Your music has been a great diversion and inspiration to me. Hey Bronwyn, I appreciate your music more than ever. You know Kara

told me I had better finish for you. I did, here it is, I won't forget you.

Finally, I would like to acknowledge the volleyball crowd of Memphis. It takes a great bunch of folks to drag me away from anthropology!

ABSTRACT

Accurate interpretation of saw marks on human bone is an essential part of tool mark examination in the forensic sciences, but appears neglected in practice and in the forensic sciences literature. With a basic understanding of saws and principles of cutting action, residual saw characteristics remaining on human bone can be recognized and interpreted.

Two basic areas of saw cut bones are examined. Kerf floors can be examined in false starts and break away spurs. This area of a cut potentially reveals kerf size, striae patterns, and contour differences. Kerf walls, or the cut cross section of bones, reveal striae specifics such as contour, direction of stroke, and patterns of cutting action. These areas of cut bone potentially reveal observable and quantifiable characteristics that can be related to predictable saw actions. These characteristics may indicate distances between saw teeth, type and amount of tooth set, tooth and blade shape, manner in which a saw is powered, and direction of saw cut.

These characteristics, utilized individually or in combination, narrow the number of possible saws that potentially create a particular cut. This narrowing of the field of saws allows the examiner to assess the class, subclass, or type of saw utilized in a cut. Ultimately, examination of human bone remains will allow anthropologists to go beyond the descriptive level of analysis to confront modified bone with an appreciation for its potential forensic value.

PREFACE

Interest in tool marks on bone was initiated in 1987 when three human dismemberment cases were investigated by Dr. Charles Harlan and this author for the Metropolitan Nashville, Davidson County Medical Examiner's Office. This interest continued in 1988 when this author became employed by the Department of Pathology, University of Tennessee, Memphis, and began to work closely with Drs. Hugh Berryman and O. C. Smith. It soon became apparent that the topic of tool marks and the biomechanics of fracture production on human bone was a common interest for this mixed group of two anthropologists and a pathologist. This collaboration of interests and efforts resulted in the origination of the ***S.O.B.*** team (Steven Symes, O. C. Smith and Hugh Berryman).

While this author takes full responsibility for this project, the ***S.O.B.*** collaboration initiated much of the groundwork for saw mark research by outlining the scope of such a project, and defining the basic components of a saw mark on bone. Many of these original definitions are included in this work.

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INTRODUCTION

History of Saw Mark Analysis

Introduction

Criminalistic comparisons of tool marks have evolved into highly technical procedures that contribute to numerous areas of the forensic sciences (Thomas 1967). The area of saw marks on bone appears to show less technological sophistication and successes than other tool mark areas of criminalistics. This deficiency of saw mark analysis is evident in the criminalistics approach to saw marks, and in the volume and quality of research that has occurred in the last 20 years.

Past criminalistics hypotheses concerning saw marks have abided by the notion that saw teeth destroy characteristics with consecutive marks as the tool progresses in the cut (Bonte 1975:318). The value of saw marks for the identification of type characteristics specific to saws has been described as "limited" and "rare" (California Department of Justice Firearms/Toolmark Identification Training Syllabus 1991:582) and apparently restricted to used and damaged saw blades (Bonte 1975).

Existing research in the examination of class characteristics of saw marks on bone is not only lacking, but also falls prey to inadequate knowledge of the tool and its cutting action, poor comprehension of saw cut characteristics, and a deficiency of comparable characteristics essential for the process of narrowing the field of possible tools utilized in a homicide.

Early German criminalistic studies represent initial attempts of saw mark classifications, although all analyses are limited to cuts in wood (see summaries in Bonte 1975 and Guilbeau 1989). Bonte (1975) is quick to point out that the publication of his analysis of German human dismemberment cases, is the first article of its kind in American literature. This research represents the first concentrated effort to closely examine saw mark striae in human bone. Bonte recognizes saw striae differences distinguishing the deep furrow of the return stroke to the parallel rills of the forward cutting stroke. Still, the two attempts to quantify saw tooth size, lack accuracy and comparable techniques to validate these estimations. Bonte (1975:318) calculates what is projected as two thirds of the teeth in a saw blade by doubling the number of rills. Bonte also examines vertical scratches of the sawed surface that are produced by removing a jammed saw from the cut. While these scratches represent a specific distance between teeth, there is no assurance that this measurement accurately represents distance of two teeth.

Andahl (1978) describes numerous saw cut characteristics in metal and animal bone, and even describes how these characteristics can be applied to a medicolegal case of human dismemberment. Andahl examines shapes of false starts, patterns of striae in the bottom of saw cuts created by three differing saw sets, and wave striae patterns that represent the distance between teeth.

These interpretations of blade and tooth patterns represent an awareness of differences in saw tooth design expressed in cuts. Andahl does take saw cut analysis further than previous investigators, but interpretations of cuts with no reference to the principles of sawing actions make these techniques difficult for the untrained observer.

Recent forensic anthropological treatment of this research problem is limited. Symes et al. (1988) examined two human mutilation cases and made comparisons of these case studies to experimental cuts in human bone. All analysis concentrated on the cut surface of the bone, and on the "break away spur." The break away spur is a projection or spur of uncut bone at the terminal side of the cut that remains after the saw breaks the remaining tissue. This research also attempted to examine individual sawing skill by comparing cut mark characteristics of experimental cuts in human bone by individuals experienced with saws, novices, and the those totally inexperienced with using a hand saw. These results appeared inconclusive to the features compared even though cutting efficiency greatly varied (Symes et al 1988).

Symes and Berryman (1989a) build on many of these characteristics to successfully demonstrate statistical separation of saw classes, hand versus power saws. Explanation of saw class cutting action differences and the characteristics separating these were minimally treated.

Guilbeau (1989) closely examined the early German literature detailing criminalistic analysis of saw marks in wood and goes on to examine hand saw marks on pig bones. The topic of individual skill influencing saw cuts was tested, this time with an emphasis on handedness of the individual. Once again, no conclusive results were reported. Five discrete characteristics were tallied for each saw cut but little interpretation of these characteristics was offered.

Two other researchers have recently detailed descriptions of medical legal dismemberment cases in which characteristics of a hand saw (Blake 1985) and a power saw cut (Symes et al 1990) were traced to a subclass of saw in each case, but little standardized information of technique or accuracy was offered.

While each of these saw mark examiners have contributed to the overall value of saw mark tool comparisons, there appears to be a need for an improved understanding of the tool creating the characteristics, the principles of tool action in a cut, and the value and potential of residual characteristics remaining after a cut. Even though criminalistics have determined that there is limited potential for positive identification of a saw from comparisons of saw marks, the value of class characteristics of saw marks has been recognized.

This research attempts to develop an increased awareness of a variety of characteristics on cut bone while data gleaned from these cut characteristics are applied to saw blade and tooth characteristics of size, set, shape, and power. This information will be used to indicate saw class, subclass, or type. It is this narrowing of the field of possible tools potentially utilized in a crime that makes saw mark characteristics a valuable "tool" for the forensic examiner.

Criminalistics Approach to Tool Marks

Criminalistics has defined tool mark identification as the discipline in forensic science concerned with matching a tool with a particular mark (AFTE Criteria for Identification Committee Report 1990:278). The question forensic examiners must ask is, how are saw cuts on bone classified in criminalistics, and what is the range of possible conclusions to be made from saw marks?

The Association of Firearm and Tool Mark Examiners (AFTE Criteria for Identification Committee Report 1990) has recently established and revised standards and definitions of tool mark examination and comparison. They classify saw marks as striated tool marks, or marks produced when pressure is applied from one object to another producing a striated mark. These marks can be described as friction, abrasion, and scratch marks.

The ultimate goal of tool mark analysis, and in this case examination of saw cut marks, is positive identification of a tool from tool mark comparisons. Positive identification of tool marks involves the comparison of unique characteristics resulting in "sufficient agreement." Agreement is significant when, "it exceeds the best agreement demonstrated between tool marks known to have been produced by different tools" (AFTE Criteria for Identification Committee Report 1990:276).

Since positive identification is a rare occurrence with saw mark comparisons, other conclusions must be considered. Tool mark comparisons allow three other conclusions. A second conclusion besides identification is inconclusive results, where there is insufficient agreement of individual characteristics, a lack of ability to reproduce the characteristic, or insufficient agreement for elimination. Significant disagreement can result in a third conclusion, elimination of a tool mark; and finally there is always a possibility of tool mark comparisons being unsuitable for comparison (AFTE Criteria for Identification Committee Report 1990:276-277).

This research proposes that these four conclusions are appropriate only in certain comparisons where specifics of a saw are determined initially, then all saws fitting these descriptions are tested. With a standardized and improved analysis of saw marks, class characteristics such as saw size, set, shape and power can be identified. Class characteristics facilitate a narrowing of potential saw possibilities. This narrowed field of tools can aid in the search for an appropriate tool utilized in a crime, and may even allow the individual characteristics produced by the questioned saw to be compared with those produced by a suspect saw. It is these individual characteristics that are subject to the interpretations of positive identification, elimination, insufficient results, or unsuitable for comparison.

Anthropologist's Taphonomic Approach to Tool Marks

While involvement of anthropologists in criminalistic investigations is rare in this country, anthropological examination of tool marks on bone is not a new topic to anthropology. A major concern of paleoanthropology is detecting and understanding early butchering and carcass processing practices by hominids as a means of interpreting diet and subsistence activities. These interpretations weigh heavily on the examination and evaluation of bone cut marks.

> . . . Cutmarks do constitute a signature for hominid involvement with carcasses, regardless of the intent of that involvement. This observation, in turn raises a new major issue: can cutmarks be recognized reliably without being confused with other like marks? If techniques cannot be devised that enable the positive identification of cutmarks, then this new criterion represents no substantive advance over the co-occurrence of bones and artifacts as a means of identifying butchery or other types of sites (Shipman and Rose 1983:62).

Walker and Long (1977:606), with a criminalistics-like approach, outline the potential of anthropological tool mark analysis on bone:

> Butchering and skinning marks and grooves left on bone . . . record the function of specific tools. They may, therefore, yield information concerning the association of different classes of tools with specific tasks and they might also provide information on force, work angle, and direction of movement during a tool's use .

An appreciation of the value of cutmark analysis coupled with the call for clarity of interpretation has been addressed rigorously in the literature (Binford 1981; Bunn 1981; Potts and Shipman 1981; Shipman 1981a, 1981b; Shipman and Rose 1983; Shipman and Rose 1984; and Walker and Long 1977). These analyses emphasize a basic taphonomic approach to the problem of understanding of causal mechanisms, where certain events manifest particular effects (for information on taphonomy, its history, and applications, see Efremov 1940; Olson 1980; and Shipman 1981a, to mention just a very few).

Anthropologist's Changing "Role"

Recent emphasis on taphonomic examination of cutmarks on bone in the last 15 to 20 years has taken anthropologists everywhere from the East African Rift System, where data of two million year old human butchering sites are indicated from simple stone tool cuts on animal bone (Bunn 1981); to historic American back yard privies, where numerous saw marks on amputated human limbs indicate a scenario for surgical "practice" (Mann et al 1990). The "role" of the applied anthropologist may be expanding still as public awareness of the forensic sciences increases, and as the experts in the forensic sciences's demonstrate their new awareness of the diagnostic value of human bone trauma (Smith et al. 1990). These new interests involve anthropologists, especially those familiar with and active in skeletal biology. This interest in skeletons of the "recently dead" has stimulated an increasing number of researchers to focus their investigations on topics in forensic anthropology.

This dissertation concentrates on saw mark dismemberment in the forensic setting; more specifically, saw markings on bone. Efforts will be made to first understand saws, their construction, their history and especially the fundamental principles behind saw blade and tooth cutting action. Combinations of sawing characteristics indicating blade and tooth size, set, and shape, can be assimilated to determine saw class, subclass, or type. Only then will this information allow the forensic examiner to test the range of conclusions criminalists have established for tool mark analysis.

CHAPTER II

SAW DESIGN

Saws Defined

A saw by definition, is a strip of metal with teeth cut into one edge of the blade (Blackburn 1974:193; Salaman 1975:405). From a novice point of view, saws differ only in outward appearances, while all blades produce the same results since each cuts with teeth. From the forensic scientist's point of view, saw blades and teeth are more numerous and unstandardized than bullet types. Saws must be considered by their major components, size, set, shape, and power.

Saw Typology

Since it is not possible in this study to investigate all saws that potentially have forensic value, attempts were made to examine representative samples of all saws. However, saws have no universal classification. Generally, the only information about a saw that consumers are allowed to scrutinize is size (saw length and teeth per inch) and occasionally shape (rip versus crosscut).

The types of saws selected for this study were chosen on the basis of those that are most commonly used by the public. Table II-1 represents all major saw classes, subclasses, and types. Classes are sorted by saw power, subclasses are sorted by saw utility and design, and types are sorted by saw blade and tooth size, set, and shape.

History

Hand saws have been in existence for more than four millennia. The earliest saws were predisposed to bending and binding. Original saws were exclusively made of copper but this eventually changed when iron became plentiful in the 8th Century B.C. Iron allowed the saw to become a commonly used tool

Table II-1. Master classification of saws. This outline represents a classification of all major saws into classes, subclasses, and types. Classes are sorted by power, subclasses by utility and design, and types by size, shape, and set.

Saw Class, Subclass, and Type	Average* Saw Length	Average Tooth Size
I. Hand Powered (Three quality levels: standard, premium or professional) (Consumer Guide Editors 1978)		
A. Open saws		
1. Crosscut	16 to 18	PPI** 5 to 12 (7 to 9)
2. Rip	26	PPI 3-1/2 to 7 (5 to 6)
3. Backed	10 to 30	PPI 10 to 15
4. Tenon (European name)		
5. Miter box	26	
6. Dove tail/Cabinet: file type handle	10	PPI 15 to 21
7. Flooring/Inside start (Curved blade with teeth on 2 sides)	12-1/2	
B. Pruning and Log saws (includes open and frame saws)	10 to 24	
1. Pole tree trimmer/Brashing		
2. Folding pruner		
3. Double edged pruner (for tight spots or different sizes of limbs)		
4. Buck (cut both directions with chipper teeth around a raker tooth and deep gullets) (Salaman 1975: 536)	24 to 30	PPI
5. Bow	18 to 26	PPI 6 to 8
6. Scroll bow		PPI 8 to 16
C. Fine Toothed Saws and Fine Toothed Bow Saw (FTBS)		
1. Coping (FTBS) (Blade mounted to cut either direction, never sharpened)	6-1/2 to 12	TPI >10
a. Jig/Scroll		
b. Fret	6-1/2	TPI >10
c. Deep-throat		
d. Jeweler's		

Table II-1 (continued).

Saw Class, Subclass, and Type	Average* Saw Length	Average* Tooth Size
2. Hack		TPI 18 to 32
(FTBS cut on push stroke. Set: alternating, raker, and wavy)		
3. Compass/Key Hole Saws (Pistol grip, cuts in arch, tapers at the end)		
a. Compass		PPI 8 to 10
b. Key hole		PPI 10 to 14
c. Wallboard/Drywall		
d. Pad (English)	10	PPI 8
e. Panelling		
f. Mini-hack		
g. Nest (Includes many blades that fit a single handle. Power reciprocating saw manufacturers make handles to fit power saw blades.)		
D. Kitchen (butcher/Hunting) saws		
1. Chef/Meat	14	PPI 11
2. Kitchen/Hunting (specialty saws designed to cut meat and bone)		
3. Serrated knife		
E. Specialty saws		
1. Japanese saws (Noko giri) all saws cut with a pull stroke		
a. Ryoba (crosscut and rip)	6 to 16	PPI variable-6 to 20
b. Dozuki (tenon or backed)	8 to 11	TPI 18 to 28
c. Sokomawashi (compass) and Hikimawashi (keyhole)		PPI 12 to 15
d. Silky Gomboy (folding arched saw)		
e. Razor saw(American term for Japanese saws)		
E. Specialty saws (continued)		
2. Flexible saws		
a. Chain		
b. Gigli/Pocket		
c. Rod /Abrasive saw: grit edge attached to hack saw frame, flexible		
3. Medical saws		
a. Bone		
b. Metacarpal		
c. Plaster		

Table II-1 (continued).

Saw Class, Subclass, and Type	Average* Saw Length	Average* Tooth Size
II. Mechanical Powered		
A. Continuous Action Saws		
1. Circular/utility/Skilsaw: includes portable, table, bench, radial arm. (Circular saw blade types 5-1/2 to 8, 9 to 10, 12, 14 to 16.) (Portable saws usually have 5-1/2 to 7-1/4 inch blades.) (Cunningham and Holtrop 1974)		
a. Tungsten carbide and non carbide		
b. Planer: hollow ground blade with no set-blade thins from teeth to mid blade.		
c. Plywood blade: high number of teeth per inch		
d. Combination: crosscut and rip with wide set		
e. Crosscut: many small teeth with narrow set		
f. Rip: larger teeth with chisel shape		
g. Framer: very fine teeth		
h. Masonry: "fiber discs impregnated with abrasive particles" (Consumer Guide Editors 1978:63)		
2. Band saw (teeth are usually regular, skip, or hooked)		
3. Chain saws	8 to 20	
a. Crosscut and Rip		
b. Gasoline and Electric powered		
B. Reciprocating Action Saws		
1. Reciprocating/Bayonet saw (related to compass saw, stroke is commonly 3/4 to 1-1/4) (Consumer Guide Editors 1978)	3 to 12	Numerous blade types
2. Autopsy/Cast (specialty/medical)		TPI 16 to 23

* All measurements in inches and are reproduced from sources below.
** PPI refers to points per inch.

Note: This outline is the product of this author's research facilitated by numerous sources (Blackburn 1974; Blake 1991; Consumer Guide Editors 1978; Cunningham and Holtrop 1974; Drake 1975; Jackson and Day 1978; Lanz 1985; Salaman 1975; Stanley Tools, Division of the Stanley Works No Date).

Table II-1 (continued).

Sources:

Blackburn, Graham
1974 *The Illustrated Encyclopedia of Woodworking Handtools, Instruments, and Devices.* Simon and Schuster, New York, NY.

Blake, Cleland C.
1991 Personal Interview, May 26, Morristown, TN.

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1978 *The Tool Catalog: An Expert Selection of the World's Finest Tools.* By the editors of Consumer Guide. Beekman House, New York, NY

Cunningham, Beryl M. and William F. Holtrop
1974 *Woodshop Tool Maintenance.* Chas. A. Bennett Co., Inc., Peoria, IL.

Drake, George R.
1975 *The Complete Handbook of Power Tools.* Teston Publishing Company, Inc., Reston, VA.

Jackson, Albert and David Day
1978 *Tools and How to Use Them.* Alfred A. Knopf, New York, NY.

Lanz, Henry
1985 *Japanese Woodworking Tools.* Sterling Publishing Co., Inc, New York, NY.

Salaman, R. A.
1975 *Dictionary of Tools Used in the Woodworking and Allied Trades, c. 1700-1970* . Charles Scribner's Sons, New York, NY.

Stanley Tools, Division of the Stanley Works,
No Date *The Stanley Tool Guide.* New Britain, CT.

(Jackson and Day 1978:74; Salaman 1975:406). These prototypes were designed to cut on the pull stroke while the more powerful and accurate push stroke was utilized only after the advent of wood frame saws and the innovation of tooth set. This newly created form had a frame suspending and supporting a blade with teeth that were designed with an alternate lateral bending of each tooth. These blades produced a wider kerf (sawed groove), reducing binding. The frame saw appeared about the time of the Roman Empire and was not altered to any great extent until the middle 1600s. The process of rolling wide strips of metal, made it possible to manufacture "open" saws, thus reducing dependence on wood frames. English hand (carpenter) saws and backed saws, typically made of Sheffield steel, were taking their modern form by the 1700s (Salaman 1975:406; Jackson and Day 1978:74).

Variations in handsaw designs have been introduced throughout history to improve sawing performance and general appearance.

> Henry Disston, the British immigrant who was to found one of the largest handsaw firms of the 19th Century,

> designed many varieties of the open-frame handsaw. The "Skewback" was introduced in 1874 and became one of the most popular variants of this handsaw shape. In this case the back of the saw has been slightly hollowed out. This serves to lighten the saw while improving its balance, imparting at the same time a very graceful appearance (Consumer Guide Editors 1978:27).

Traditional saws appeared in the New World as imports from England, but with time this trend changed.

> Pioneers brought their own tool kits with them to the New World and early ship's manifests show a heavy importation of tools and the material with which to make them. Later, as forges and iron works were established in the colonies, men created their own tools or had it done for them by the village smith. Nineteenth Century tradesmen ordered their tools from the Sheffield catalog or traveling salesmen who carried their wares around on pack animals. By the middle 1800's, companies like Stanley Rule and Level were established in North America; industries whose output would swiftly outrun that of England. The domestic market came first, then the final success at capturing the world market [came] after the First World War (Consumer Guide Editors 1978:31).

At a time when hand saws were reaching their peak in efficiency and design, power saws were first introduced. While the earliest saw mills were driven by wind power, the first water-wheel saws begin to appear in the 13th century in Central Europe, and the early decades of the 17th century in North America. These earliest mills are the precursor to gang-saws, or the enlistment of a number of blades cutting in unison used to cut logs into boards (Henry Disston & Sons Promotion Pamphlet 1922; Peterson 1973).

> . . .Ever since the first settlement of the American colonies, the grand demand for boards, planks, rafters, etc., was supplied by another apparatus which had been doing the same work in Europe before the discovery of America, namely THE SAW MILL in which a frame saw, with one or more blades, was worked vertically up and down by a crank revolving on the end of the horizontal axle of a water wheel (Mercer 1929).

Although the date of origin of the circular saw is still debated, there are different references to this saw in the mid to late 1700s (Ball 1975). Band saws probably came into existence soon after. The advent of these new types of power saws and the value attributed to them is recognized by the rapid change in the efficiency of lumbering industries of North America in the early 1800s (Curtis 1973; Peterson 1973).

Handsaw Components

In order to understand and diagnose saw mark characteristics, it is first important to understand the saw that creates these characteristics. While there are certain standards that are followed by saw manufacturers world wide, there are also discrepancies in the basic styles of saw manufacturing.

Figure II-1 examines the basic components of a handsaw while closely comparing and contrasting two basic types of carpenter saws, the rip and crosscut. The rip saw is designed to "rip" wood with chisel shaped teeth. Crosscut saws are designed to "cut" fibers across the wood grain.

An illustration of points and teeth per inch is furnished since all saws are measured by the frequency of their teeth. There is generally one more point than tooth per inch. Cunningham and Holtrop (1974:75) classify rip saws as having three and one half to seven points per inch while crosscut saws have smaller teeth in the range of five to twelve points per inch.

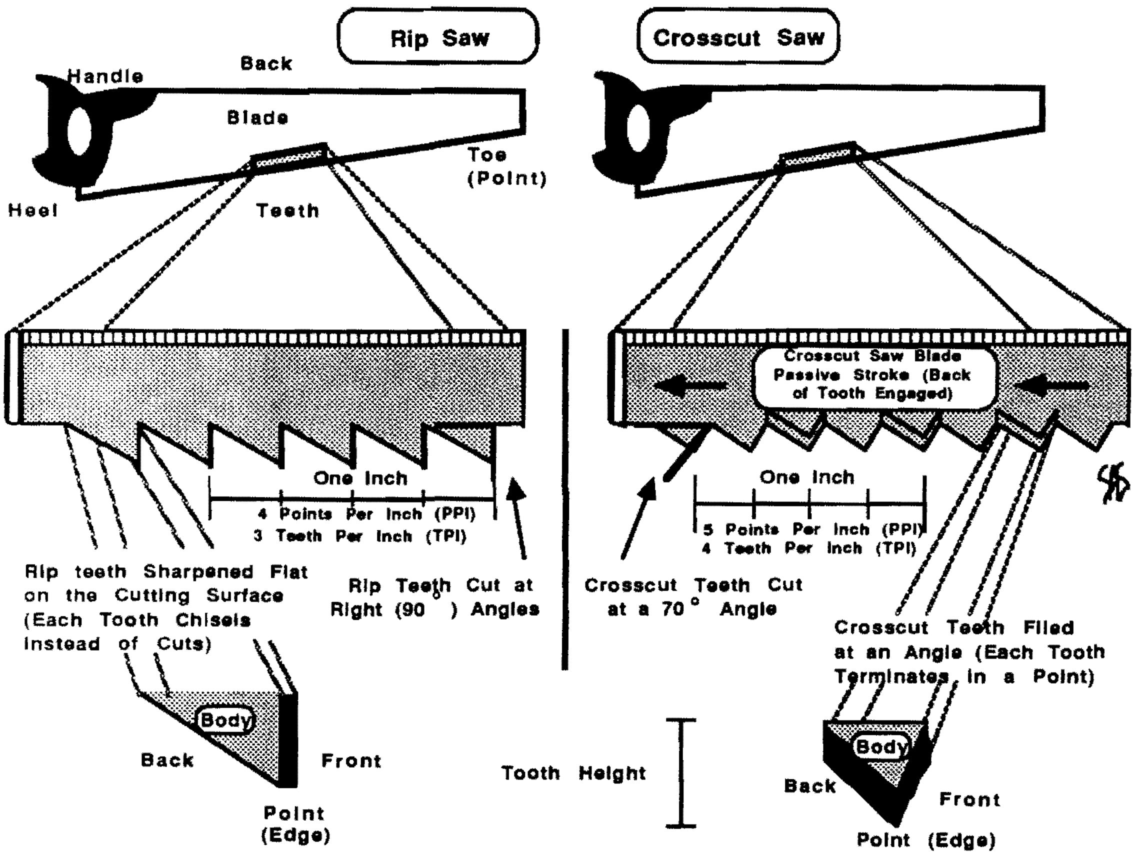


Figure II-1. Illustration of common carpenter saws, rip and crosscut. Each is displayed with blades and teeth enlarged to demonstrate the number of teeth per inch, tooth shape, sharpening angles and features of a tooth.

While all saws have teeth, there are differences in design. Teeth in most saws have a front and back. The front of the tooth is designed to do the majority of the cutting since it bites into the material. Reciprocating saws are generally designed to saw with a cutting stroke and a passive stroke. The front side of the tooth bites during the cutting stroke while the back side of the tooth slides on the passive stroke. Enlarged sections of two saw blades in Figure II-1 each have arrows indicating one of two possible directions of motion. The rip saw is shown in a forward motion exemplifying a push stroke. The push stroke is a cutting stroke, since this direction of motion engages the front edge of the teeth. The crosscut saw is shown in a backward motion, exemplifying a pull stroke. The pull stroke is the passive stroke since this direction of motion engages the back side of the teeth. Both the rip and crosscut saws are designed with the cutting stroke on the push, and the passive stroke on the pull.

Differences between crosscut and rip teeth are illustrated in Figure II-1 by (1) filing (sharpening) angle, (2) angle of bite, and (3) size. Rip saws have a flat chiseling tooth that is designed to cut along the grain of the wood, whereas crosscut saws have consecutive teeth filed at opposing angles (usually 70 degrees). This filing creates a tooth that terminates in a point and essentially takes on the shape of a sharpened blade and cuts material rather than chisels. The angle of bite to the plane of the blade is usually 90 degrees in rip and approximately 70 degrees in crosscut saws (Figure II-1). The angle formed by the front and back of the tooth is approximately the same for most saws (60 degrees). Finally, Rip saw teeth are commonly larger than those of crosscut saws. Cunningham and Holtrop (1974:75) give the largest ranges of tooth size, referencing rip and crosscut saw points per inch at 3-1/2 to 7 and 5 to 12 respectively.

CHAPTER III

METHODS

Saws Utilized

Table II-1 provides a population from which a sample of saws can be extracted for analysis. Table III-1 describes 38 saws utilized in this study. This sample only consists of those saws considered practical, affordable, or obtainable in forensic settings. All saws analyzed in this study have bone cutting capabilities although some saws perform better than others. All descriptions, photographs, and measurements are generated from the sample of saws listed in Table III-1 unless specifically noted. These saws are classified in outline form, with each type of saw described in terms of set, size and shape.

Medical saws, including surgical bone, metacarpal, Gigli, and electric autopsy saws, have been included into this study. The examination of medical saws or saws utilized for medical

Table III-1. Listing of all saws utilized in this study with information concerning set, size, and shape. All measurements are recorded to the nearest 0.01 of an inch.

	Size						Set	Shape	
Saw Class, Subclass And Type	Teeth Per Inch	Points Per Inch	Between Teeth	Blade Length	Blade Height	Blade Diameter	Type	Tooth Type	Direction Of Cut
Hand Powered									
Open saws									
"Crosscut" (standard)	6.0/7.0	7.0/8.0	0.14	26.0	5.50		Alternating	Chisel	Push
"Crosscut" (premium)	6.0	7.0	0.17	24.0	6.00		Alternating	Chisel	Push
Rip	4.5	5.5	0.22	26.0	5.50		Alternating	Chisel	Push
Backed (premium)	11.0	12.0	0.09	10.0	3.00		Alternating	Chisel	Push
Dove tail (premium)	14.0	15.0	0.07	10.0	2.00		Alternating	Chisel	Push/Pull
Pruning saws									
Arched pruner	7.0	8.0	0.14	13.0	1.50		Alternating	Cut	Pull
Arched Folding pruner	6.0	7.0	0.17	7.0	0.07		Alternating	Cut	Pull
Frame saws									
Buck (peg toothed)	4.0	5.0	0.25/0.33	21.5	0.70		Alternating	Cut	Push/Pull
Buck (lance tooth)	4.0	5.0	0.25	20.0	0.07		Raker	Cut	Push/Pull
Fine toothed bow saws (FTBS) and fine toothed open saws									
Coping (FTBS)	16.0	17.0	0.06	6.4	0.10		Alternating	Chisel	Push/Pull
Hack saws (FTBS)									
Hack	18.0	19.0	0.06	10.0	0.50		Alternating	Chisel	Push
Hack	18.0	19.0	0.06	10.0	0.50		Raker	Chisel	Push
Hack	24.0	25.0	0.04	10.0	0.50		Wavy	Chisel	Push
Hack	32.0	33.0	0.03	10.0	0.50		Wavy	Chisel	Push

Table III-1. (continued)

	Size						Set	Shape	
Saw Class, Subclass And Type	Teeth Per Inch	Points Per Inch	Between Teeth	Blade Length	Blade Height	Blade Diameter	Type	Tooth Type	Direction Of Cut
Key hole									
Key hole alternating	10.0	11.0	0.10	7.5	0.80		Alternating	Chisel	Push
Key hole wavy (FTBS)	25.0	26.0	0.04	7.0	0.70		Wavy	Chisel	Push
Wall board	6.0	7.0	0.17	6.3	0.80		Alternating	Chisel	Push
Kitchen (butcher/hunting) saws									
Chef (standard)	10.0	11.0	0.10	14.0	0.06		Alternating	Chisel	Push
Meat (premium)	10.0	11.0	0.10	14.0	0.39		Alternating	Chisel	Push
Serrated (steak) knife	8.0	9.0	0.13	5.0	0.75		None	Cut	Push/Pull
Specialty saws									
Japanese saws include:									
Ryoba crosscut (Japanese)	15.0	16.0	0.07	9.0	3.50		Alternating	Cut	Pull
Ryoba rip (Japanese)	6 to 8	7.0/9.0	0.12/0.17	9.0	3.50		Alternating	Chisel	Pull
Flexible saws (no measureable teeth) include:									
Gigli (wrapped wire)				18.0					Push/Pull
Rod (grit edge)				10.0					Push/Pull
Medical saws include:									
Bone	8.0	9.0	0.13	8.0	2.00		Alternating	Chisel	Push
Metacarpal	30.0	31.0	0.03	4.5	0.30		Alternating	Cut	Push

Table III-1. (continued)

Saw Class, Subclass And Type	Size						Set	Shape	
	Teeth Per Inch	Points Per Inch	Between Teeth	Blade Length	Blade Height	Blade Diameter	Type	Tooth Type	Direction Of Cut
Mechanical Powered									
Continuous Action									
Circular saw blades (all blades used were 7-1/4 inch diameter)									
Piranha (tungsten carbide)	0.8		2.26			7.25	Alternating	Chisel	
Framer (tungsten carbide)	0.8		2.22			7.25	None	Chisel	
Plywood blade	7.0		0.16			7.25	Alternating	Chisel	
Combination (crosscut & rip	1.8		0.56			7.25	Alternating	Chisel	
Masonry (abrasive particles	0.0		0.00			7.25			
Band saw (skip tooth) (premium)	4.0	5.0	0.25		0.60		Alternating	Chisel	
Chain saw									
Electric powered crosscut	0.7		1.50	10.0	3.10		Alternating	Cut	Pull
Reciprocating Action									
Reciprocating/bayonet saws									
Reciprocating	7.0	8.0	0.14	5.0	0.50		Alternating	Chisel	Pull
Reciprocating	10.0	11.0	0.10	5.0	0.70		Alternating	Chisel	Pull
Reciprocating	18.0	19.0	0.06	5.0	0.62		Wavy	Chisel	Pull
Autopsy (Stryker)									
Round blade	23.0	34.0	0.04			2.67	Alternating	Chisel	Push/Pull
Large sectioning blade	16.0	17.0	0.06			2.67	Alternating	Chisel	Push/Pull

purposes has obvious forensic significance. Human remains exhibiting cuts from medical saws may well turn up in a legal setting due to legal or illegal exhumations, improper disposal, theft and other unusual situations.

Human Bone Processing

All experimentation has been done on fresh human bone which most closely replicates potential legal cases and condition of cuts. Human long bone shafts were procured from the Tennessee Donor Service of Nashville, Tennessee. These bones are donated femora and tibiae shafts primarily from young to middle aged Caucasoid adults. Bone shafts are procured in a defleshed, fresh state. Each bone was immersed in a diluted bleach (sodium hypochlorite) solution at approximately 3% for 25 minutes then simmered over low heat in a solution of water and degreaser for one to two hours. This process disinfects and degreases bone and assumes that visible evidence or elastic properties of the bone are not seriously compromised.

Saws and Saw Marks on Bone

Technique

Every blade in Table III-1 was used to make 10 consecutive cuts on a bone shaft. Each saw blade utilized in this research is new and unused except for the chain saw blade which was commercially resharpened. Bones were supported on one end by a vise, and consecutive cuts from single blade made by the same individual. Each cut was accompanied by two false starts. False starts serve as indicators of the initial cut, while specifics of direction of the cutting stroke, passive stroke, order of consecutive cuts, and location of initial cuts were inscribed on bone.

The cutting and cleaning process is designed to deviate as little as possible from natural taphonomic processes. After the cuts were made, each specimen was again simmered in water and degreaser. Cut surfaces were lightly scrubbed with a soft bristled brush to facilitate close examination of the bone without oils and dust obstructing features. This process closely simulates typical cleaning practices applied to specimens by forensic examiners.

All cuts were produced consecutively for each blade in initial stages of this study. Saw marks on bone were examined for diagnostic features only after experimental cuts were completed. In no instance were cuts made in bone in attempts to replicate or create characteristics. Saw marks in chalk and bone were occasionally attempted during initial experimentation or for illustrative purposes but were not used for data collection.

Cut Bone Examination

Examination of all saw marks was performed on cleaned bone using a *Wild Heerbrugs* model operating microscope magnifying at powers 6, 10, 16, 25, and 40. A *Nikon* MKII fiber optic light source provided angled lighting to enhance features.

Photography of saws and cuts were taken with two Canon T70 35 millimeter cameras focused through the operating scope. All bone cross sections illustrated in this study are oriented with the initial cut at the top and terminal cuts at the bottom of the picture. All scales in photographs represent 0.1 or 0.01 of an inch. Measurements were taken by *Starrett* metal rules accurate to 0.01 of an inch, and an *American Optical* stage micrometer accurate to 0.001 of an inch. Measurements were taken at 25 or 40 power magnification and rounded to 0.01 of an inch. All drawings and tables were computer generated by the author.

Saws and saw marks were measured for size and assessed for set and shape. Size includes blade and tooth dimensions, tooth spacing, set width and minimum and maximum kerf (groove or trough cut by the action of saw teeth) widths. Set width measurements were obtained by placing two metal straight edges along each outer limit of the teeth points (edge). The distance between straight edges is considered the set width. The exception to this involves the subclass of circular saws, where no accurate means of measuring the set of these large teeth on a curved axis was attempted.

Residual Characteristics

Saw cuts or attempted saw cuts on bone create standard cuts and characteristics of cuts that will be referred to in this research. There are basically three types of cuts to bone, the false start cut, where the saw teeth have established a kerf or definable cut in the bone, but have not cut completely through the bone. This is not to be confused with false start scratches where saw teeth cut or chisel the bone but do not establish a definable kerf, where the total blade width is reflected in the defect on the bone. A second type is a snapped false start cut. This is a deep false start in bone that has had leverage applied to the bone resulting in a fractured bone. This pressure is assumed to be greater than force applied by the typical act of sawing alone. The final type of cut in bone is a completely sectioned bone. This type of cut bone will still have a residual kerf floor in the form of a break away spur. Opposite the break away spur is a section of the bone which has the corresponding break away notch. Keep in mind that reconstruction of completely sectioned bone recreates the kerf.

As a cut initially strikes a bone and forms a kerf, the two corners formed in bone are called initial corners of the kerf (Figure III-1). These corners develop into kerf walls and the kerf floor as the cut progresses. The area where the walls meet the floor is called the kerf floor corners. Completely sectioned bones have the same features with a break away notch and break away spur replacing the floor.

Saw mark analysis basically must examine two areas of a cut bone, the walls and the floor of the kerf. The floor is expressed in all false starts, and partially expressed in break away spurs, therefore kerf floors, when present, offer the most information about the points of each tooth and the relation of the points of the blade. Break away spurs offer less reliable information than false start kerfs, but occur more commonly than false starts. Kerf walls offer information about the sides of the teeth. Wall striae often represent only those teeth set to one side.

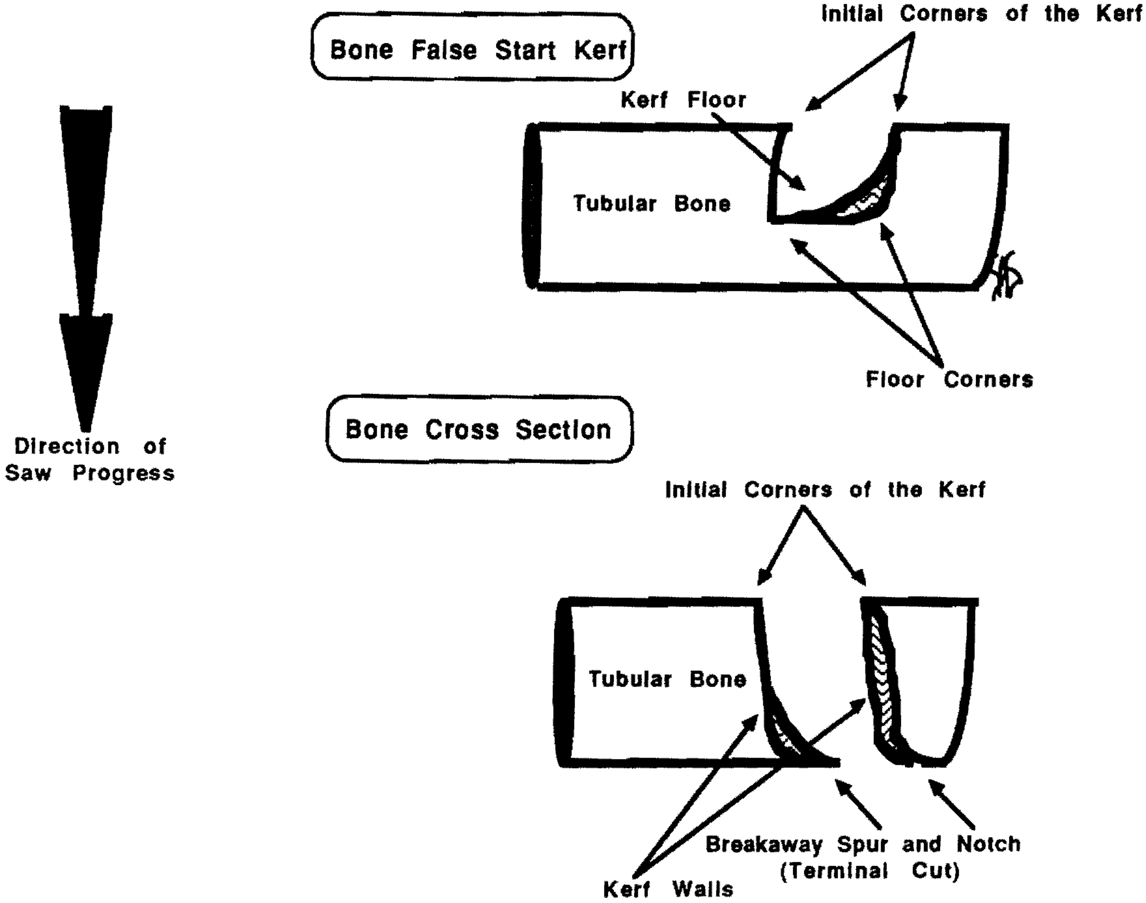


Figure III-1. Illustration of sawed tubular bone labeling the basic components of a false start and cross sectioned bone.

CHAPTER IV

PRINCIPLES OF CUTTING ACTION

Introduction

To understand the residual characteristics of saw cuts, it is necessary to examine saw blade action. This action includes the individual knife or chisel tooth that slices or shaves through the material, as well as actions of banks of teeth working in unison as a blade. The act of sawing is essentially pushing, pulling or rotating these teeth 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. Since saw teeth do the cutting, actions of each tooth and combinations of teeth on a blade, will be examined. Saw actions will be examined in terms of size, set, shape, and power.

Blade and Tooth Size

Blade and tooth size is another important factor in the design of the saw. Tooth size is universally classified by the number of teeth per inch represented on a blade. This is represented in two ways, points per inch (PPI) or teeth per inch (TPI). The number of points per inch generally being one greater than the number of teeth per inch (see Figure II-1). Fine toothed bow saws are classified by TPI while larger toothed saws are classified by PPI (Jackson and Day 1978:74). It is important to note here that quantifiable characteristics of saw cuts to be considered below most easily reflect the number of teeth per inch as opposed to points per inch. All reference to the size of teeth will universally be in terms of TPI. Circular saw blades are generally classified by blade diameter and number of teeth per blade.

More teeth per inch increases the smoothness of cutting characteristics while slowing the speed of cut. Fewer, larger teeth are designed to efficiently saw softer materials. A wide alternating set with narrow width teeth is common in larger toothed saws. If this combination produces a cut that is similar in width to two teeth side by side, islands of uncut material may be evident 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.

Three saws in this study are not classified by teeth or points per inch. These include the power circular masonry blade and the flexible saws, Gigli and rod. These blades do not have teeth cut out of a blade like other saws, rather the teeth are formed by grit impregnated blades, or by wrapped wire. While each has teeth that are negligeable for size or shape, these blades still fit the definition of a saw by having "teeth."

Blade and Tooth Set

Even though the above definition of a saw implies nothing of set, the altering of teeth to reduce binding is an integral and age tested part of saw design that has existed for 2000 years. While set is essential to the effectiveness of most saws, set is not required. Only four saws in this study have no definable set, the serrated knife, the metacarpal saw, and both flexible saws, rod and Gigli.

Lateral bending of the top half of saw teeth (or blade) to create a kerf wider than the blade of the saw allows the back of the saw to follow the teeth without binding. Teeth are generally set according to their size. The amount of tooth set is generally between 0.003 to 0.005 of an inch with saws that fall into 4 to 16 points per 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. The ranker the set, the more lateral bending of the teeth, and the wider the kerf. A ranker set is defined as more bending of the tooth and is designed for softer material (Salaman 1975:405).

Alternating Set

There are certain actions that all alternating set blades follow, even though alternating set applies to many shapes and sizes of teeth. In order to understand this motion, it is important to first examine the actions of a single tooth, then combine this with actions of consecutive teeth. Saw teeth are set so that the cut produced is wider than the saw blade. As a set single tooth first enters the material, the tooth seeks an orientation parallel to the direction of the blade and midline in the material. This midline orientation is compromised as the next tooth enters the material. The second tooth is alternately set and therefore enters the material from a position opposite the previous tooth and seeks a different midline from the original tooth, actually attempting to cross the path left by the original tooth. This pull to the midline by the latter tooth sends the initial tooth in a direction parallel to the second tooth until a compromise is reached. This parallel drift is reversed every time a new tooth enters the material, with new teeth essentially entering the same two patterns by approximately the same grooves. Thus a very predictable pattern is established since there are essentially two rows of teeth set in an alternating pattern. This pattern of teeth drifting across the kerf floor is defined here as tooth drift. Once the blade is immersed in the material, most drift is suppressed. Drift pattern is 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.

Raker Set

The introduction of a different design in the cutting edge of a saw creates a more complicated picture of residual kerfs. These complications in the raker set occur for two reasons. First of all, as the term implies, rakers are specialized teeth designed to rake sawdust or imperfections from the kerf floor rather than consistently cut or chisel, so they are essentially cleaning up after the other teeth and modifying the kerf. The second reason rakers complicate saw striation examination is that rakers are not placed symmetrically between every tooth. Rakers appear in series to teeth, most commonly every third, fourth, or fifth tooth.

This design alters kerf floor shape, 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 by the teeth. Rakers are generally shorter than the regular teeth since they are designed to rake and clean the kerf. Jackson and Day (1978:77) describe the lance tooth set that has 4 teeth bordered by rakers with a large gullet on each side of the raker. This set is designed for cutting unseasoned wood. Variations of this set are found in common hand pruning saws.

Fine toothed bow saws are designed to cut through harder materials, and rakers are designed to smooth the kerf floor and clear the debris from these cuts. FTBS rakers are identical to the other teeth, only they have no lateral bending (set).

Raker teeth inhibit the side to side movement of the blade, referred to here as tooth drift. The raker tooth enters the material on its central path since it is not set to one side. The raker chiseling midline inhibits the set teeth from diverting into their side to side movement, especially in FTBS. It is also conceivable that saw blades with shortened raker teeth (like pruning saws) could be diverted from their central path by falling into a deeper groove created by a previous alternating tooth, therefore creating a unique kerf floor or an unsymmetrical floor contour. Keep in mind that rakers in pruning saws generally occur at the rate of one out of five teeth or less and they are shorter than the cutting or chipping teeth. With this design, raker influence on blade drift is likely minimal.

Wavy Set

While the wavy set is quite unique to the other types of set, it still cuts on the same principle as alternating set blades. These blades generally have very small teeth which would make setting each tooth difficult. Rather than set each tooth, groups of teeth, blade and all, are alternately bent side to side. The blade forms a wavy pattern when examined on edge. Each wave functions like a single tooth comprised of many smaller teeth.

Blade and Tooth Shape

Saws are further described by their shape. Shape applies to the contour of the blade, the tooth as it is cut out of the saw blade, and the angle in which teeth are filed. The most common classification of saws in terms of tooth shape is the rip and crosscut saw, as was discussed in the introduction and illustrated in Figure II-1. 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. 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, Lance

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 trail off on the back side of the tooth, forming a gullet angle of about 60 degrees with the front of the next tooth. This 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 filed teeth.

Crosscut saws, as the name implies, are designed for cutting across the grain of wood. Crosscut teeth are smaller and bite less material with teeth 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 like rip teeth (Figure II-1). Crosscut teeth are filed on the cutting edge at about a 60 to 75 degree angle making the front of each tooth a knife edge right down to a needle point, rather than a chisel (Jackson and Day 1978:76). Each tooth progresses through wood fibers with a sharp edge, slicing wood rather than chiseling blocks of wood (Figure II-1).

As mentioned above, there are variations in tooth raker angles, rip saws have a near 90 degree bite while the crosscut generally has a tooth biting at 60 to 75 degrees. One other variation that is common is the peg toothed design where the tooth is sloped at 45 degrees. This means that the gullet angle must also be 45 degrees or simply, the tooth is designed to bite identically in either direction. This design is termed "push/pull" in Table III-1.

Different shaped teeth are sometimes placed on the same blade to enhance a particular type of cut. For example, many pruning saws have raker teeth inserted into a bank of crosscut teeth. Since this saw is designed to cut quickly through soft wood logs, the teeth and gullets are large to accommodate the sawdust. Raker teeth rake the kerf while crosscut teeth cut. Raker teeth in large saws are generally rip filed and shorter so they chisel only the high points of the kerf floor while the crosscut teeth are cutting.

Tooth shape also determines whether a saw is cutting on the push or pull stroke (Figure II-1). This cutting stroke can occur on the push or pull stroke, depending on the blade and tooth shape. Worldwide, the typical hand saw uses the more powerful push stroke, similar to those illustrated in Figure II-1. Continuous cutting (not reciprocating) power saws have teeth designed to cut only on the front side of the tooth.

The major exception to the push designed saw is the Japanese pull saw. The Japanese have retained and perfected designs of pull saws to the point of producing a saw quite different than Western saws. Because of the force being exerted on the pull, tension can be maintained even on very thin blades. This design is similar to a pull stroke frame saw without the frame. Japanese saws utilize a more hardened metal (Rockwell Hardness Rc 54) than their Western counterparts since they do not need to be ductile on the push stroke. Thus, these saws are more brittle and likely to break teeth or blades rather than bend. The narrower blade with minimal set of hardened teeth creates a narrower kerf and therefore the pull saw wastes less wood and demands less effort for the same job (Lanz 1985:13-17).

Other exceptions to push stroke saws are some pruning saws (it is easier to pull than push when in awkward positions), buck saws (may have a push and pull stroke for a person on each end of the saw), and power reciprocating saw blades (cuts on the pull stroke to avoid binding during high speed reciprocating motions). Flexible saws generally cut in either direction.

Chain saws represent another type of tooth shape design. Chain saws are designed to cut soft material at high speeds. When cutting hard material like bone, these saws create wavy edged walls as the blade moves at high speeds but the teeth bite very little. This action appears to "melt" through the bone.

Saw blade shape or the shape of the delivery of the teeth is also an identifying feature of saws. While most blades are designed to propel teeth in a straight line, some saw blades are arched or flexible. How teeth are introduced into the material may influence residual characteristics by leaving striae resembling blade shape.

Saw Power

There are obvious differences in how a saw is powered. Through most of the history of saws, power has been supplied physically by the person or persons using the saw. Human power varies in speed and strength, as well as handedness and skill. Mechanically powered saws refer mainly to gas, electric motor, or pneumatic powered tools that all but eliminate human variation from the sawed byproduct, while adding speed and uniformity. These saws are designed to be reciprocating or continuous cutting and may be supported by a frame or hand held. In the forensic setting, powered saws are more common than in the past due to mass production of lower quality and lower priced power saws for use in the home.

Differences occur in the design of saws that are mechanically powered as opposed to hand powered. The power source has a great influence on the saw and the sawed by-product. Principles of sawing rely on blade and tooth design and manner in which energy is transferred to the blade and material. Increased speed and torque of power saws dictate their tooth design. High cutting speed combined with potential pressures applied by the operator requires a design of short and wide teeth. Therefore power saws commonly cut faster but waste more material.

CHAPTER V

RESIDUAL CHARACTERISTICS ON SAWED BONE

Introduction

Up to this point, saws have been described in terms of design and construction. These basic designs were then examined for their sawing potential and blade action. With these premises it is now possible to work in reverse. Characteristics on cut bone will now be examined in an attempt to diagnose features as the product of specific blade actions. Preferably, these will indicate saw characteristics such as saw size, set, shape and power. The goal of this research is to use these class characteristics on cut bone to narrow the range of saws that could have possibly been used to make the cut. An ultimate goal would be to match saw mark characteristics with a specific class, subclass, or type of saw. Saw cut characteristics are arranged by observable or quantifiable characteristics found on the two major areas of a cut, false starts and break away spurs (kerf floor), or cross sections of cut bone (kerf walls).

Observable Features: False Starts and Break Away Spurs

The value of false starts in sawed bone analysis is immediate. While false starts do not always exist, the presence of a kerf is analogous to a completely sectioned bone reconstructed. The false start kerf diagramed in Figure III-1 is composed of two initial corners, two walls, two floor corners, and a floor. While these features may not instantly appear to reflect saw blade design, it is important to recognize that they are indicative of the total cutting mechanism of a saw.

This concept is best understood by comparing the signature of a knife and a saw used on bone. Knives cut grooves that mimic dimensions of a blade's cutting edge. A saw is simply a set of miniature knife blades called teeth. This simplified picture is somewhat more complex when these teeth are bent laterally, or set. Kerfs reflect tooth actions rather than the dimensions of a single tooth. This can be visualized by comparing kerf cross sections to the edge of a saw examined from heel to toe. A saw kerf does not reflect the image of a single tooth, like a groove carved by a knife blade, rather, saw kerfs reflect the combined cutting actions of blade teeth.

False start kerf examination can be approached in two ways. The first technique is to examine cuts on end. This allows you to view down the cut and examine profiles of walls and floors. A second method is to examine initial cuts with the floor as the primary surface of interest. These techniques examine even the most superficial cuts in a standardized manner allowing comparisons and classifications.

False start analysis techniques also apply to break away spurs and reconstructed bone cuts, although they generally contribute less information since a spur is created by the action of a blade sliding out of the material as it breaks. This type of exit may alter or disguise cutting characteristics of kerf floors.

Kerf Cross Section Shape

Cross sections of kerfs are placed into four major classifications, A, B, C and D. Each classification is illustrated with common variants of this class. Each variant is illustrated in Figure V-1, and represents common variation that may occur, but is not exclusively representative.

Class A represents a narrow kerf with a rounded floor corner or corners. Class A is illustrated with eleven common variants (Figure V-1). This is associated with narrow blades and small teeth. The presence of a Class A kerf cross section represents two basic types of saws, fine toothed bow saws (FTBS) and serrated edge knives.

In general, fine toothed bow and open saws create cross sections similar to larger saws; major exceptions to this rule are the common occurrence of a single or double rounded kerf floor corner. This appears to be related to the small size of the teeth and blade drift of a fine toothed saw. Rounding occurs when blades or teeth drift away from one corner while chiseling out

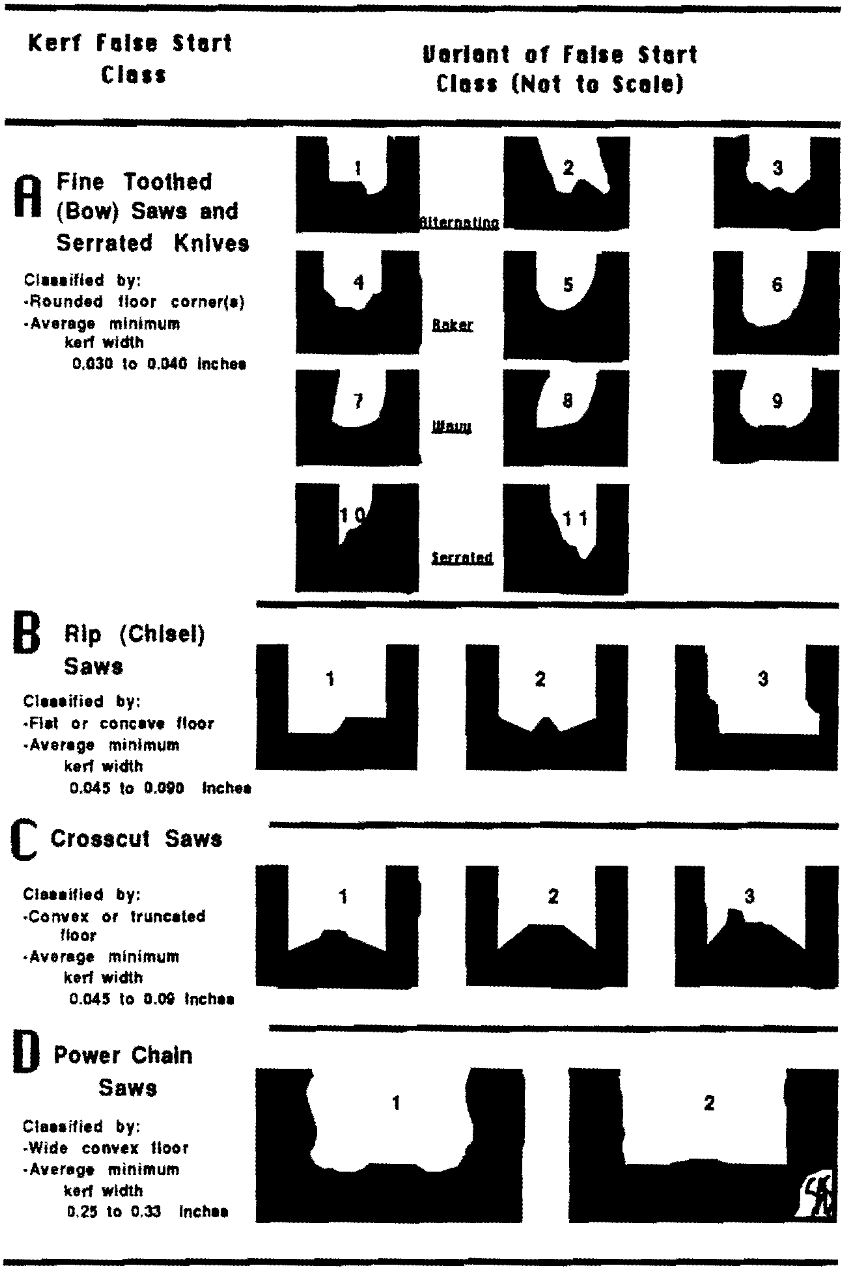


Figure V-1. Four major classes of kerf cross section shape. Classes include fine toothed bow saws and serrated knives, rip saws, crosscut saws, and power chain saws. Each class is accompanied by common variants of each class. Variants are not exclusive or to scale.

the other. This is why it is common to see a square corner paired with a round corner. Serrated knives (also classified as a saw due to the presence of teeth), produce narrow kerfs with rounded floor corners. Since there is no set to the teeth, cross sections of the kerf are a reflection of knife blade edge. Class A variants 1 through 3 illustrate chiseling teeth with no rakers (alternating set). These variants indicate fine toothed bow saws rather than all larger toothed chisel saws since they are narrower and generally have one rounded corner. Variant 1 is typical of a kerf exhibiting asymmetrical sets of the teeth. Figure V-2 illustrates a Class A, alternating kerf cross section.

Raker variants 4 through 6 are discretely different than the alternating set in that the walls are very straight, there are no bone islands, and the kerf floor has a noticeable slope or concavity (Figure V-3).

This is indicative of a blade with no blade drift and teeth chiseling out the floor midline. This pattern describes a fine toothed bow saw with a raker set where every third tooth rakes

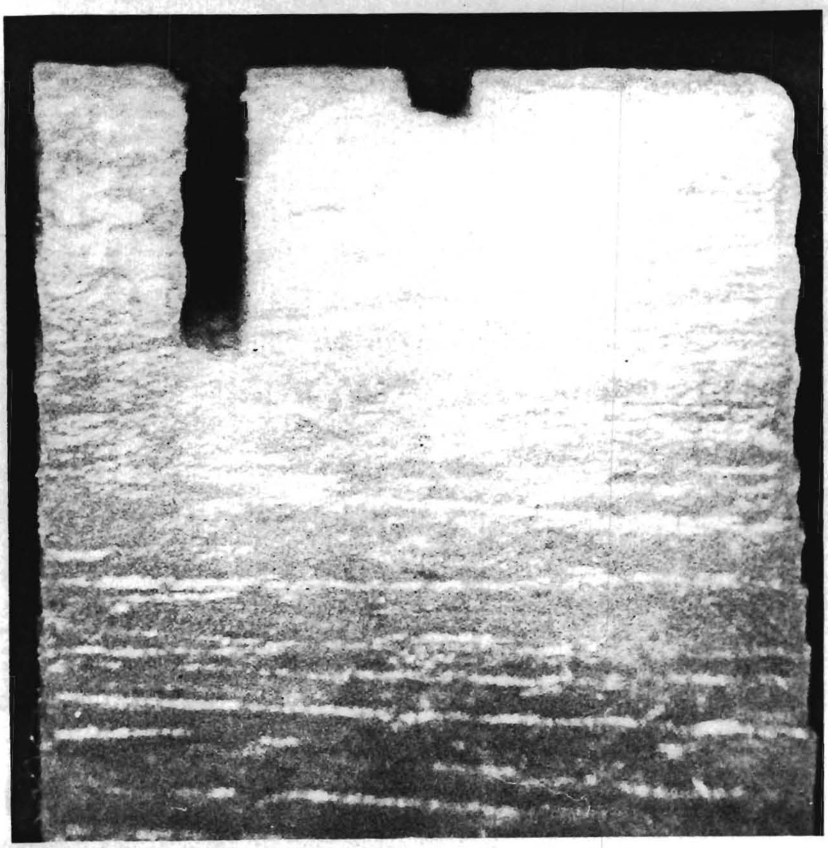


Figure V-2. Photograph of a rather straight walled and flat floored kerf formed by an alternating set hacksaw (18 teeth per inch).

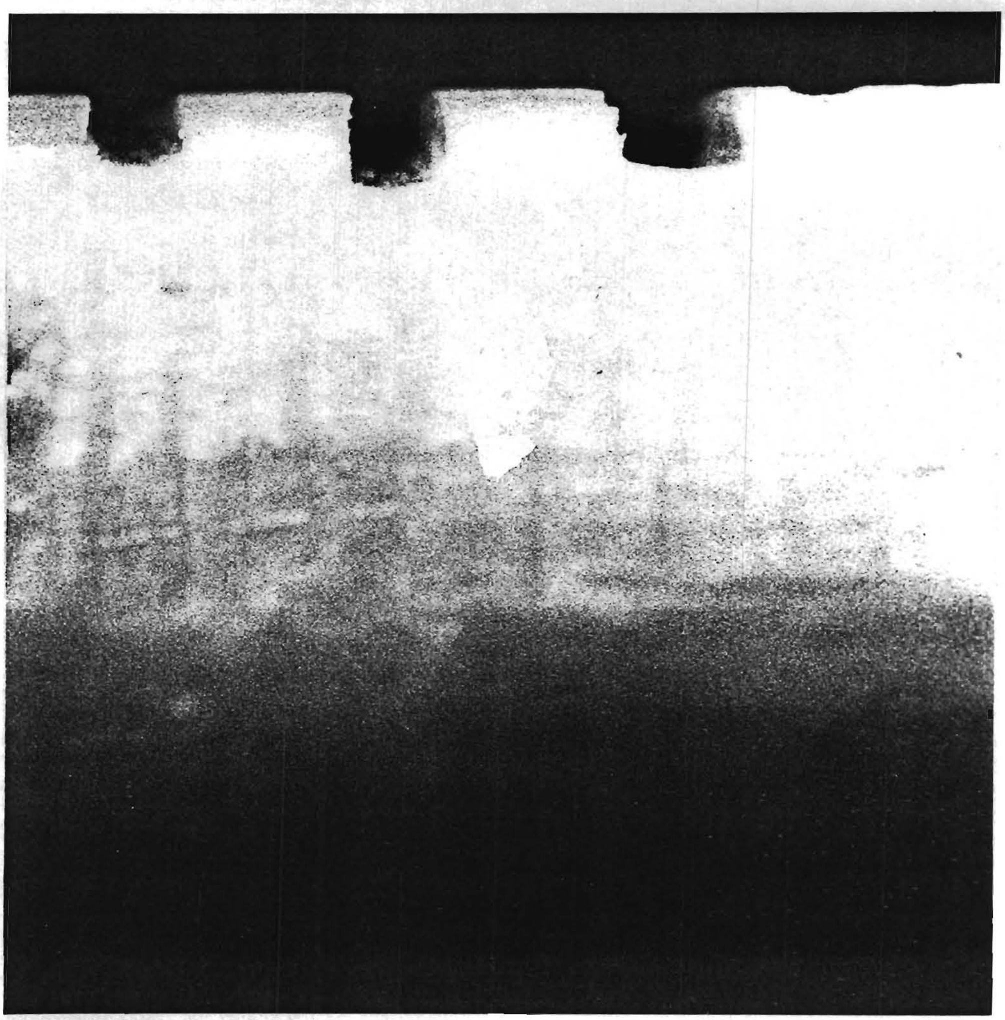


Figure V-3. Photograph of a straight walled and concave floored kerf formed by a raker set hacksaw (18 teeth per inch).

the bottom of the kerf. Keep in mind that a fine toothed bow saw raker tooth is identical in shape to other teeth in the blade and therefore it forms the deepest cut since the other teeth are deviated out of midline. Uniformly set blades create smooth and rounded floors similar to variants 5 and 6. Nonuniformity of set, usually associated with cheaper grades of hack saw blades, creates a variant 4 type of stepped or multiple cornered kerf floor that is often not symmetrical.

Walls of variants 7 through 9 do not appear straight or parallel. They seem to expand as they form their initial kerf corners. Adding to this non-symmetrical appearance is the tendency for these walls to meander producing cross sections with walls that are somewhat uneven. Floors of wavy set blades are very flat in appearance to the unaided eye but actually exhibit gradual rounding (concavity). Kerf cross sections with bending or ballooning walls and slightly rounded floors, are indicative of wavy set fine toothed saw blades (Figure V-4 and V-5).

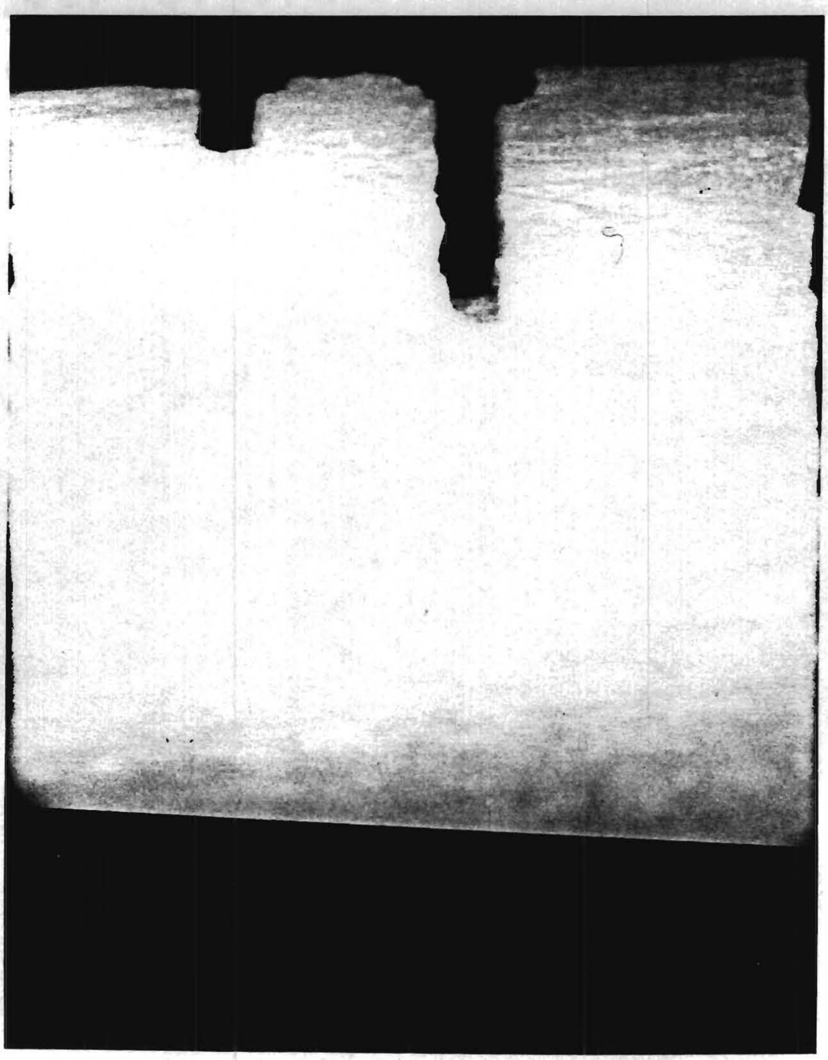


Figure V-4. Photograph of a kerf formed by a wavy set hack saw (24 teeth per inch). Note the wavy walls that appear to expand or bend as the kerf ascends into the bone, and a floor with gradual bending (concavity).

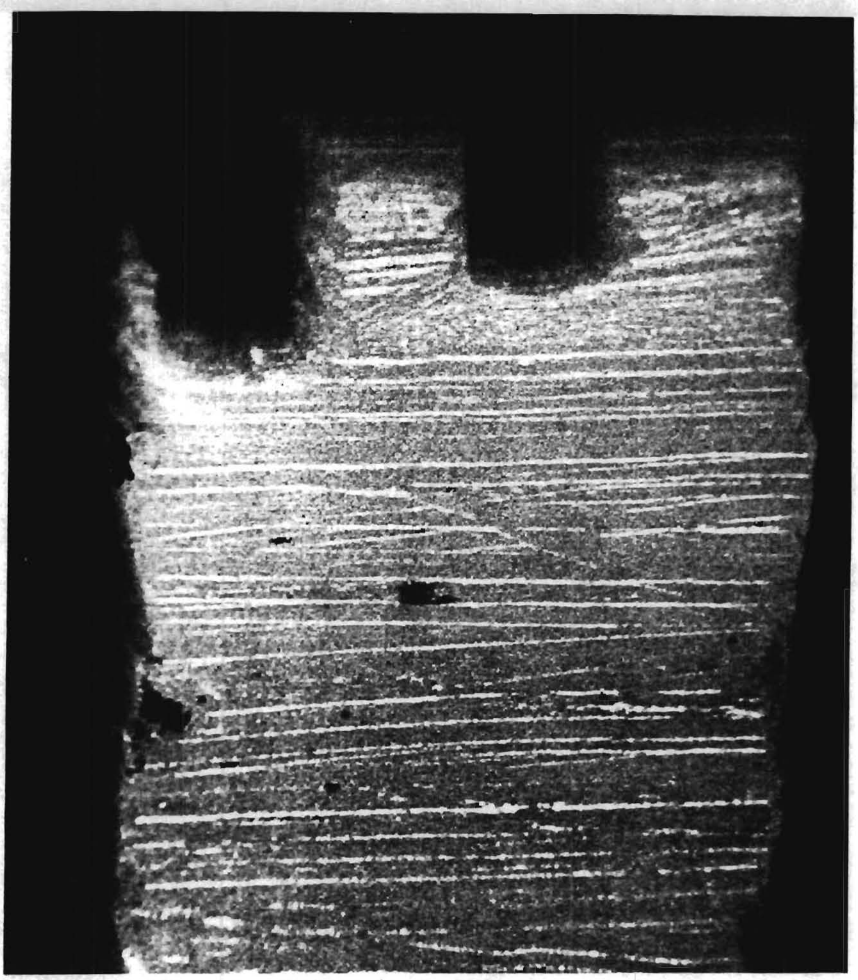


Figure V-5. Photograph of a kerf formed by a wavy set keyhole saw (25 teeth per inch). Notice that the walls appear to expand as the kerf ascends into the bone, and a floor with gradual bending (concavity).

Serrated knives also produce a narrow kerf with a rounded floor corner, and therefore have been included in Class A under variants 10 and 11. Serrated knives generally have one straight kerf wall, while the other has a rounded, accentuated (almost shouldered) floor corner. There are numerous variations in design of serrated blades. Tapering can occur on one (variant 10) or both sides of the cutting edge (variant 11) and can extend variable distances up the blade, but kerf cross sections of serrated blades reliably reflect blade size since there is no set to the teeth.

Class B kerf cross sections are the result of larger teeth with enough set to potentially create islands of bone (variant 2) and a chiseling form that may create a floor that is flat (attributed to identical overlapping teeth), stepped (due to non-identical teeth), or concave in the midline (attributed to teeth bent laterally; this may involve the formation of a bone island). Walls are generally straight or stepped. This class is indicative of non-raker chisel saws, where hand saws usually resemble variants 1 or 2. Many power saws, such as circular saws, produce variant 3.

Class C differs from B mainly in the convex shape of the kerf floor (Figure V-6). This shape indicates angled filing of teeth which is characteristic of crosscut saws. These kerfs always have a convex floor, and therefore create a need for specialty (raker) teeth. Specialized teeth are indicated by truncated kerf floors, as in variant 2. Since raker teeth are generally designed to clear kerfs of soft wood, they may not function properly in hard material and therefore may produce asymmetrical truncations as illustrated in variant 3.

Class D is unique in size and undulating wall shape and the by-product of unique teeth. Figure V-1, variant 1 illustrates the "melting" appearance of a crosscut chain cut in bone (see Figure V-7). Also depicted here is variant 2, the kerf created by rip chain saws. While rip chain saws are not a common household saw and therefore not formally examined for this study, it does appear to create a tidy kerf as compared to crosscut chain saws. For this reason variant 2 was included in this Figure V-1 to show that chain saws can create a kerf similar in width, but with

Figure V-6. Photograph of a kerf created by a ryoba Japanese crosscut pull saw (16 points per inch). Notice the convexity of the floor created by saw teeth filed at an angle.straight edges and nearly square floor corners. There is still a slight arch (convex) to the kerf floor.

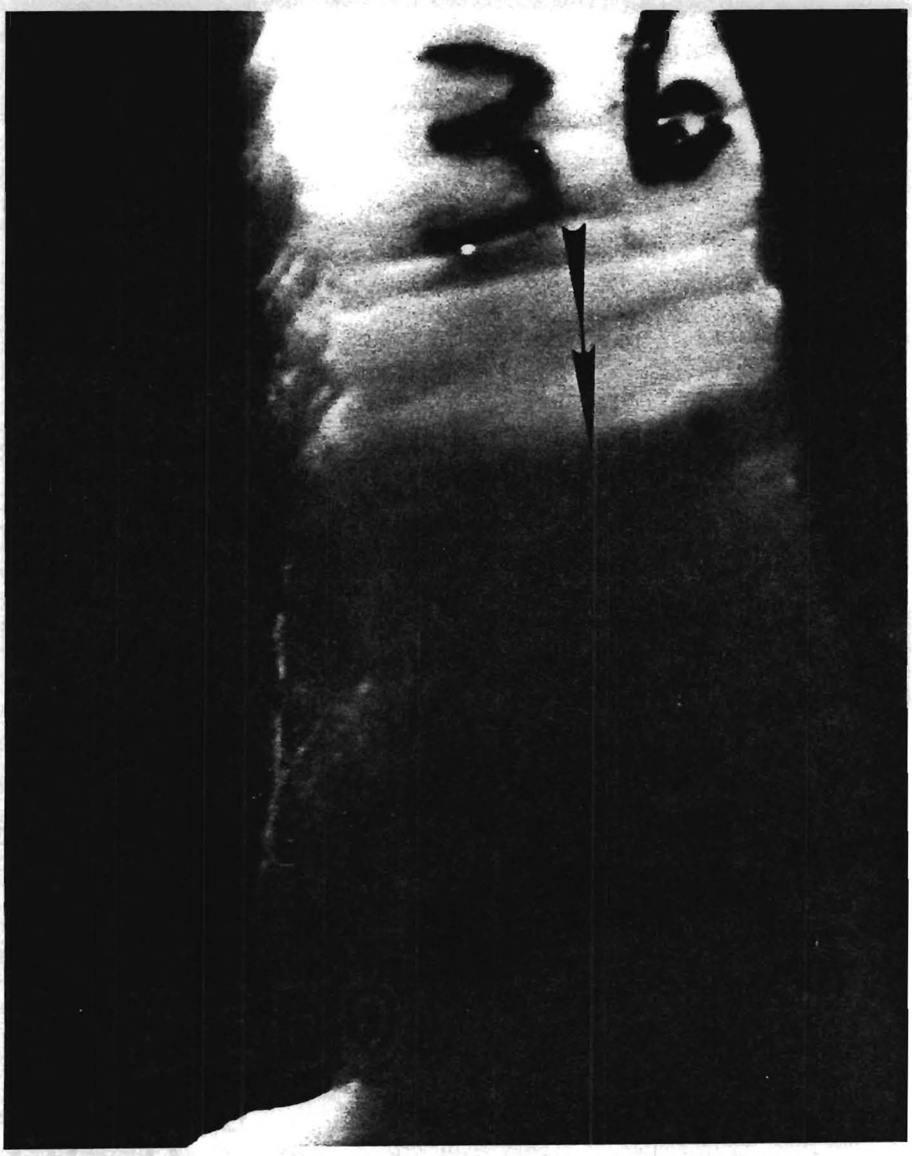


Figure V-7. Photograph of a kerf created by a crosscut power chainsaw (10 inch). Notice the "melting walls" and the wide, slightly convex floor.

straighter edges and nearly square floor corners. There is still a light arch (convex) to the kerf floor.

Fine Toothed Bow Saw Kerf Floor Characteristics

The second aspect of examining false starts concentrates on differences in floor striae of differently set blades. Andahl (1978) discusses differences of floor striae with different set saws but does not consider how the mechanisms of blade drift affect blade and tooth cutting characteristics.

This method does little to separate subtypes of saws with alternating set and chiseling teeth, two characteristics that apply to most household and professional saws. However, identification of alternating set teeth is important when considering fine toothed bow saws since this type of set appears to be no more common than raker and wavy set saw blades.

Excluding differences in set, these saws are designed similarly in that all have small teeth and are often designed for materials other than wood. Teeth per inch commonly lie within 18 to 32 and tooth width ranges in studied saws range from 0.02

to 0.03 of an inch. Differences in set for this subclass of saws can be identified using floor striae.

Primary set differences in fine toothed bow saws are illustrated in Figure V-8. Alternating set has each consecutive tooth bent alternately. Raker set has the same pattern, but with the addition of a raker (identical tooth with no set) placed every third tooth. Wavy set is simply a bend in the blade instead of the tooth, so groups of teeth bend alternately from side to side.

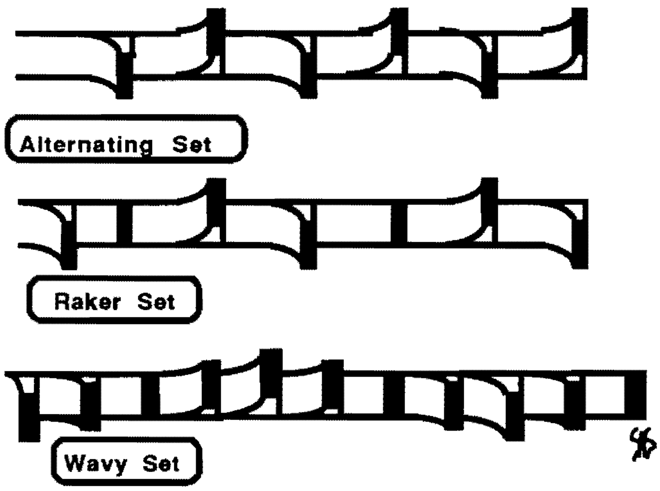


Figure V-8. Points up images of three types of set for fine bow saws, each enlarged.

Fine toothed bow saws receive exceptional consideration in this study because they are generally inexpensive, readily available, simple to use, and designed to cut through most materials. This research assumes that fine toothed bow saws are one of the most frequently found saws in average households, and therefore are likely candidates of forensic scrutiny. Fine toothed saws studied in this project include four kinds of hack saw blades, a coping saw and a fine toothed key hole saw. The key hole saw is not a bow saw by design but the blade itself is constructed similar to FTBS so this study is actually examining kerf floor characteristics of fine toothed bow and open saws. Kerf floor characteristics are most easily observed when viewing a shallow false start from above with tangential light.

Figure V-9 displays three drawings of kerf floors A, B, and C, as seen by observing false starts in bone from initial cuts of fine toothed saws. Floor A is characteristic of a kerf with bending walls and sharp floor striae. These striae appear to represent

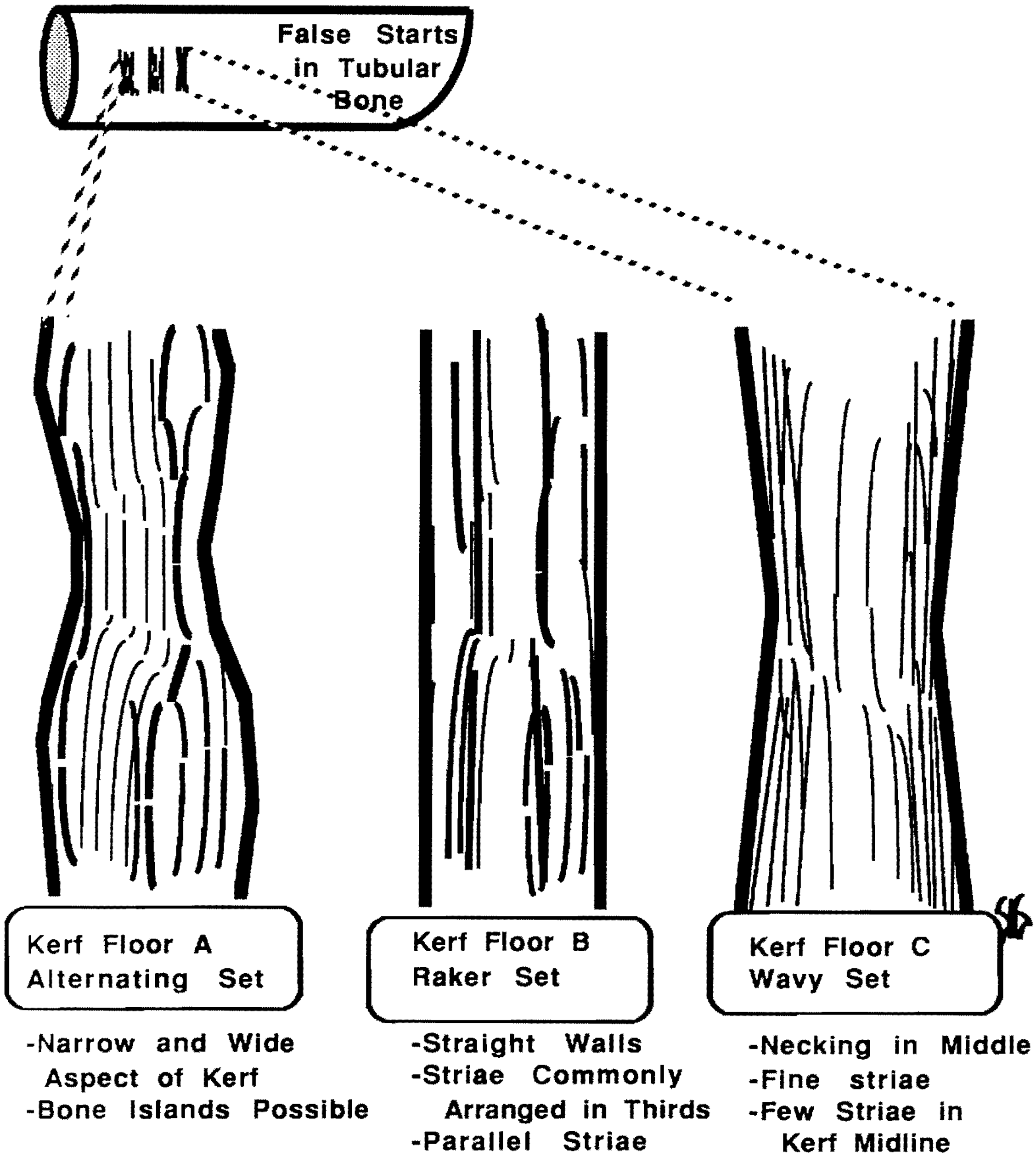


Figure V-9. Three false start floors from fine toothed bow saws. These represent alternating, raker, and wavy sets. Major unique characteristics are listed below each figure.

images of a single tooth at the narrow aspect, and two teeth side by side at the wide aspect (Figure V-9, Kerf Floor A). Bone islands can be present with this type of pattern. Striae curve repeatedly in a regular formation to create this wide to narrow undulating pattern (Figure V-10). This floor is indicative of alternating set teeth that combine to create blade action. Figure V-9, Kerf Floor A is not only characteristic of alternating set fine toothed bow saws, it is also characteristic of most hand powered chisel toothed saws available today.

Floor B is characterized by sharp striae and extremely straight walls (Figure V-11). Striae are commonly oriented in thirds (three teeth wide). There is overlap of consecutive teeth but a majority of striae are still oriented to either side of kerf midline. This orientation can be appreciated by examining teeth of a raker blade. Figure V-12 is a photograph of a new 18 teeth per inch hack saw blade (top blade) used to make a single cut on a bone. This blade retains its original painted appearance in all areas except where the tooth has encountered the most friction

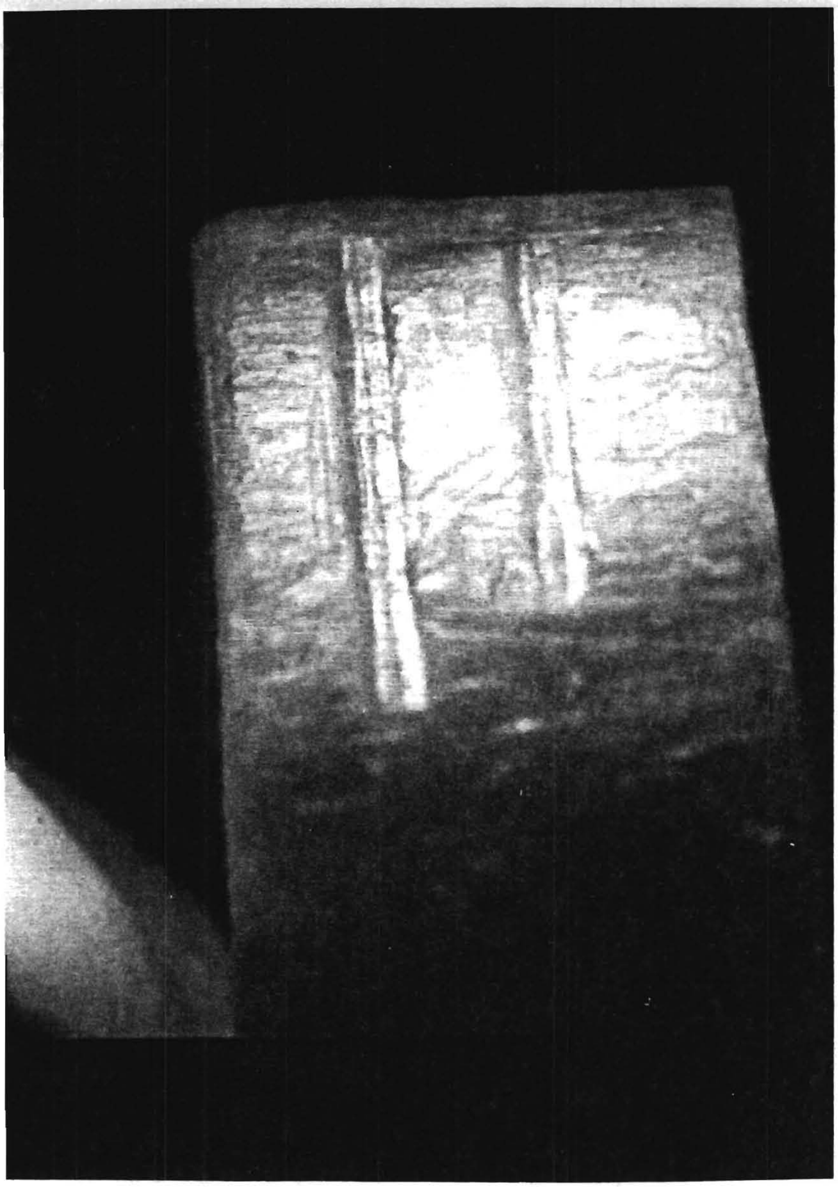


Figure V-10. Photograph of a false start produced by an alternating set hacksaw (18 teeth per inch), illustrating blade drift and bone islands.

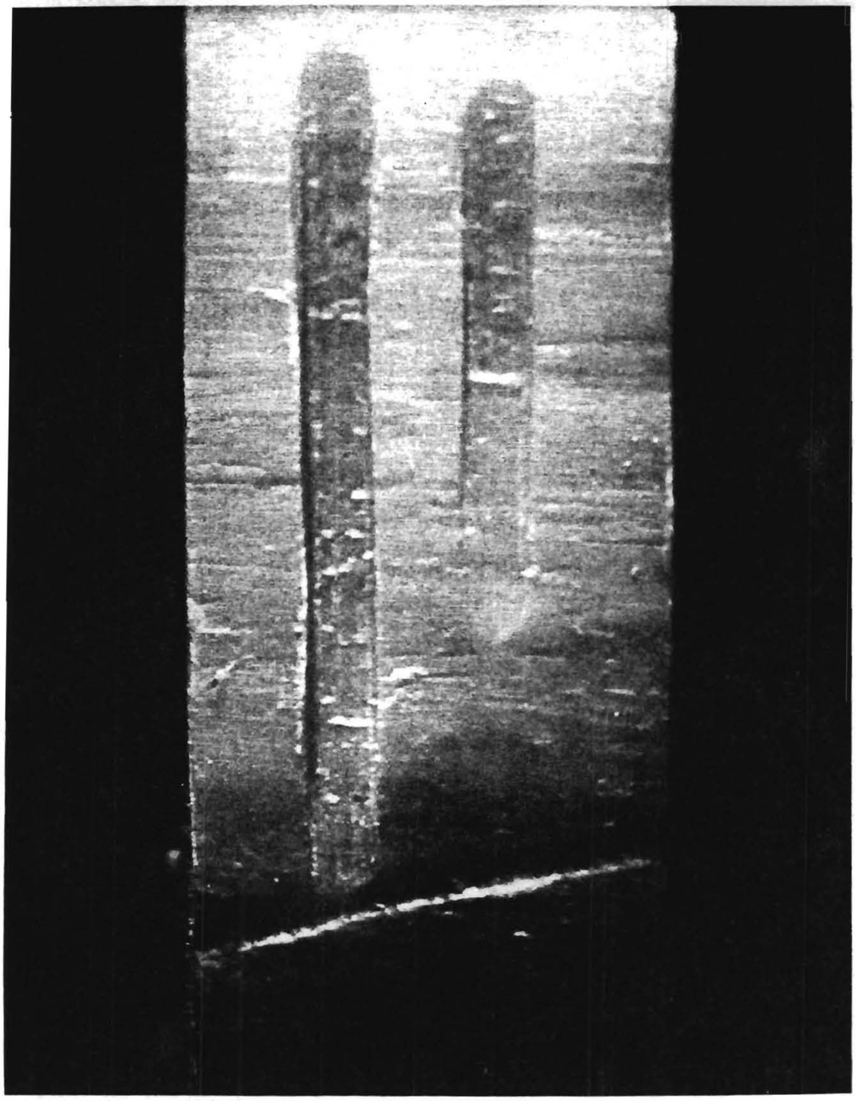


Figure V-11. Photograph of false start of a raker set hacksaw (18 teeth per inch) illustrating straight, parallel walls and no blade drift.

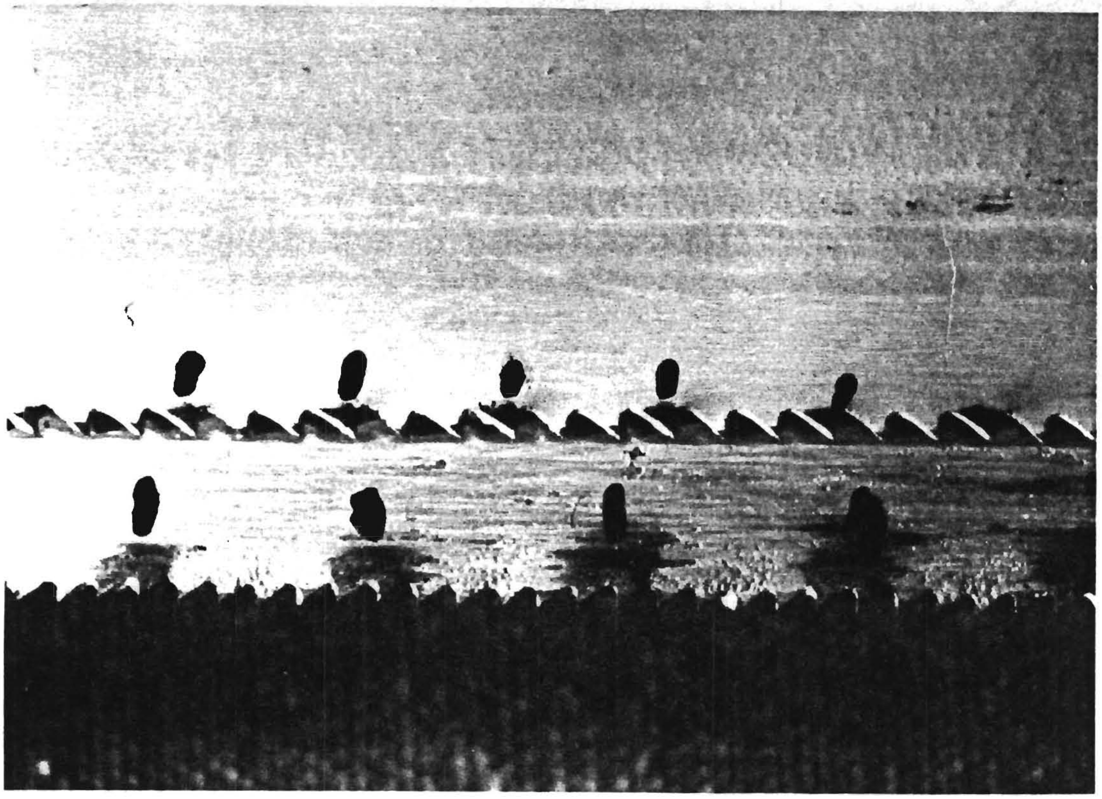


Figure V-12. Photograph of two new hacksaw blades after one pass through a bone. The top blade is a raker set, the bottom is a wavy set. Notice the missing paint indicates the area of increased friction (cutting) of the teeth.

from the bone walls or floor. Notice that every tooth is either worn free of paint, half painted, or untouched. This pattern represents the cutting action of one side of a blade, where teeth set to the right are abraded while shaving the kerf wall, teeth set to the left do not touch the right wall, while rakers cut down kerf midline. Friction from the bone is removing either all paint, no paint, or paint from the tooth tip. The opposite side of the blade shows the identical pattern, demonstrating that each tooth in this blade has a very specialized cutting action, while cutting an overlapping third of the kerf.

Since raker teeth in fine toothed bow saws occur at a rate of one in three, it is not surprising that these specialized teeth alter blade drift in a predictable manner. Raker teeth keep blades on a central path, therefore reducing (and for all purposes eliminating) blade drift. This is evident in false start walls, in that they are very straight and do not exhibit wide to narrow bending like other alternating set blades. Striae are frequent across the floor, but remain parallel, not bending. These striae are prominent and deep, similar to striae of alternating set blades.

Long and numerous parallel striae on kerf floors are indicative of wavy set blades, shown by Kerf Floor C, Figure V-9. A reliable characteristic of wavy set blades is "necking" of the kerf, where shallow cuts of Floor C taper to the middle of the cut bone and flair at the edge. Andahl (1978:39) refers to this as the "dumb bell" shape.

Changes in striation patterns are also observable. Striae are fine in construction and concentrated toward the walls, leaving fewer striae at kerf midline (Figure V-13). This pattern gives floors a more polished appearance. These characteristics are indicative of a wavy set blade. This can be conceptualized with the aid of Figure V-12. The bottom blade in this figure is a 24 tooth per inch wavy set blade used for only one cut in bone. Notice the wear on sets of teeth (about three) where the blade bends into the kerf side.

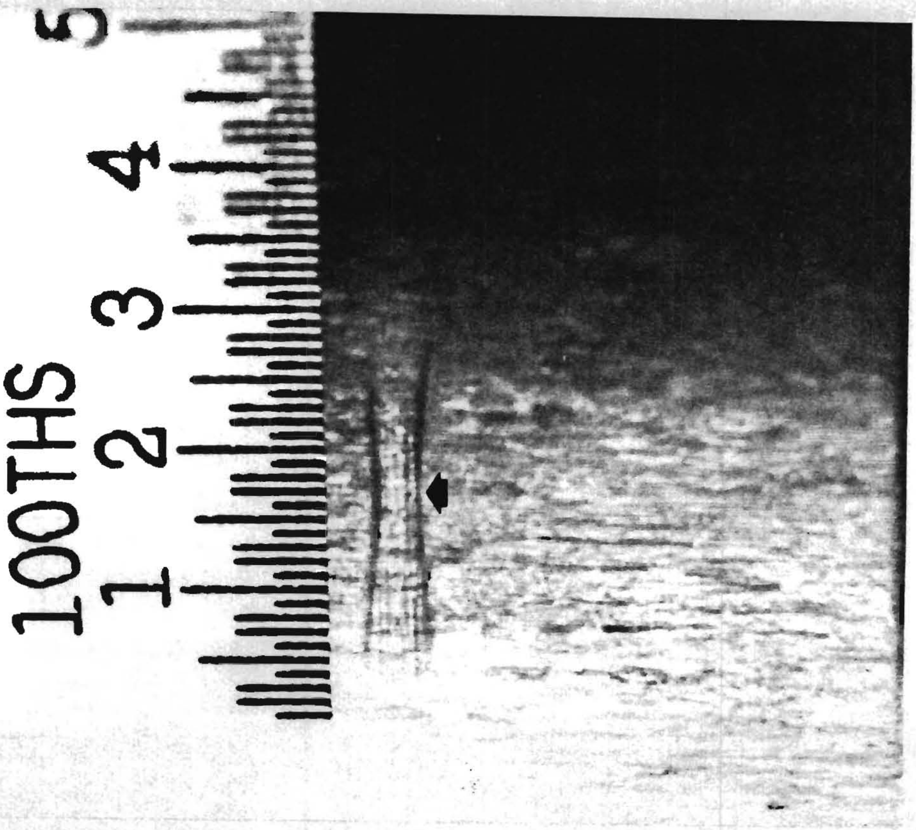


Figure V-13. Photograph of false start of a wavy set hacksaw (32 teeth per inch). Kerf shows straight walls that neck in shallow cuts. Striae are concentrated laterally in the kerf.

Wavy set fine toothed bow saws blades have been shown to exhibit blade drift resultant of waves of teeth rather than individual teeth seeking midline. This gradual bending of striae is difficult to observe on round bone. Measurement of wide to narrow blade drift patterns in wavy set blades is difficult. Necking is the obvious narrow aspect of blade drift but identifying wide aspects of kerfs is often futile because human bone is commonly too small and rounded for this aspect to be established. Since there is blade bending and no set to individual teeth, groups of teeth have similar angulation and parallel striae are shallow, creating a polished appearance on the floor. Increased frequency of striae at the walls indicates more angulation of the tooth as it deviates from midline. This increased angulation forces corners rather than the flat end of the tooth to cut.

Quantifiable Features: False Starts and Break Away Spurs

Blade Drift

Material is altered by the entrance of each successive tooth of all alternating set saw blades, where the forward motion of the blade is complicated by lateral forces. Figure V-14 demonstrates that alternating blade teeth cutting material in different directions, creates a different pattern. Figure V-15 illustrates blade drift with consecutive cuts in chalk, where each cut allows more teeth to saw chalk. The ensuing kerfs slowly create (left to right) distinctive kerf characteristics. Patterns produced involving the forward motion combined with lateral motion of a blade are called blade drift. Blade drift is important to this research because it potentially reflects distance between teeth or numbers of teeth per inch.

When the first tooth encounters bone, it seeks to align itself with the plane of the blade as it travels over bone seeking

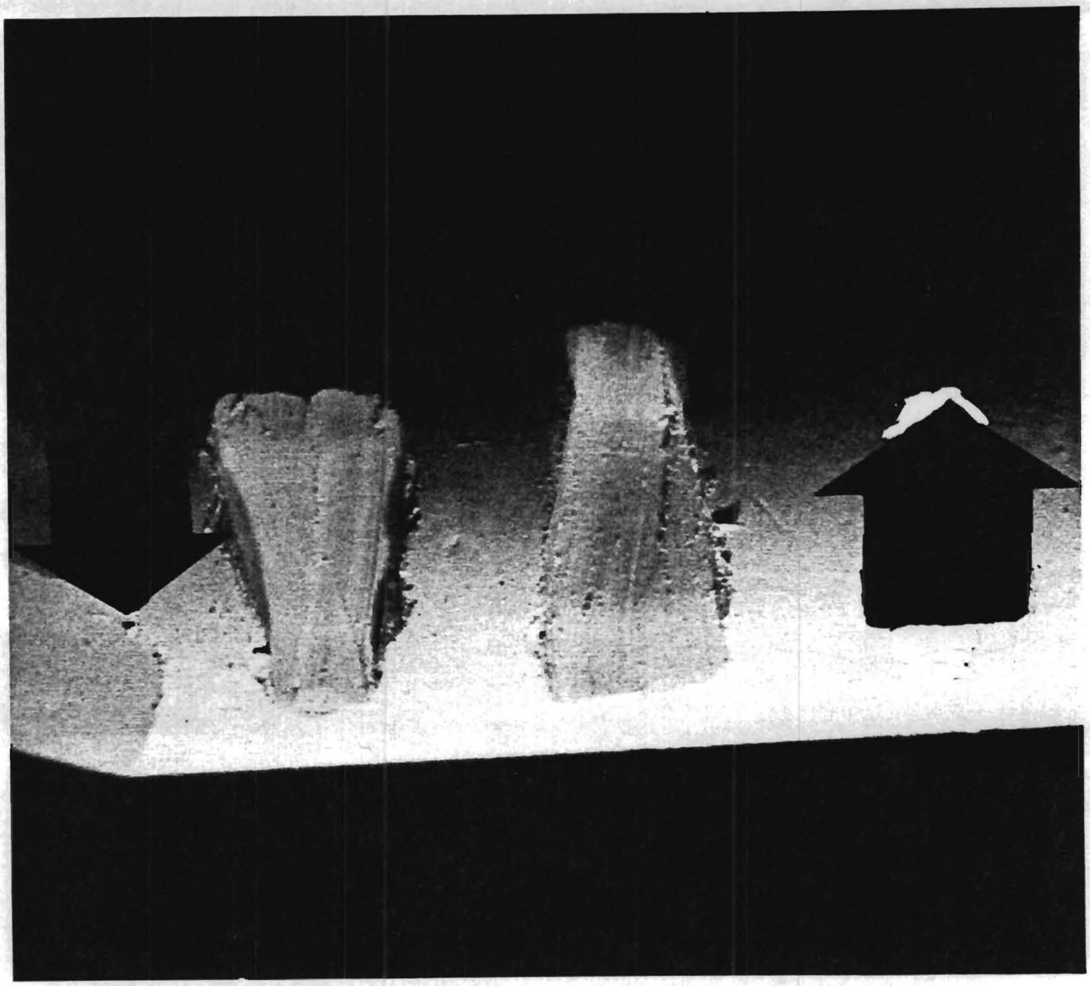


Figure V-14. Two experimental cuts in common chalk with an alternating set blade. Note that the shape of the shallow kerf created is dependent upon the direction of the cutting stroke.

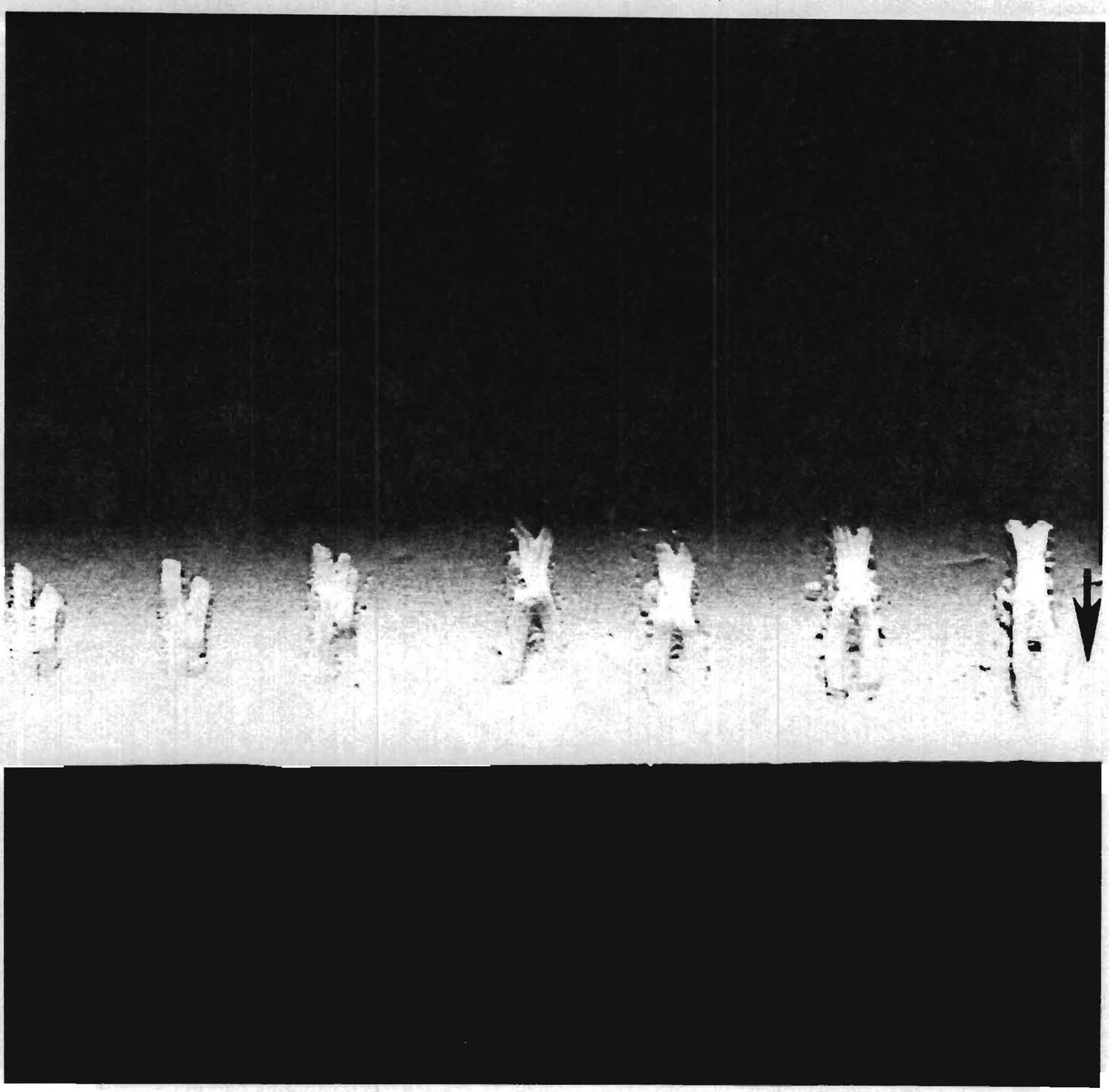


Figure V-15. Experimental cuts in common chalk where each cut (moving left to right) allows more teeth to interact with the chalk. Note the formation of the wide to narrow and bone islands.

midline by the entrance of the second tooth (Figure V-16, Cut 2). The second tooth is set in the opposite direction and is also attempting to seek midline. Forces on the saw blade change with each consecutive entrance of a tooth (Figure V-16, Cut 1). This tooth is diverted in direction forces and their compromise produce blade drift that is indicative of tooth spacing (Figure V-16, Cut 3). The more set to the teeth, the more the blade is forced to drift. Maximum set produces bone islands in the kerf where consecutive teeth drift to the extreme of missing material in the midline of kerfs.

As consecutive teeth seek midline or are pushed to compromise, the direction of forward progress of each tooth is affected. Each direction change of a tooth is caused by the introduction of a new tooth, thus the distance from direction change to direction change (two direction changes) in false starts is the distance of one tooth (Figure V-16, Cut 3). It is often less

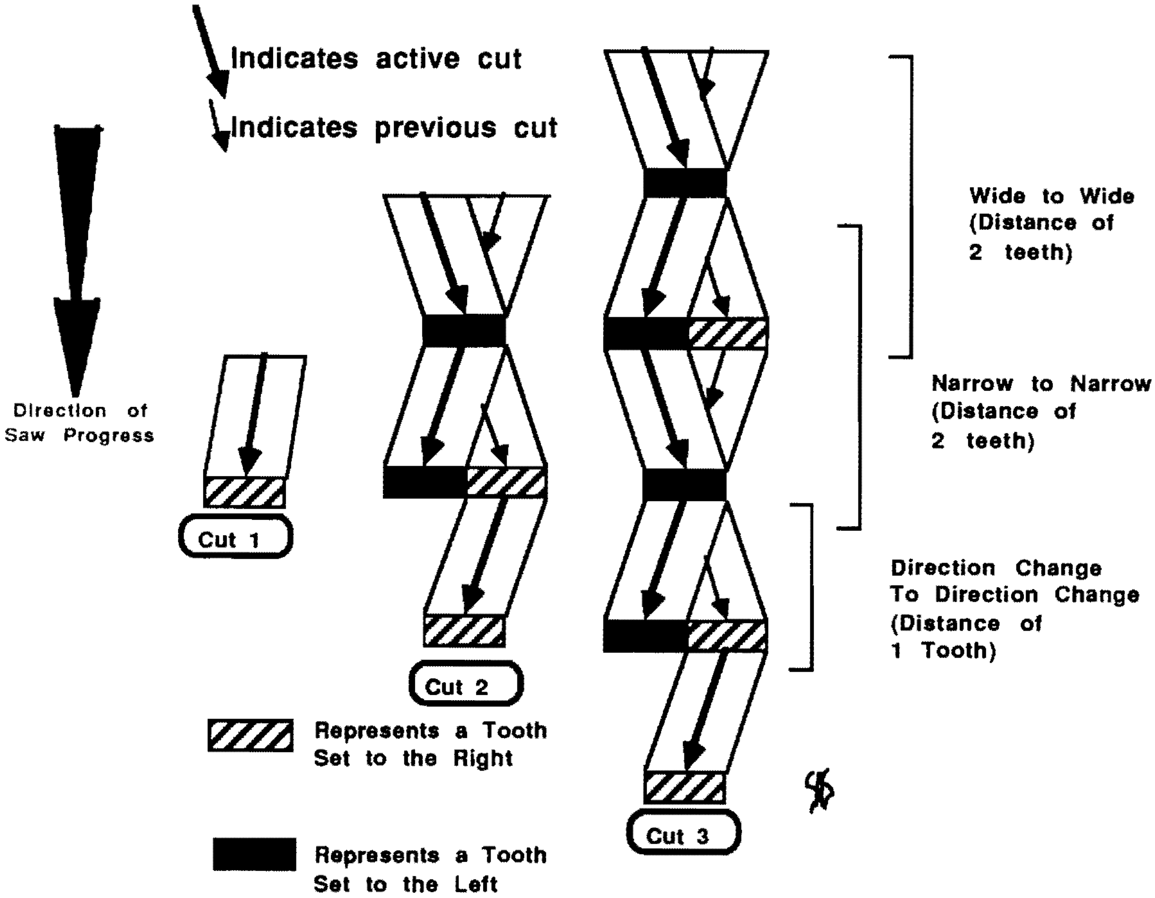


Figure V-16. Graphic illustration demonstrating the action of three initial saw cuts on a kerf floor by alternating set saw teeth. Cut 1 is so superficial that only one tooth set to the right has grazed the surface. Cut 2 is a longer cut allowing teeth set to the left to also enter the material, pushing the original tooth to compromise then allowing it to come to midline again. Cut 3 allows visualization of a saw cut that is producing a wide to narrow pattern that is indicative of distance between one or two saw teeth.

complicated to measure the distance from narrow to narrow (kerf midline), or wide to wide (kerf flare). This is equivalent to three direction changes and represents the distance of two teeth.

This rule also applies to islands of bone since islands represent the widest point of blade drift; where mid-island to mid-island represents three direction changes and therefore the distance of 2 teeth (Figure V-17). Figure V-18 illustrates that even fast moving power blades like those used with Stryker autopsy saws, create blade drift. This feature makes it possible to examine false starts and break away spur kerfs to initially determine saw set, and indicates teeth per inch of the blade used in a particular cut of an alternating set blade.

Blade drift is 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. Once the blade is immersed in the material, much of the side to side movement is suppressed until the kerf length tapers down making the kerf less restrictive.

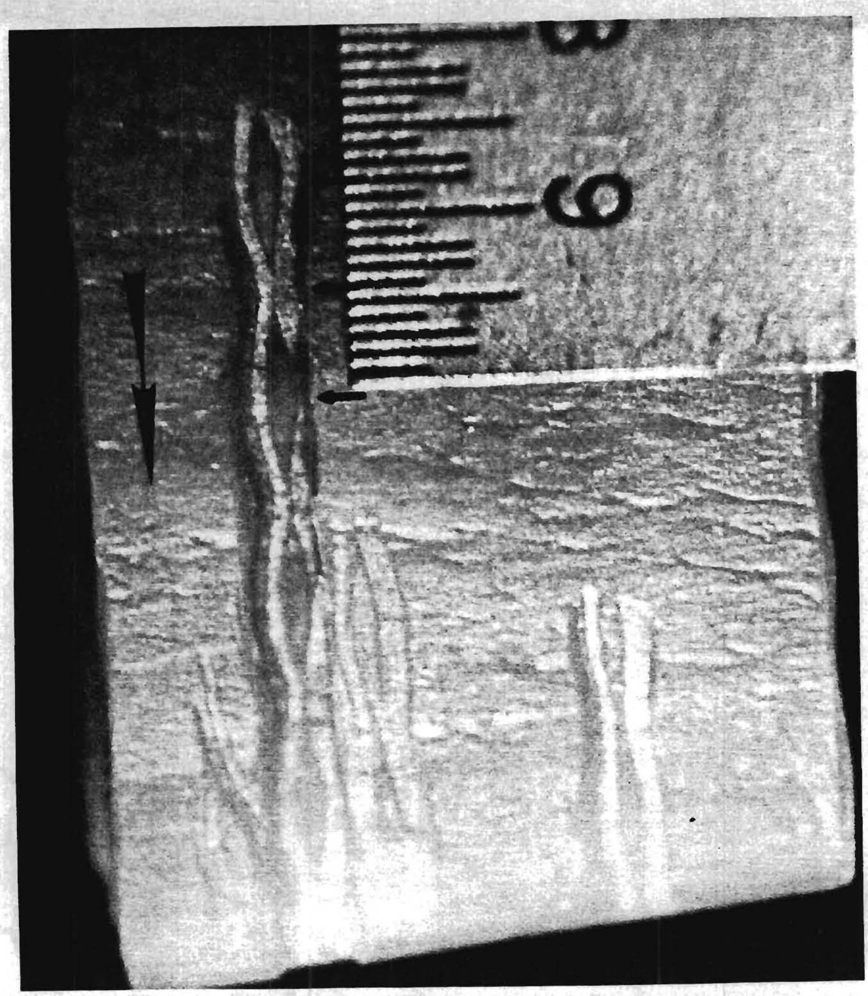


Figure V-17. Photograph of blade drift in a false start kerf created by a dove tail saw (15 points per inch). Note drift produces wide to narrow (0.07 of an inch) aspects of the kerf with bone islands (0.14 of an inch from island to island). Large arrow indicates direction of cutting stroke.

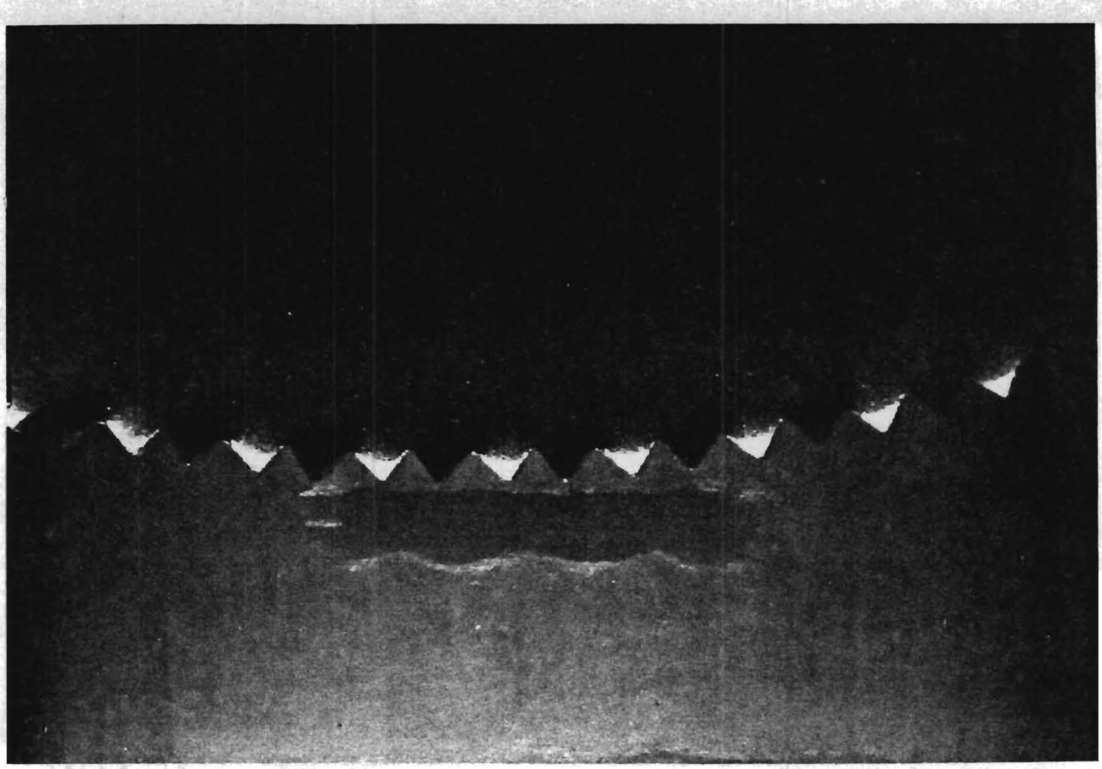


Figure V-18. Photograph of autopsy saw blade (17 points per inch) and false start kerf illustrating blade drift. Note the wide to narrow aspects of the kerf match the distance between each saw tooth.

Rakers inhibit the lateral movement of blades and therefore make it all but impossible to measure blade drift. Wavy set does not appear to create blade drift relating to each individual tooth. Rather, each wave (sets of teeth) appears to react in material like individual teeth. Therefore blade drift is present but at the frequency of a wave rather than a tooth. Estimation of tooth bank set (wave) distance has been accomplished experimentally, where measurements of wide to narrow indicate distance between waves. This distance is large and has limited utility (except as a class characteristic) when examining dismembered human bone. Calculations of this sort are also considered an estimation and of diminished value compared to accurate teeth per inch calculations of alternating set blades.

Kerf Width

Bonte (1975:319, 321) mentions the correlation of the kerf "groove" to the saw "setting." Original mention of this correlation of saw cuts in wood occurs in Mezger, et al (1927), Mayer (1933), and Pelz (1956). Blake (1985) utilizes the correlation of kerf width and saw blade total width to describe dimensions of a saw used in a serial murder case that involved a human mutilation in Tennessee.

Table V-1 lists saws utilized in this study with measurements of TPI, distance between teeth, tooth dimensions, set width, and average minimum and maximum kerf (false start) width cut in human bone. All measurements, except for TPI have been rounded to the nearest 0.01 of an inch due to the variability of the features measured and the difficulty involved with calculating accurate measurements under magnification.

Measurements of minimum kerf width can be compared with set width measurements to determine the close correspondence in each case. Maximum kerf width has been included in Table V-1 to demonstrate the variability of this measurement. Variability that can creep into these tool marks is remarkable, especially when created by saws that are hand held or hand powered.

Table V-1. Listing of saws utilized in this study with measurements of saw teeth and kerfs in human bone. Measurements in inches.

		Tooth				Set*	Kerf**	
Blade (Saw Type) Name	Class	Per Inch	Distance	Width	Height	Width	Minimum	Maximum
"Crosscut" saw (standard)***	Hand	6.0 to 7.0	0.14	0.03	0.10	0.06	0.06	0.07
"Crosscut" saw (premium)	Hand	6.0	0.17	0.03	0.10	0.06	0.06	0.08
Rip saw	Hand	4.5	0.22	0.04	0.16	0.07	0.05	0.08
Backed saw (premium)	Hand	11.0	0.09	0.03	0.04	0.06	0.06	0.06
Dove tail saw (premium)	Hand	14.0	0.07	0.02	0.06	0.04	0.04	0.05
Arched Pruning (peg toothed)	Hand	7.0	0.14	0.06	0.13	0.08	0.08	0.08
Arched Pruning (folding)	Hand	6.0	0.17	0.04	0.13	0.08	0.08	0.09
Buck (peg toothed)	Hand	4.0	0.25 to 0.33	0.03	0.20	0.05	0.05 to 0.10	0.14
Buck (lance tooth)	Hand	4.0	0.25	0.03	0.24	0.05	0.04	0.08
Coping	Hand	16.0	0.06	0.02	0.03	0.03	0.03	0.04
Hack (alternating)	Hand	18.0	0.06	0.02	0.03	0.04	0.03	0.04
Hack (raker)	Hand	18.0	0.06	0.03	0.02	0.04	0.04	0.04
Hack (wavy)	Hand	24.0	0.04	0.02	0.02	0.04	0.03	0.04
Hack (wavy)	Hand	32.0	0.03	0.03	0.01	0.04	0.03	0.04
Key Hole (alternating)	Hand	10.0	0.10	0.03	0.05	0.06	0.06	0.07
Key Hole (wavy)	Hand	25.0	0.04	0.03	0.02	0.06	0.05	0.06
Wallboard	Hand	6.0	0.17	0.06	0.15	0.10	0.09	0.12
Chef (standard)	Hand	10.0	0.10	0.02	0.06	0.05	0.05	0.07
Meat (premium)	Hand	10.0	0.10	0.02	0.05	0.04	0.04	0.04
Serrated Steak Knife	Hand	8.0	0.13	0.02	0.03 to 0.05	0.03	0.03	0.03

Table V-1. (continued)

Blade (Saw Type) Name	Class	Tooth Per Inch	 Distance	 Width	 Height	Set* Width	Kerf** Minimum	 Maximum
Japanese Ryoba (crosscut)	Hand	15.0	0.07	0.03	0.15	0.04	0.05	0.05
Japanese Ryoba (rip)	Hand	6.0 to 8.0	0.12 to 0.17	0.02	0.13 to 0.20	0.04	0.05	0.07
Gigli	Hand					0.05	0.05	0.05
Rod	Hand					0.10	0.10	0.10
Bone	Hand	8.0	0.13	0.03	0.06	0.05	0.05	0.05
Metacarpal	Hand	30.0	0.03	0.07	0.04	0.07	0.06	0.07
Circular (Piranha carbide)	Power	0.8	2.26	0.08	0.30		0.11	0.12
Circular (Framer carbide)	Power	1.0	2.22	0.09	0.50		0.09	0.11
Circular (Plywood)	Power	6.0	0.16	0.04	0.10		0.08	0.09
Circular (Combination)	Power	1.6	0.56	0.06	0.35		0.11	0.12
Circular (Masonry)	Power			0.14		0.14	0.14	0.16
Band (skip tooth)	Power	4.0	0.25	0.02	0.05	0.04	0.04	0.04
Chain (electric)	Power	0.7	1.50	0.14	0.14	0.23	0.25	0.32
Reciprocal (alternating)	Power	7.0	0.14	0.05	0.08	0.08	0.08	0.09
Reciprocal (alternating)	Power	10.0	0.10	0.03	0.05	0.07	0.06	0.07
Reciprocal (wavy)	Power	18.0	0.06	0.03	0.03	0.05	0.05	0.05
Autopsy (round)	Power	16.0	0.06	0.02	0.05	0.04	0.04	0.05
Autopsy (large sectioning)	Power	23.0	0.04	0.02	0.03	0.05	0.04	0.05

* Set width is the total set width of the saw blade at the level of the tooth point (edge).

** Kerf measurements are taken on false starts cut in human tubular bone.

***Three quality levels of saws: standard, premium or professional (Consumer Guide Editors 1978)

Source:

Consumer Guide Editors, 1978 *The Tool Catalog: An Expert Selection of the World's Finest Tools.* By the editors of Consumer Guide. Beekman House, New York, NY.

Minimum kerf width appears to be an excellent reflection of the cutting width of the saw since each blade used in this study (excluding circular saws) measures to within 0.02 of an inch of minimum kerf width.

Tooth Trough Width

Another measurable feature of the false start or break away spur is tooth trough width. Saw tooth width can be calculated in two ways, measurement of floor patterns and 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 actual tooth. Difficulties arise commonly when teeth overlap and create overlapping striae.

Measurement of residual tooth image simply utilizes kerf floors with islands to estimate tooth width. Islands occur in alternating set blades and appear when the total tooth set combined with blade drift produces a kerf width greater than two times the width of a single tooth. Tooth width from floor patterns can be calculated using these formulae:

$$\frac{\text{kerf width} - \text{greatest island width}}{2} = \text{tooth width or}$$

$$\frac{\text{kerf width (with islands)}}{2} > \text{tooth width}$$

for kerfs with no islands, use

$$\frac{\text{greatest kerf width}}{2} \leq \text{tooth width}$$

One must be careful to measure at the floor of the kerf for greatest accuracy. Crosscut teeth (those filed at approximately 70 degrees to the plane of the blade) may create a pseudo-island as this type of blade has teeth that are filed to points (see again Figure V-1, Class C). This point does not represent the tooth width. Calculating tooth width on crosscut saws appears to be tentative at best but separating angle filed teeth from chiseling teeth should be relatively straightforward.

Measurement of residual tooth mark is the most accurate appraisal of saw tooth width, and may be the most misleading. This technique requires the examination of the kerf floor under magnification. In theory, the last tooth sliding off of the kerf floor should leave an imprint (square cornered trough) of a single tooth. Measurements of this imprint reveal exact tooth width. Problems arise when attempting to confirm that this imprint is not the combination of more than one tooth. Teeth sliding over other teeth marks create an altered image that reflects a tooth width measuring less than one tooth.

Saw tooth width should be calculated with each of the above methods, measurement of floor patterns and measurement of residual tooth trough image. Figure V-19 demonstrates each method. Floor patterns produce a ball park measurement confirming the more accurate residual trough image method. This

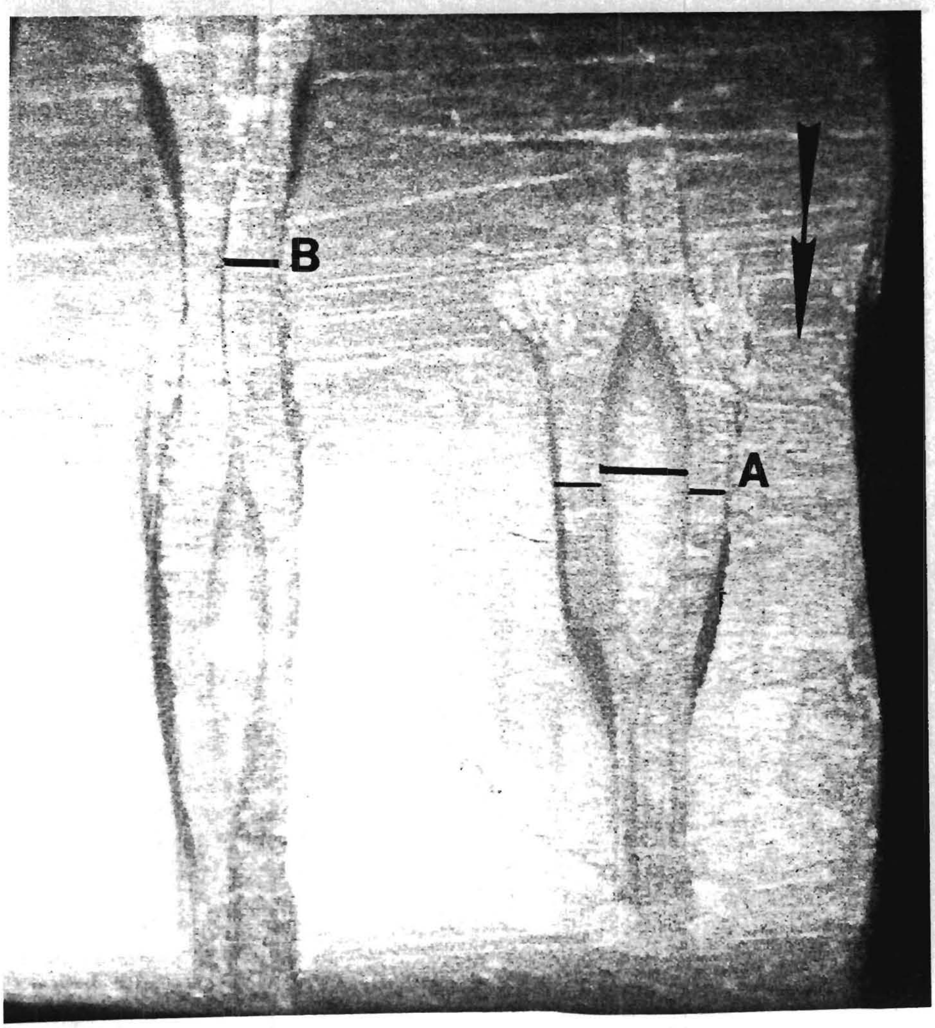


Figure V-19. Two false starts in bone produced by a Japanese ryoba rip saw (7 to 9 points per inch). The cutting stroke and pull stroke is from top to bottom of photograph. Tooth width can be calculated from floor features (A), or from individual tooth trough width (B).

technique avoids miscalculation of tooth width, where errors of 0.01 of an inch are substantial when trying to sort saws by tooth size.

Floor Dip

Saw teeth combine actions to cut a kerf floor. When the floor of the kerf is examined longitudinally at an angle, the seemingly flat bottomed kerf may actually be wavy. Andahl (1978:36-37) demonstrates this wave formation in experimental cuts in metal. This pattern of waves is the result of consecutive teeth entering the bone and hopping across the floor. This hopping is created every time a new tooth attempts to engage the entrance edge of the material. The introduction of each tooth forces the blade to jump. Since this jump is tooth induced, these features should be indicative of tooth spacing. Figures V-20 and V-21 are photographs of a false start and a break away spur exhibiting wavy floors. Each peak or dip corresponds with a new

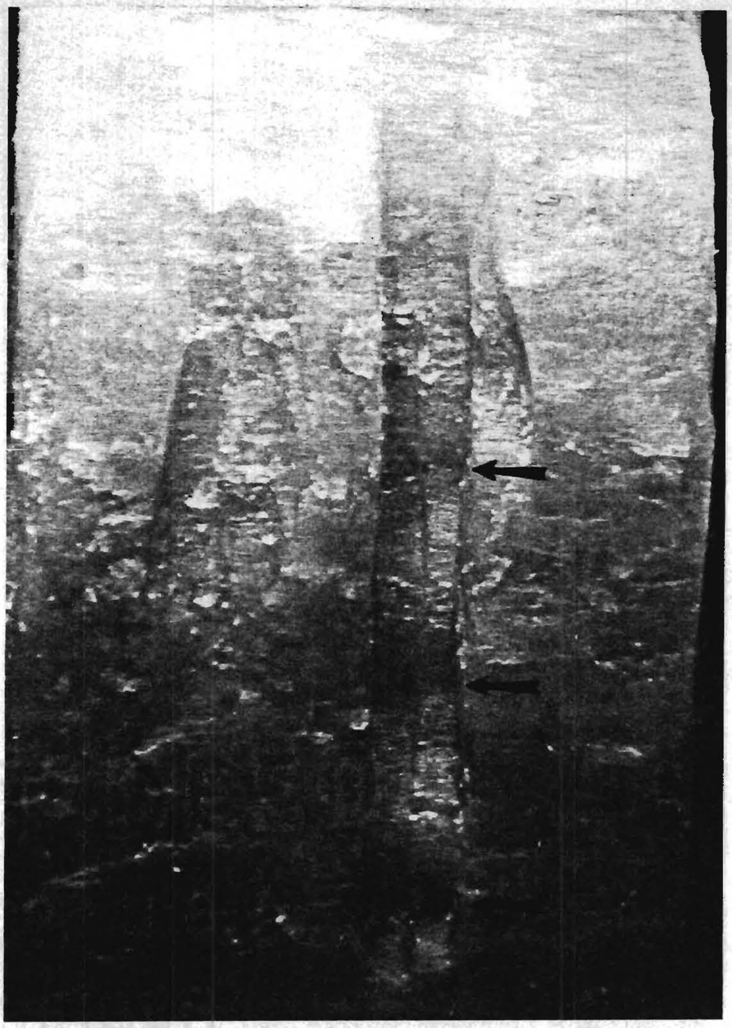


Figure V-20. Photograph of a false start exhibiting wavy kerf floors created by a carpenter saw. Each peak or dip corresponds with a new tooth engaging the material and therefore the distance between each peak or dip is the distance of one tooth.

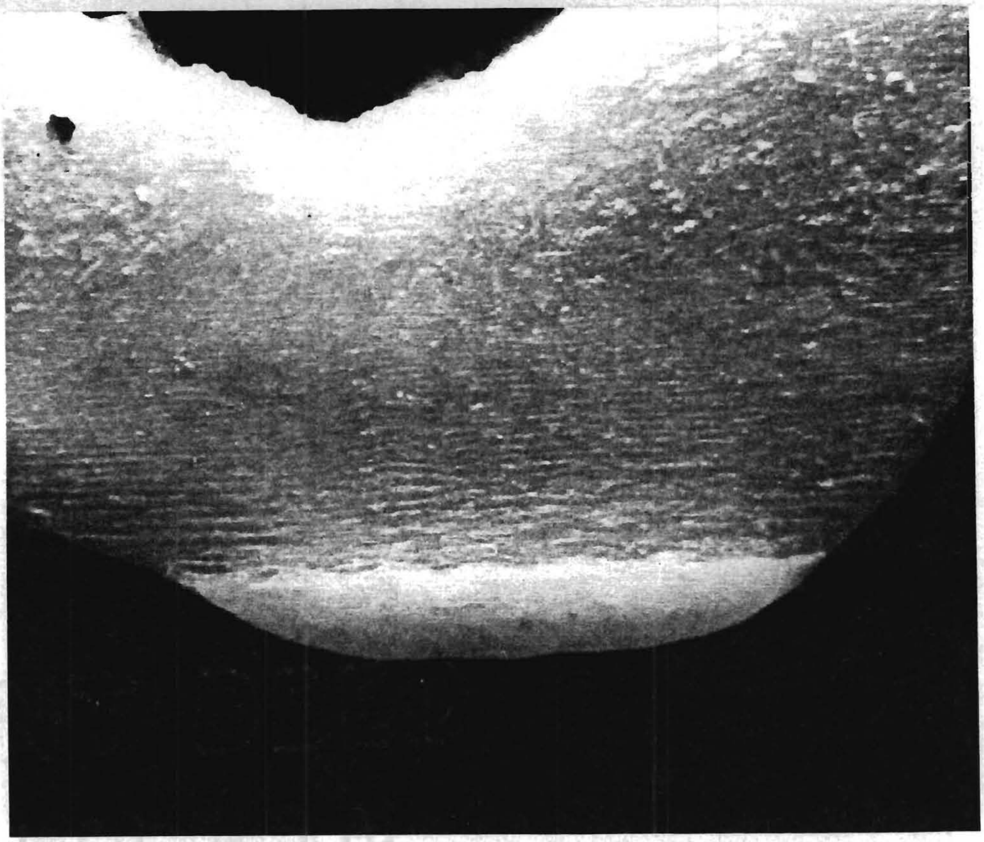


Figure V-21. Photograph of a break away spur (bottom) exhibiting a wavy floor produced by a power reciprocating saw with a wavy set blade. Each peak or dip corresponds with a new tooth entering the material and therefore the distance between each peak or dip is the distance of one tooth.

tooth entering the material and therefore the distance between each peak or dip is the distance of one tooth.

Floor dip combined with blade drift adds a third dimension to actions of a blade in a kerf. Calculating floor dip is similar to calculating blade drift, except that the distance from floor dip to dip, or peak to peak, is indicative of a single tooth. Remember that in blade drift, the distance of wide to wide or narrow to narrow, is indicative of two teeth due to the alternating set.

Tooth Imprints

Tooth imprints are similar to floor dip, in that residual imprints from tooth points in the kerf floor may remain after a saw is interrupted in the cutting or passive stroke. Consecutive tooth imprint features, like floor dip, can be measured in false starts and break away spurs to represent the distance between teeth. These features have been recognized in medical examiner cases (Blake 1985) and mentioned in research (Guilbeau 1989).

Problems arise in calculations of floor dip and tooth imprint distances with certain variations of tooth shape. Irregularities in tooth shape can easily interrupt the dip patterning or disguise the tooth imprint. These irregularities usually arise with the introduction of specialty teeth. An example of this would be floor dip created by a pruning saw that has a short raker tooth inserted between groups of crosscut teeth. This shorter tooth may not leave an imprint, therefore giving the appearance of twice the distance between teeth.

Observable Features of Cross Sections

Residual Kerf Shape: Tooth and Stroke Striae

Bonte indirectly addresses stroke and tooth striae:

> During-and only during-the unpowered return stroke of the saw blade do all the saw teeth lie on approximately one level, which produces a rather crude and deep furrow. During the forward stroke [of a push stroke saw], however during which the actual sawing is done, the saw blade at the same time shifts deeper in a movement diagonal to the axis of the blade. At this each tooth leaves a fine mark which is slightly inclined towards the rougher furrow. Thus between two rough grooves there develop several very thin parallel rills (Bonte 1975:318).

Cutting actions of a single tooth combined with actions of all teeth create predictable and measurable characteristics. Cross sections of a sawed surface of a bone always grossly exhibit one type of residual kerf while most reciprocating saws produce two types of residual kerfs: tooth and stroke striae. Even though motions of sawing involve teeth following teeth, individual tooth striae, or Bonte's thin parallel rills, are evident on all cuts. A reciprocating action produces "rough grooves" or stroke striae that consist of combined tooth striae. Figure V-22 illustrates a bone with tooth and stroke striae.

Stroke striae are evident in most hand powered saws and many mechanically powered saws. Saws that produce no stroke striae include power saws that cut in a continuous rather than reciprocating motion. Continuous motion saws studied in this research include circular, band, and chain saws. It should be

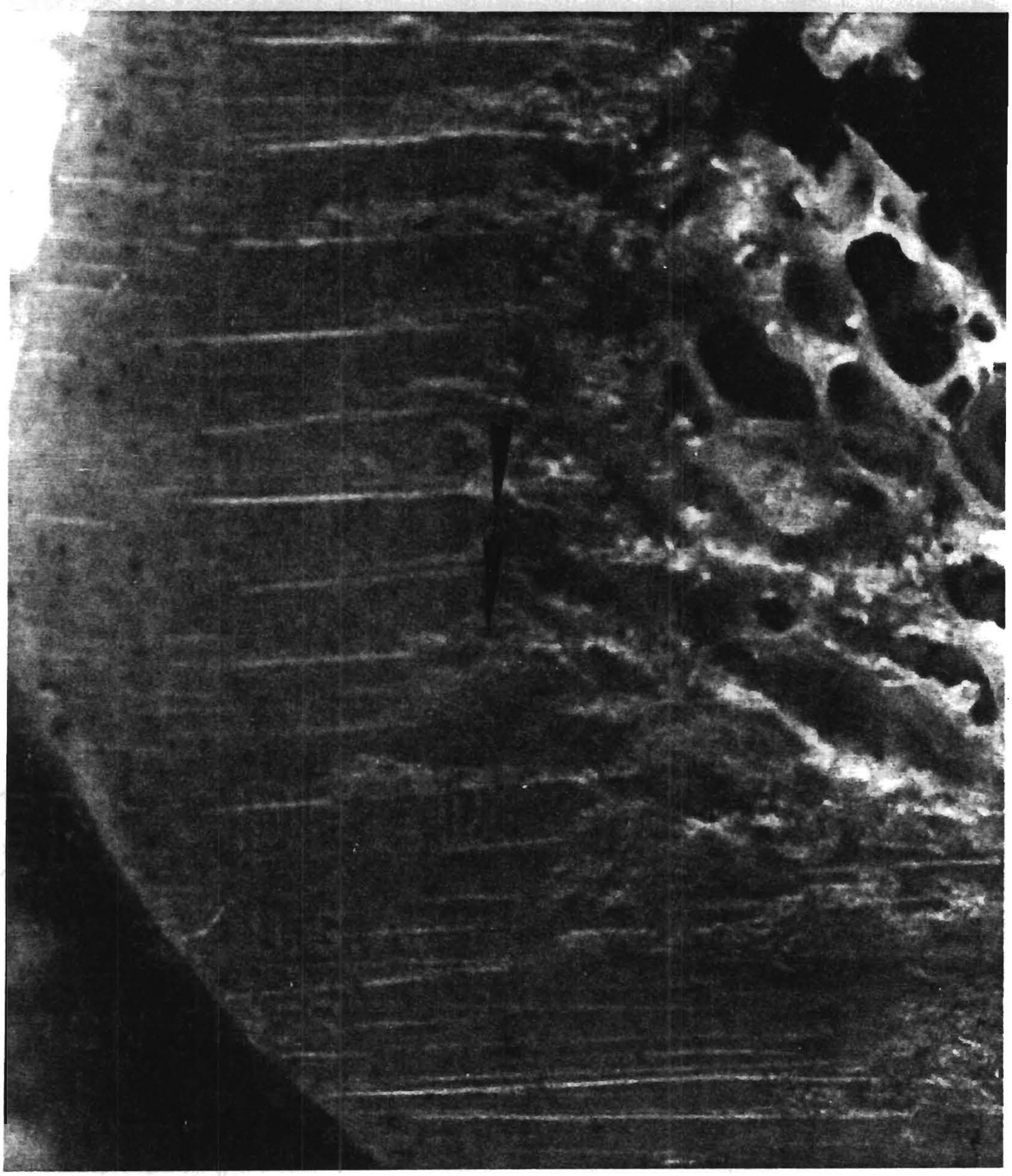


Figure V-22. Photograph of a cut bone created by a hack saw (with 32 teeth per inch). These blade creates tooth (fine) and stroke (coarse) striae.

noted that even continuous cutting saws can create what appear to be stroke striae. These occur in the band saw, as the splice in the blade rotates through the material, creating a stria every rotation of the blade. This pattern exhibited on the cross sectioned bone can be mistaken for strokes.

Large toothed saws also leave characteristic patterning of residual kerfs. This patterning, at first appearance, is a confused shuffle of striae. Closer examination reveals predictable patterns, where cuts of large filed teeth leave prominent striae on the bone.

The shape of striae change as the saw progresses through tubular bone. The initial aspect of the cut reveals wavy tooth striations characteristic of large toothed saws. As the cut progresses to level of the marrow cavity, the saw encounters two narrow pillars of bone (the bone bordering the marrow cavity) instead of teeth riding over a long flat kerf. This bone is often narrower than the distance of two saw teeth, thus the teeth are raking this material as they bounce over the pillars. Therefore large toothed saws (large in the height and the distance between teeth) create striae that are wavy but essentially straight at the top and bottom of the cuts on tubular bone, but hopping at the level of the marrow cavity.

Residual Kerf Shape: Striae Contour

Residual kerf shape also refers to the contour of saw striae. Straight versus curved residual kerfs is an excellent characteristic to indicate certain saw types. Curvature in striae can take two forms, curvature with fixed or unfixed radius. Curvature with a fixed radius implies a round, rigid blade. The most common example of this is the circular saw (Figure V-23).

This author omitted circular saws from initial saw mark research due to the unlikelihood of this type of saw being utilized in a forensic setting. This strategy was recently revised when a hand held circular saw was shown to be the tool of choice in a recent case of mutilation and body disposal on the state line of Georgia and Tennessee (Symes et al 1990).

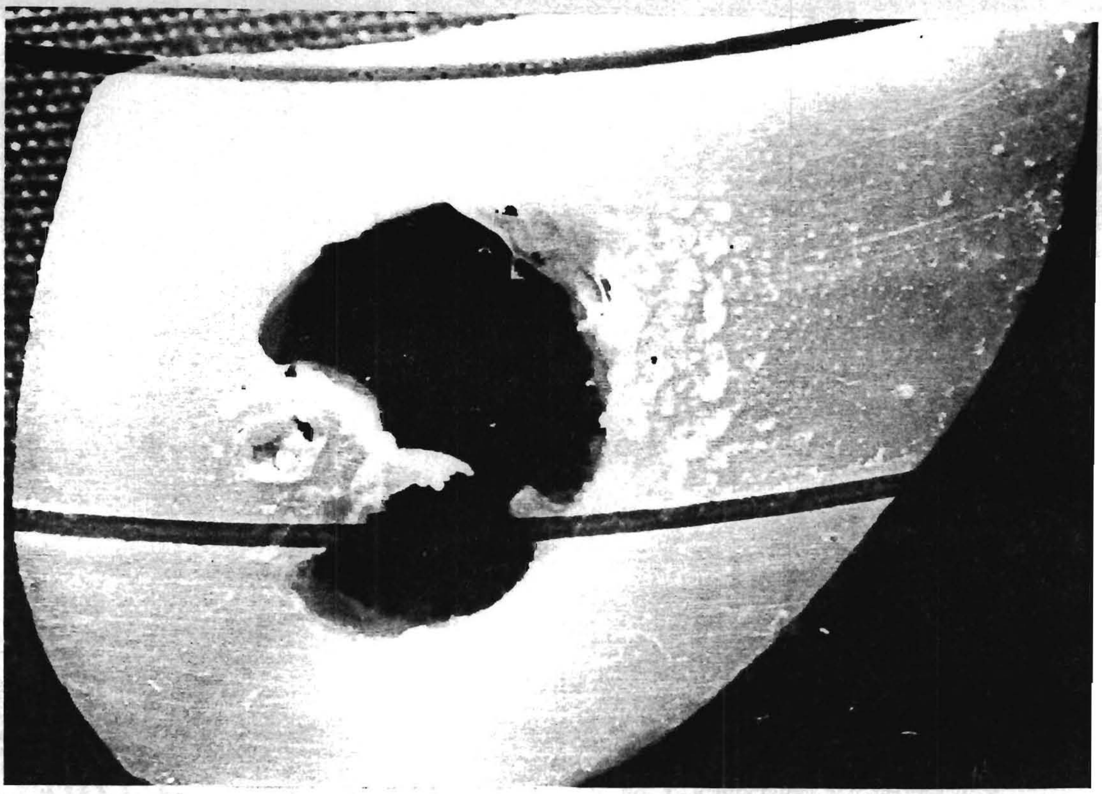


Figure V-23. Photograph of a circular saw cut in bone with curved line overlay. Notice the bending striae with a fixed radius forming concave striae.

Circular saws have different types and sizes of rigid blades producing striae with fixed radius curvature. Cunningham and Holtrop (1974:174) list common circular saw blade diameter sizes as 6 to 8, 9 to 10, 12, and 14 to 16 inch blades. Figure V-24 demonstrates a method utilized to estimate the diameter of striae of the cross section of a bone. By drawing these different diameters on an acetate overlay, exposed striae can be compared to these measured arcs. This is used to verify a fixed radius curve, and the approximate diameter distance. While this technique has limited accuracy when sorting blades of similar diameters, it is successful in sorting common blade size differences, such as the difference between hand held circular saws and table saws.

Hand held circular saws commonly use blades six to eight inches and table saws generally start at ten inches in diameter. These blades are easily sorted in the laboratory when using the overlay on cuts exhibited in large bones.

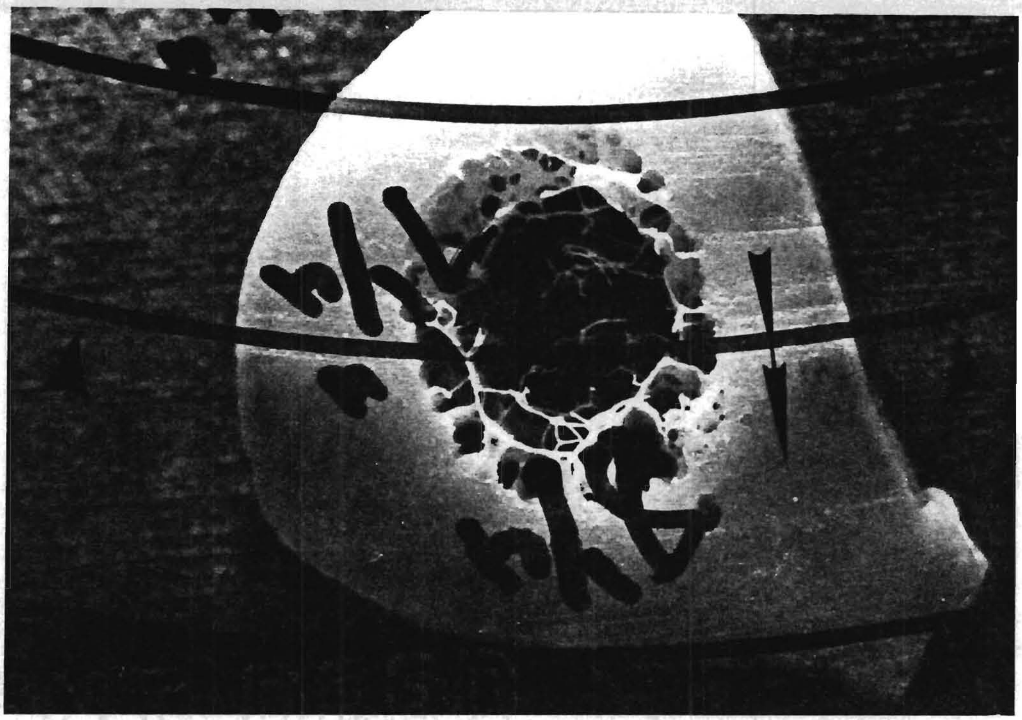


Figure V-24. Photograph of a circular saw cut in bone with a 7-1/4 inch curved line overlay. Notice the better fit than the 8-1/2 inch diameter arch.

Another fixed curvature blade is the autopsy saw with sectioning or round blades. These saw residual kerfs show a slight bending in cross section (Figure V-25), although detection of this curvature is difficult without magnification. Power chain saws can also create curved striae, but only in the event that the toe of the saw is doing the cutting.

Non-fixed radius curvature occurs from various types of flexible saws, such as the Gigli saw (Figure V-26). This saw is commonly utilized in surgery and therefore must be considered a saw with forensic potential. Gigli saw cuts are easily diagnostic and reveal direction of cut and even handedness of the individual sawing by detecting the direction of the cutting stroke due to more powerful pulling of the dominant hand.

Pruning and rod saws are two other types of saws producing slight curvature in striae. Pruning saws have such a gradual curve that this researcher has not been able to readily verify

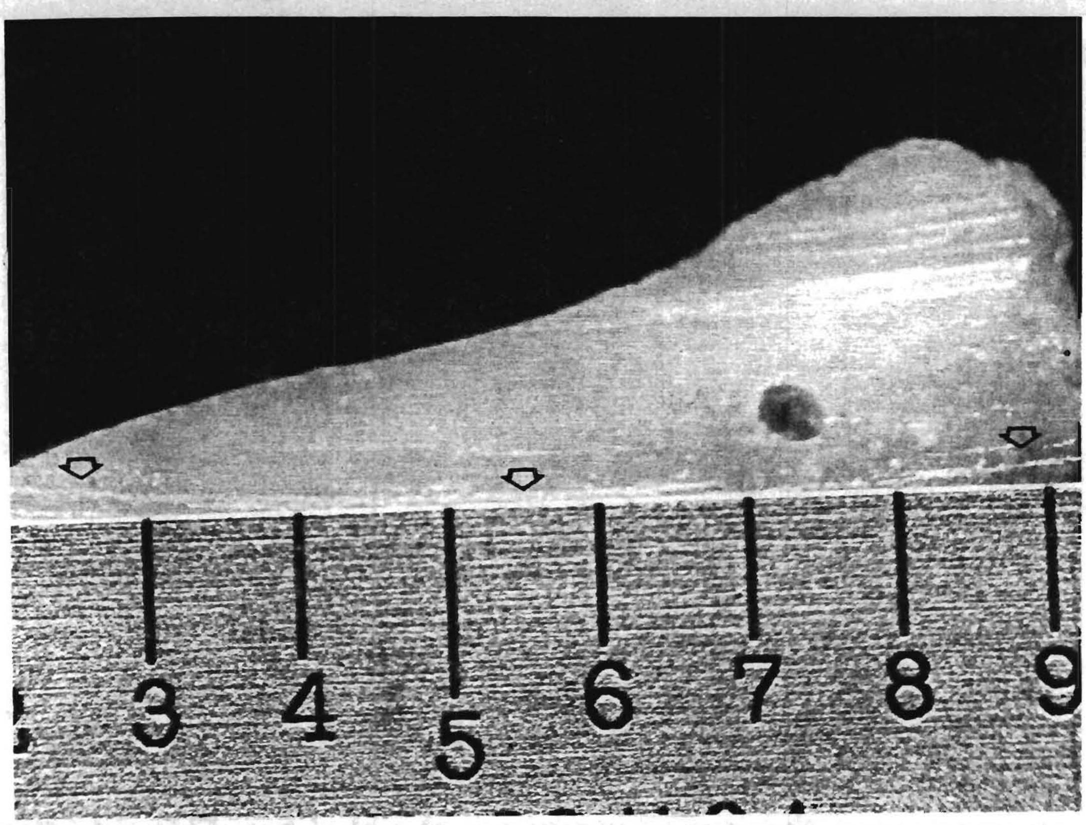


Figure V-25. Photograph of initial stages of a cut on sectioned bone. Note the concave bending at the level of the ruler produced by a power autopsy saw with a round blade.

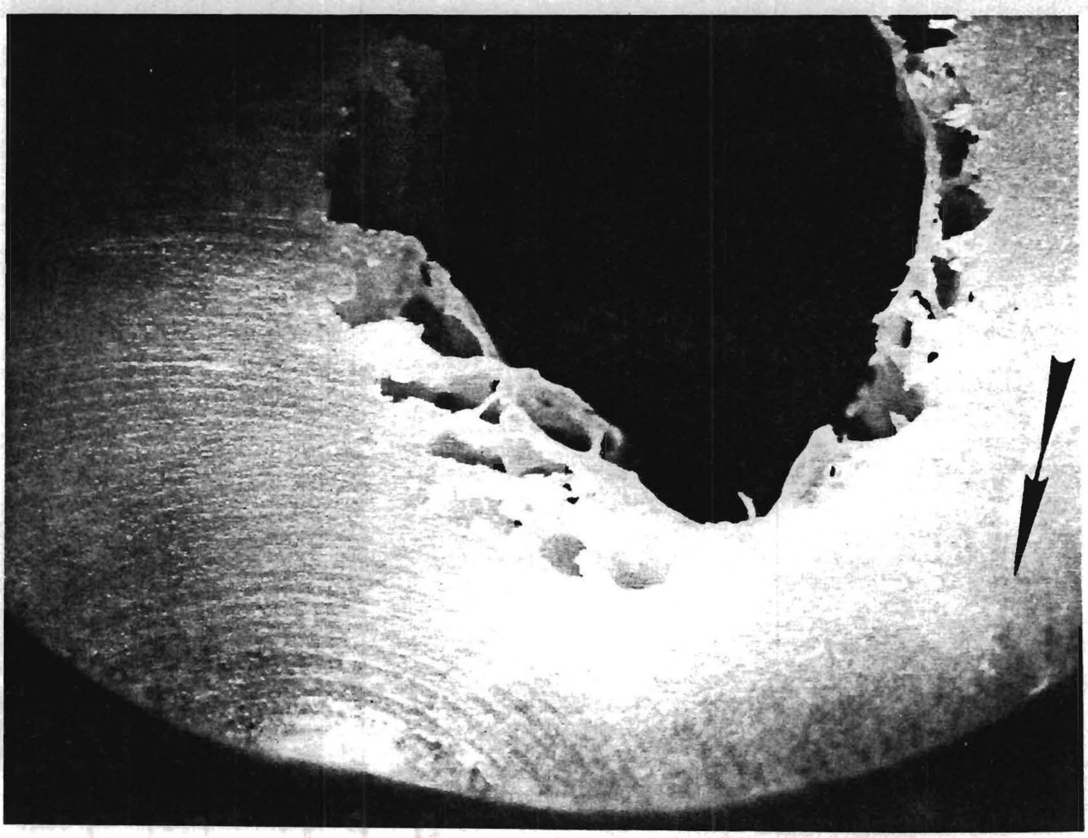


Figure V-26. Curvature of Striae in cross sectioned bone created from a Gigli (flexible) saw. Notice the non-fixed radius with striae bending convexly around the break away spur.

striation bending on human bone samples, however, a rod (grit embedded blade fitted into a hacksaw frame) saw was found to bend, especially at the initial and terminal stages of the cut where a false start and break away spur reveal definite arching in cross section. Keep in mind that the Gigli, pruning, and rod saw bend around material while the circular, power chain, and autopsy saw arch away from material being cut, as determined by the curvature of striae around the break away spur (Figure V-27).

Like many identifying characteristics on cut bone, bending striae are sometimes deceiving. If a hand saw is rocked repeatedly while cutting, a pattern similar to curved striae may be detected. Figure V-28, Photograph A, represents striae that appear concave at the initial entrance of the cut. However, Photograph B is the opposite side of this sectioned bone and examination of this surface reveals no curving, simply striae oriented at different angles. This cut is produced by a straight bladed hacksaw.

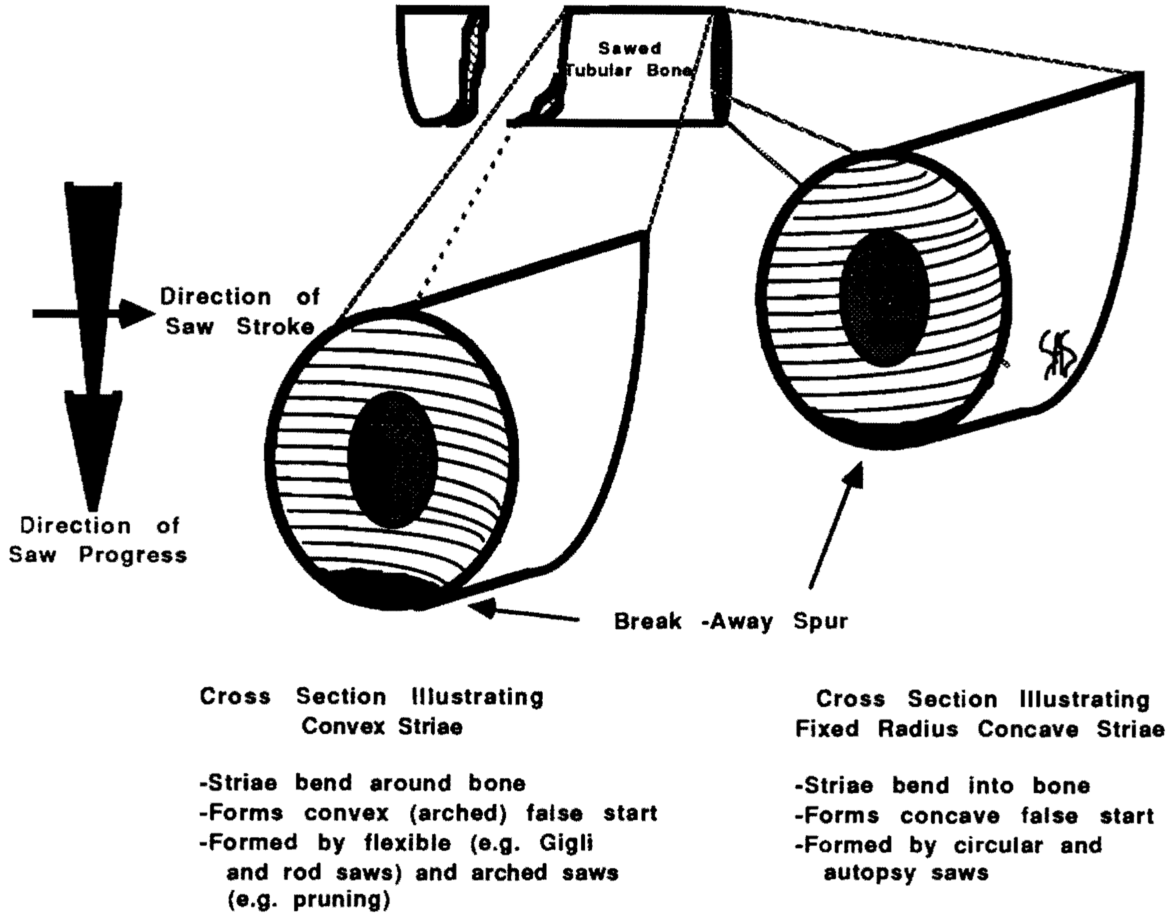
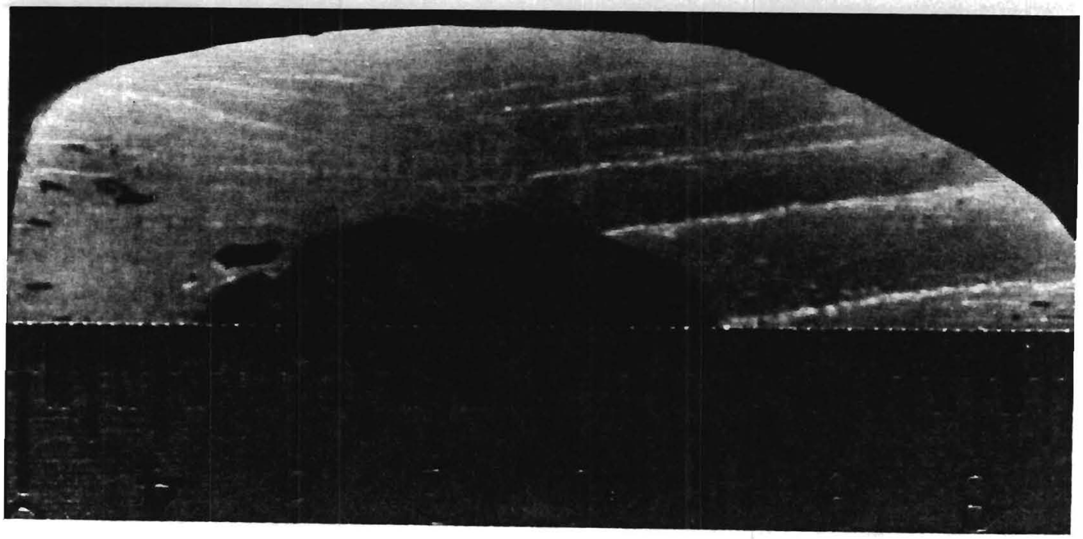
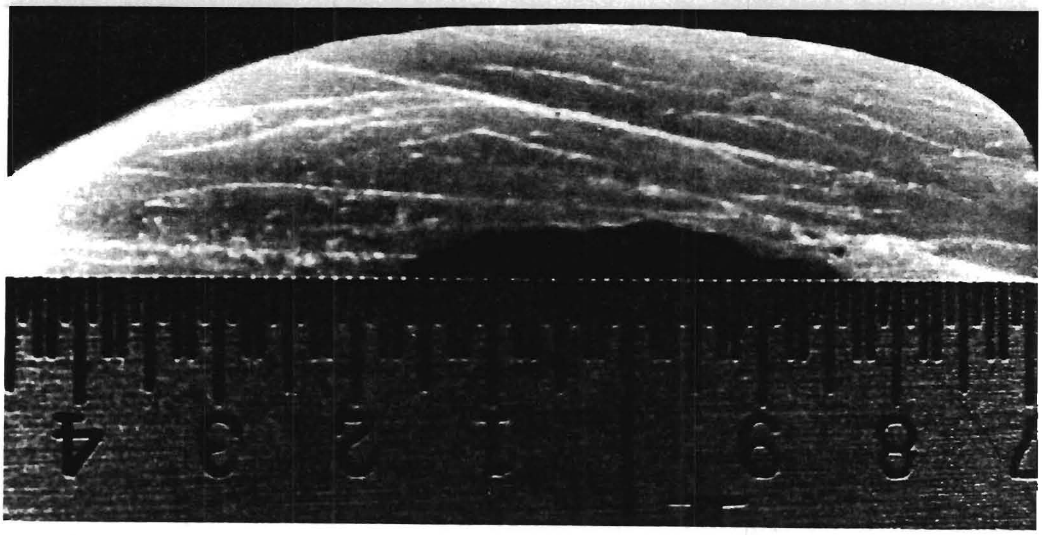


Figure V-27. Illustration of cross sectioned bone demonstrating two types of curved residual kerfs. Also listed are saws commonly responsible for these diagnostic features.



Photograph A



Photograph B

Figure V-28. Photograph A and B represent the two sides of a single cut with a hacksaw. Photograph A gives the false impression of residual kerf "curving," while B is obviously straight edged striae. Close examination of A reveals a combination of straight striae combined to form a false "curved" appearance.

Close examination reveals that this "curved" pattern in Photograph A is actually a series of short, straight stria linked into a curved pattern. Close examination of striae utilizing a straight edge should eliminate false curves. Thus residual kerf contour is an excellent indicator of blade shape and therefore an essential part of residual kerf examination.

Cut Surface Drift

Cut surface drift is a fluctuation in the plane of cutting progress where the surface of the sawed cross section of bone is not flat, but irregular or wavy (Figure V-29). These irregularities are produced by saw blades that progress through the material drifting one way then another into the material. Initial research in this area presumed that saws with reduced blade height dimensions were most likely to drift. This was immediately disproved when all carpenter saws exhibited surface drift while raker set hacksaws cut extremely straight sided kerfs.

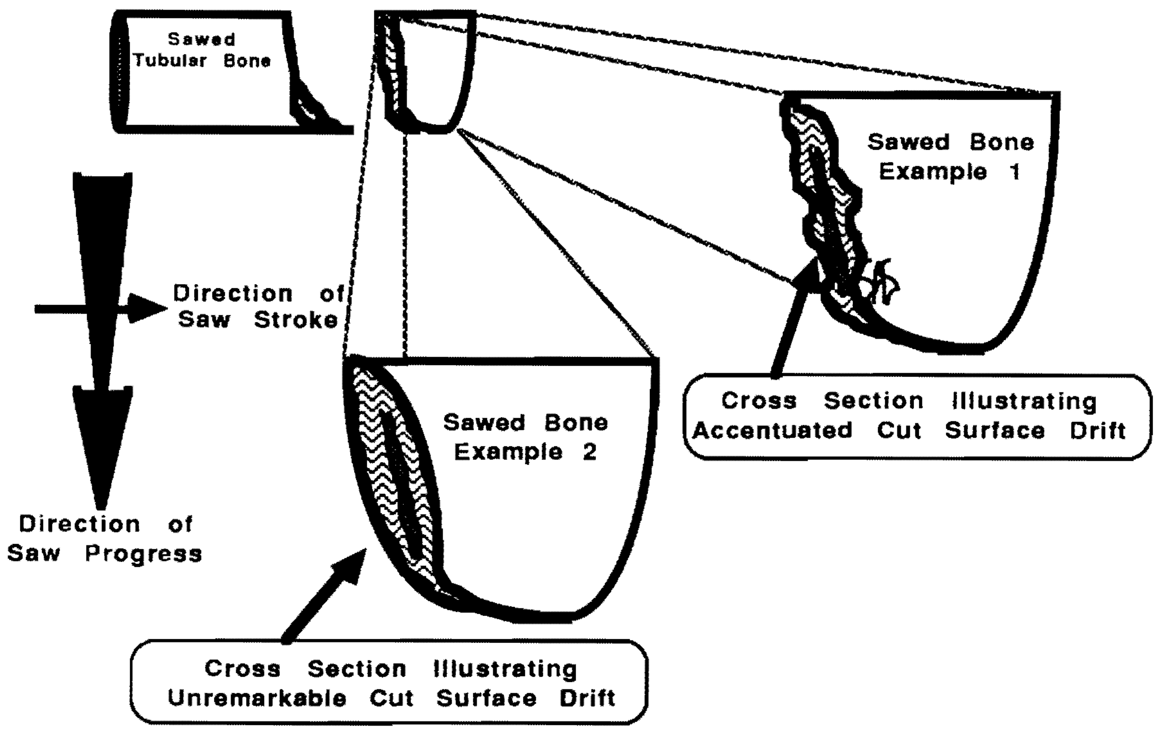


Figure V-29. Two illustrations of variation in sawed tubular bone. Example 1 has been sectioned by a saw that drifts as it progressed through the cut. Example 2 shows little cut surface drift.

Cut surface drift has proven a difficult quality to recognize, and at this point, impossible to accurately quantify. Visually, this feature was first recognized in kerf cross sections of wavy set fine toothed bow saws. As mentioned above, these kerf walls seldom progress into the material in a straight fashion, and may flare or change directions as the cut progresses (again see Figures V-4 and V-5) so it seems logical that cut surface drift is accentuated in wavy set saws. Hand powered saws with file type handles and all saws with short blades are suspected of producing surface drift. These designs inhibit long, consistent strokes and may contribute to more variability in the shape of the cut bone (Figure V-30).

Finally, it is not unusual to see cut surface drift in saws designed to cut soft materials, like carpenter, pruning, and chain saws. Surface drift does appear to be less apparent in raker set saws, and power saws designed to cut hard materials since the movement of the blade through the material is more easily controlled.

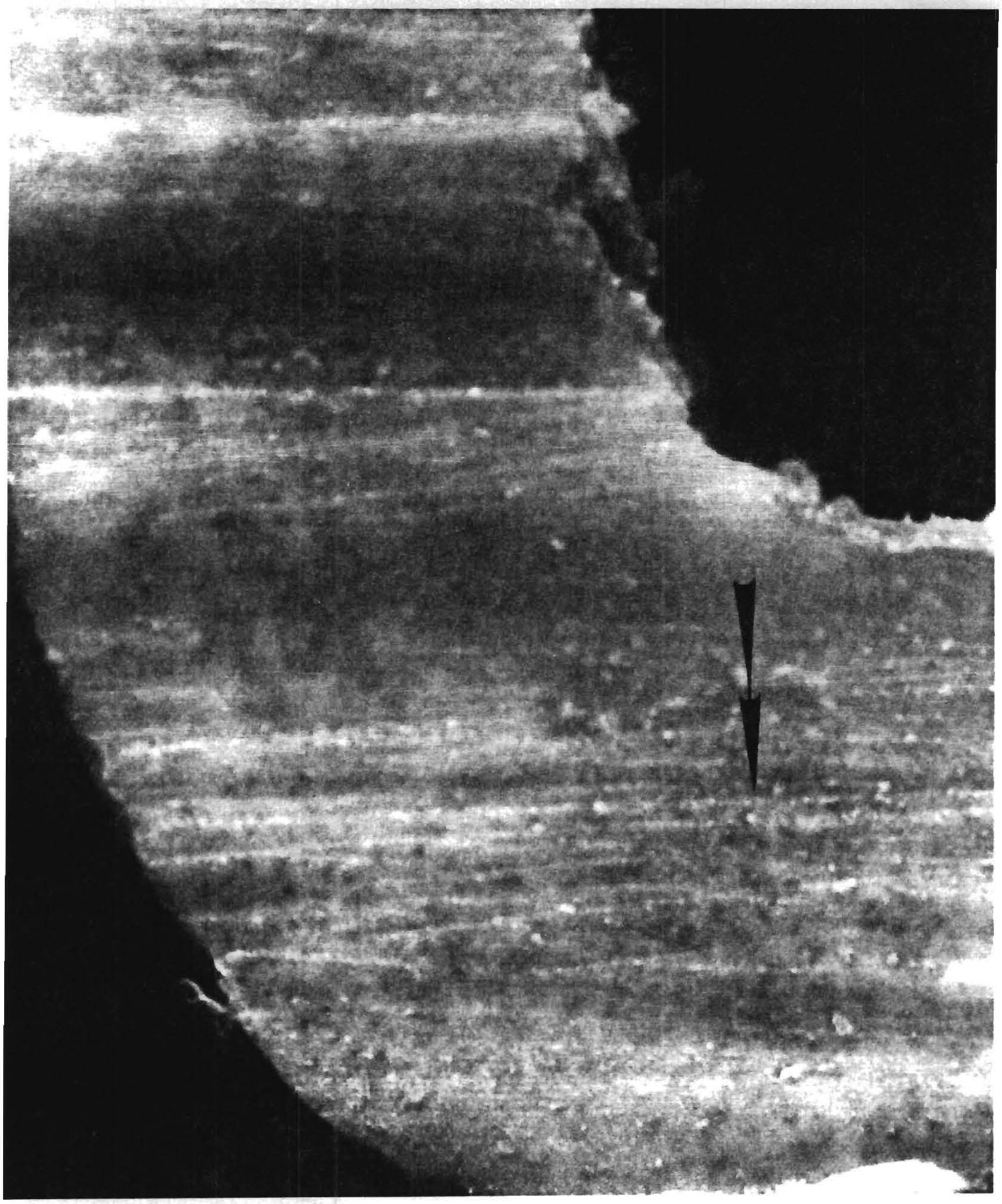


Figure V-30. Photograph of cut human bone with accentuated cut surface drift. This drift is at least partially attributed to the file-type handle of the backed saw that cut this particular bone.

Quantifiable Features of Cross Sections

Tooth Hop

Tooth hop is the cross section signature of floor dip. Striae across the face of the bone generally progress in a straight pattern. With close observation, these straight residual kerfs occasionally begin patterned hopping or as Andahl (1978:39) points out, create predictable waves. Hopping is created as teeth begin to enter the kerf and each successive tooth strikes bone, producing movement of the whole blade. Figures V-31, V-32, and V-33 illustrate striae hopping in human femur shafts cut with different saws. Tooth hopping is the likely product of a slight direction change in the stroke. Guilbeau (1989:45) alludes to these wave patterns in meat and hacksaws, and even suggests a correlation between the number of teeth and measurements between wave "crests." These features were observed in at least one cut in all reciprocating saws with rigid blades, with the exception of autopsy saws.

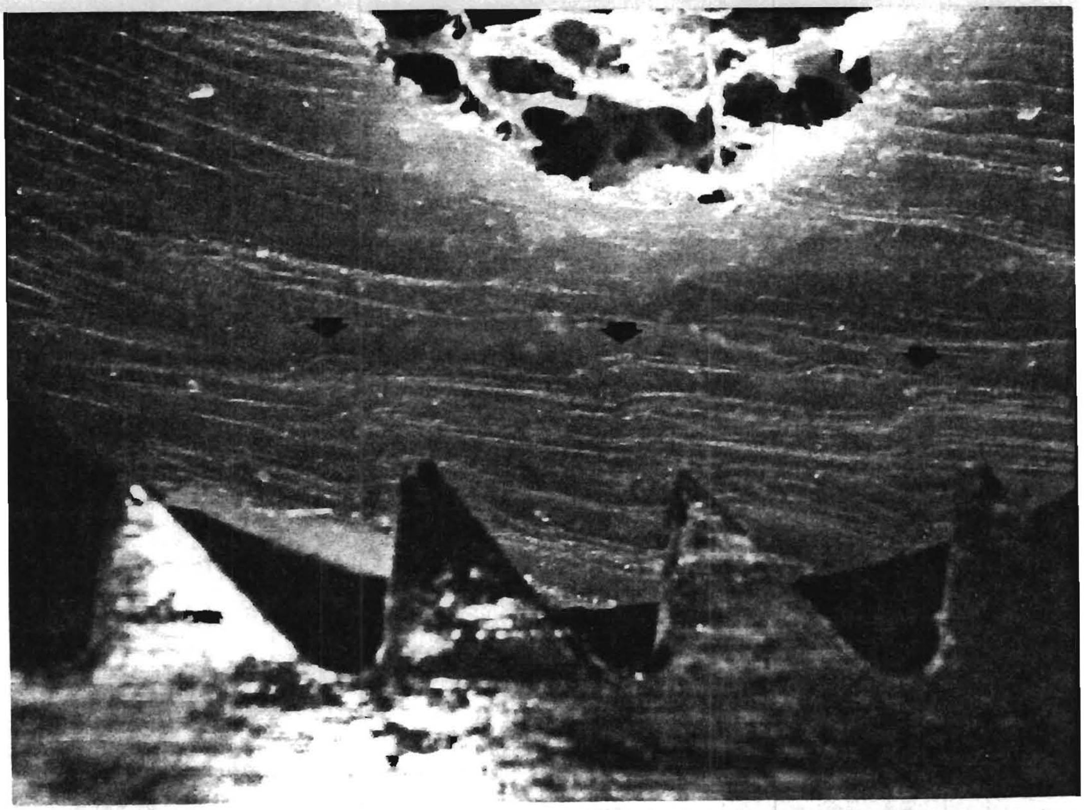


Figure V-31. Bone cross section exhibiting tooth hop (jumping striae), indicating distance between teeth of a blade 8 teeth per inch. This blade is from a power reciprocating saw, attached to a handle and hand powered.

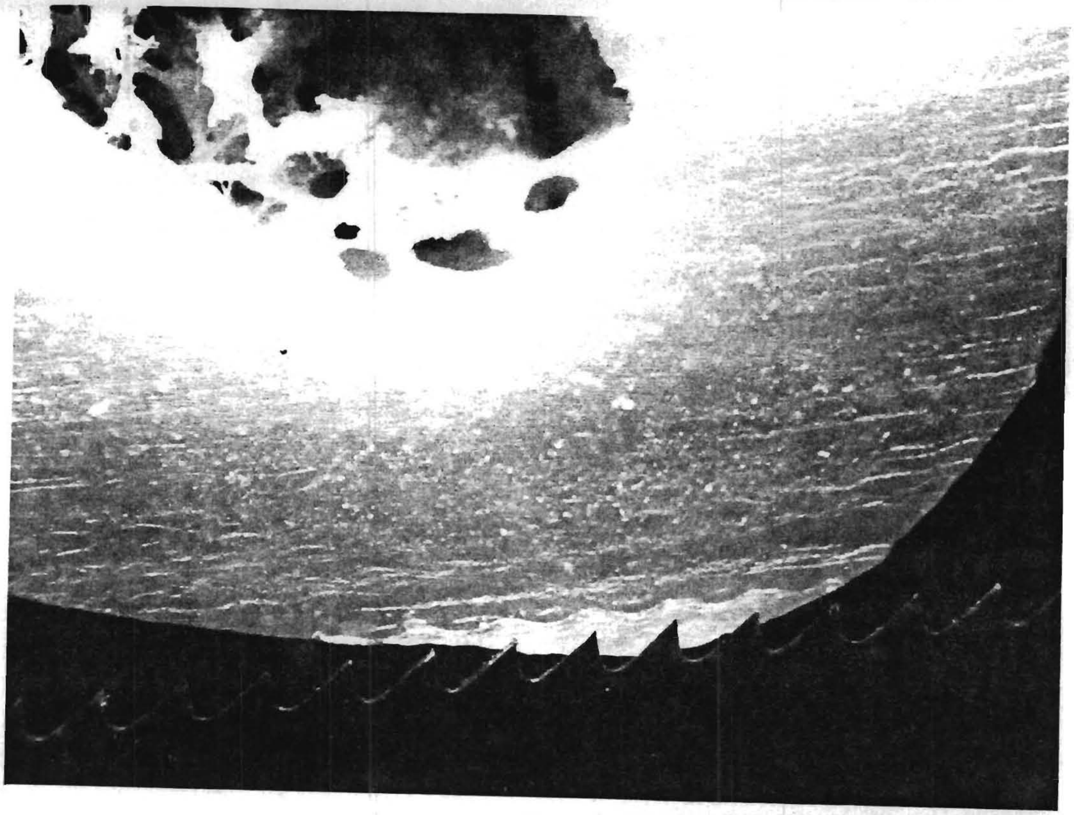


Figure V-32. Bone cross section exhibiting tooth hop (jumping striae), indicating distance between teeth of a blade 18 teeth per inch. This blade was removed from a power reciprocating saw, attached to a handle and powered by hand.

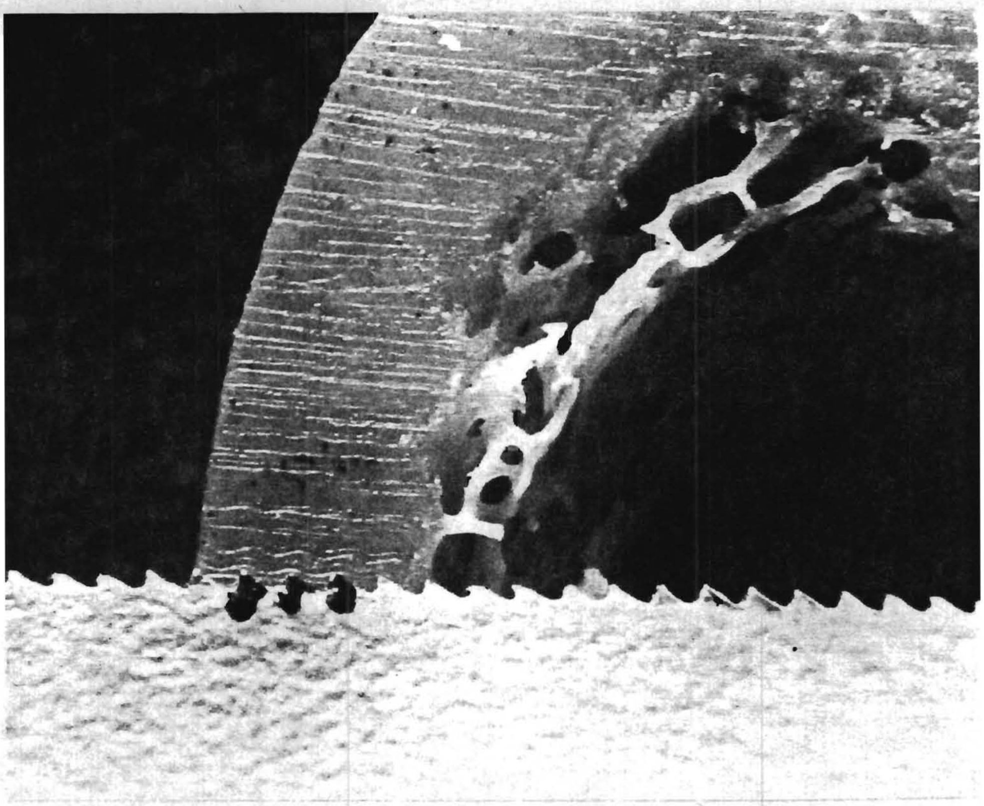


Figure V-33. Bone cross section exhibiting tooth hop (jumping striae), indicating the distance between even the smallest saw teeth. Numerous consecutive hops is recommended for improved accuracy. Cut made by a hacksaw with wavy set (32 teeth per inch).

Tooth Scratch

Tooth scratch is simply the presence of striae on the cut surface of the bone created when the saw is withdrawn from the kerf. This has been documented by Bonte (1975:319) as they appear "vertical to the sawing level which extend[s] over several saw marks . . .corresponds, with normally set saws, to twice the distance between the teeth." The term "normal" can be a misleading one. Figure V-34 illustrates tooth scratch found on one of the research bone cross sections. This patterned scratching is not twice the distance of a tooth but is the distance of three teeth since this saw is a raker set. Tooth scratch is a characteristic that should not stand alone, and should be used to corroborate other more reliable estimations of tooth distance.

Experimental cuts with serrated knives produced numerous scratches as the knife jumped out of the kerf etching the bone surface. These scratches, when measured parallel to the cutting

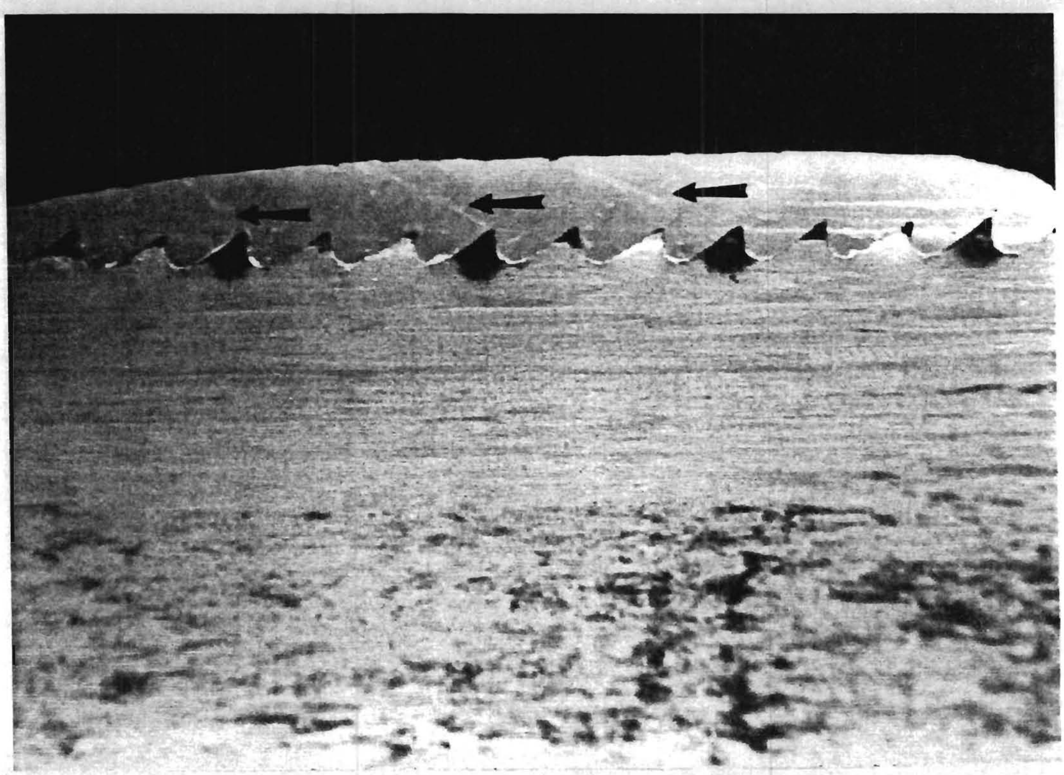


Figure V-34. Initial cut in bone with tooth scratch subtlely evident. Note that Raker hacksaw blade creating scratches retains two teeth between scratches rather than the assumed single tooth. This illustrates the weakness of tooth scratch as an accurate diagnostic characteristic for saw determination.

stroke appear to accurately represent the distance between a single tooth or the distance between the longest teeth in saws with variable length sets of teeth.

Harmonics

Saw mark harmonics are described in Figure V-35 as peaks and valleys exhibited on bone cross sections. Harmonics were initially described as "patterned oscillations" of high speed power saws, not necessarily found parallel to the direction of stroke (see power saw harmonics in Figure V-36). It was suggested that harmonics are created by defective saws or blades straying from the designed path, or essentially a by-product of blade wobble (Symes and Berryman 1989a). Closer examination of numerous cross sections of nearly 100 types of saws demonstrates that these early assessments are in error on two counts; 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.

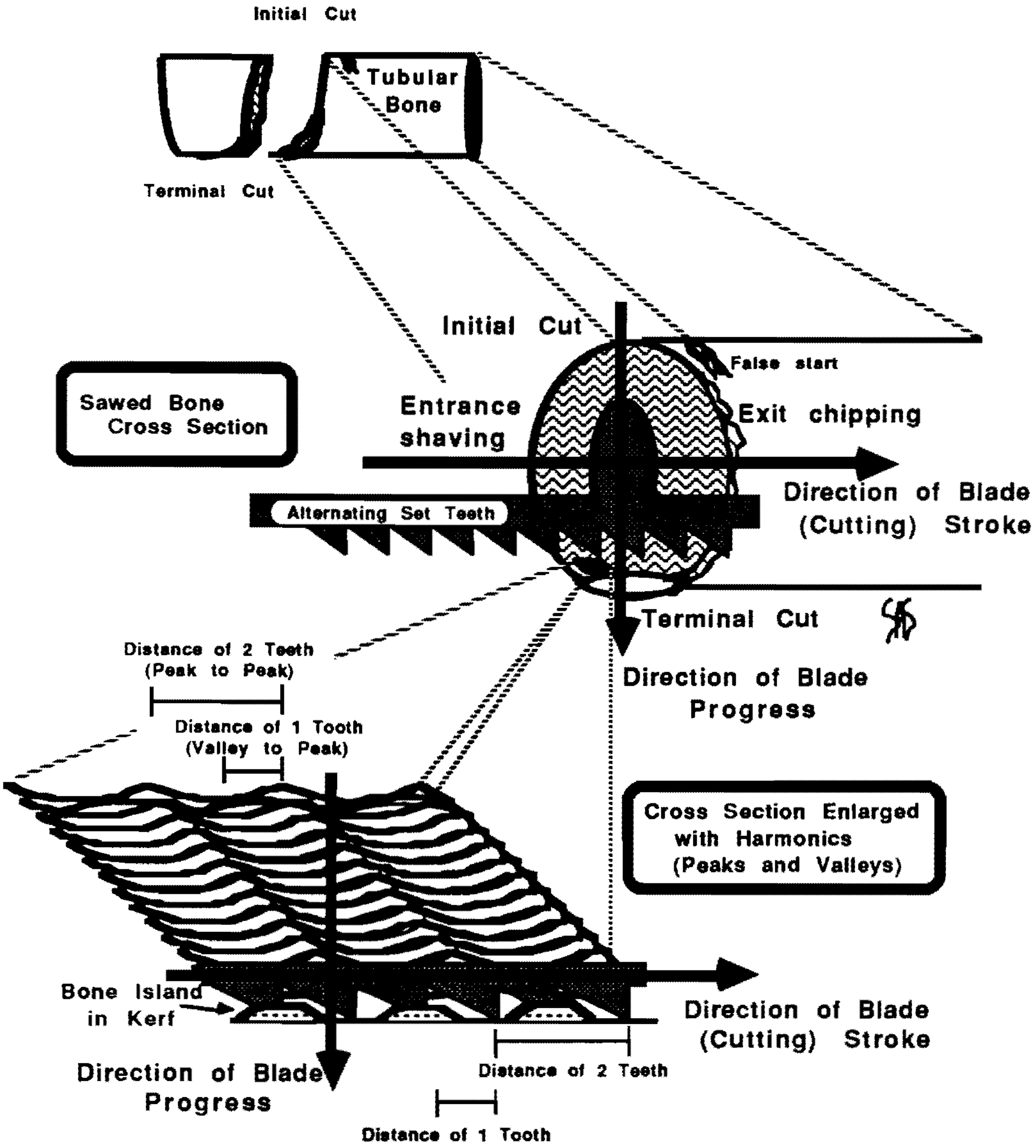


Figure V-35. Three images of a sawed bone. Cross sections identify typical features of saw tool marks and the enlarged cross section illustrates peaks and valleys of harmonics. The latter images demonstrate two types of saw cut direction, blade stroke and blade progress.

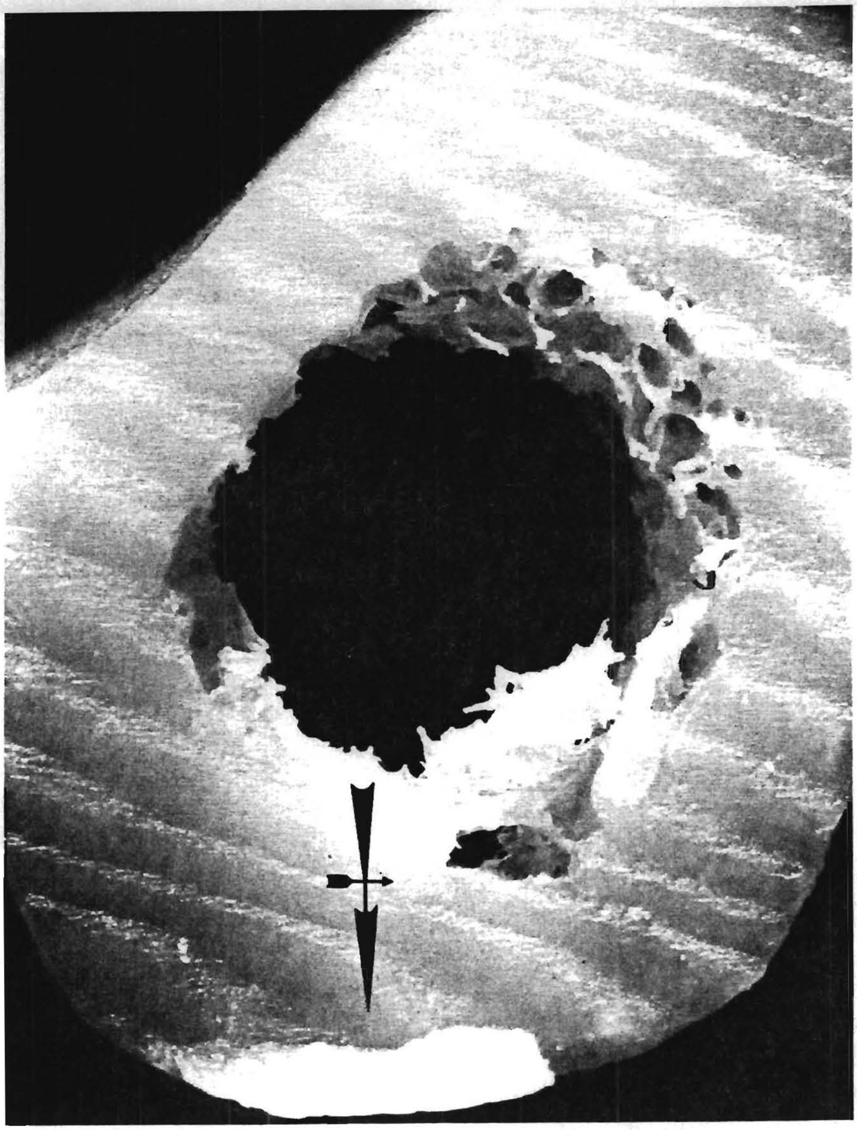


Figure V-36. This photograph illustrates accentuated harmonics on sectioned human tibia bone created by a power reciprocating saw blade (10 teeth per inch). Note how the harmonics are oblique to the direction of cutting stroke (left to right) and the direction of blade progress (top to bottom).

Harmonics are simply the expression of blade drift progress. This characteristic has been associated with certain saws in the literature, but little consideration has been given to the cause of this pattern:

> Band saws, like any other power saw, have certain peculiar traits that are characteristic of the saw and its method of operation. One of these is known as "washboarding," meaning that the blade leaves a characteristic mark in the surface of any wood it cuts. This may be slight or heavily pronounced, but a wavy pattern will be there no matter what is done. Some control over the amount of washboarding can be obtained through a choice of blades. The smoothest cuts are made possible by choosing a blade with minimum set, which will cut down on the washboard effect (Consumer Guide Editors 1978:105).

The editors's statement alludes to the cause of harmonics by stating that minimum set create reduced harmonics. This is a correct assumption since they are reflections of blade drift on the kerf floor, and wide to narrow aspects of blade drift are directly related to tooth set.

Up to now, blade drift has only been considered when examining false start floors, but the development of these features cannot be ignored as the blade progresses through the bone. It is the wide to narrow aspects of horizontal blade drift in kerf floors that form the peaks and valleys (washboarding) in cross section, where a peak in cross section corresponds to a wide aspect (or islands if present), and a valley corresponds to a narrow aspect of a floor. Since harmonics are a by-product of blade drift, they must also be directly related to the distance between teeth. Measurements of harmonics are identical to measurements of blade drift. Distance between peaks and valleys is equivalent to distance of two teeth (again see Figure V-35). Distance between direction changes, or in this case, between a peak and a valley, is the distance of one tooth. It is exceedingly important that these measurements are taken parallel to the direction of stroke, or on the same plane as the residual kerfs. Figure V-37 is a photograph of a human tibia sawed by a chef saw. This saw is classified as 11 points per inch or 10 teeth per inch. The rule in the photograph measures 0.2 of an inch from valley to valley, or 0.10 from valley to peak. This corresponds exactly to the distance of the saw teeth.

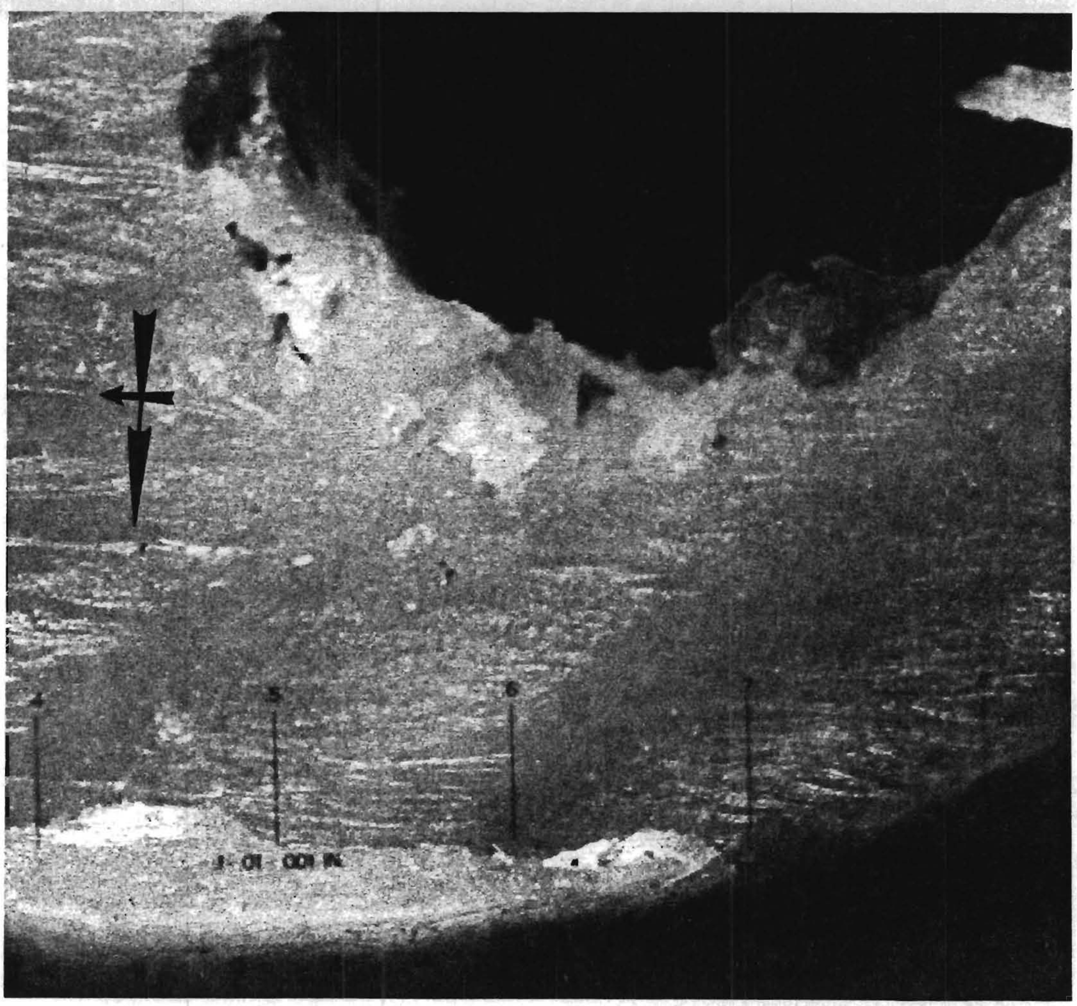


Figure V-37. Photograph of a human tibia sawed by a chef saw. This saw is classified as 11 points per inch or 10 teeth per inch. The rule in the photograph measures 0.2 of an inch from valley to valley, or 0.10 from valley to peak. This corresponds exactly to the distance of the saw teeth. Note that the direction of the cutting stroke is right to left.

Remember that blade drift is defined as occurring most frequently at initial or terminal aspect of the cut. This was attributed to the blade cutting little bone at this point, which allows the blade to drift. This is evident when examining numerous false starts made by the same saw but at different depths. In some instances, bone islands cease to be created because of the restriction put on the blade as it becomes immersed in material. This same principle applies to harmonics, in that they can usually be measured only at the initial cut or terminal cut. The widest portion of bone cross section generally has no harmonics, with a few exceptions.

Direction of Saw Cut

Establishing direction of cut on bones is feasible and contributory to crime scene investigation. However, "direction," when pertaining to saw marks, may be misleading unless clearly defined. Direction of cut indicates two separate saw actions, the direction of blade progress, and the direction of blade stroke

(Figure V-35). Direction of blade progress is the plane of advancement from the initial contact to the terminal cut. Direction of blade stroke is the direction of each stroke, whether it is passive or cutting. So direction of cut refers to the (1) direction that saws progressed to create kerfs or residual kerfs or (2) direction that continuous or reciprocating saw blades must take for a tooth to cut or chisel. Therefore the direction of stroke produces residual kerfs, while direction of cut is the saw progress, advancing perpendicular to residual kerfs.

Direction of Blade Progress

The most difficult aspect of determining accurate direction of saw cut, is allowing for all variables that influence saw actions. Indicators of direction of saw progress center on the false start and break away spur. Initial cuts are seldom perfectly devoid of stray striae (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 (See Figure V-35, middle figure, where the arrow indicating "Direction of Blade Progress" begins at the false start, or initial cut, and ends at the break away spur, or terminal cut.

Direction of Blade Stroke

Cutting stroke is defined as a continuous action or a single direction of a reciprocating action that produces a majority of the cut. If an equal force is applied to a reciprocating blade, the direction of stroke cutting or chiseling the most bone is the direction of the cutting stroke. Cutting stroke is determined by two variables. The primary variable (as discussed with Figure V-1) is tooth design. Most teeth are designed to bite material when moving in a particular direction. A secondary factor is sawing technique, which becomes evident when tooth design allows cutting in either direction, called here push/pull. Push/pull designed saw teeth are essentially peg teeth designed to take the same bite on the push or pull. Exit chipping may occur more frequently on one surface over another due to sawing technique, where the emphasis is placed on the push or pull.

Direction of cutting stroke may be indicated by numerous factors. The most universal, and easily qualified is entrance shaving and exit chipping. (Keep in mind here that the terms entrance and exit refer to blade stroke. Initial and terminal refer to blade progress). As the saw enters the side of the bone, the blade many times shaves the bone entrance to give it an almost polished and scalloped appearance. This shaving can be due to twisting of the saw such that the blade is not allowed a direct path into the kerf, but more often it is simply due to the tooth set being wider than the blade, forcing each tooth to cut a kerf. Seldom is there chipping as the tooth enters the bone, and if present, it is difficult to observe.

Exit chipping is variable in saw cuts, but is present with few exceptions. Even in saws designed with no front or back to the teeth (e.g. peg toothed pruning saw), exit chipping will occur on the side of the stroke emphasized by the individual sawing. In other words, if an individual is accustomed to using Western saws that generally cut on the more powerful push stroke, the push will be emphasized and chipping will be produced on the push stroke. Power circular saws appear to complicate these features somewhat by creating chipping on the initial aspect, the blade entrance edge and the exit edge. Again, the largest chips of bone are consistently removed on blade exit.

The autopsy saw will have exit chipping if the saw is being pushed along an edge of bone. If little pushing occurs and the saw is allowed to progress straight into the bone as it cuts, miniature chipping can occur on all edges.

Examination of bone on each end of the striae will reveal entrance shaving versus exit chipping and indicates direction of blade cutting stroke. Difficulties arise in the interpretation of these features. It is not possible to separate saw user preference versus the design of the saw. Since most saws do have a tooth designed to cut in a certain direction, pronounced chipping generally does indicate the direction of teeth exiting on the cutting stroke.

While the direction of the cutting stroke is detectable, it is still not possible for the examiner to determine positively that this occurs on the push stroke. Even though most Western saws historically have been designed to cut on the push stroke, saws exist that cut on the pull or that can be assembled to cut on the pull stroke. These primarily include pruning, Japanese, and any saw that allows the blade to be attached in either direction.

Even though the cutting stroke can be separated from the passive stroke, it is still not possible to indicate positively which stroke is the push or pull. The only exceptions to this may result from extenuating circumstances. Bonte (1975) discusses the diagnostic value of the handle hitting the material at the end of a stroke. While no evidence of saw handle impact was detected in this study, this would readily indicate the side the saw handle is located.

Examination of kerf floors also may give clues to cutting stroke direction. As teeth drift in the kerf, certain blade designs allow the formation of bone islands at the widest portion of drift. These islands, while quite symmetrical in appearance, do tend to begin abruptly on the formative edge, and are more tapered at the terminal end. This subtle pattern can be seen in Figure V-17 with close examination, where the islands form at the top and trail off at the bottom.

Harmonics have been discussed as the peak and valley by-product of blade drift. These features are not parallel to the direction of stroke or progress. Rather they can be visualized as a feature dependent on the direction of stroke and progress. Harmonics are oblique to each, but always progress from the initial to the terminal aspect of the cut, in the direction of the cutting stroke, as opposed to the passive stroke (see Figure V-37 where the direction of progress is top to bottom and cutting stroke direction is right to left).

Separating Hand from Power Saws

Introduction

Separating classes of saws by saw cut characteristics was attempted by Symes and Berryman (1989a). They used 12 characteristics coded present or absent and tested correlation between the groups with a single-linkage cluster analysis. The characteristics used in this study are listed in Table V-2. The results, duplicated in Figure V-38, indicated that power and hand saws, shared fewer characteristics between groups than within groups, suggesting that saw classes do differ in class characteristics of saw cuts.

Differences between hand and power saws can be examined in two ways. The first and most obvious differences occur because of manufacturer's design. Power saw blades are manufactured to accommodate added stress of torque, leverage and high speed. Therefore power saw blades are short in length and usually thicker with short teeth and smaller gullets. Since this design inhibits the creation of bone islands, no power saws in this study reliably created this feature except band and autopsy saws. These power saws are designed to efficiently saw hard material with the rare combination of thin blades with wide sets. Except for these two saws, power saws create no bone islands and can

Table V-2. Saw mark characteristic codes used to test differences between hand and mechanical powered saws in 1989.

Cut Characteristic	Coding With Brief Explanations

1. IMPACTED BONE DUST:
   - 0=absent
   - 1=present--Particles of bone deeply seated into cortical spaces or pores of lamellar bone.

2. RESIDUAL KERF DIRECTIONAL CHANGES
   - 0=multiple directions
   - 1=uniform direction

3. RESIDUAL KERF SPACING
   - 0=nonuniform--irregular spacing, frequently characterized by abrupt changes in kerf space across the cut surface
   - 1=uniform spacing--appear regularly spaced across the cut surface, or progressively increase or decrease
   - NOTE: if there is any doubt in uniformity, it must be nonuniform.

4. RESIDUAL KERF SHAPE
   - 0=straight
   - 1=curved--implies a radius
   - NOTE: unless it is obviously curved with a consistent radius, it must be considered straight

5. ENTRANCE OF CUT
   - 0=straight--no angulation from the sectioning plane
   - 1=beveled--distinct angulation from the sectioning plane at the point of entry, and distinguished from chipping by eburnation, i.e. "angled and eburnated"
   - NOTE: if not obviously beveled with eburnation, it must be considered straight

6. UNDULATION OF CUT SURFACE (HARMONICS)
   - 0=non-undulating or non-uniform undulations
   - 1=uniform undulations in a parallel pattern
   - NOTE: if patterning is questionable, it must be considered non-uniform

Table V-2. (continued).

Cut Characteristic	Coding With Brief Explanations
7. EBURNATION	
	0=absent
	1=present
	NOTE: If eburnation is not obvious and predominant, it is considered absent
8. CORTICAL SURFACE CHIPPING	
	0=absent
	1=present--repetitive confluent, adjacent chips removed
9. LIPPING	
	0=absent
	1=present
	NOTE: lipping is absent if not obvious
10. KERF FLOOR	
	0=flat
	1=curved or stepped
11. PAINT CHIPS	
	0=no paint
	1=paint flakes
12. CURVATURE OF BONE ALONG THE PLANE OF THE SAW	
	0=no curvature (flat cut)
	1=noticeable curvature on cut surface (not flat under straight edge)

Source: Symes, Steven A. and Hugh E. Berryman, 1989a, Dismemberment and mutilation: General saw type determination from cut surfaces of bone. Paper presented to the 41st Annual Meeting of the *American Academy of Forensic Sciences*, Las Vegas, NV.

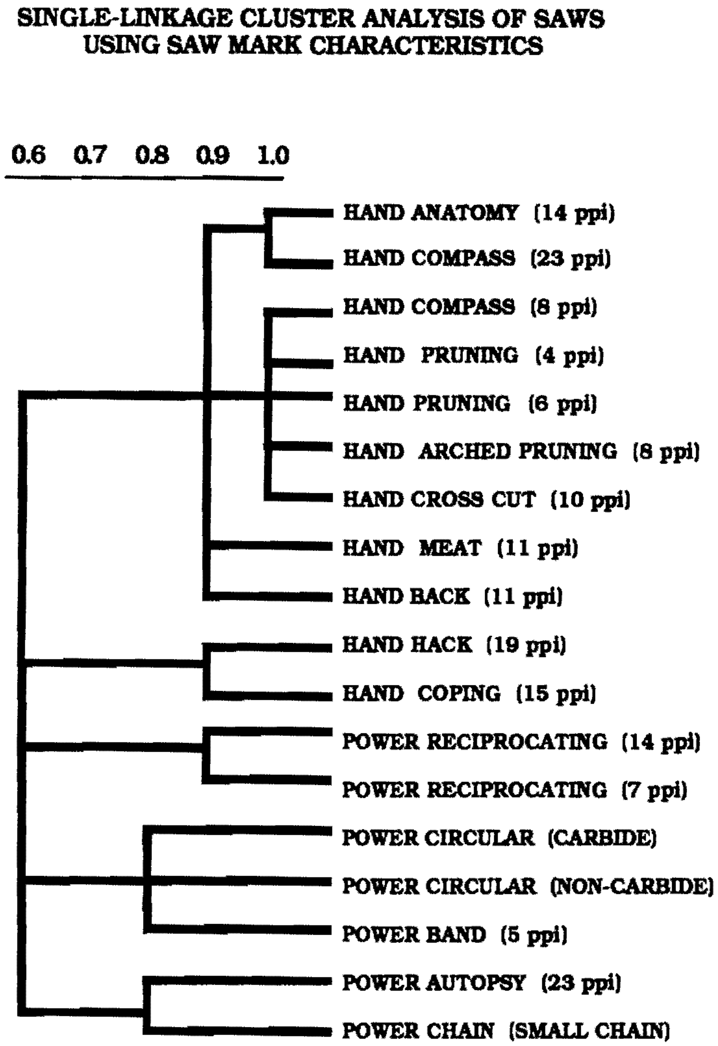


Figure V-38. Duplicated handout from Symes and Berryman (1989) illustrating attempts to classify hand versus powered saws based on 12 discrete characteristics.

Source: Symes, Steven A. and Hugh E. Berryman, 1989a, Dismemberment and mutilation: General saw type determination from cut surfaces of bone. Paper presented to the 41st Annual Meeting of the *American Academy of Forensic Sciences*, Las Vegas, NV.

be expected to cut a wide kerf with a Class B or D shape (Figure V-1), and are limited in reach.

A more valuable method of separating power from hand saws, other than by examining kerf size and shape, is by the examination of blade action. Power saw blade action is evaluated by consistency of cut, elevated energy transfer, and an increase in material waste.

Consistency Of Cut

Consistency of cut is anticipated in continuous cut 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 of cut is difficult to describe or measure, but easily illustrated. Figure V-39 is a cut created by a power reciprocating saw with a wavy set blade. This photograph illustrates the patterned effect to the cut and an increase in polish. The bone in Figure V-40 is a power reciprocating saw cut with an alternating set blade, 7 teeth per

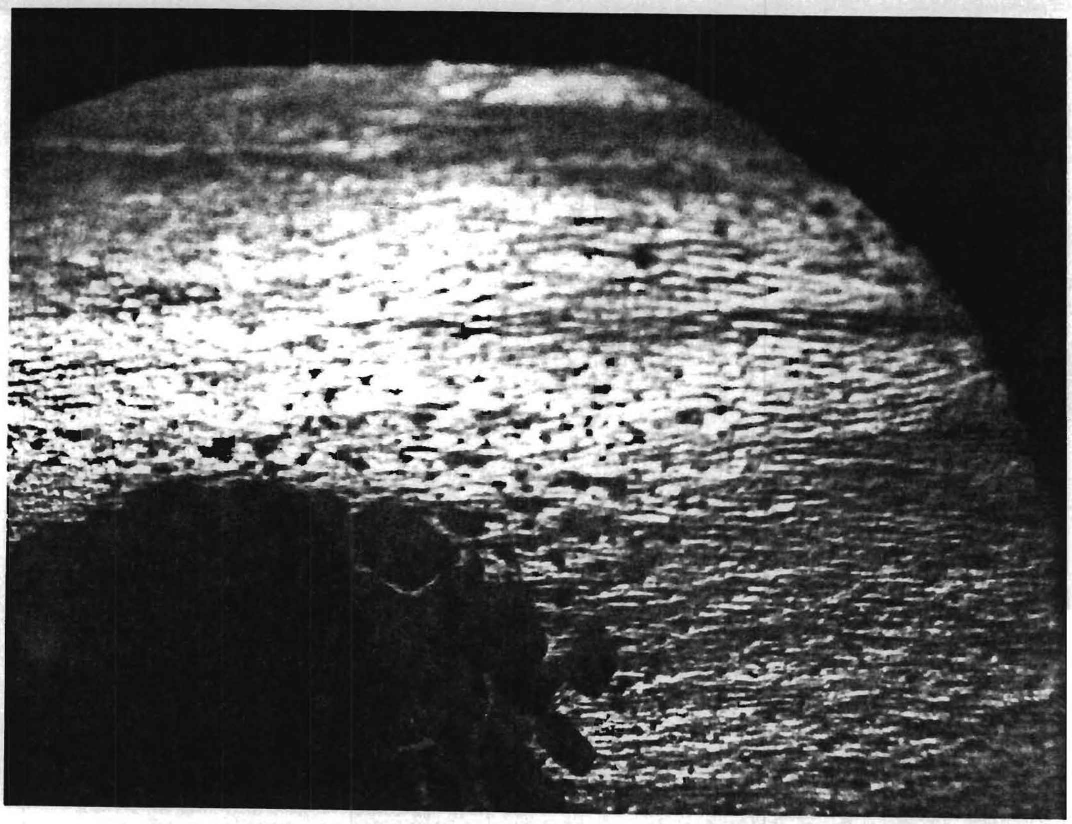


Figure V-39. Cross section of human femur cut with a power reciprocating saw with a wavy set blade (18 teeth per inch). Notice the striae patterning and accentuated polish typical of wavy set blades and power saws.

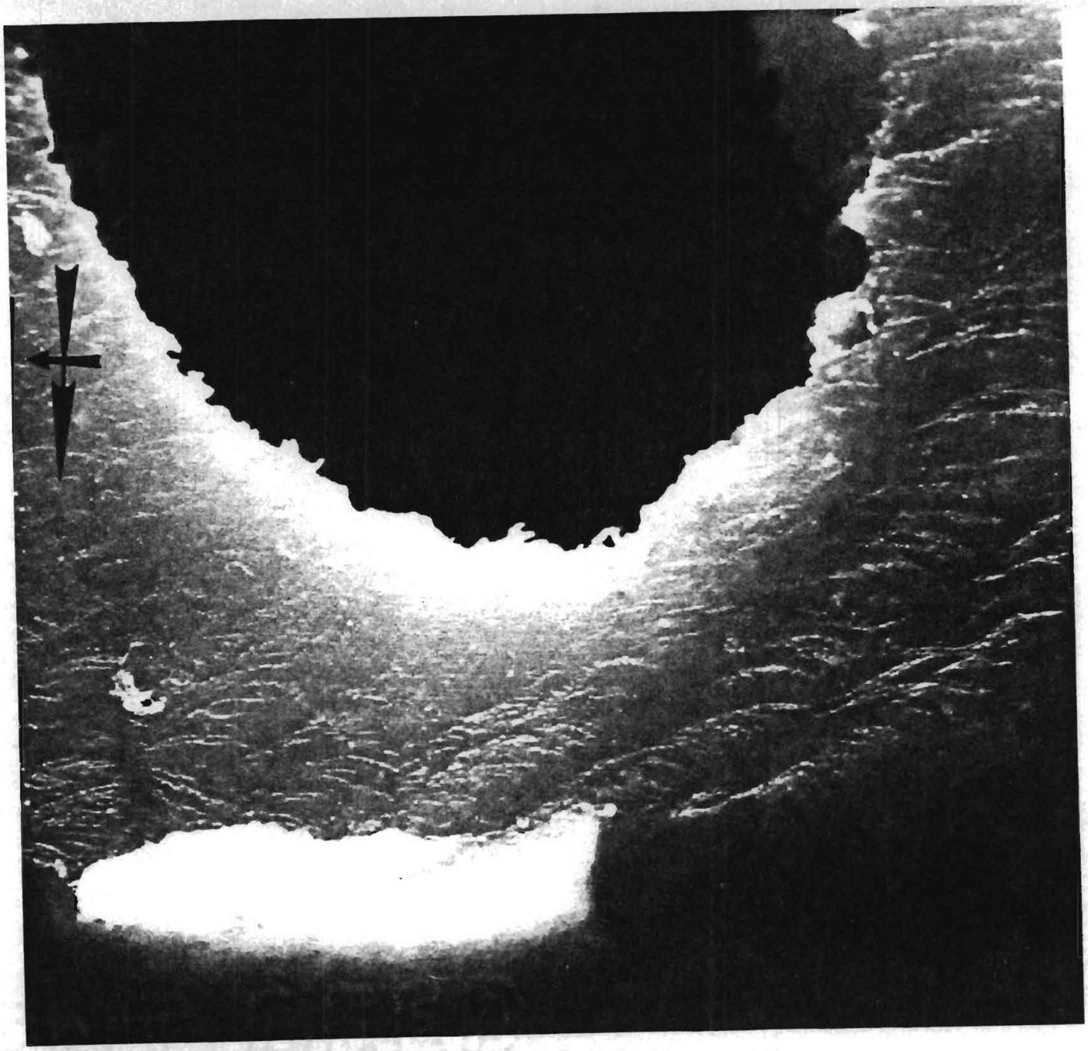


Figure V-40. Cross section of human femur cut with a power reciprocating saw with an alternating set blade (7 teeth per inch). Notice the tooth hop striae patterning and harmonics.

inch. Close examination reveals a patterned tooth hop striae and patterned harmonics across the face of the bone. Stroke striations are essentially missing in power reciprocating saws since the length of stroke is just over an inch, and may not be long enough for the saw to establish a recognizable pattern before the direction is reversed. Figure V-36 is another example of a power reciprocating saw cut. While each is unique, all demonstrate a remarkable consistency of cut. This consistency is established and retained across the face of a cut. Any changes in patterns should be gradual except where the progress of the cut is stopped, then resumed.

Increased Energy Transfer

Increased energy transfer of power saws is due to increased tooth speed, saw weight, and torque. Initial cut areas on bone are commonly marred by scratches where the saw is working at high speeds but not actually getting a big enough bite on the material to create a kerf. High speeds also create an increased frequency of false starts. It is common to inadvertently jump out of the kerf while sawing. If this occurs with a handsaw, it is a natural reaction to attempt to reinsert into the established kerf and continue cutting. However, when cutting with power saws, so little energy is expended by the individual sawing, it may be easier to create a new cut rather than attempt to find the original kerf.

Despite the number of false starts, the direction of progress of cut appears uniform in power saws. These saws continue to cut as long as pressure is applied. Hand saws require pressure and reciprocating motion, all supplied by the user. Power saws should reveal more uniform cuts since pressure is easily applied without combining reciprocating motion.

Increased weight and leverage in cut bone may be indicative of power saws. Weight of a hand held circular saw, or leverage that can be applied with a chain or a power reciprocating saw blade that is 8 to 20 inches in length, is often reflected by large exit chipping (produced when the front of a tooth exits the material), and large break away spurs. Increased weight and leverage also produce larger break away spurs and notches. This occurs as the bone structurally gives away to pressure rather than allow teeth to cut the bone completely. Break away spurs and notches appear large in chain saw cuts.

Another indicator of energy transfer is torque. Torque is responsible for bone eburnation; accentuated polish and burning of material through friction. Polish is created by obliterating residual characteristics of the original cut through extended contact of the blade to the bone. This contact may be due to a lack of set, high speed blade movement, blade bending in the kerf, blade binding, or any combination of these. Power saws, with increased speed and torque can eburnate bone if any of these factors occur for an extended time.

Material Waste

Power saws are generally characterized as wasteful of material. This may be accredited to the stout blade design or the "ease" of producing a cut. If power saw cuts are produced with little energy expended, it is likely that more cuts are produced and more material is wasted.

Criminalistics also consider sawdust comparisons a valuable diagnostic characteristic of saw mark analysis (see Bonte 1975:318; Guilbeau 1991). While sawdust was not compared or analyzed in this study, greatest obvious differences in dust appears when comparing hand to power saws. Increased speed greatly influences sawdust production since teeth bite less material for the same amount of pressure applied, but more often. Therefore, in general, high speeds create finer sawdust.

Type Characteristics of Saw Marks

This research has dealt exclusively with class characteristics of saws expressed on cut marks. Type characteristics are considered rare and of limited value (California Department of Justice Firearms/Toolmark Identification Training Syllabus 1991:582). Positive identification of saw marks involves the comparison of unique features resulting in sufficient agreement. Positive identification of a particular saw from tool marks is difficult for a number of reasons. Saws by definition have teeth or interruptions in a blade. Saw marks are classified as striated tool marks where one object rubs over another object (AFTE Criteria for Identification 1990:276). A saw blade creates tool marks similar to many miniature tools rubbing over the same area where each proceeds to destroy previous features.

Unique characteristics of saw cuts have been suggested to be limited to damaged or extremely worn saws, creating unusual and unique characteristics (Bonte 1975). Examinations of new saw blade cuts on bone revealed few patterns that could be classified as unique. Most unusual features generally were related to improper manufacturing techniques and therefore were not considered a type characteristic.

Andahl (1978) also examines the possibility of matching paint residues left on the material from new blades. Paint found on a cut bone is indicative of a new blade while the color may enable the observer to narrow the possibilities of what saw blade was used. Figure V-41 is a sectioned bone cut with a new

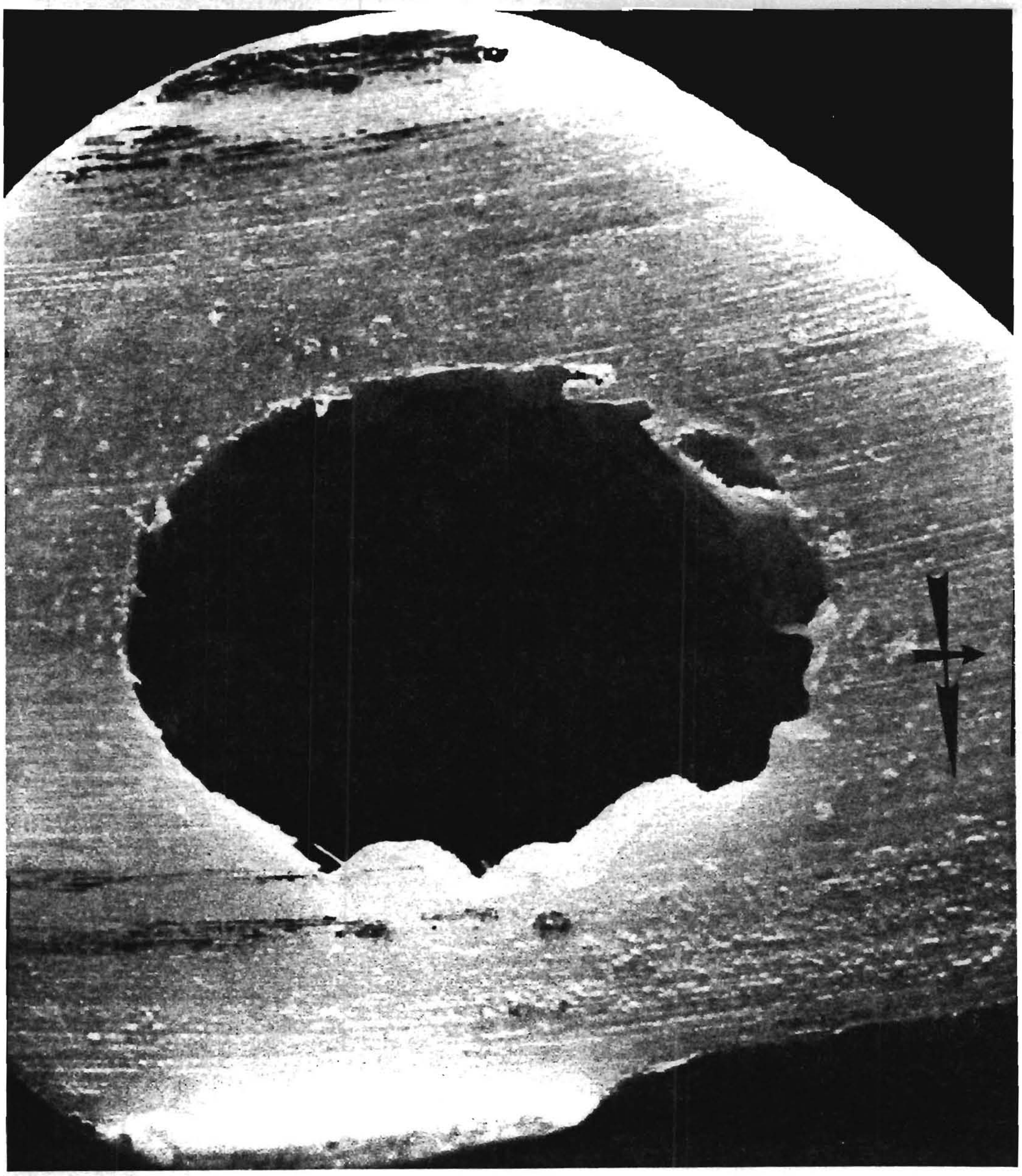


Figure V-41. Sectioned bone cut by a new painted power circular saw blade. Large arrow indicates direction of saw progress while the small arrow indicates cutting stroke direction. Note the gray paint residue retained on the bone from the saw blade.

circular saw blade painted gray. While paint residue does limit the possibilities of saw subclass or types, it is still considered a class rather than a type characteristic.

CHAPTER VI

INTERPRETATION

Introduction

Saws selected for this study are essentially a sample of saw subclasses and types. These saws fit at least one of two catagories, those that are readily available and affordable to the general public, and those that have potential to be used in a forensic setting, i.e. for cutting tissue and bone.

This chapter will build on earlier chapters by applying principles of sawing action (Chapter IV) and examining the classifying characteristics (Chapter V) of individual saws in this study. This should allow the reader to apply much of this information to similar types of saws not specifically examined in this research. Tables III-1 and V-1 contain specifics on saws and saw cuts examined in this study. Specific information from each of these will be summarized at the beginning of each subclass or type of saw, along with unique or unusual information (in italics) that specifically applies to that saw. These abbreviated saw action specifications and saw cut characteristics will serve as a quick cross reference to the examiner attempting to obtain information on a specific saw. Saws are listed similarly to the overall saw classification outline in Table II-1 and follow the same order as Table III-1. Cross reference data will be followed by a brief summary of information that may make that specific saw unique or unusual. Kerf width refers to minimum kerf width and all teeth sizes listed below (unless otherwise stated) are in teeth per inch for consistency. All measurements listed are in inches.

Open Saws

"Crosscut" Carpenter Saws

<u>Saw Specifics</u>		<u>Saw Cut Specifics</u>	
Set:	alternating	**Kerf Class:**	*B* 

TPI:	6.0 & 7.0	**Minimum Kerf Width**:	0.06
Tooth Distance:	0.14 & 0.17	**Blade Drift in Kerf:**	yes
Tooth Type:	*chisel*	**Cut Surface Drift:**	yes
Cut Direction:	push	**Exit Chipping**:	yes
Power:	hand	**Harmonics:**	occasionally

The two saws examined in this study are similar in construction, differing only in quality, where one saw is standard quality and the other is premium quality, signified by differences in wood and steel quality and craftsmanship.

The primary distinction of crosscut saws in definition (see Figure II-1) is that the teeth are sharpened at an angle (see for example Cunningham and Holtrop 1974:73-75, Jackson and Day 1978:76; Stanley Tool Guide, No date) . This sharpening creates a distinctive Class C (Figure V-1) kerf cross section and makes this type of saw quite diagnostic from rip saws. Other identifying characteristics of crosscut saws include size (7 to 8 PPI) and tooth shape (reduced rake angle).

The "crosscut" saws examined here fit the appropriate tooth size and raker angle for crosscut saws, but each lack angled filing on the front of the teeth (Figure VI-1). Each produce a kerf cross section of Class B, typical of rip sharpened saws. In any case, these saws are classified as crosscut by their manufacturers. This discrepancy should be recognized and this should be a reminder to examiners that saw cuts exhibiting rip saw features may still be identified as crosscut by manufacturers. "Crosscut" saws are characterized by deep striae in cross section with recognizable stroke and tooth striae. Problems may arise with these saws using floor dip as a measurable feature for determining tooth distance. Figure VI-2 illustrates what appears to be two separate patterns of dip in the kerf, where the larger pattern is the actual representation of the tooth points digging into the material. No conclusive explanation of this discrepancy can be given. It is possible that these large teeth are also cutting on the return stroke, creating dips on the return stroke. These theoretical "return stroke dips" are shallow

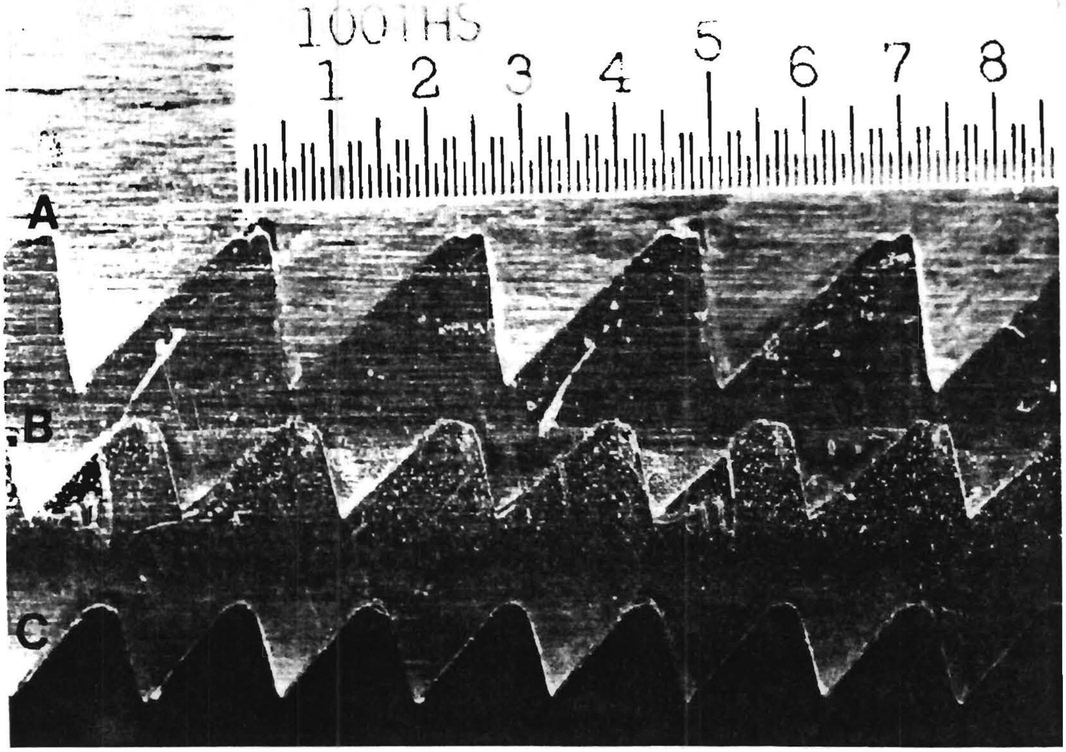


Figure VI-1. Photograph of three saw blades with blade A being a rip saw (5.5 points per inch), B is a premium quality "crosscut" (7 points per inch), and C is a standard quality "crosscut" (6 to 7 points per inch). While B and C differ from the top rip saw in tooth size and shape, all saws have 90 degree filing on the front of the tooth.

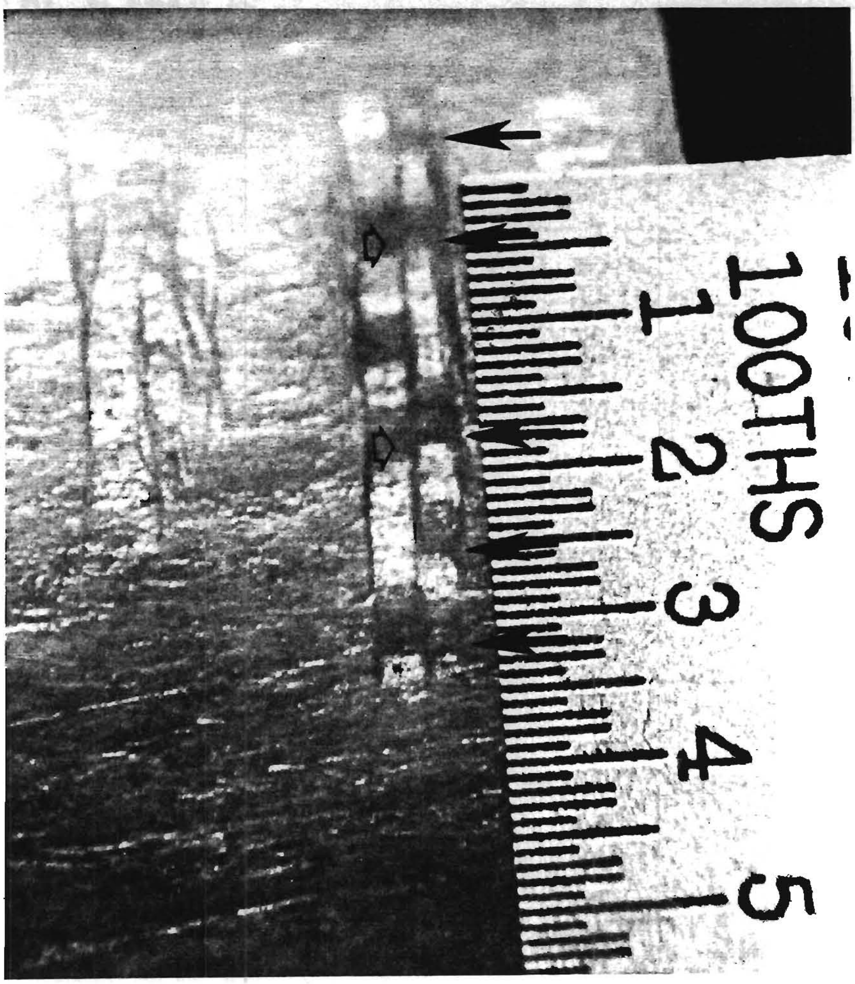


Figure VI-2. Photograph of kerf floor dip patterns created by a carpenter saw, 6 teeth per inch. The right (black) arrows point to all dip characteristics along the border of this kerf. The outlined arrows on the left point to the actual floor dip registering distance between teeth (0.17 of an inch). This demonstrates the potential error that can occur when attempting to assess distance between teeth with floor dip.

and do not obliterate the existing dips, but rather blend in or double the number of dips per inch. The teeth may also be hopping out of the kerf prematurely where the blade is essentially skipping across the bone surface or biting the bone at an angle. Floor dip, especially with this type of saw needs to be regarded with caution, and should be used with other measurable features to corroborate the distance between teeth.

There is the possibility of black paint from a labeled saw being retained on a cut surface.

Rip Saw

Saw Specifics		**Saw Cut Specifics**	
Set:	alternating	**Kerf Class:**	B 
TPI:	4.5	**Minimum Kerf Width:**	0.05
Tooth Distance:	0.22	**Blade Drift in Kerf:**	yes
Tooth Type:	chisel	**Cut Surface Drift:**	*yes*
Cut Direction:	Push	**Exit Chipping:**	yes
Power:	hand	**Harmonics:**	*occasionally*

Bone islands appear on kerf floors although determination of direction of cutting stroke by looking at bone islands is difficult. This saw is characterized by large teeth producing large exit chips. Blade drift and harmonics are recognizable, even in this large toothed saw.

Since manufacturer's "crosscut" saws have been shown to actually have rip shaped teeth, caution must be used in attempts to separate rip from crosscut saws. There is the possibility of black paint from a labeled saw being retained on a cut surface.

Backed Saw

Saw Specifics		**Saw Cut Specifics**	
Set:	alternating	**Kerf Class:**	B
TPI:	11.0	**Minimum Kerf Width:**	0.06
Tooth Distance:	0.09	**Blade Drift in Kerf:**	yes
Tooth Type:	chisel	**Cut Surface Drift:**	*accentuated*
Cut Direction:	push	**Exit Chipping:**	yes
Power:	hand	**Harmonics:**	yes

There is remarkable surface drift. This may be attributed to the design of the saw, where file handled saws in this study appeared to show more surface drift. This backed saw also exhibits deceptive floor dip. Once again, floor dip measurements indicate a tooth distance of half the real measurement, requiring caution for this characteristic.

There is the possibility of black paint from a labeled saw being retained on a cut surface.

Dove Tail

Saw Specifics		Saw Cut Specifics	
Set:	alternating	**Kerf Class:**	B
TPI:	14.0	**Minimum Kerf Width:**	0.04
Tooth Distance:	0.07	**Blade Drift in Kerf:**	yes
Tooth Type:	chisel	**Cut Surface Drift:**	accentuated
Cut Direction:	*push/pull*	**Exit Chipping:**	*yes*
Power:	hand	**Harmonics:**	yes

This specialty saw is designed for detailed cabinet work. Because of this emphasis, it cuts equally well on the push or pull stroke. In other words, these teeth are peg shaped and are not designed or sharpened to cut more efficiently in either direction. Even with this design, bone sawed with this instrument exhibit entrance shaving and exit chipping. As mentioned above, this is an example of exit chipping due to individual sawing technique, where the person sawing prefers to emphasize, in this case, the push stroke.

The dove tail saw analyzed in this research is on the large end of the scale for this type of saw (14 TPI) where Table II-1 lists saws of this type as falling in the range of 15 to 21 *points* per inch. Dove tails with smaller teeth will likely behave similarly to fine toothed bow saws. This has been confirmed by the observation of an occasional rounded kerf floor corner.

While no dove tail saws were witnessed to have painted labels on the blade, it is likely that some brands of this saw can leave black paint on a cut surface.

Pruning Saws

Arched Pruning Saws

<u>Saw Specifics</u>		<u>Saw Cut Specifics</u>	
Set:	alternating	**Kerf Class:**	C 
TPI:	6.0 & 7.0	**Minimum Kerf Width:**	0.08
Tooth Distance:	0.17 & 0.14	**Blade Drift in Kerf:**	yes
Tooth Type:	cut	**Cut Surface Drift:**	yes
Cut Direction:	*pull*	**Exit Chipping:**	*yes*
Power:	hand	**Harmonics:**	occasionally

Typical of large toothed saws is the common occurrence of numerous false start striations where there is difficulty in getting a kerf started. Kerf floors immediately indicate Class C (crosscut) shape with a wide to narrow pattern indicating distance between teeth (Figure VI-3). There is the possibility of black paint from a labeled saw being retained on a cut surface.

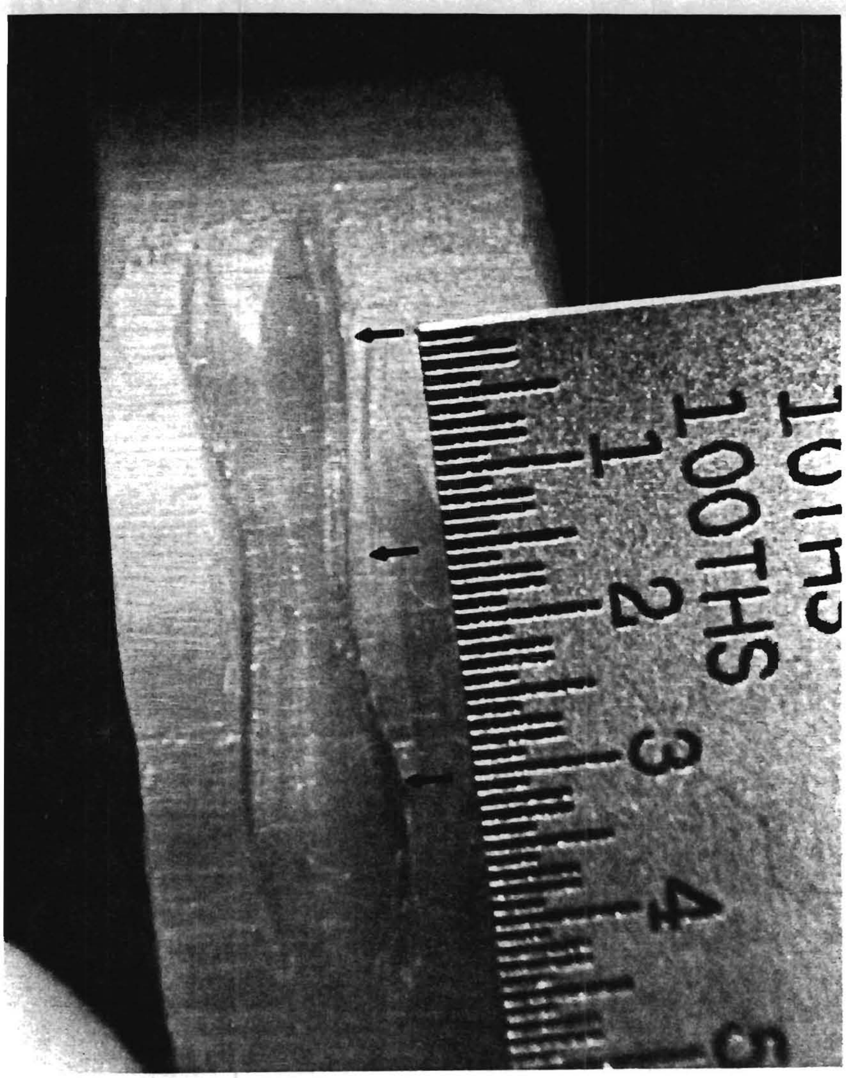


Figure VI-3. Photograph of false start in human bone created by arched pruning saw (7 teeth per inch). Note the Class C (convex floor cross section) indicating crosscut filing of saw teeth. Arrows indicate wide to narrow to wide aspects of kerf allowing accurate determination of distance between teeth (0.14 of an inch).

These large toothed saws also leave characteristic patterning of tooth striae. These striae may produce a slightly bending contour due to the arched shape of the blade, but this is so gradual that it is difficult to see, much less quantify.

These residual kerfs, at first appearance, are a confused shuffle of striae, with seemingly no definable pattern. But closer examination reveals a somewhat predictable configuration, where the shape of striae change as the saw progresses through tubular bone. The initial aspects of this large toothed saw as it cuts through tubular bone revel wavy striations characteristic of large toothed saws. As the cut progresses into the marrow cavity, the saw encounters two narrow pillars of bone, so instead of teeth traveling through a long flat kerf, these large teeth encounter these individual pillars of bone. This bone is often narrower than the distance of two saw teeth, thus the teeth are raking this material as they bounce over the pillars. This bouncing or patterned shuffle is visible in Figure VI-4 where the

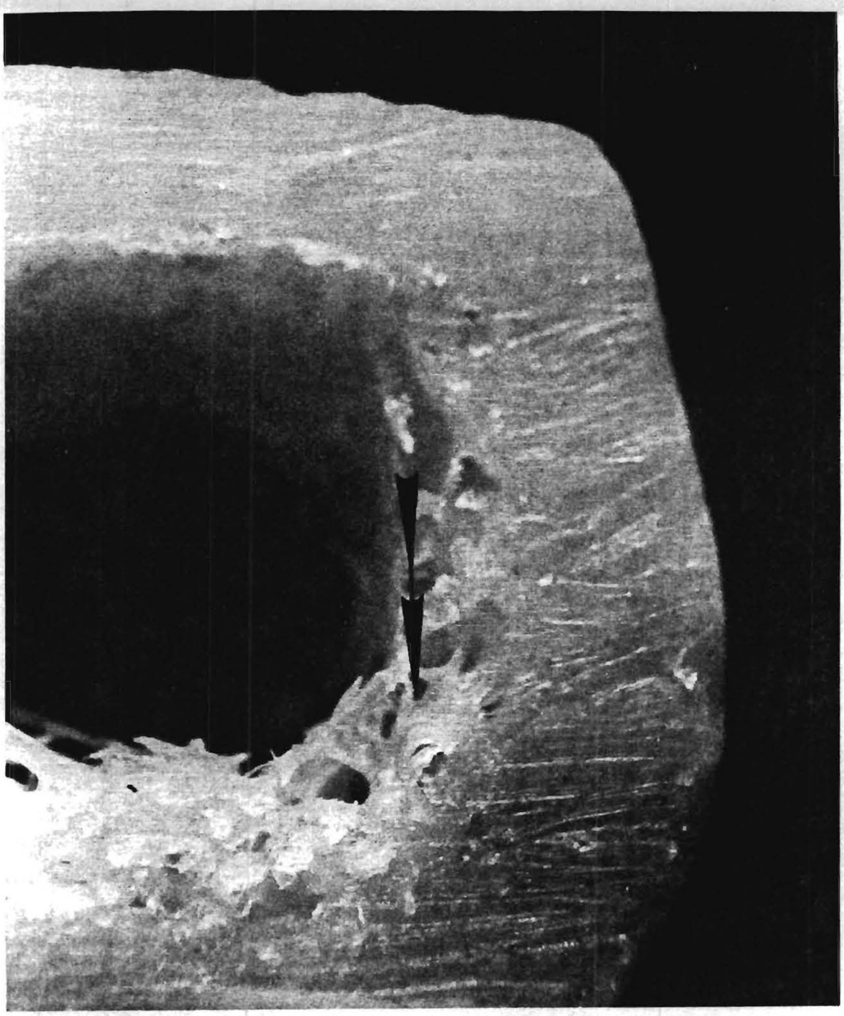


Figure VI-4. Illustration of sawed bone cross section created by an arched pruning saw (7 teeth per inch). Large arrow indicates direction of cut progress. Notice the patterned shuffling appearance at the level of the marrow cavity as the large teeth hop over these narrow aspects of bone. Striae are straight or wavy at the initial (top) and terminal (bottom) aspects of the saw cut.

striae are wavy at the top and bottom, but hop at the level of the marrow cavity. Keep in mind that this raking pattern is quite unpredictable since there are two pillars of bone at this level of cut for these large teeth to encounter. Accentuated raking at the level of the marrow cavity may also produce increased exit chipping as the saw seems to require more power to continue the progress through the bone. Guilbeau (1989:21) suggests that this chipping will be evident on the inner marrow cavity as well as the exit area of the cortex.

Frame Saws

Buck Saw: Peg and Lance Toothed

<u>**Saw Specifics**</u>		<u>**Saw Cut Specifics**</u>	
Set:	alternating	**Kerf Class:**	*C* 
TPI:	4.0	**Minimum Kerf Width:**	*0.04 & 0.10*
Tooth Distance:	0.25 & 0.33	**Blade Drift in Kerf:**	yes
Tooth Type:	cut	**Cut Surface Drift:**	accentuated

Cut Direction:	push/pull	**Exit Chipping:**	yes
Power:	hand	**Harmonics:**	yes

These frame saws are designed for cutting green logs. Frame saws are designed to put tension on the blade to allow a narrower blade. Note that these frame saws are consistently 0.03 of an inch thinner than pruning saws. Therefore, minimum kerf widths range as narrow as 0.04, but because of these teeth being long and thin, they can distort to form a kerf 0.10 of an inch.

The lanced tooth saw is essentially identical to the peg toothed saw except for every fifth tooth is a raker tooth. Each saw has a Class C kerf cross section but the lance toothed saw may exhibit the truncated forms of kerf floor (see Figure V-1, Class C, variants 2 and 3).

Note that these teeth are even larger than those of pruning saws mentioned above. Therefore the patterned shuffle discussed for arched pruning saws also applies to these bow saws, where a different shape of striae appears at the level of the marrow cavity as opposed to the initial and terminal aspects.

There is the possibility of black paint from a labeled saw being retained on a cut surface.

Fine Toothed Bow and Open Saws

Coping Saw (FTBS)

Saw Specifics		Saw Cut Specifics	
Set:	alternating	**Kerf Class:**	A
TPI:	16.0	**Minimum Kerf Width:**	0.04
Tooth Distance:	0.06	**Blade Drift in Kerf:**	yes
Tooth Type:	chisel	**Cut Surface Drift:**	*minimal*
Cut Direction:	*push or pull*	**Exit Chipping:**	yes
Power:	hand	**Harmonics:**	yes

Alternating set blades in FTBS react in bone similarly to larger saws, only on a smaller scale. Crosscut shape and filing is not present in these saws since they have such small teeth.

Coping saws are designed to cut around corners and are therefore used for various small carpentry projects and to cut scrolling and fretwork on instrument sounding boards (Consumer

Guide Editors 1978:39). This blade can be mounted to cut on the push or pull, depending on the project.

Even though the coping saw is designed to cut on the curve, this saw produced 10 cuts in this study that had very little cut surface drift. Potentially this saw should be able to change directions in mid cut.

Label markings are evident on the bone when using a new blade.

Hack Saw (Alternating Set)

<u>Saw Specifics</u>		**<u>Saw Cut Specifics</u>**	
Set:	alternating	**Kerf Class:**	A
TPI:	18.0	**Minimum Kerf Width:**	0.03
Tooth Distance:	0.06	**Blade Drift in Kerf:**	yes
Tooth Type:	chisel	**Cut Surface Drift:**	minimal
Cut Direction:	push	**Exit Chipping:**	yes
Power:	hand	**Harmonics:**	no

Alternating set hacksaws of all sizes exhibit tooth drift in the kerf. When viewing the surface entrance of the kerf, there is patterned bending of the entrance edge to form the wide to narrow pattern as described for larger saws. Cross sections are again similar to alternating saws with larger teeth, exhibiting stroke and tooth striae. Fine toothed bow saw patterning is miniaturized due to the small teeth. The pattern produced in the floor of a kerf by a hack saw, for example, is metrically less than half the size of a typical crosscut carpenter handsaw.

The key to alternating hacksaw identification is features that are small yet identical to larger alternating saws. Hacksaws are found with different colors of paint and black labels. This coloring can possibly be retained on a cut surface.

Hack Saw (Raker Set)

Saw Specifics		**Saw Cut Specifics**	
Set:	raker	**Kerf Class:**	A 
TPI:	18.0	**Minimum Kerf Width:**	0.04
Tooth Distance:	0.06	**Blade Drift in Kerf:**	no
Tooth Type:	chisel	**Cut Surface Drift:**	*minimal*

Cut Direction:	push	**Exit Chipping:**	yes
Power:	hand	**Harmonics:**	*no*

The initial entrance of the false starts when viewed superiorly is extremely straight. Kerf corners are similar to alternating set hack saws. Wide to narrow patterns of the kerf are all but invisible. There may be an occasional bend in the entrance edge but it does not appear symmetrically patterned. This creates an extremely straight sided kerf. Kerf cross section shape appears to be more concave than that of any other fine toothed saw, although this is difficult to measure. Cross section patterns consist primarily of stroke striae with tooth striae difficult to visualize.

Hacksaws are found with different colors of paint and black labels. This coloring can possibly be retained on a cut surface.

Hack Saw (Wavy Set)

<u>**Saw Specifics**</u>		<u>**Saw Cut Specifics**</u>	
Set:	wavy	**Kerf Class:**	A 

TPI:	24.0 & 32.0	**Minimum Kerf Width:**	0.03
Tooth Distance:	0.04 & 0.03	**Blade Drift in Kerf:**	*minimal*
Tooth Type:	chisel	**Cut Surface Drift:**	*accentuated*
Cut Direction:	push	**Exit Chipping:**	yes
Power:	hand	**Harmonics:**	no

Wavy set FTBS are similar to raker set saws with a few exceptions. The initial entrance in false starts when viewed superiorly, is very straight edged like the raker, but close examination does reveal necking (narrowing of the kerf) in the middle of the length of a shallow false start (see Figure V-9, Kerf Floor C). This wide to narrow to wide pattern is similar to the alternating set blade drift, only this pattern is created by a series of teeth set to the right and left. This creates an observable necking of the kerf.

False start cross sections are unique to the above saws in that the kerf seems to expand as it goes deeper into the bone. The initial entrance into the bone is often narrower than the rest of the cut. Kerf floors are flat (actually flat with a slight arch) and highly polished. Kerf floors also lack the halves or thirds orientation of striae in alternating set blades. Rather, there appears to be fewer striae in the middle of the kerf with most occurring near the kerf corners.

Cut surface cross section of bone has two major differences from alternating and raker sets. Cut surface drift is noticeable, where fluctuations occur as the blade progresses through the bone. These fluctuations may be the result of the blade design, where most blades are set in such a manner that every other or every third tooth is following in the cut trough of another tooth or literally following in each other's track. Wavy set teeth do not have this readily repeating pattern, rather the blade create a repeating pattern of groups of teeth following in the cut trough of groups of teeth. It is hypothesized by this author that this design does not allow the teeth to produce straight sided cuts like the alternating and raker sets.

The second feature outstanding to wavy set cuts in bone is the polish of the bone. There is more polish on the cut surface using wavy set blades since there is no set administered to the teeth, rather the "set" is the bending of the blade and it is this bending of the blade that smooths the material as the saw progresses through it.

Hacksaws are found with different colors of paint and black labels. This coloring can possibly be retained on a cut surface.

Key Hole (Alternating Set)

Saw Specifics		Saw Cut Specifics	
Set:	alternating	**Kerf Class:**	B
TPI:	10.0	**Minimum Kerf Width:**	0.06
Tooth Distance:	0.10	**Blade Drift in Kerf:**	yes
Tooth Type:	chisel	**Cut Surface Drift:**	*accentuated*
Cut Direction:	push	**Exit Chipping:**	yes
Power:	hand	**Harmonics:**	accentuated

This saw is identical to larger alternating set saws, with the exception of a short blade and a rather wide set for the width of the teeth. Since wide set produces remarkable harmonics, cut surface drift is noticeable in cuts made with this saw. This may be attributed to the short length of the blade necessitating a high number of strokes for each bone cut. It seems likely that an increasing number of strokes in a hand powered saw allows for more variation in cuts.

Paint or dark metal treatment markings are evident on the bone when using new blades.

Key Hole (Wavy)

Saw Specifics		**Saw Cut Specifics**	
Set:	wavy	**Kerf Class:**	A [redacted]
TPI:	25.0	**Minimum Kerf Width:**	0.05
Tooth Distance:	0.04	**Blade Drift in Kerf:**	yes
Tooth Type:	chisel	**Cut Surface Drift:**	*accentuated*
Cut Direction:	push	**Exit Chipping:**	yes
Power:	hand	**Harmonics:**	no

Kerf cross sections, false starts, kerf floors, and cut cross sections of key hole saws are similar to other wavy set FTBS. Again, blade drift reflects distance of sets of teeth rather than individual teeth, and tooth width measurements generated from impressions chiseled into the kerf floor are difficult to calculate due to overlapping teeth distorting floor features.

Cut surface drift is again accentuated. This is attributed to the wavy set of the teeth and possibly the short length of the blade combined with a file type handle.

Paint or dark metal treatment markings are evident on the bone when using a new blade.

Wallboard, Drywall

Saw Specifics		**Saw Cut Specifics**	
Set:	alternating	**Kerf Class:**	B 
TPI:	6.0	**Minimum Kerf Width:**	0.09
Tooth Distance:	0.19	**Blade Drift in Kerf:**	yes
Tooth Type:	chisel	**Cut Surface Drift:**	*accentuated*
Cut Direction:	push	**Exit Chipping:**	yes
Power:	hand	**Harmonics:**	yes

Wallboard saws have remarkably wide teeth for a small hand saw. Using blade drift to calculate distance between teeth is difficult on small rounded surfaces like tubular bone. Cut cross sections show stroke and tooth striae with a shuffling pattern in mid cut similar (but smaller) to the large pruning saws. The wallboard saw produces the widest consistent kerf of all handsaws examined with the set width of this saw being 0.10 of an inch wide. This glaring feature must not be confused for power circular saw features since kerf cross sections and minimum kerf widths are similar in shape and size.

The wallboard saw is not well adapted to sawing hard material although cuts on bone were accomplished for this study. This saw shows cut surface drift which may be attributed to the short blade and file type handle.

Nest Saws

Power reciprocating saw manufacturers design handles to attach to their power reciprocating blades. This universal handle adapted to numerous blades produce what is called nest saws. These blades are stout and cut on the pull stroke since they are designed for powered saws. These blades were analyzed in this study, since they are easily affordable and efficiently cut bone. However, results of this type of saw have been omitted since the same mechanical properties appears to apply to these saws as to other alternating and wavy set hand saws of similar tooth size. It is important to remember that these blades differ only in the direction of cutting stroke (pull instead of push) and in increased thickness of the blades.

New reciprocating blades often have a dark colored metal treatment on the blade, as well as painted labels, that may be rubbed onto a cut surface.

Hand Specialty Saws

Kitchen Chef/ Meat Saws

<u>Saw Specifics</u>		<u>Saw Cut Specifics</u>	
Set:	alternating	**Kerf Class:**	B 
TPI:	10.0	**Minimum Kerf Width:**	0.04 & 0.05
Tooth Distance:	0.10	**Blade Drift in Kerf:**	*accentuated*
Tooth Type:	Chisel	**Cut Surface Drift:**	no
Cut Direction:	push	**Exit Chipping:**	*accentuated*

Power: hand **Harmonics:** *yes*

The chef/meat saw appears to efficiently do what it is designed to do, cut meat, gristle and bone. While designed like a large hacksaw with 10 teeth per inch, this blade chisels the material clear and cuts very efficiently. The set is wide enough to avoid binding and there are often islands of bone created in the kerf.

Blade drift for these saws is remarkable making tooth distance assessments uncomplicated. Harmonics, the cross section expression of blade drift, is also easily recognized and measured. Other features notable include large exit chipping, floor dip and measurable tooth width characteristics.

Serrated Kitchen Knife

Saw Specifics		**Saw Cut Specifics**	
Set:	*none*	**Kerf Class:**	A
TPI:	8.0	**Minimum Kerf Width:**	0.03
Tooth Distance:	0.13	**Blade Drift in Kerf:**	no

Tooth Type:	cut	**Cut Surface Drift:**	possible
Cut Direction:	push/pull	**Exit Chipping:**	minimal
Power:	hand	**Harmonics:**	no

Serrated blades saw bone amazingly well in shallow cuts, having teeth that are filed on only one side of the blade. This design, combined with no set, makes binding inevitable as the blade saws deeper into the bone. Serrated saw teeth show little emphasis on exit chipping on the push or pull stroke.

Knife blades taper from the back to the sharp edge. Most tapering appears to occur on the side of the blade that has tooth filing. Since there is no set, false starts are quite diagnostic because kerf cross sections mimic blade dimensions (see Figure V-1 Serrated). Blade drift is not observable.

While borders appear to have minimal chipping, there is no obvious exit chipping. There is unusual chipping at initial corners of the kerf corresponding to the flat edge (as opposed to the tapered edge) of the blade (Figure VI-5). It is assumed here

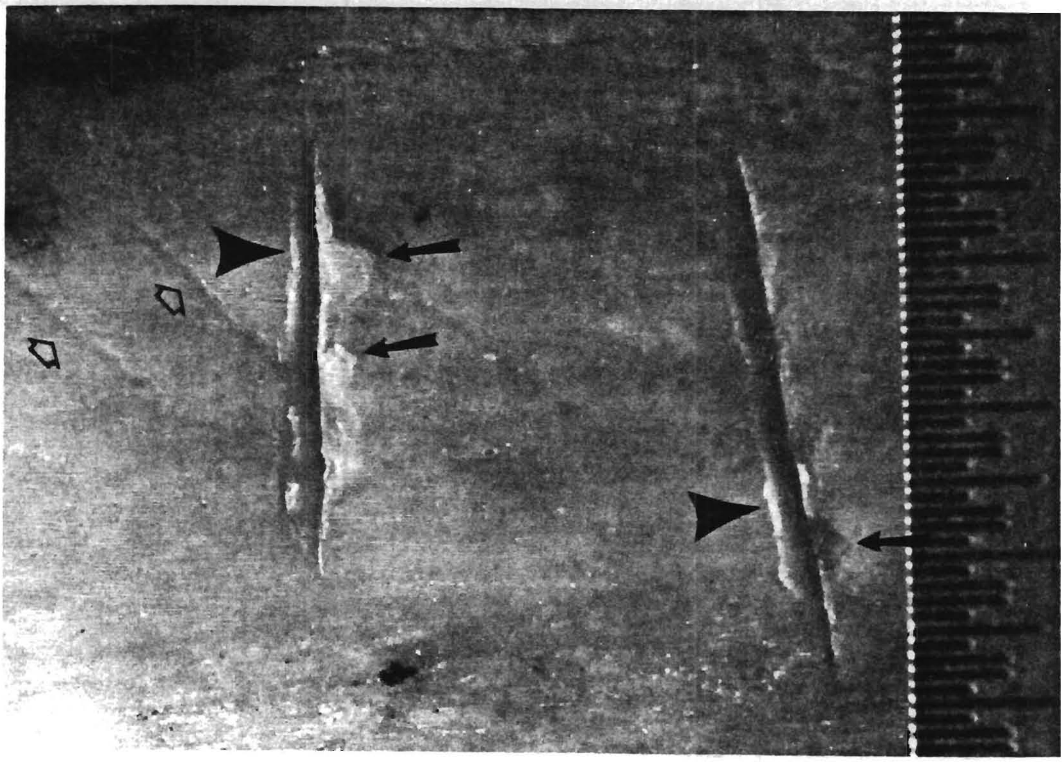


Figure VI-5. Photograph of false starts in bone created by a serrated knife. Outlined arrows indicating tooth scratch, as a blade slid from the kerf. Small arrows point to initial entrance chipping that occurs on the bone edge associated with the flat edge of the knife. Large arrows point to subtle lipping of bone created on the initial edge of bone corresponding to the tapered edge of the blade.

that the tapered edge wedges the knife into the material forcing pressure flakes of bone. This appears mainly on the side of the bone corresponding with the straight (non-tapered) edge of the blade (Figure VI-5, small arrows). Similar to this is lipping of the initial kerf corners, where bone is compressed as the blade is wedged into the material forming a lip on the outer surface of bone. This appears to correspond with the edge of bone cut by the tapered edge of the knife (Figure VI-5, large arrow). Therefore, this small sample of serrated knife cuts produce initial aspects of cut chipping and lipping, with the chipping corresponding to the flat edge, and the lipping corresponding to the tapered edge of the knife blade. On many experimental cuts, the knife slid sideways out of the kerf and the teeth created scratches corresponding to distance between the most prominent projecting teeth. Pressure flaking, lipping, and tooth scratches can each be seen in Figure VI-5.

Another type of scratch is evident at one end of the kerf (Figure VI-6). Trailing scratches represent the knife blade being

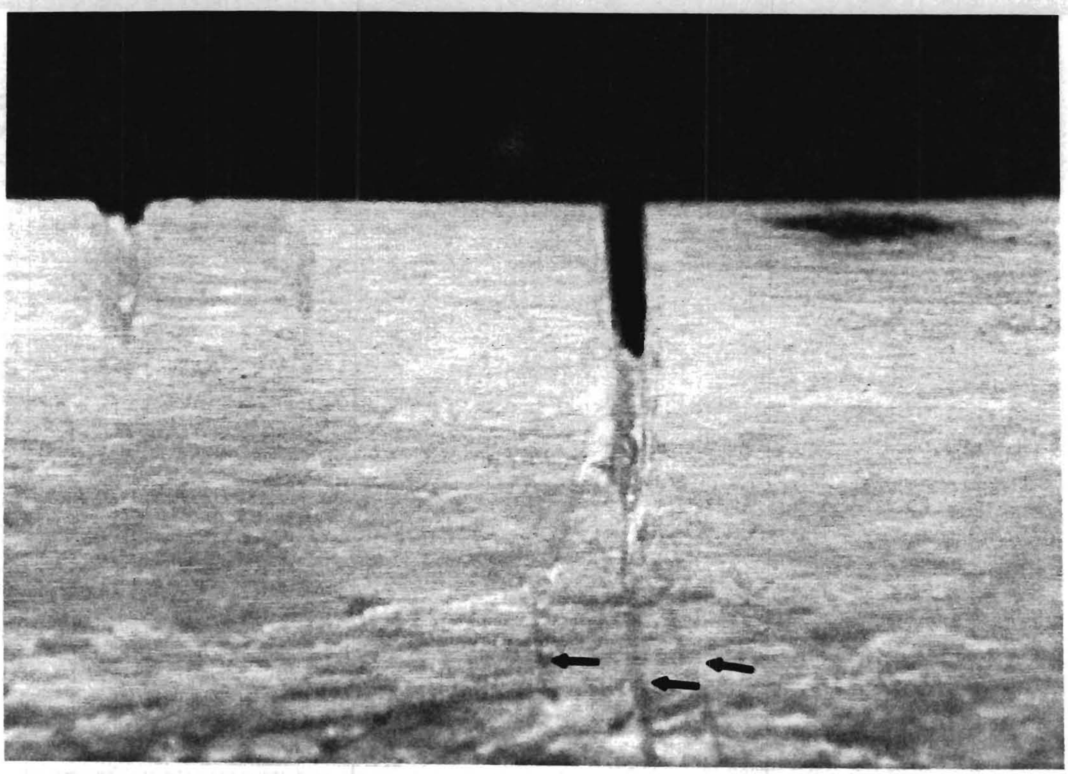


Figure VI-6. Cross section false start view of serrated knife (8 teeth per inch) saw cut on bone. Arrows mark three trailing scratches where the blade is rotated around the shaft or the blade tip slipped completely out of the kerf.

pulled out of the end of the kerf at the peak of the pulling stroke (Figure VI-6) and trailing down the side of the bone. This trailing scratch indicates the side from which the person is doing the sawing since it occurs on the side of the individual sawing. This feature can be confused for sawing marks on the bone if the knife is rotated half way around the bone while sawing, but these always appear in a straight line with the kerf, unlike the striae in Figure VI-6.

Ryoba (Crosscut) Pull Saw

Saw Specifics		Saw Cut Specifics	
Set:	alternating	**Kerf Class:**	C
TPI:	15.0	**Minimum Kerf Width:**	0.05
Tooth Distance:	0.07	**Blade Drift in Kerf:**	yes
Tooth Type:	cut	**Cut Surface Drift:**	no
Cut Direction:	*pull*	**Exit Chipping:**	*yes*
Power:	hand	**Harmonics:**	yes

This is a combination saw with two cutting edges, one edge has crosscut filed teeth and one side is rip filed (see below for rip description). The blade between these two edges is thinly tapered to the middle to avoid binding. Japanese saws differ from other saws in numerous ways (Lanz 1985:13-17). The most noticeable difference is that these saws cut on the pull stroke as opposed to the push. It must be remembered that exit chipping will occur on the side of the person sawing. Japanese saws are manufactured harder since they do not need to be ductile on the push stroke, making these saws more brittle and more likely to break teeth or blades rather than bend.

The narrower blade with minimal set of hardened teeth creates a narrower kerf that wastes less wood and demands less effort from the person sawing (Lanz 1985:13-17). Even the low quality Japanese blades cut bone with ease.

Tooth and stroke striae are emphasized on bone due to the sharpness of the teeth and steep raker angle.

Ryoba (Crosscut) Pull Saw)

Saw Specifics		Saw Cut Specifics	
Set:	alternating	**Kerf Class:**	B 
TPI:	6.0 & 8.0	**Minimum Kerf Width:**	0.05
Tooth Distance:	0.12 & 0.17	**Blade Drift in Kerf:**	yes
Tooth Type:	chisel	**Cut Surface Drift:**	no
Cut Direction:	*pull*	**Exit Chipping:**	*yes*
Power:	hand	**Harmonics:**	yes

Refer to the Japanese Crosscut saw above for differences between Western and Japanese saws.

Japanese rip saws have tall teeth with their size increasing from toe to heel (handle to far edge in Japanese saws). These large teeth create a patterned shuffle similar to the large pruning and buck saws, where tooth striae begin to jump mid cut in the area of the marrow cavity.

Flexible Saws

Gigli

Saw Specifics		Saw Cut Specifics	
Set:		**Kerf Class:**	unclassified
TPI:		**Minimum Kerf Width:**	0.05
Tooth Distance:		**Blade Drift in Kerf:**	no
Tooth Type:		**Cut Surface Drift:**	*accentuated*
Cut Direction:	push/pull	**Exit Chipping:**	*minimal*
Power:	hand	**Harmonics:**	no

Since this saw cuts with wrapped wire teeth, cuts are quite distinctive as illustrated in Figure V-26. As these wrapped wires cut or abrade bone, movements in the wire create irregularities in the striae to give an occasional wavy appearance in the longitudinal axis. While these irregularities are very subtle and difficult to see, they are unique to other saws.

Overall, striae from this saw are remarkably uniform. Stroke striae bend themselves around the break away spur leaving a non-fixed radius curvature, convex in shape. Cut surface drift is limited only by the individual holding the saw. Flexible saws go in any direction pulled, so surface drift is remarkable with this saw. This unique saw has very few of the features discussed in Chapter V but is so unusual it is not difficult to interpret. Kerf floors are extremely concave and uniform. Gigli saw kerf cross sections have not been compared or classified like other saws since determinations of tooth size and shape are all but impossible.

Rod Saw

Saw Specifics		Saw Cut Specifics	
Saw Set:		**Kerf Class:**	unclassified
TPI:		**Minimum Kerf Width:**	0.10
Tooth Distance:		**Blade Drift in Kerf:**	no
Tooth Type:		**Cut Surface Drift:**	*accentuated*
Cut Direction:	push/pull	**Exit Chipping:**	yes
Power:	hand	**Harmonics:**	no

This grit impregnated blade inserted into a hacksaw frame creates a wide, smooth kerf with bending striae that could easily be confused for a power saw to the untrained eye. Distinctive characteristics include an often scalloped entrance or exit edge. False start scratches do not look like teeth etching, and when impressions in the kerf floor are measured, no uniform tooth size can be calculated. Lipping at the initial cut surface (similar to the serrated knife) is present. Kerf cross sections are large with a concave floor, although no comparisons or classifications were made since tooth size and shape assessments are impossible. Striae have non-fixed radius curvature and bend slightly around the break away kerf leaving it convex shaped. Like the Gigli, this saw is likely to have noticeable surface drift.

Medical Saw: Bone

Saw Specifics		**Saw Cut Specifics**	
Set:	alternating	**Kerf Class:**	B
TPI:	8.0	**Minimum Kerf Width:**	0.05
Tooth Distance:	0.13	**Blade Drift in Kerf:**	yes
Tooth Type:	chisel	**Cut Surface Drift:**	yes

Cut Direction:	push	**Exit Chipping:**	yes
Power:	hand	**Harmonics:**	yes

There is slight polishing of cut surfaces from this saw suggesting that the blade is dragging and binding due to a lack of set. Bone edges appear to be abraded suggesting that this saw does a poor job of chiseling material it was designed to chisel. It would seem unlikely that all medical saws are designed to create such a crude cut.

This bone saw cuts with actions similar to non-medical saws with comparable dimensions and shape.

Medical Saw: Metacarpal

<u>Saw Specifics</u>		<u>Saw Cut Specifics</u>	
Set:	alternating	**Kerf Class:**	C 
TPI:	30.0	**Minimum Kerf Width:**	0.06
Tooth Distance:	0.03	**Blade Drift in Kerf:**	no
Tooth Type:	cut	**Cut Surface Drift:**	accentuated
Cut Direction:	push	**Exit Chipping:**	no

Power:	hand	**Harmonics:**	no

This is an unusual saw due to its tooth set, size, and shape. This wide blade essentially has staggered points erupting into an alternating pattern with no set. This blade is not adapted to large bones or deep cuts due to its limited set, and therefore exhibits no blade drift or harmonics.

Power Circular Saws

Tungsten Carbide Teeth/Piranha and Framer Blades

Saw Specifics		**Saw Cut Specifics**	
Set:	alternating	**Kerf Class:**	B 
TPI:	0.8	**Minimum Kerf Width:**	0.11 & 0.09
Tooth Distance:	2.26 & 2.22	**Blade Drift in Kerf:**	no
Tooth Type:	chisel	**Cut Surface Drift:**	*minimal*
Cut Direction:	push	**Exit Chipping:**	yes
Power:	mechanical	**Harmonics:**	*no*

These blades are very similar in design, as the above descriptions reveal. Tungsten carbide teeth possess an undeniable hardness that allows teeth to be designed with a wide cutting edge. This overlapping cutting edge creates a smooth cut and eliminates the need for tooth set. The tip of the points of the Piranha blade are designed with a slight slope, alternating between each tooth. This slope gives the kerf cross section a somewhat convex shaped floor. Close examination reveals this floor shape is not due to angled filing of the teeth, and therefore does not make this a crosscut filed blade. Exit chipping is present in all circular saw blades but interestingly enough, there is also minimal chipping in the entrance and initial cut aspects of the kerf. This is likely the by-product of high energy transfer of this fast moving circular blade. Blade drift and harmonics are not present due to the large spacing of the teeth and also the high blade speeds. Cut surface drift is minimal in circular saws. The most characteristic feature of circular saw cuts is the fixed radius curvature in striae. This bending occurs in the opposite direction of flexible saws forming a concave break away kerf.

Tungsten carbide teeth on circular blades are unique in that they form extremely smooth cut characteristics. This is sometimes disguised when the observer views bulky features, such as large exit chipping or the occurrence of occasional interruption striae (reflecting hesitation in the progress of the cut). However, with these features aside, tungsten carbide teeth create a cut that is unparalleled in cross section surface uniformity.

Non Tungsten Carbide Teeth/Plywood and Combination Blades

Saw Specifics		**Saw Cut Specifics**	
Set:	alternating	**Kerf Class:**	B 
TPI:	7.0 & 1.8	**Minimum Kerf Width:**	0.08 & 0.11
Tooth Distance:	0.16 & 0.56	**Blade Drift in Kerf:**	no
Tooth Type:	chisel	**Cut Surface Drift:**	*minimal*
Cut Direction:	push	**Exit Chipping:**	yes
Power:	mechanical	**Harmonics:**	no

Designs of non-tungsten carbide teeth are limitless, but they differ from tungsten carbide teeth in one major aspect. Tungsten carbide teeth are extremely hard and are able to maintain a sharp edge for an extended period of time. Non-tungsten carbide teeth lack this hardness and are designed with a narrow cutting edge. This narrow tooth requires a wider set to prevent the blade from binding. Finally, this wider set produces a more variable cross section cut, in that individual tooth striae are observable to form a less uniform cut. Cut surface drift is minimal in circular saws. Again, the most characteristic feature of circular saw cuts is the fixed radius curvature in striae. These striae have a predictable bend that can be measured. This bending occurs in the opposite direction of flexible saws such that the break away kerf has concave contours.

These saws also have exit chipping coupled with minor entrance and initial cut chipping. All non-tungsten carbide blades tested appeared to dull rapidly when cutting hard material. A reduced efficiency was noticed with each of these blades before 10 cuts in bone could be made.

Abrasive Masonry Blade

<u>**Saw Specifics**</u>		<u>**Saw Cut Specifics**</u>	
Set:		**Kerf Class:**	
TPI:		**Minimum Kerf Width:**	0.14
Tooth Distance:		**Blade Drift in Kerf:**	
Tooth Type:		**Cut Surface Drift:**	no
Cut Direction:	push	**Exit Chipping:**	accentuated
Power:	mechanical	**Harmonics:**	no

This unique saw blade cannot be examined in terms of tooth size and shape and therefore was not compared or classified in terms of other saws. This blade did create a wide concave kerf floor with longitudinal striae that continue across the floor and up the walls. All striae, however, lack uniformity in spacing and dimensions. Bone eburnation is sometimes present due to the increased temperatures of this type of cutting.

Power Band Saw

Skip Tooth

Saw Specifics		**Saw Cut Specifics**	
Set:	alternating	**Kerf Class:**	B 
TPI:	*4.0*	**Minimum Kerf Width:**	*0.04*
Tooth Distance:	0.25	**Blade Drift in Kerf:**	yes
Tooth Type:	chisel	**Cut Surface Drift:**	*minimal*
Cut Direction:	push	**Exit Chipping:**	yes
Power:	mechanical	**Harmonics:**	yes

This is a very versatile saw that combines high speed with a high tension thin blade to produce a saw that will cut most materials efficiently. Common blade types for band saws include the typical alternating, raker and wavy set with skip tooth or saber (hook tooth) designs. The particular blade examined here is a "skip tooth" alternating blade which essentially means that it has half the number of teeth per inch than most other blades fitting these specifications. Take special note the unusual features of these cuts, where this extremely narrow kerf combined with power saw characteristics and a wide to narrow blade drift that indicates only 4 teeth per inch.

False starts created with this band saw appear similar to fine toothed saw kerfs with very straight edges and necking in the middle of the length of kerf (Figure VI-7). This appearance is due to the skip tooth design of the blade. Close examination reveals a "stretched" alternating set pattern of wide to narrow with bone islands (very long and narrow) evident.

Cross section patterns are very regular with patterns that can mimic stroke striae. By definition, stroke striae could not occur since this is a continuous cutting saw, but hesitations in forward progress, flaws in the blade support, or irregularities in the blade splice may create a patterned unevenness.

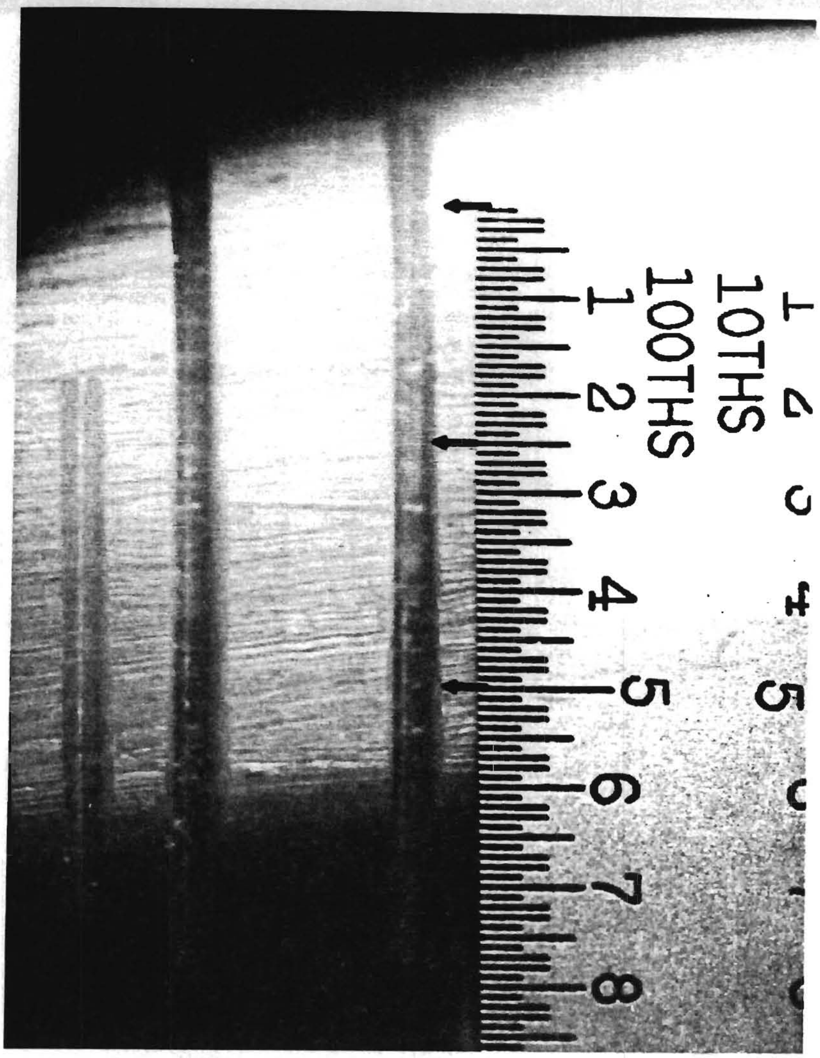


Figure VI-7. False starts in human bone created by an electric band saw with a skip tooth blade (4 teeth per inch). Notice the very straight orientation of the cut and the subtle blade drift creating the wide to narrow pattern with the right kerf narrow at 0.25 and 0.75, and wide at 0.0 and 0.5 of an inch. This indicates a distance between saw teeth of 0.25 of an inch.

Power Chain Saw

Electric Crosscut

Saw Specifics		**Saw Cut Specifics**	
Set:	alternating	**Kerf Class:**	D 
TPI:	0.7	**Minimum Kerf Width:**	*0.25*
Tooth Distance:	1.50	**Blade Drift in Kerf:**	no
Tooth Type:	*cut*	**Cut Surface Drift:**	accentuated
Cut Direction:	push	**Exit Chipping:**	*yes*
Power:	mechanical	**Harmonics:**	no

This saw is obviously designed for soft materials, and therefore is not a well adapted saw for human bone. This poor adaptation is evident in the frequent false start striae where saw teeth slide over the bone surface until a kerf can be created.

This large power saw with large "L"-shaped teeth transfers a tremendous amount of energy to the bone. This is displayed by the large exit chipping and break away spur or notch.

There is no blade drift or harmonics but cut surface drift can be pronounced since teeth are sliding across the material at such a high rate of speed but biting little. The kerf is very wide (kerf measurements from six different set and size chain saws fell within the range of 0.25 to 0.32 of an inch) with a convex floor in crosscut designs.

Power Reciprocating Saws

Alternating Set Reciprocating

<u>Saw Specifics</u>		<u>Saw Cut Specifics</u>	
Set:	alternating	**Kerf Class:**	B
TPI:	7.0 & 10	**Minimum Kerf Width:**	0.08 & 0.06
Tooth Distance:	0.14 & 0.10	**Blade Drift in Kerf:**	yes
Tooth Type:	chisel	**Cut Surface Drift:**	minimal
Cut Direction:	*pull*	**Exit Chipping:**	*yes*
Power:	mechanical	**Harmonics:**	*accentuated*

Power reciprocating saws, as the name implies, cut with a reciprocating action. The length of blade stroke in most saws of this design is just over one inch. The Mikita saw utilized in this study had a length of stroke of 1.19 inches. Three different sizes of blades were examined in this study to test for differences in tooth size and set. All reciprocating blades have similar shape with wide sharp teeth designed to cut on the pull stroke. This indicates that exit chipping occurs on the side of the bone closest to the individual holding the saw. This blade design also suggests that bone islands are rare due the stout nature of the blade.

Basic cutting action of this power saw is similar to hand saws with similar blades. The obvious differences occur due to the powering of the blade. This high speed reciprocating action is quite diagnostic. Each of these blades create their own diagnostic features on the bone cross section. Figure V-40 illustrates the striae from the largest of the blades examined here. The striae appear to be aligned in small arches across the bone. Figure V-36 shows the smaller toothed alternating set blade that produces incredible harmonics. This may be due to the length of the reciprocating stroke and the size of the teeth. The blade moves through a cycle of harmonics (drift) then reciprocates. Each of these saws exhibit blade drift. Stroke striae are not emphasized, but tooth striae are.

New reciprocating blades often have a dark colored metal treatment on the blade as well as painted labels that may rub onto a cut surface.

Wavy Set Reciprocating

Saw Specifics		**Saw Cut Specifics**	
Set:	wavy	**Kerf Class:**	A [redacted]
TPI:	18.0	**Minimum Kerf Width:**	0.05
Tooth Distance:	0.06	**Blade Drift in Kerf:**	minimal
Tooth Type:	chisel	**Cut Surface Drift:**	yes
Cut Direction:	pull	**Exit Chipping:**	minimal
Power:	mechanical	**Harmonics:**	no

Wavy set power reciprocating blades produce a predictably different pattern of cut than the alternating blades mentioned above. Wavy set blades are characterized as lacking harmonics and noticeable blade drift with accentuated polish. Figure V-39 illustrates the polish and fine tooth striae produced by this saw.

New reciprocating blades often have a dark colored metal treatment on the blade as well as painted labels that may be rubbed onto a cut surface.

Power Specialty Saws

Autopsy Saws (Round and Large Sectioning Blades)

Saw Specifics		**Saw Cut Specifics**	
Set:	alternating	**Kerf Class:**	B
TPI:	16.0 & 23.0	**Minimum Kerf Width:**	*0.04*
Tooth Distance:	0.04 & 0.06	**Blade Drift in Kerf:**	yes
Tooth Type:	chisel	**Cut Surface Drift:**	minimal
Cut Direction:	*push/pull*	**Exit Chipping:**	yes
Power:	mechanical	**Harmonics:**	yes

Autopsy or cast saws are common tools in the medical field. They are designed to cut hard tissue without damaging soft tissue with a very quick motion and a short reciprocating action that extends only a fraction of an inch.

A Stryker autopsy saw with a "large sectioning blade" creates a smooth but complicated saw pattern (Figure VI-8). The cut is multidirectional, especially in large bones. This is due to the small cutting radius of the blade that cannot cut completely through the whole bone. Since the saw is designed to be held in the palm of the hand, direction changes are also enhanced. Harmonics are present which suggest that there is side to side movement of the blade in the kerf, even at these high speeds with minimal stroke lengths (see Figure V-18). The autopsy saw will have exit chipping if little pushing occurs and the saw is allowed to progress straight into the bone as it cuts, miniature chipping can occur on all edges. Cut surface drift occurs but it is usually a function of the blade being moved around the shaft of the bone.

This saw exhibits the finest stroke and tooth striations of all saws studied. Close examination also reveals the short reciprocating action of the saw (Figure VI-8).

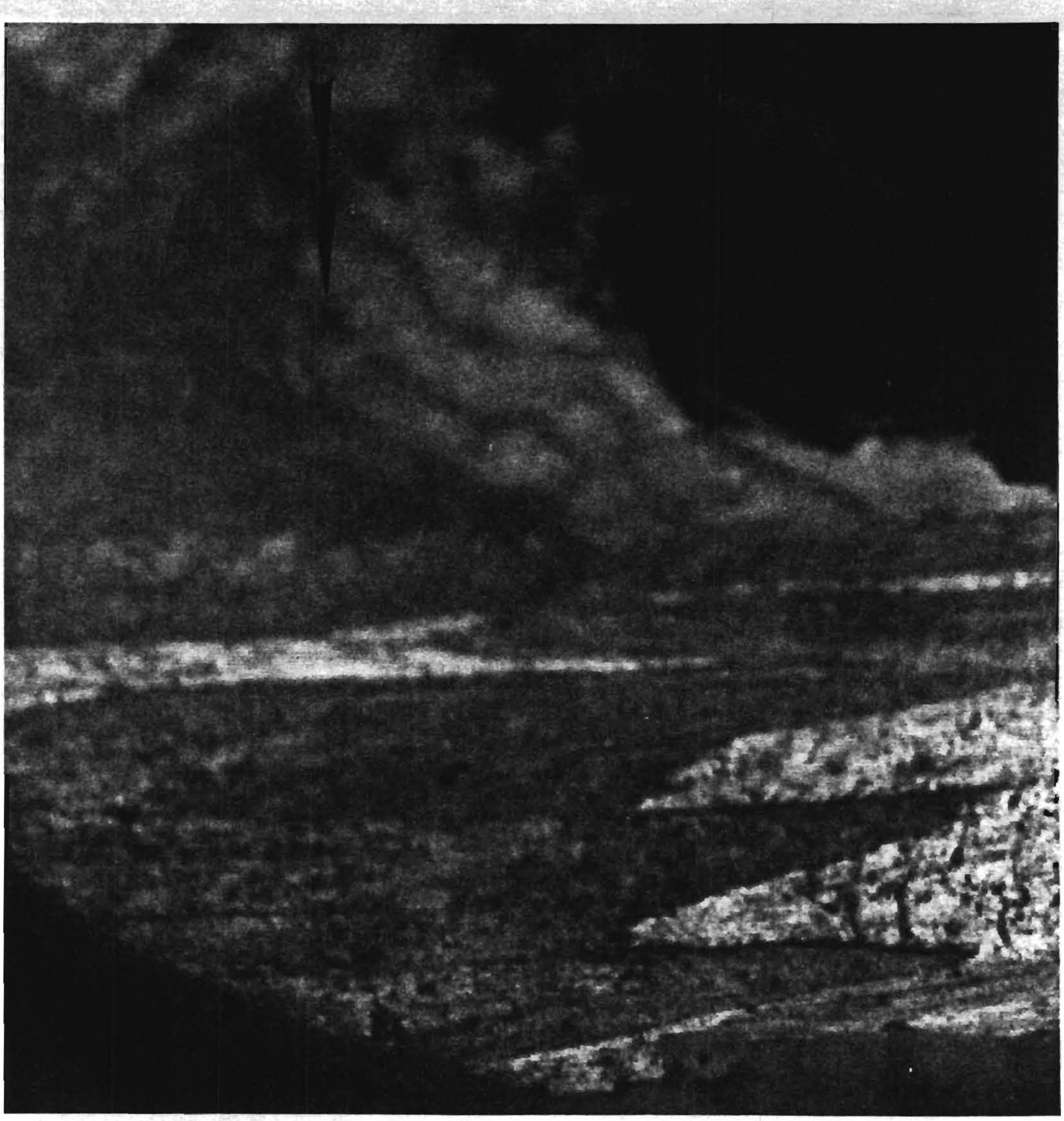


Figure VI-8. Sectioned human bone using a Stryker autopsy saw. Note the polish and short reciprocating motion features.

CHAPTER VII

CONCLUSION

Introduction

Existing research in the examination of class characteristics of saw marks on bone is vague in terms of evaluating saw size, set, shape, or power source (see Bonte 1975; Guilbeau 1989; Symes and Berryman 1989a). This research has identified saw cut characteristics that distinguish basic class characteristics on bone. Information gleaned from these cut characteristics is applied to saw blade and tooth characteristics of size, set, shape, and power. These characteristics can be used individually or in combination, to narrow the number of possible saws that could potentially create a particular cut. This narrowing of the field of saws, allows the examiner to assess the class, subclass, or even the type of saw utilized in the cut.

This information permits the examiner to predict the suspected weapon or tool used in a crime. The ultimate potential of bone saw mark comparisons is the narrowing of the range of possible conclusions.

Saw Blade and Tooth Size

Saw blade and tooth size can often be predicted from numerous saw mark features. Individual saw tooth width can be calculated in many saws from kerf features or from the actual measurement of a trough carved by a saw tooth in the kerf floor. Blade set width (width of the set teeth) has been shown to be similar to minimum kerf width. This measurement can be calculated from false starts and occasionally break away spurs.

Teeth per inch or the distance between teeth is an important saw characteristic since most saws are classified by manufacturers in terms of teeth or points per inch. Blade drift is one of the most common and easily identified features found in the false starts or break away spurs that indicate tooth distance. The wide to narrow pattern of blade drift in kerf width indicates two striae direction changes, thus the distance of a single tooth. Three direction changes, or the measurement of wide to wide, narrow to narrow, or island to island, is the equivalent of the distance of two teeth. Bone islands are also important for indicating direction of blade stroke, where the islands appear to taper or trail off in the direction of the cutting stroke.

Floor dip and tooth imprint are two other tooth per inch indicators in the false start or break away spur area. These features essentially reflect the location of tooth points as they cut or are interrupted in mid-cut. Dip to dip or peak to peak measurements indicate the distance of one tooth in a saw blade. This feature is treated with caution in this study since overlapping cuts in the kerf may complicate these features.

A similar feature in the cross section of a bone cut is tooth hop. This feature appears on the cut surface with some regularity. This feature is likely related to the blade hopping in the kerf as the teeth consecutively strike the bone edge. Tooth hop accurately reflects the distance of a single tooth, if measurements are made from peak to peak or dip to dip.

Tooth scratch is the product of a saw drawn from the kerf, allowing the teeth to scratch the bone surface. These features have been suggest to accurately represent the distance between teeth (Bonte 1975; Guilbeau 1989). This feature has been treated with caution in this research since differences in saw blade set influence the interpretation of the number of teeth between the scratches. This feature accurately indicates the distance between teeth of a saw, but not the number of teeth.

Harmonics is the name given to the vertical expression of blade drift. These features have been recognized in the literature, but have been largely misunderstood or ignored. An example of this is illustrated in Bonte's (1975:320, Figure 4) photograph of a saw cut surface with the blade positioned on the cut. While discussing the correspondence of tooth scratches to every other saw tooth, harmonic features are easily visible in the photograph. Each peak and valley line up perfectly with each tooth. Harmonics, like blade drift, are interpreted by direction change. Peak to valley or valley to peak represents the distance (two direction changes) of one tooth while measurement of peak to peak or valley to valley corresponds with the distance of two teeth. All measurements must be parallel to tooth striae or the direction of stroke.

Harmonics are also important as cut characteristics due to their durability. The specimens examined for this research were subjected only to simmering in degreaser. Specimens recovered by the forensic scientists can be subjected to endless numbers of taphonomic factors that deteriorate the bone, much less frail saw cut characteristics. A simple test of water and gravel action on saw mark features was attempted using a rock tumbler filled with water and gravel. Bones sectioned with a meat saw were subjected to differing amounts of time in the tumbler. Figure VII-1 shows a rather smoothed cross section of bone that has been allowed to tumble for 7.5 hours. While most features have been "smoothed," harmonics are still quite obvious and measurable.

Figure VII-1. Sectioned human bone subjected to 7.5 hours of tumbling in a rock tumbler intended to simulate river tumbling. Note the rather smoothed features along with the still prominent harmonic ridges and valleys.

Tooth size is also indicated by tooth striae. Large toothed saws commonly exhibit a changing striae pattern in cuts of tubular bone. These striae are described as straight or bending in the initial and terminal aspects of a cut. Striae at the level of the marrow cavity begin to create a patterned shuffle as the teeth hop over the two sides of bone. This is a subjective observation but this pattern is indicative of teeth that are widely spread.

Saw Tooth Set

Saw tooth set is basically indicated by variations in kerf cross section, blade drift, and polish. Kerf cross sections have been classified into four major groups (Figure V-1). These groups are essentially dependent on tooth set and shape. Tooth set basically takes the forms of alternating, raker, and wavy, with raker sets varying on different forms in large buck saws than fine toothed bow and open saws. Alternating set is the most commonly found design in saws and is characterized by predictable blade drift in false starts and break away kerfs. Bone islands are sometimes created in the wide aspects of this drift. The existence of blade drift with bone islands is a good indicator of alternating set. Raker patterns in larger saws may have remnant islands but they are generally modified by a shorter raker tooth. Usually wavy sets chisel out a polished concave kerf floor devoid of any features. These three types of set in fine toothed bow saws create a definable floor pattern (Figure V-9). Alternating set has the wide to narrow pattern. Raker set (where the raker is one out of every three teeth) produces very straight walls and parallel striae due to the lack of drift. Wavy set produces necking (rather than wide to narrow pattern) mid-way in a false start kerf, with a polished floor seemingly devoid of striae in the middle with most parallel striae occurring closer to the floor corners.

Cut bone cross sections often times exhibit harmonics. These, like blade drift, are indicative of alternating set blades. Bone polish and cut surface drift characteristics are difficult to observe or measure and are attributed to many factors, usually related to the design of the saw and how the saw is powered.

Polish and cut surface drift are commonly present in wavy set saw cuts.

Saw Blade and Tooth Shape

Saw blade and tooth shape take many forms. These are indicated by numerous saw cut characteristics. The false start and break away spur cross sections reveal the type of filing on the front of saw teeth, where crosscut filing has a Class C or D shape and rip sharpened saws have a shape resembling Class A or B (Figure V-1).

Cut surface drift, is likely the result of certain saw designs (listed here as shape). Surface drift may be increased due to the design of the saw handle, wavy set blades (where the bending of the blade instead of setting the teeth increases the change of progress of the saw), and saws adapted to cutting soft material. If wavy set characteristics are not in evidence, accentuated cut surface drift may suggest a large toothed saw designed for soft wood logs. Cut surface drift is usually reduced in power saws.

Hand Versus Mechanical Power

Power saw blades are stout in design. These blades exhibit consistency of cut, elevated energy transfer, and an increased material waste. These features are present when examining cut bone false starts, break away spurs, and cut cross sections. Most power saws cut a wide kerf with a Class B shape. They show little cut surface drift, extremely smooth crosscut surfaces, large exit chipping and large break away spurs. The major exceptions to this are the band and autopsy saws, where each of these saws have small toothed blades with very subtle features.

All power saws create tooth striae but seldom form stroke striae. This is due to the design of continuous cutting saws or reciprocating saws that have a very short stroke. Pseudo-stroke features are created by interruptions of cuts (hesitation marks within a cut), and defects or splices on continuous cut blades. High frequencies of initial cut scratches or false starts with increased polish and eburnation may also indicate a high speed cutting tool. Hand powered saws typically cut narrower kerfs with less exit chipping and less uniformity overall. Hand saws exhibit stroke as well as tooth striae and readily change direction of stroke.

Tooth striae contour with fixed radius curvature forming a concave break away spur is indicative of circular, autopsy and possibly chain power saws. Fixed radius striae producing convexly shaped break away spurs are created by arched hand saws, such as pruning saws. Non-fixed radius striae are typical of flexible saws like the Gigli or rod saw.

Saw Cut Direction

Certain features are indicative of how a bone was cut. The path from initial cut (false start) to terminal cut (break away spur) indicates the direction of blade progress. Direction of blade stroke is indicated by tooth and stroke striae, which are perpendicular to direction of progress. The direction of the cutting stroke (cutting with the front side of the teeth) is indicated by exit chipping. Passive strokes generally produce little chipping although circular saws did appear to create some entrance chipping. Most Western saws cut on the push stroke while Japanese, pruning, and power reciprocating saws commonly cut on the pull stroke. Peg toothed saws (those with teeth designed to cut on the push or pull stroke) can exhibit exit chipping due to the technique of the individual using the saw.

Determination of saw cut direction can be useful in different ways, but must be approached with extreme caution. Andahl (1978:45-46) examines a case in which human bones were severed using a hacksaw. Andahl describes not only the position of the body as it was mutilated, but also the order in which limbs were removed. While this information is of interest to investigators, its value is limited by its accuracy. There has been no method devised to positively indicate if a saw's cutting stroke is on the push or pull. There is no doubt that hacksaws are designed to cut on the push stroke, but the blades are interchangeable and can be mounted to cut on the pull stroke. Secondly, body position is always a difficult variable to assess since limbs can be manipulated into different positions, especially arms.

Saw cut direction also becomes complicated when dealing with unpredictable behaviors. Figure VII-2 is a photograph of a right femur from a medical examiner's case in which an adult White female was dismembered and deposited in a river. This bone at first glance reveals numerous diagnostic features.

High frequencies of prominent striae at the bottom of the photograph show fixed radius curvature that bends into the bone, suggesting this was cut with a power circular saw, using a non-tungsten carbide blade. This cut progressed from medial to lateral aspects of the bone. Since circular saws have a predictable blade action (the cutting stroke can only progress in one direction) and pronounced exit chipping, it is tempting to predict certain variables relating to the crime scene. The direction of striae curvature, location of the break away spur, and exit chipping suggest that the saw operator must have been standing on the medial side of femur with the body lying face down.

Figure VII-2. Photograph of a dismembered right femur belonging to an adult White female. Note the prominent bending striae at the right of the photograph indicating a power circular saw cut progressing from the medial to the lateral aspect of the bone.

However, close examination with angled light reveals striae that indicate numerous directions of cuts. Figure VII-3 is a duplicate of the hand drawing submitted in the descriptive analysis of this case. Note that there are numerous cuts on the bone demonstrating an unusual and unpredictable behavior with a saw. An examiner, viewing all evidence, should refrain from making concrete conclusions on body position and saw operator location since saw cuts on this bone indicate many directions, and possibly more than one saw (Symes and Berryman 1989b).

Indicating Saw Features Through Cut Characteristics

Numerous cut bone features have been shown to be direct or indirect indicators of some aspect of saw class, subclass, or type used in the cut. Just how important each feature is as an indicator of some dimension of the saw, is variable and dependent upon numerous factors. These factors may even include unpredictable variables, such as sawing technique.

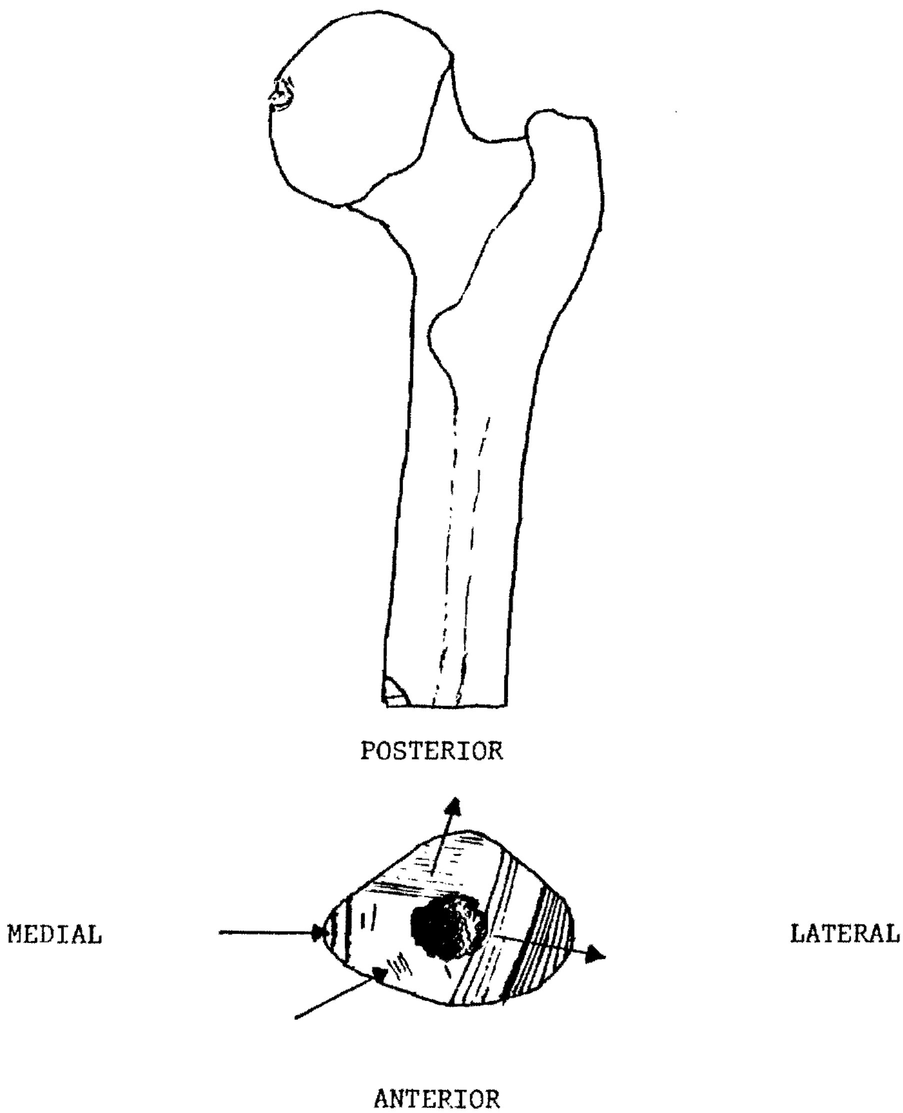


Figure VII-3. Duplication of hand drawing from descriptive report on dismembered human remains. Note the numerous directions of cuts attributed to a single bone. (Drawing courtesy of Hugh E. Berryman).

Source: Symes, Steven A. and Hugh E. Berryman, 1989b, Examination of tool markings on bone from a white female from Hamilton County, TN., Case Number FA89-49. Unpublished manuscript on file at the Shelby County Medical Examiners Office, Memphis TN.

Table VII-1 attempts to indicate the diagnostic value of each cut characteristic examined, in terms of saw blade and tooth size, set, shape, power, and cut direction. This table is useful as an indicator of cut characteristics and may be useful for the determination of a particular saw feature. It is interesting to note that numerous characteristics indicate saw size, a feature that is most valuable when comparing saws.

Summary

One would assume by the lack of literature on the subject that human dismemberment and mutilation with saws is rare, or that the topic generates little interest in the forensic community. However, this author's ongoing saw mark research, has resulted in the consultation or the examination of a total of nine dismemberment cases in the past four years. In each case, the forensic examiner requested a means of narrowing the range

Table VII-1. Evaluation of saw cut characteristics that contribute to saw blade size, set, shape, power, and saw cut direction.

	Saw				
Cut Characteristic	**Size**	**Set**	**Shape**	**Power**	**Cut Direction**
False Starts and Break Away Spurs	(X)			(X)	X
Kerf Cross Section Shape	X	(X)	X	(X)	
Kerf Floor Examination of FTBS*		X			
Blade Drift	X	X			X
Kerf Width	X			X	
Tooth Trough Width	X		X	(X)	
Floor Dip	X	(X)	(X)		
Tooth Imprints	X	(X)	(X)		
Bone Islands					X
Cross Sections					
Tooth and Stroke Striae	X			(X)	X
Patterned Striae Shuffle	(X)				
Stria Contour			X	X	

Table VII-1. (continued.)

Cut Feature	Saw				
	Size	Set	Shape	Power	Cut Direction
Cut Surface Drift		X	X	X	
Tooth Hop	X				
Tooth Scratch	(X)	(X)			
Harmonics	X	(X)			X
Entrance Shaving					
Exit Chipping		(X)		(X)	X
Consistency of Cut				X	
Energy Transfer				X	
Material Waste	(X)			(X)	
Polish		(X)		(X)	

* Fine toothed bow saws
X Commonly contributory
(X) Sometimes contributory

of tools that could have possibly been used in the dismemberment. In every case, the forensic examiner requested added insight into criminal behavior.

It is this author's opinion that the lack of literature in saw mark research is due to preconceived notions of the "limited" value of saw marks on bone as previously stated by criminalistics experts. The lack of substantial accomplishments in this area is likely related to difficulty in interpreting saw marks for class characteristics, and near impossibility of identifying a specific saw. The lack of positive results has likely been a deterrent of past research.

Finally, Bonte (1975:323) identifies tool mark examinations, especially when applied to bone and cartilage, as a primary interest of the forensic physician since explanations of unnatural deaths include the determination of criminal action. It is this author's opinion that saw mark research in the applied field of Forensic Anthropology can produce researchers that are prepared to go beyond the descriptive level of collaboration with medical examiners, and confront all modified bone with an appreciation for its potential forensic value, while contributing to an overall knowledge of bone as living tissue.

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VITA

Steven A. Symes was born in Wessington Springs, South Dakota on April 10, 1954. After graduating from Wessington Springs High School in 1972, he attended The University of South Dakota as an Anthropology and History major, graduating with a Bachelor of Arts degree in May of 1976.

His next two years were spent as an archaeologist employed mainly by the State of South Dakota. In 1978, Steven had the opportunity to meet and begin a long professional relationship with Dr. William M. Bass, head of the Department of Anthropology at The University of Tennessee. With a little encouragement, Steven was convinced to come to The University of Tennessee, Knoxville, to begin a graduate career where he performed the duties of graduate assistant to Dr. Bass for many years.

Steven completed his Master of Arts degree in Anthropology in 1983 and began to work toward a doctorate degree. In 1986, he was hired as administrative assistant to Dr. Charles C. Harlan, Medical Examiner of Metropolitan Nashville, Tennessee, and Davidson County Government. In 1987, he accepted a position as Assistant Director of the Regional Forensic Center, for the Department of Pathology, University of Tennessee, Memphis, where he is currently employed.