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The effects of thermal alteration on saw mark characteristics

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Thesis

THE EFFECTS OF THERMAL ALTERATION ON SAW MARK CHARACTERISTICS

by

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THE EFFECTS OF THERMAL ALTERATION ON SAW MARK
CHARACTERISTICS

JORDAN ELIZABETH BROUCHOUD

ABSTRACT

This project examined the effects of burning on saw mark characteristics of isolated semi-fleshed white-tailed deer (Odocoileus virginianus) long bones as a substitute for human remains. Different classes of saws were examined to determine which type of saw mark characteristics are obliterated when burned and which are not. The saw mark characteristics that were examined are superficial false start scratches, false start kerfs, and completely sectioned cuts with breakaway spurs/notches. The long bones were burned at the Boston University School of Medicine using a muffle furnace, at differing temperatures and at differing time increments. The author hypothesized that the higher the temperature and the longer the duration of bone burning, the greater will be the oblitative effect on saw mark characteristics. All samples were examined using a Motic® Digital Light Microscope 12 VDC with a Nikon® MKII Fiber Optic Light attached with accompanying Motic® imaging and measuring software. Distances were measured between striations on complete cuts, false start kerf widths, and false start scratch widths using the Motic® imaging and measuring software. Images were also taken of the cross sections of the kerf floors. The striations on the kerf walls, false start
kerf widths, and false start scratch widths were compared to the control samples. Measurements taken from false start scratches, false start kerfs, and complete cuts were averaged and compared to the averages from each temperature and the control samples, to assess the degree of shrinkage from thermal alteration. The false start kerf profile shapes were blindly examined and classified into Class A, B, C, or D (following the system of Symes 1992) and compared to the control samples. Kerf flare and blade drift were examined to determine if thermal alteration obliterated those saw mark characteristics. The chainsaw false start kerfs and complete cuts were examined macroscopically to determine what effects thermal alteration had on those types of marks.

All thermally altered samples were assessed for color change, heat-related fracturing, and whether or not the saw marks were still visible. The author found that all saw marks made with the mitre saw, crosscut saw, and bow saw were still visible and identifiable, even in a fractured state and, when burned up to 700°C for one hour. Most of the false start kerf samples were classified into the correct kerf profile shape as outlines in Symes (1992). False start kerfs and complete cuts made with the chainsaw were blindly examined and showed that these marks are distinct and easily identifiable when the bone is completely intact or has very minimal fracturing.

The crosscut saw false start scratch and crosscut saw complete cut samples showed signs of shrinkage. The average width of the false start scratch samples burned at 700°C for one hour was about 50% smaller than the control sample’s average width. The same was true for the complete cut striation widths. Shrinkage did not appear to alter the
crosscut saw false start kerf widths or the bow saw false start scratch widths. For all cuts made with the mitre saw shrinkage did appear to alter the samples. Warping did occur where some of the burned averages were larger than the control sample averages. This suggests that some warping did take place by widening the kerf, thus changing the analysis of the saw mark characteristics. Blade drift and kerf flare were seen in the samples and thus were not affected by thermal alteration.

The author’s hypothesis was not rejected, because in some cases thermal alteration did modify the saw mark characteristic measurements and in some cases thermal alteration did not alter the measurements. Some of the saw marks were affected by shrinkage, while others were not. False start kerf profile shape classification was not affected by thermal alteration. The chainsaw samples were affected most by the thermal alteration, because of the obliterative effects of heat-related fracturing which progressed generally with the greater temperature.
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CHAPTER 1: INTRODUCTION

The author hypothesized that the higher the temperature and the longer the duration of bone burning, the greater will be the obliterative effect on saw mark characteristics. This research focused on sharp force trauma to bone, specifically saw mark trauma, and the effects of thermal alteration on bone. Both saw mark trauma and thermal alteration irreversibly alter bone, and the degree to which these factors alter bone in conjunction with one another have not been studied extensively. When faced with a dismembered body, that has been burned, there is not a known point in which the saw mark characteristics can still provide reliable information. This research will aid in narrowing that gap and will provide information on whether thermal alteration does or does not affect saw mark characteristics. Also, the temperature range is not known in which measurements can be taken and still be used to correctly identify the class of saw used in the dismemberment. This research will help determine if there is a temperature range in which measurements taken of saw mark characteristics are more or less reliable. It is the goal of this research to identify a temperature range, in which measurements and characteristics of saw marks can be accurately used to identify the class of the saw used to create the marks.

Trauma

A forensic anthropologist will use bone fracture patterns and characteristics of the trauma found in bone to interpret what type of tool, weapon, or other object hit the bone.
There are three main classifications of trauma: sharp force trauma, blunt force trauma, and projectile trauma (Berryman and Symes 1998; Houck 1998; Reichs 1998; Symes et al. 1998; Thompson and Inglis 2009; White and Folkens 2005). While all types of trauma inflict a wound, each type of wound can look different, however this is not always the case, especially if pieces of bone are missing.

**Blunt Force Trauma (BFT)**

Blunt force trauma involves a broad, blunt object that tears or crushes tissues, such as a hammer, pipe, gun butt, or club (Berryman and Symes 1998; Dolinak and Matshes 2005; Kimmerle and Baraybar 2008; Spitz 1993). This can also involve a body hitting or crashing into something, such as in a car crash. Blunt force trauma includes direct impact, crushing, and acceleration-deceleration (Kimmerle and Baraybar 2008). There are two ways that blunt force trauma can be incurred: through low-force injuries, which result from an object hitting a person, and through high-force injuries, which result from a person being pushed into a stationary object (Galloway 1999; Kimmerle and Baraybar 2008). In bone these types of injury sites can have an absence of fracturing to complete failure which can include fractures and sometimes a tool mark impression (Berryman and Symes 1998). Most often these patterned injuries or tool mark impressions are most easily seen in the cranial vault or other flat bones (Berryman and Symes 1998; Kimmerle and Baraybar 2008).
Sharp Force Trauma (SFT)

Sharp force trauma involves a sharp, pointed object that cuts or incises tissues by being drawn with enough pressure to produce an injury that is longer than it is deep (Dolinak and Matshes 2005; Kimmerle and Baraybar 2008; Spitz 1993). Sharp force trauma can also involve a stab wound inflicted by the same type of object, but creating a wound that is deeper than it is wide (Dolinak and Matshes 2005; Kimmerle and Baraybar 2008; Spitz 1993). There are several types of objects used to create a wound with these characteristics including, a non-serrated knife, a serrated knife, and saws. Knives typically leave behind a V-shaped pattern in bone, while saws leave behind a U-shaped pattern in bone. The reason that saw marks leave behind a U-shaped pattern is because the teeth of the saw are designed to chisel out material rather than cutting through the material and pushing that material to the side, which creates a v-shaped pattern (Kimmerle and Baraybar 2008; Reichs 1998; Symes 1992; Symes et al. 1998; Symes et al. 2008b).

The analysis of saw mark characteristics has become more prevalent in forensic cases. Previous research (Burd and Kirk 1942; Bonte 1975; Symes 1992; Symes et al. 1998; Symes et al. 2010) has identified saw classes and how each saw may leave behind differentiating features on bone. There are many characteristics left behind on bone that will be discussed in the following chapter. The class characteristics that are produced with sawing can give accurate information on the saw’s size, set, shape, and how it is powered (i.e., hand or electrical) (Symes 1992; Symes et al. 1998; Symes et al. 2010). Examining saw kerf marks can aid in an investigation by possibly identifying the saw
which created the marks or by narrowing the range of possible tools used in the
dismemberment, which could lead law enforcement in the right direction. Knowing what
type of saw was used to commit a crime can also help law enforcement to narrow down
suspects in an investigation. Specific knowledge is needed concerning how saw marks
are created and the mechanisms behind the creating of those marks, because these
techniques will be scrutinized in a court of law.

In the past it was believed that the saw teeth erased any identifiable characteristics
with every stroke as the blade was cutting through a material (Bronte 1975; Symes et al.
1998). Throughout years of research this has been proven false; in fact, Symes et al.
(1998) shows that the reciprocating action of a saw enhances rather than erases the details
needed for a saw identification. While all saw mark characteristics may not be present
there can be enough identifiable features on the bone to make an identification.

This type of analysis can aid in archaeological research as well. Being able to
identify what type of instrument was used to inflict trauma on archaeological specimens
could benefit an archaeologist in determining if the trauma was inflicted as a ritual
sacrifice, during war, or possible dismemberment for burial (Gaither et al. 2008; Paolello
and Klales 2013; Parry 1982; Tung 2008; Verano 2001). The likelihood if saws being
used in an archaeological context is improbable, however, this information could be
useful in ruling out this type of trauma.
Ballistic Trauma

The study of gunshot trauma frequently focuses on the cranium (Baraybar and Gasior 2006; Kimmerle and Baraybar 2008; Berryman and Symes 1998). Due to the high variation in ammunition and firearms involved, each case must be examined on an individual basis. Gunshot trauma involves concentric and radiating fractures, entrance and exit beveling, and occasionally keyhole defects (Kimmerle and Baraybar 2008; Berryman and Symes 1998). Fracturing is usually extensive, due to the high magnitudes of force, and thus should not be confused with fracturing that is caused by blunt force trauma since there is usually no plastic deformation present (Berryman and Symes 1998).

Thermal Alteration

A misconception concerning burned human remains is that a body is dismembered and burned the entire body, all of the bones and soft tissue, is completely eliminated by the fire (Bass 1984; Fairgrieve 2008). Even when remains have been thermally altered knife marks or cut marks can be identified (de Gruchy and Rogers 2002; Kimmerle and Baraybar 2008; Pope and Smith 2004). Surrounding soft tissue protects and insulates bone (Pope 2007; Pope and Smith 2004). Differing thicknesses of initial soft tissue determine in part at what point bone will be exposed directly to a thermal source (Pope 2007; Pope and Smith 2004). A body can be damaged not only from direct flame but also from heat radiation (Pope 2007; Pope 2008). A compromise in skin integrity, such as locations where a saw was used to dismember the remains, can prematurely expose bone to thermal destruction, much like decomposition around a
perimortem injury (Pope and Smith 2004). The factors that influence the burning of human remains are how long the flame was sustained, the amount of oxygen to which the fire has access, materials used to start the fire, the use of an accelerant, the environment in which the fire took place, the presence of other flammable materials present to fuel the fire, and if the remains are fleshed (Fairgrieve 2008; Marciniak 2009; Symes et al. 2008; Walker et al. 2008).

While examining a fire scene where human remains are present, the victim’s body should not be overlooked as something that contributes to the burning process. Each type of body tissue burns in a different way. The skin, fat, muscle, and bone all contribute to the fuel load. This fuel load depends on the thickness, moisture content and layered anatomical arrangements of those tissues (Pope 2007). All of these tissues are essentially protecting or shielding the bones from fire.

Skin is the first tissue to become exposed to fire and is the thinnest. When skin reacts to heat it shrink, blisters, and splits. First the heat causes the skin to become waxy, glossy, bloat, and then tighten, shrink and split. The surfaces that are closest to the heat undergo color changes from red, to brown, to black char (Fairgrieve 2008; Pope 2007; Symes et al. 2008b). Perimortem trauma can be distinguished from heat-induced skin splitting, because incisions in the skin and muscle cause the tissues to be physically opened before the fire; thus, the tissues do not burn as an intact structure. This will cause deeper tissues to bulge and retract around an open wound (Pope 2007; Fairgrieve 2008).

Once the skin splits the underlying fat is exposed, and once it has been exposed to the heat, it liquefies. This liquefied fat provides a localized fuel source, which may
sustain the fire in those areas. Since muscle thickness varies throughout the body, differing areas will be more or less protected. As the muscles shrink, contract, retract, and burn during a fire certain bones are protected while others become more exposed (Fairgrieve 2008; Pope 2007; Symes et al. 2008b). The thinner layers of muscles, tendons, and ligaments burn away more quickly, thus exposing bones earlier, such as in the fingers. Cartilage and fibrocartilage protect bone during burning. Cartilage is often found on articular surfaces of joints and in other areas of the body. When cartilage is heated, it becomes dehydrated and shrinks (Pope 2007). Heat causes injured tissues to react differently than intact areas, as a result the burn patterns are different for areas on a body that have experienced trauma.

Tendons and ligaments are dense connective tissues that play a factor in the pugilistic posture (Fairgrieve 2008; Pope 2007). The pugilistic posture is induced by fire and heat and aids in the protection of bone by other tissues (Fairgrieve 2008; Pope 2007; Symes et al. 2008b). The muscle fibers are heated, which causes them to shrink and contract. The largest and most powerful muscles and ligaments override the smaller tissues, thus defining the pugilistic pose. This causes exposure of some areas, while shielding other areas. Using the forearm as an example, high temperatures cause adduction of the shoulder and flexion of the elbow and wrist. As the wrist flexes the dorsal carpals and the posterior distal radius and ulna have little protection from fire. The dorsal wrist and posterior elbow are two of the first areas to be affected by a fire, as these areas are drawn away from the torso of the body. The anterior elbow is afforded protection due to elbow flexure (Fairgrieve 2008; Symes et al. 2008b). The distal and
proximal ends of the radius and ulna will almost always be destroyed before the
diaphysis. The remains will exhibit the pugilistic pose after about 10 minutes (Bohnert et
al. 1998). After 20 minutes of exposure the vault of the skull would be free of soft tissue,
and after 30 minutes the internal organs become visible. The extremities are destroyed
after 50 minutes, and between one hour and an hour and a half the torso is broken down.
In this temperature range the breakdown of an entire body takes from two to three hours
(Bohnert et al. 1998).

Spitz’s (1993) study suggests that exposure of the arms, rib cage, and face to a
flame would cause them to exhibit differential charring at about 650º C in about 20
minutes. When a house fire reaches temperatures between 670º and 810º C and after
about 10 minutes of exposure a body will show the pugilistic posture and after 20
minutes the vault of the skull will no longer have any soft tissue present. According to
Fairgrieve (2008), at this temperature range, it would take two to three hours for the
entire body to become cremains. Flame temperature and duration in a house fire would
not be sufficient to destroy adult skeletal remains or even the soft tissue, because of the
uneven exposure to temperature, various types of fuel present, the fire not being in a
confined area, and the high amount of water present in the tissues (DeHaan 2002;
Fairgrieve 2008). There would, however, be significant alterations to the bones due to fire
exposure. This change to the bone due to fire is significant to this research, because there
is little known about the degree to which thermal alteration changes or alters saw marks
on bone.
Using Non-human Remains

One benefit of using nonhuman remains in a study stems from their availability and accessibility. The type of bone used, size, level of development, and fewer restrictions that are placed on nonhuman remains are all reasons in favor of utilizing nonhuman remains for research studies. Symes et al. (2012) conducted a study in which they compared saw marks in human bone and pig (*Sus scrofa*) bone, before and after burning and addressed the validity of using animal bone as a substitution for human bone in this type of research. Through this research they set out to determine if there was a significant difference in the degree of kerf deformation between the animal and human samples. The concluding results of this study were that class characteristics and traits were preserved after exposure to fire. This study also determined that there was evidence supporting the use of animal bone as an “appropriate proxy for accessing preservation of class characteristics in saw trauma analysis” (Symes et al. 2012). Through analysis this study concluded that there was evidence supporting that animal bone was a suitable proxy for accessing trait preservation and analysis of saw marks in humans, even though the animal bone has a higher density and surface area.

The author hypothesized that the higher the temperature and the longer the duration of bone burning, the greater will be the obliterateive effect on saw mark characteristics. This project examined the effects of burning on saw mark characteristics of isolated semi-fleshed white-tailed deer (*Odocoileus virginianus*) long bones. A crosscut saw, mitre saw, bow saw, and chain saw have been used to determine which type of saw mark characteristics are obliterated when burned and which are not. The saw mark
characteristics that were examined are superficial false start scratches, false start kerfs, and completely sectioned cuts with breakaway spurs. The long bones were burned at the Boston University School of Medicine using a muffle furnace, at differing temperatures and at differing time increments. These samples were examined microscopically with accompanying imaging and measuring software to assess color change, the effects of heat-related fracturing, the rate of shrinkage to the various saw marks, and the effect of thermal alteration on false start kerf classification, kerf flare, and blade drift.

This research is relevant to the field of forensics, because it will aid in determining if and at what point saw mark characteristics are changed by thermal alteration in such a way that those marks would no longer be a viable to use in a forensic case to help identify the class of saw that created the marks.
CHAPTER 2: PREVIOUS RESEARCH

Thermal Alteration

The effects of burning on masking previous bone trauma has been a topic of increasing research (Emanovsky et al. 2002; Fairgrieve 2008; Marciniak 2009; Smith 2003; Pope and Smith 2004; Pope 2008). Through the last several years, the topics of bone trauma and thermal alteration in a forensic setting have merged and have started to become studied as one unit. There is a vast knowledge about trauma (Berryman and Symes 1998; Houck 1998; Reichs 1998; Symes et al. 1998; Thompson and Inglis 2009; White and Folkens 2005) and thermal alteration (Bass 1984; Fairgrieve 2008; Pope 2007; Pope 2008; Pope and Smith 2004), however both of these topics being studied together is a recent venture.

Heat changes the composition of bones as they burn, because the organic compounds are being destroyed, leaving the inorganic compounds behind. Heat, pyrolysis, dehydration, soft tissue shrinkage and destruction, and damage to skeletal structures are all effects of fire to human remains (Pope 2007). The composition changes are exhibited through various color changes which are associated with increasing temperatures and differences in the environment in which the burning is taking place (Fairgrieve 2008; Symes et al. 2013; Symes et al. 2008b). At temperatures below 200º C bones begin gradually to darken and become dark brown. At 300º C bones turn from brown to black, which signifies all the non-carbon organic elements have been destroyed, leaving only the carbon behind (carbonization). The next color change is from black to
tan to gray, which happens at temperatures above 300º C. The next stages are dependent on the environment in which the burning is taking place. Bones being burned in the open air begin to turn gray at around 600º C and often become slightly purple at about 1100º C (Fairgrieve 2008; Symes et al. 2008b). When bones are burned on topsoil, they retain the gray color, which is normally seen around 300º C, until about 800º C, which can be caused by the carbon contained in the soil which delays carbonization of bone until the fire has reached a higher temperature (Symes et al. 2008b). Furthermore, calcined bone, white in color, can retain tool mark characteristics at sectioned ends (Marciniak 2009; Smith 2003) but, not as consistently as bone that is black or gray in color (Marciniak 2009).

A study conducted by Marciniak (2009) used adult pig (Sus scrofa) semi-fleshed hind limbs that had been dismembered using handsaws (crosscut saw, mitre saw, bow saw, hacksaw, and keyhole saw) and power saws (table saw, mitre saw, circular saw, jigsaw, reciprocating saw, and chainsaw). These types of saws were used, because they are commonly available at hardware stores. Each saw was used to cut through the bone completely and to create one false start kerf on the bone. An outdoor fire was used, and the bones were burned but were removed from the fire before full calcination was reached. The bones were removed from the fire every five to ten minutes to assess the changes and then placed back into the flames. The bones were removed from the fire if they met one of these conditions: (1) if there was a significant amount of cracking or fragmentation which threatened the quality of the bone (2) if the bone exhibited deformation, warping, or twisting that would affect the cut ends of the bone or the surface
details of the false starts to such a degree that those aspects would not be capable of being analyzed (3) if the bone reached the color range of grey, blue, and white, in order to prevent complete calcination of the limb and subsequent fragmentation due to fragility of the bone and (4) if the temperature of the fire exceeded 800º, shrinkage was considered to be playing an active part in the destruction of the bone. The bones were left in the fire for a maximum of three hours and during this period the temperature was only taken once, measuring at less than 400ºC.

After burning the marks (complete cuts and false start kerfs) were examined visually to determine the tool type and the energy source of the cuts (mechanically or hand powered). Then, the direction of the saw cuts were examined to assess the position of the body at the time of dismemberment. Under microscopic analysis the handsaw (crosscut and mitre) striae were less recognizable in the gray to white color range. The other handsaws (bow saw, hacksaw, and keyhole saw) striae were identifiable in varying degrees throughout the burning process. The power saws (table saw, mitre saw, and circular saw) striae in the calcined bone that were retained showed very little or no diagnostic patterns. The striae of the jigsaw, reciprocating saw, and chainsaw were observed on all of the bone fragments, regardless of color. Thus, under microscopic and macroscopic examination the false start kerfs of handsaws and power saws were not affected by burning and did not exhibit thermal damage aside from color change.

Similarly, Pope and Smith (2004) replicated typical fires to reproduce heat-related changes to crania with and without antemortem trauma. These crania exhibited ballistic trauma, blunt force trauma, and sharp force trauma, compared with a non-traumatized
control group. Open-air fires were used to burn the remains and temperatures ranging from 204°C to 871°C were reached. This research found that sharp force injuries were the easiest to recognize during post-burn analysis. The authors found that burning did not significantly alter the morphology of sharp force trauma in bone and that subsequently, each injury was able to be identified. These marks were visually identifiable as uniform linear depressions or incisions in the external table of the crania. Specifically, the marks created by scalpels, knives, and saws were easily distinguishable from one another morphologically.

**Time and Temperature**

Pope (2007) states that the differences in time and temperature are important in forensic investigations where these variables are not always known, and knowing these variables can contribute to the reconstruction of events. Fires produce distinctive burn patterns whether one is investigating destruction of property or human remains. The most basic variables that affect the amount of destruction are time, temperature, exposure, rate, and intensity of heat (Bass 1984; Bohnert et al. 1998; Fairgrieve 2008; Mayne Correia 1997; Pope 2007; Symes 2008b; Symes 2012).

**Heat-Related Fractures**

Postmortem heat-related fractures need to be separated from perimortem fractures due to trauma and from taphonomic changes to bone, mainly weathering (Bohnert et al. 1998; Fairgrieve 2008; Mayne Correia 1997; Pope and Smith 2004; Symes et al. 2008b;
Symes et al. 2013). Pope (2007) relates this to understanding the differences between breaking a dry wooden stick, which breaks with a clean snap and results in a transverse, jagged break, and a fresh green stick, which will bend before breaking and has a combination of transverse and angular breaks with deformation (Bohnert et al. 1998; Fairgrieve 2008; Pope and Smith 2004; Symes et al. 2013). This type of difference is also seen in postmortem heat-related fractures, with the absence of grease and the element of heat added, this causes the bones to break apart and shrink. Postmortem heat-related fractures only occur after direct exposure to heat and are usually found in carbonized and calcined bone. This type of fracture typically has a similar coloration to the fracture margin and adjacent cortical surfaces (Fairgrieve 2008; Murad 1998; Pope 2007). This means that all of these surfaces were exposed and burned during the fire. Heat-induced fractures can occur on bones with or without soft tissue present. Dry bones generally lack grease content and soft tissue protection, thus this type of bone will burn uniformly and shrink and fracture as a homogenous structure. Longitudinal fractures propagate along the long access of the bone, while transverse fractures occur perpendicular to the shaft of long bones.

Post-fire fractures typically occur during the search, recovery, transport, and analysis of the remains. When the organic material in bone has been burned off, the remaining inorganic material becomes very fragile and can fragment during any stage of the recovery process. In post-fire fractures, the fracture margins are often different in color than the areas of bone that were exposed to heat (Fairgrieve 2008; Pope 2007; Pope and Smith 2004; Symes et al. 2013).
Components of a Fire

The fire tetrahedron is made up of the elements that a fire requires to sustain combustion (DeHaan 2002, 2008; Fairgrieve 2008), these are fuel, heat, oxygen, and a chemical reaction. Fuel sources include solids, liquids, and gases and can change from one state to another during the burning process. Some fuel types burn quickly, while others burn more slowly; accelerants are used in some fires, common accelerants are gasoline, diesel fuel, kerosene, lighter fluid, or any alcohol based product. If an accelerant is poured directly onto a body, it is important to consider that the clothing, carpet, furniture, and wood floor will absorb this fuel and become additional factors in the combustion process (DeHaan 2008; Pope 2007).

Phases of a Fire

There are five phases that a basic unchecked compartment fire moves through, they are, ignition, growth, full involvement, decay, and extinguishment (DeHaan 2008; Fairgrieve 2008; Pope 2007). The ignition phase involves a small localized fire which progresses into the growth phase, where more fuels are consumed, which creates more heat and smoke. This heat causes fuels to pyrolyze, producing gases that eventually ignite. Full involvement, or flashover, happens, in structures, when all materials from floor to ceiling ignite and burn. Flashover does not always occur. Depending on fuel and oxygen availability fires will continue to burn until there is a reduction of heat and flame production, which is the decay phase. Flames and heat can fluctuate from increase to
decay if the fire accesses new fuel sources or if oxygen is introduced, until all fuel sources are consumed. Natural extinguishment occurs when all fuels have been consumed, when all combustible materials have degraded, or if there is a lack of oxygen (DeHaan 2008; Fairgrieve 2008; Pope 2007).

How a fire grows, spreads, and travels depends on where walls, ceilings, furniture, and hallways are located, also, if windows and doors are open or closed. The dynamics of a fire can also be affected by a body, which is a localized fuel source (DeHaan 2008; Fairgrieve 2008; Pope 2007). A body, during the early stages of a fire, can undergo a variety of injuries from superficial damage from radiating heat to direct flame. The temperature of the fire and the proximity of the body to the fire are key factors to the amount of damage a body suffers.

Time and temperature are important variables in the amount of tissue damage sustained during a fire. The same physical damage can occur with a slow, low intensity fire over a long period and a fast, accelerant fueled fire (DeHaan 2008; Fairgrieve 2008; Pope 2007). Color changes to bone reflect the extent of pyrolysis or organic breakdown from heat exposure (DeHaan 2008; Fairgrieve 2008; Pope 2007; Symes et al. 2008b; Symes et al. 2013).

**Misconception: Bone Color Indicates Temperature of a Fire**

There is a common misconception that bone color indicates the temperature of a fire. The aim of this theory was to be able to say that “If you have a bone that is ______
color, then the temperature the bone was burned at was ______.” (Pope 2007). What was not considered were the variables that are responsible for this color change, the organic content of bone, pyrolysis of organic materials, the availability of oxygen, and the smoke. When these variables are not accounted for the information gleaned about temperature and/or the deration of the fire can be misleading (Fairgrieve 2008; Pope 2007). The terms unburned, initial zone of pyrolysis, charred bone (carbonized), and calcined apply to the correlation between the stages of tissue reduction, pyrolysis of organic materials from bone, and the relative amounts of oxygen available in the surrounding area, rather than an indicator of temperature levels (Fairgrieve 2008; Pope 2007; Symes et al. 2013).

**Heat Induced Color Changes to Bone**

With prolonged heat exposure, fleshed bone undergoes several color changes. The first change is in the initial zone of pyrolysis where the bone begins to turn yellow with the denaturing of organic materials (collagen, proteins, water, and lipids). The next change is charring or carbonization where the bone turns black. The carbon contained in the bone then combusts leaving a white/grey brittle, very fragile, calcined structure behind. This color change is due to the carbon based organic components (collagen, proteins, and lipids) in bone being destroyed, through denaturation and pyrolysis, the carbon is also eventually removed, leaving behind the inorganic components (hydroxyapatite, calcium, and phosphates). The inorganic components that are left behind
is recognized as calcined bone, which is dry and brittle (Devlin and Herrmann 2008; Fairgrieve 2008; Pope 2007; Symes et al. 2008b; Symes et al. 2013; Walker et al. 2008).

*Initial Zone of Pyrolysis*

The initial zone of pyrolysis is the first transitional color after the soft tissue has been burned and the bone has become exposed. This boundary is temporary between exposed bone and unburned bone which is still protected by soft tissue. There is a slight color change to a lighter more translucent tone and is the initial stage of denaturation of organic materials (Devlin and Herrmann 2008; Fairgrieve 2008; Pope 2007; Symes et al. 2008b). This zone differs from fresh bone visually with variations in lighter to darker color depending on the grease saturation. This is also the area where heat exposure begins to shrink and change the structure of bone. Also, small tensile heat-related fractures can extend beyond this zone of initial pyrolysis to areas of unburned bone. These fractures are superficial and reside on the external cortical bone and do not penetrate into or radiate into areas of unburned bone.

*Charred, Carbonized Bone*

In this stage the bone will turn black from charring due to a reduction of organic materials and involves carbonization. This reduction of organic materials produces color variations with the amount of grease persisting in the carbonized blackened stage before the remaining organic components are pyrolyzed during calcination (Devlin and Herrmann 2008; Fairgrieve 2008; Pope 2007; Symes et al. 2008b; Symes et al. 2013).
The charring stage begins as a superficial discoloration and progressively moves to deeper cortical structures as the heat penetrates deeper into the bone. From these heat changes, the bone becomes progressively more fragile and brittle with the loss of the organic components, which are responsible for the strength of a bone (Fairgrieve 2008; Pope 2007; Symes et al. 2008b).

Calcined Bone

When the carbon in bone has become completely oxidized, the bone becomes gray to white and very brittle. This calcined bone is comprised mainly of inorganic hydroxyapatite crystals and the mineral components of bone (Devlin and Herrmann 2008; Fairgrieve 2008; Pope 2007; Symes et al. 2008b). With longer periods of heat exposure, calcined bone becomes more fragile, fragmentary, and deformed, and heat-related fractures become more common. Longitudinal, transverse, curved tissue regression, and delamination fractures can all be present in calcined bone.

Shrinkage Due to Fire

Researchers (Fairgrieve 2008; Pope 2007; Symes et al. 2008b; Symes et al. 2013) have discussed how heat can change the dimension of bone, both length and width. Rates of shrinkage result from taking measurements of a long bone before the fire, measuring it after the fire, and calculating the amount of shrinkage after the organic materials have been removed (Pope 2007). Studies inspected by Fairgrieve (2008) indicated that when comparing unburned bone to burned bone yielded 5 to 12% shrinkage. Three phases of
shrinkage were determined by Herrmann (1977) To be: Phase I 150°C- 300°C = 1-2% shrinkage; Phase II 750°C- 800°C = 1-2% shrinkage; and Phase III 1000 °C- 1200°C = 14-18% shrinkage. This study by Herrmann (1977) outlined four criteria that should be considered when examining shrinkage to bone due to fire:

1. Distribution of bone types in the bone (compact, spongy, and lamellar)
2. Temperature of exposure
3. Mineral content of bone
4. Aspects of the mineral content of bone tissue

Cortical thickness, size, shape, and distribution of trabecular structures (Fairgrieve 2008; Pope 2007) also contribute to the differing amounts of shrinkage to bone. Thus, when one bone is exposed to the same amount of heat for the same amount of time the shrinkage could be different throughout the bone.

**Sharp Force Trauma**

The effects of sharp force trauma on bone has been researched extensively (Bartelink et al. 2001; Bonte 1975; Burd and Kirk 1942; Lynn and Fairgrieve 2009; Saville et al. 2007; Symes 1992; Symes et al. 1998; Symes et al. 2010; Tucker et al. 2001; Turner and Turner 1999; White 1992; White and Folkens 2005) to identify characteristics which various types of blades, knife or saw, leave behind. Early research on tool marks in bone and cartilage was conducted by Bonte (1975). His findings indicated that the width of the groove left in an incomplete sawing displays evidence of the setting of the blade and the creation of rills (striations) which are seen on the bottom of the partially sawed portion of bone (breakaway spur or floor of a false start kerf) and
are in accordance with the findings of Symes (1992). Burd and Kirk (1942) found that even apparently smooth edged tools (even blades that have been polished) will leave striations on bone. Burd and Kirk (1942) tested the vertical angle (ranging from 25° to 65° at 10° intervals) at which a set of screwdrivers were held to determine if the marks left behind differed. They found that when counting the total lines (striations) which matched between two marks made by the same tool that was held at the same vertical and horizontal angles, might show that the lines match, the striations are the same distance apart, 80% of the time. However, when marks made by the same tool, but differing by 10° vertically were compared, only about 60 to 65% of the lines (striations) matched. When the vertical angle differed by 20°, the marks matched only about 40%, and the appearance of the mark to the eye was noticeably different. They found that with two marks made with the same tool, the vertical angle must be between 10° and 15° to attain a recognizable match. Furthermore, Burd and Kirk (1942) found that the degree of irregularity of the edge of a blade, if it is altered or damaged, will influence the character of a saw mark. These data can relate to examining saw mark characteristics, because if the saw was not held at the same angle or the angle was changed these characteristics might appear different.

Tool mark identification has been defined as the discipline in forensic science that is concerned with matching a tool with a particular mark (Symes 1992; Symes et al. 1998; Symes et al. 2010). This positive identification involves the comparison of unique characteristics resulting in “sufficient agreement”. Agreement is sufficient when, “it exceeds the best agreement demonstrated between tool marks known to have been
produced by different tools” (Symes 1992:8). With saw mark comparisons positive identification is rare; thus, other conclusions must be examined in conjunction with the tool marks. Having inconclusive results means there is insufficient agreement of individual characteristics, the lack of ability to reproduce the characteristic, or the insufficient agreement for elimination. Significant disagreement results in the elimination of a tool mark and the possibility that the tool mark is unsuitable for comparison (Symes 1992).

When examining a saw, the major components (size, set, shape, and power) must be regarded (Symes 1992; Symes et al. 1998; Symes et al. 2010). Saw teeth, in most saws, have a front and back, where the front of the tooth is designed to do the majority of the cutting. During the cutting stroke, the front side of the tooth bites into the material, while during the passive stroke the back side of the tooth slides along the material. Typically, the push stroke is the cutting stroke since this direction of motion engages the front side of the teeth. The pull stroke is usually the passive stroke since this direction of motion engages the back side of the teeth (Symes 1992; Symes 1998; Symes et al. 2010).

Saw cuts or attempted cuts on bone create characteristics that Symes and colleagues (Symes 1992; Symes et al. 1998; Symes et al. 2010) have analyzed extensively. Symes and colleagues (Symes 1992; Symes 1998; Symes et al. 2010) name three types of cuts to bone, false start cut, snapped false start cut, and completely sectioned bone. According to Symes and colleagues (Symes 1992; Symes et al. 1998; Symes et al. 2010) analysis of saw marks concerns two main areas of cut bone, the walls and floor of the kerf. The floor is present in all false starts and partially present in
breakaway spurs. When a kerf floors is present it offer the most information about the points of each tooth and the relation of the points of the blade (Symes 1992; Symes et al. 1998; Symes et al. 2010). Although, breakaway spurs occur more frequently these features offer less reliable information than false start kerfs. Kerf walls present information about the sides of the teeth and often only represent the teeth set to one side (Symes 1992; Symes et al. 1998; Symes et al. 2010).

**Saw Types and Terminology**

Saw mark analysis examines two areas of cut bone, the walls and floor of the kerf. The kerf floor is seen in false starts and partially expressed in breakaway spurs. Superficial false start scratches are made when the blade is drawn across the bone without a kerf being made, and these scratches can be confused with marks made by other tools. False start cuts are defined by Symes and colleagues (Symes 1992; Symes et al. 1998; Symes et al. 2010) as the saw teeth establishing “a kerf or definable cut in the bone, but have not cut completely through the bone”. A snapped false start is “a deep false start in bone that has had leverage applied to the bone resulting in a fractured bone” (Symes 1992:34). The force used here is greater than the force applied by the typical act of sawing. False start kerfs are cuts that did not completely separate the bone into two halves (Figure 2.1), and they are composed of two initial corners, two walls, two floor corners, and a floor (Symes 1992; Symes et al. 1998; Symes et al. 2010). Completely sectioned bones are a type of cut that “will have a residual kerf floor in the form of a breakaway spur” (Symes 1992:34). A breakaway spur (Figure 2.1) is a projection of
uncut bone at the terminal end of the cut after the force breaks the remaining bone tissue (Symes 1992; Symes et al. 1998; Symes et al. 2010). This feature is often indicative of a residual kerf floor, and the size of the spur depends on the amount of force applied when sawing. When examining a completely sectioned bone, a breakaway spur will most likely be present and the size of the spur is dependent on the force that was used to cut the bone (Symes 1992; Symes et al. 1998; Symes et al. 2010).

False start kerfs can be examined in two ways. The first technique is to examine cuts on end, which allows you to view down the cut and examine the profiles of the walls and floor (Symes 1992; Symes et al. 1998; Symes et al. 2010). The second technique is to examine the initial cuts with the floor as the area of interest. These techniques can also be applied to breakaway spurs and reconstructed bone cuts.

Figure 2.1. Saw kerf showing walls and floor of a false start kerf and complete cut (Symes et al. 2010: 20).
Rip saws are designed to chisel material rather than cut it, where each tooth chisels a piece of the material and ejects it at the end of the stroke (Symes et al. 2010), rather than like a knife pushing the material into the walls of the cut. Each tooth is filed at a 90º angle to form a flat chiseled face, which trails off to the back side of the tooth, forming a gullet angle of 60º with the front of the next tooth (Figure 2.2). These types of saws are made to cut with the grain of wood. Crosscut saws are smaller and bite less material than a rip saw. Crosscut teeth are the same shape as rip saw teeth; however, the front angle is rotated on the blade forming a 60º to 75º angle (Figure 2.2). The tip of each tooth forms a point rather than a chisel, thus slicing through the material. Crosscut saws are made to cut across the grain of wood (Symes 1992; Symes et al. 1998; Symes et al. 2010).

Figure 2.2. Rip versus crosscut saws, with typical alternating set (Symes et al. 2010:19).
Bow saws are a raker-set saw, which means that a raker tooth is set between every couple of teeth. The raker tooth will rake material from the kerf floor, rather than the wall, essentially cleaning up after the other teeth. Specifically, the rakers are identical to the other teeth, but they lack lateral bending. Raker teeth limit blade drift, because the tooth enters the material on the center path, meaning that this tooth does not have to seek the midline, much like laterally bent teeth would (Symes 1992; Symes et al. 1998; Symes et al. 2008b; Symes et al. 2010). Chain saws are intended to cut soft materials at a high speed with teeth that are shaped like a “J”. When cutting hard material, including bone, the chain saw leaves wavy-edged walls, and the teeth bite very little into the bone. Each tooth will jump back and forth, because of the high speed, as it enters into the bone, which creates a J-shaped pattern in the bone (Figure 2.3). Because of the design of a chain saw the sawing action appears to melt the bone, rather than cut it (Symes 1992; Symes et al. 1998; Symes et al. 2010).

Figure 2.3. Two different views of chainsaw dismemberment cuts to a femur, showing the J-shaped tooth “beating” the bone, while the blade bounces back and forth with the introduction of each tooth (Symes et al. 2010:30).
Blade and Tooth Size

Blade and tooth size are other important factors in the design of a saw. Tooth size is recorded in Teeth per Inch (TPI) or Points per Inch (PPI). Soft materials are cut with blades that have a lower TPI, while blades with higher TPI are made to cut harder materials. The number of points per inch is usually one greater than the number of teeth per inch (Symes 1992; Symes et al. 1998; Symes et al. 2010). Having more teeth per inch increases the smoothness of cutting characteristics while slowing the speed of the cut, while saws having fewer, larger teeth are designed to saw softer materials more efficiently. Saw tooth width can be calculated by measuring the floor patterns and by measuring the residual tooth trough, according to Symes (1992; Symes et al. 1998; Symes et al. 2010). Floor patterns give an average estimation of saw tooth width. Residual tooth image uses kerf floors with islands to estimate tooth width. These islands are created by alternating set blades and appear in material when the total tooth set combined with blade drift produce a kerf with greater than two times the width of a single tooth. This can be calculated by using these formulae in Formula 2.1 described in Symes (1992):
Kerf width – greatest island width = \frac{\text{tooth width or}}{2}

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

For kerfs with no islands, use

\frac{\text{Greatest kerf width}}{2} \leq \text{tooth width}


Blade and Tooth Shape

Blade and tooth shape are comprised of the contour of the blade, the tooth as it is cut out of the saw blade, and the angle in which teeth are filed (Symes 1992; Symes et al. 1998; Symes et al. 2010). Rip and crosscut saws are the most common classifications of saws in term of tooth shape. Rip saw teeth are filed at a flat angle to form a flat chiseled face (Symes 1992; Symes et al. 1998; Symes et al. 2010). Large-tooth saws with these types of teeth are designed to cut with the grain of wood. Crosscut teeth are usually the same shape as rip teeth, but the front side of the tooth is visibly sloped back on the blade rather than, like rip teeth, aligned perpendicularly to the blade (Symes 1992). The tooth shape determines if the saw cuts on the push stroke or the pull stroke. A typical hand saw uses the push stroke, the more powerful stroke, to cut the material. Japanese pull saws are an exception to this. These types of saws use the pull stroke to cut through a material and because of the force being exerted on the pull stroke, tension can be maintained on very
thin blades. These saws are more brittle and the blade or teeth are more likely to break than bend (Symes 1992). Because these types of saws have narrower blades they produce a narrower kerf which wastes less wood. Chain saws have a very different type of tooth design, because these types of teeth are made to cut soft materials at high speeds.

**Blade and Tooth Set**

Blade and tooth set are essential to reduce blade binding (i.e., the freezing up of the blade as it gets stuck in the material that it is cutting). The lateral bending of the top half of the saw teeth (or blade) allows for the creation of a kerf that is wider than the back of the saw, allowing it to follow the teeth without binding (Symes 1992; Symes *et al.* 1998; Symes *et al.* 2010). Teeth are normally set according to their size and the size of the blade and Symes *et al.* (1998) indicated that the kerf width does not exceed 1.5 times the thickness of the blade. Teeth are set according to size and blades are set in three ways: alternating, raker, and wavy (Figure 2.4).
Figure 2.4. Illustrations of the three major types of saw blade set (Symes et al. 2010:23).

**Alternating Set**

An alternating set is when the teeth are alternately bent laterally (Symes 1992; Symes et al. 1998; Symes et al. 2010). For example, the first tooth may be bent laterally to the right, the second tooth bent laterally to the left, the third tooth bent laterally to the right, and so on. The alternating set of saw teeth reduces binding; thus, blade drift is produced when teeth alternate crossing the kerf floor.

Blade drift is produced when a new tooth enters the kerf, causing the blade to move laterally. When using an alternating set blade, the teeth are set to create a wider cut, thus allowing the blade to pass through the material. When the first tooth enters the bone it seeks to become parallel with the direction of the blade and the midline of the material. When the second tooth, which is set to the opposite side of the previous tooth, enters the material in a different position it also seeks the midline, thus diverting the first tooth out
of the midline until a compromise has been reached (Symes 1992; Symes et al. 1998).

The introduction of a new tooth causes a direction change, thus the distance from
direction change to direction change, equaling two direction changes, in false starts is the
distance of one tooth (Symes 1992; Symes et al. 1998). It is easier to measure the
distance from narrow to narrow or wide to wide, which is the distance between two teeth,
which is depicted in Figure 2.5. This results in a drift that resembles a figure eight
pattern. The drift pattern is most visible at the beginning or end of a cut in a tubular bone.
Once the blade has become immersed in the material, most of this drift is suppressed.
Rakers inhibit lateral movement of the blade, because they are centrally located on the
blade, thus making it impossible to measure blade drift (Symes 1992).
Figure 2.5. Three initial saw cuts on a kerf floor by an alternating set saw (Symes 1992:83).

**Raker Set**

Rakers are intended to rake the imperfections and sawdust from the kerf floor rather than cut or chisel it, thus cleaning up after the other teeth and modifying the kerf (Symes 1992; Symes *et al.* 1998; Symes *et al.* 2010). Raker teeth are placed in between every third or four tooth and can alter the 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 (Symes *et al.* 2010; Symes 1992). Raker set blades are often seen in pruning and fine toothed bow saws (FTBS). Pruning saws have large teeth combined with rakers and gullets, which are large spaces between large teeth, to clear the wood debris.
from the kerf (Symes 1992). Rakers are typically shorter than the regular teeth since they are designed to clean the kerf and not to cut into the material. Fine toothed bow saws are designed to cut through harder materials with their rakers designed to smooth and clear the kerf floor. The rakers in fine toothed bow saws are identical to the other teeth, only they have no lateral bending (set) (Symes 1992; Symes et al. 1998; Symes et al. 2010). Raker teeth inhibit blade drift, the side to side movement of the blade, because the raker tooth enters the material on its central path. This is especially true for fine toothed bow saws, because the raker which is smoothing out the kerf along the midline of the blade inhibits the set teeth from into the side to side movement. However, with pruning saws, since the rakers are shorter than the other teeth and usually set one out of every five teeth Symes (1992) suggests that the influence of the rakers on blade drift is likely minimal.

Wavy Set

Wavy set blades have a group of teeth that are alternately bent from side to side, making each wave function as a single alternatingly set tooth comprised of many smaller teeth (Symes et al. 1998; Symes et al. 2010). These types of blades cut on the same principle as alternating set blades and have very small teeth (Symes 1992; Symes et al. 1998; Symes et al. 2010).

Floor Dip

When a kerf is examined longitudinally at an angle the bottom of the kerf may be wavy. This pattern is the result of consecutive teeth entering the bone and hopping across
the floor (Symes 1992; Symes et al. 1998). Hopping is created each time a new tooth enters the edge of a material. The introduction of this new tooth causes the blade to jump, and since this jumping action is caused by the teeth, this feature should be indicative of tooth spacing. Determining floor dip is similar to determining blade drift, except that the distance from floor dip to dip, or peak to peak, is indicative of a single tooth, whereas in blade drift the distance of wide to wide or narrow to narrow indicates two teeth due to the alternating set.

**Kerf Classifications**

Symes (1992) places cross sections of kerfs into four kerf profile shape classifications, A, B, C, and D. Each kerf profile shape classification and its variants are illustrated in Figure 2.6. Class A kerf profile shapes have a narrow kerf with a rounded floor corner or corners. These variants are associated with narrow blades and small teeth, typically fine toothed bow saws (FTBS) and serrated edge knives. Fine toothed bow saws create cross sections similar to large saws, except with FTBS a single or double rounded kerf floor corner is common (Symes 1992). This rounding feature appears to be related to the small size of the teeth and the blade drift present with a fine toothed saw. This rounding occurs when blades or teeth drift away from one corner while chiseling out the other, thus it is common to see a square corner along with a round corner (Symes 1992).
Figure 2.6. Classes of kerf profile shape (Symes 1992:56).

Class A

Class A variants one through three (Figure 2.6) illustrate chiseling teeth with no rakers and an alternating set. Since these variants are narrower and in general have one rounded corner, this indicates a fine toothed bow saw rather than all larger toothed chisel saws. Variant one is typical of a kerf exhibiting asymmetrical sets of the teeth. Rakers were present in the blades for variants four through six and are 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 of concavity. Since rakers are present, the teeth chisel out the...
floor along the midline, and there is no blade drift. This pattern describes a fine toothed bow saw with a raker set (Symes 1992).

Variants five and six are indicative of uniformly set blades which create smooth and rounded floors (Symes 1992). A non-uniformly set blade, generally associated with cheaper grades of hacksaw blades, creates a cross section which looks like variant four with a stepped or multiple cornered kerf floor that is often not symmetrical. In variants seven through nine the walls do not appear straight or parallel; they appear to expand as they form their initial kerf corners. This feature accompanying the asymmetrical appearance has a tendency for the walls to meander producing cross sections with walls that are somewhat uneven (Symes 1992). Kerf floors of wavy set blades are very flat in appearance to the naked eye, however these floors actually exhibit gradual rounding (concavity) (Symes 1992). Variants ten and eleven can be produced with serrated knives, none of which were used in the author’s research.

**Class B**

Class B kerf profile shapes are created with larger teeth with enough set to potentially create islands of bone, such as in variant two, 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 which could produce a bone island) (Symes 1992). Walls of class B kerf profile shapes are generally straight or stepped. Non-raker chisel hand saws generally resemble variants one or two, where many power saws produce variant three (Symes 1992).
Class C

Class C is different from class B mainly in the convex shape of the kerf floor, which indicates angled filing of teeth, which is characteristic of crosscut saws. Since these floors are always convex, there is a need for raker teeth, which are indicated by the truncated kerf floors in variant two. As raker teeth are designed to clear kerfs of wood, these specialty teeth may not function properly in a hard material and produce asymmetrical truncations, which are shown in variant three (Symes 1992).

Class D

Class D kerf profile shapes are unique in size and have an undulating wall shape, which is the byproduct of teeth that are shaped differently than teeth in Class A, B, and C. Variant one depicts the “melting” appearance of a crosscut chain cut in bone (Symes 1992). Variant two shows that the kerf is created by a rip chain saw. Although Symes (1992) did not study the rip chain saw formally, it is interesting to note that it forms a cleaner kerf when compared to the crosscut chain saw. The kerfs have similar widths, but the rip chain saw forms straighter edges and nearly square floor corners (Symes 1992).

Features Observable in Cross Sections

Tooth and Stroke Striae

Tooth and stroke striae are common features that are observable in cross sections. Stroke striae are apparent in most hand saws and many mechanical saws (Symes 1992;
Symes et al. 1998; Symes et al. 2010). Saws that produce no stroke striae include power saws that cut in a continuous rather than reciprocating motion. Chain saws, band saws, and circular saws are examples of continuous motion saws. Hand saws create both tooth (fine) striae and stroke (coarse) striae. Large toothed saws, ones that are large in height and distance between teeth, create striae that are wavy, but in effect straight at the top and bottom of the cuts on tubular bone, but create hopping at the level of the marrow cavity (Symes 1992).

**Features Quantifiable in Cross Sections**

In a cross section tooth hop is a signature of floor dip (Symes 1992). Striae on the surface of the bone typically progress in a straight pattern, but with upon looking closer these straight residual kerfs sometimes begin patterned hopping. This hopping is created when teeth begin to enter a kerf and as each successive tooth enters the bone causing movement of the entire blade (Symes 1992; Symes et al. 2010).

**Tooth Scratch**

Tooth scratch is the presence of striae on the cut surface of bone that is created when the saw is removed from the kerf (Symes 1992; Symes et al. 1998; Symes et al. 2010). In a raker set saw, this patterned scratching is usually the distance between three teeth. The characteristic of tooth scratch should be used in conjunction with or to corroborate other more reliable estimations of tooth distance and should not stand alone.
Harmonics

Saw mark harmonics are the peaks and valleys that are visible in cross sections of bone (Symes 1992; Symes et al. 1998; Symes et al. 2010). Harmonics are present in almost all blades with alternating set teeth and are the direct result of the normal cutting action in both hand and mechanically powered saws. Blade harmonics are the expression of blade drift progress. Measurements of harmonics are the same as measurements of blade drift. The distance between peaks and valleys is equal to the distance of two teeth. Distance between direction changes (between a peak and a valley) is the distance of one tooth. Symes (1992) states that it is important that these measurements are taken parallel to the direction of the stroke or on the same plane as the residual kerfs.

Direction of Blade Progress

False starts and breakaway spurs are the two main indicators of saw progress (Symes 1992; Symes et al. 1998; Symes et al. 2010). The plane in which the false start and breakaway spur or notch occur give the precise direction of saw progress. The stroke and tooth striae are perpendicular to the direction of blade progress. The direction of blade progress will begin at the false start or initial cut and end at the breakaway spur or terminal cut.

Direction of Blade Stroke

Cutting stroke is determined by tooth design and sawing technique. Symes (1992) defines cutting stroke as a continuous action or a single direction of a reciprocating action
that produces a majority of the cut. Most saw teeth are designed to bite into a material when moving in a specific direction. Sawing technique becomes evident when tooth design allows cutting in either forward or backward direction, called push/pull (Symes 1992; Symes et al. 1998; Symes et al. 2010). Direction of cutting stroke can be indicated by entrance shaving and exit chipping. Entrance and exit refer to the blade stroke and initial and terminal refer to the blade progress here. When the saw enters the side of a bone, the blade often times shaves the entrance, which gives the bone a polished and scalloped appearance. This is can be due to either the twisting of the saw, because the blade is not allowed a direct path into the kerf or more often due to the tooth set being wider than the blade, which forces each tooth to cut a kerf (Symes 1992; Symes et al. 1998; Symes et al. 2010). There is rarely chipping as the tooth enters the bone.

Exit chipping is variable, but is most often present. In a Western saw, which cuts on the push stroke, the push stroke is emphasized and the chipping will be produced on the push stroke as the teeth exit the kerf. Examination of both exit chipping and entrance shaving indicates direction of blade cutting stroke, but it is difficult to interpret these features (Symes 1992; Symes et al. 1998; Symes et al. 2010).

There are many aspects to both trauma and thermal alteration, as seen above, that need to be understood together and how these types of trauma coincide together. Both pieces must be understood and studied extensively together in order to gain valuable forensic information.
CHAPTER 3: METHODS

Preparation and Sawing

The author used white-tailed deer (*Odocoileus virginianus*) metapodials with partial skin and subcutaneous soft tissue still remaining for the most accurate available model for comparison to adult human remains in a forensic case (i.e., dismemberment of fleshed remains). The day before the sawing began the metapodials were removed from the freezer and were laid out on top of tarps to thaw.

A mitre saw, crosscut saw, bow saw, and chainsaw were all used to create superficial false start scratches, false start kerfs, and completely sectioned bones with breakaway spurs/notches. These types of saws were chosen, because they are considered affordable, practical, and easily obtained at local hardware stores and are subsequently common implements in cases of post-homicide dismemberment (Symes 1992; Symes 2010). The control samples were cut with the same types of saws and in the same manner but were not burned. Irwin® bar clamps (Figure 3.1) were used to secure the metapodials to saw horses when using the chain saw. Complete cuts and false starts were made with a standard tooth standard skip MSE 220 STIHL® chainsaw with a 16 inch bar (Figure 3.2). False start scratches were not made, because the power of the saw made it impossible. Agent Gary Reinecke made the cuts using the chainsaw. Then the fur was removed on each approximately one-inch section of bone using a scalpel and stored in a labeled bag.
The Husky® bow saw was used to make scratches on defleshed metapodials. The Husky® bow saw had a 12 inch raker set blade with 5 TPI (Figure 3.3). These metapodials were defleshed before sawing took place, because the fur and flesh would become lodged in between the teeth, making sawing extremely difficult. The metapodials
were secured in a vise, and then the false start scratches were made. Only false start scratches were made with the bow saw because the large teeth made it difficult to create a false start kerf. Once the marks were made on the metapodials, the long bones were cut into smaller pieces using a band saw so that individual marks were on separate sections of bone that would fit inside the muffle oven. Smaller pieces of bone were needed in order for them to fit into the muffle oven for the burning portion of this research. Each section of bone was placed into a labeled bag.

![Figure 3.3 Husky® bow saw.](image)

A DeWalt® crosscut saw (Figure 3.4) and Buck Bros.® mitre saw (Figure 3.5) were used to make false start scratches, false start kerfs, and complete cuts in metapodials. The DeWalt® crosscut saw had a 15 inch alternating set blade with 8 TPI. The Buck Bros.® mitre saw had a 14 inch raker set blade with 16 TPI. The same procedures used for preparing and securing the metapodials for the bow saw were used for the crosscut saw and mitre saw.
Again the band saw was used to separate the false start scratch marks and false start kerf marks onto individual pieces of bone. For completely sectioned cuts the band saw was not used in order to avoid confusion. These pieces were labeled in bags. Once the bones were cut, the samples were placed in a freezer at 0ºC until the burning process started. Dr. Donald Siwek made all of the marks using the hand powered saws (Figure 3.6 and 3.7).
Thermal Alteration

The remains were burned for a duration of one, two, three, or four hours at 200°C, and one hour at 400°C, 500°C, 600°C, and 700°C. These temperatures were chosen, because in the research conducted by Marciniak (2009) the temperature range was under 400°C and the present author wanted to replicate the results from that study as well as expand into higher temperatures. In Marciniak (2009) the microscopic analysis showed
that the handsaw (crosscut, and mitre) striae were less recognizable in the grey to white color range. The other handsaws (bow saw, hacksaw, and keyhole saw) striae were identifiable in varying degrees throughout the burning process. The power saws (table saw, mitre saw, and circular saw) striae in the calcined bone that were retained showed very little or no diagnostic pattern. The striae of the jigsaw, reciprocating saw, and chainsaw were observed on all of the bone fragments, regardless of color. Thus, under microscopic and macroscopic examination the false start kerfs of handsaws and power saws were not affected by burning and did not exhibit thermal damage aside from color change.

The first set of samples was placed into a conventional oven at 200ºC and were heated for one, two, three, and four hours. An oven thermometer was used to maintain proper temperature at the start of the session. However, the oven did not stay at a constant temperature throughout the entire session, but fluctuated 10 to 15ºC. Thawed segments of bone were placed on aluminum foil-lined baking sheets and two sheets were place into the oven at one time. The remaining samples were burned in a Thermo Scientific Thermolyne® FB1300 series small bench top muffle furnace at the Boston University School of Medicine. Six to nine samples were placed in the muffle oven at a time, depending upon the sizes of the samples. For temperatures at 400ºC and 500ºC the bone samples were placed directly onto a hearth tray designed for the muffle oven and burned for one hour. The samples were then removed and placed onto heat resistant wire mesh for cooling. For temperatures at 600ºC and 700ºC the bone samples were placed into small aluminum trays which were placed into the muffle oven. This was done for ease of
removal to avoid breaking the fragile bone samples while removing them from the muffle oven. The aluminum trays were then placed onto heat-resistant wire mesh for cooling. Once cooled, the bone samples burned at 500°C, 600°C, and 700°C were coated in Paraloid® B-72, which is an ethyl methacrylate copolymer resin used for conservation and restoration of wood, ceramics, glass, and bone (Davidson and Brown 2012). Bones burned at 200°C were soaked in a 80% Ethyl alcohol and 20% acetone solution for two to four days to remove some of the grease for ease of examination under the microscope.

**Microscopic Analysis**

After burning, the bone samples were examined macroscopically and compared to the control samples. The bone samples were also examined microscopically using a Motic® Digital Light Microscope 12 VDC with a Nikon® MKII Fiber Optic Light attached with accompanying Motic® imaging and measuring software. Distances were measured between striations and minimum kerf widths were measured using the Motic® imaging and measuring software. The kerf width on all false start kerfs made with the crosscut saw and mitre saw were measured using the same software. Kerf and scratch widths from all false start scratches made with the crosscut saw, mitre saw, and bow saw were measured. Striations on the complete cuts made with the crosscut saw and mitre saw were measured. Measurements taken (maximum false start kerf width, false start scratch width, complete cut striation widths) using the Motic® imaging and measuring software from false start scratches, false start kerfs, and complete cuts were placed into a Microsoft Excel worksheet, averages were taken of the maximum false start kerf width,
false start scratch width, complete cut striation widths and compared to the averages from each temperature to assess the degree of shrinkage from thermal alteration. The false start kerf width average, false start scratch width average and complete cut striation average were compared to the control sample. The false start kerfs made with the crosscut saw and mitre saw were blindly examined and classified into Class A, B, C, or D (Figure 2.6) and compared to the control samples. All images of the samples with cross-sections of the false start kerfs were placed into a computer folder with the labels covered. Each image was classified into A, B, C, or D. These classifications were recorded and then compared to the classification chart from Symes (1992) to determine if the false start kerfs had been correctly classified. The kerfs made with the crosscut saw, mitre saw, and bow saw were analyzed for kerf flare, blade drift, breakaway spurs, and breakaway notches. If these features were seen it was determined that thermal alteration did not obliterate them. Each chainsaw false start and complete cut were examined macroscopically, due to no actual striations being present. Damage due to thermal alteration was assessed, specifically heat-related fractures.
CHAPTER 4: RESULTS

Thermal Alteration Analysis

The samples that were burned at 200°C for one hour were very greasy with normal bone color to light brown color. The bones with more adipose tissue present when burned had light to dark brown burned tissue that had bubbled up (Figure 4.1), stuck to the samples that had to be removed manually; this did not damage the bones in any way. At this stage there was no fracturing due to thermal alteration and all saw marks were still visible.

![Figure 4.1 Samples burned at 200°C for one hour.](image)

200°C

The samples that were burned at 200°C for two hours (Figure 4.2) were slightly darker in color (some were still normal bone color) than the samples burned for one hour, but the grease remained. Again, bones that had more surrounding adipose tissue had dark brown to black burned tissue that had bubbled up in some areas, and this was removed
manually. At this stage there was no fracturing due to thermal alteration and all saw marks were still visible.

Figure 4.2 Samples burned at 200°C for 2 hours.

The samples that were burned at 200°C for three hours were dark brown to black, with greasy texture remaining (Figure 4.3). Adipose tissue, again bubbled up in certain areas and was removed manually, this was dark brown to black in color. At this stage there was no fracturing due to thermal alteration and all saw marks were still visible.
Samples burned at 200°C for four hours were very dark brown to black in color with a sticky black grease present (Figure 4.4). The aluminum foil that covered the cooking sheets was entirely covered with this black grease. The adipose tissue had bubbled up in some areas and was dark brown to black in color and was removed manually. At this temperature and time duration all saw marks were still visible and there was minimal fracturing due to thermal alteration.
400°C

Samples that were burned to 400°C for one hour were carbonized (completely black in color) with no grease or adipose tissue remaining (Figure 4.5). Many of the samples showed visible fracturing from thermal alteration. Some were complete fractures, where the bone was broken into several pieces; others showed patina fracturing or incomplete fracturing where the bone remained in one piece. All saw marks were still visible at this temperature and time duration.

Figure 4.5 Samples burned at 400°C for 1 hour.

500°C

The samples burned at 500°C for one hour were carbonized and calcined and were dark gray in color throughout with very little black adhering tissue present (Figure 4.6).
No greasy texture was retained at this stage. Most of these samples were fractured into two to three pieces. Complete fractures, patina fractures, and incomplete fractures were present. All saw marks were still visible; however, with the high degree of fracturing being able to identify the chainsaw marks might be difficult.

![Image of a sample]

**Figure 4.6 Chainsaw complete cut at 500°C for 1 hour.**

**600°C**

The samples that were burned at 600°C for one hour were completely calcined, exhibiting white, light and dark gray, and light blue colors, with very little if any carbonization remaining (Figure 4.7). These samples were highly fractured and fragile. The chainsaw samples were so fractured that it is unlikely that a correct identification could be made. The reason for this being that the complete cut edges look very similar to fractures, because the power of the chainsaw broke the bone rather than cutting through the entire bone. The heat-related fracturing makes determining the cause behind the fracturing difficult. The fracturing consists of mainly complete fractures with some
patina fracturing. The saw marks made with the crosscut saw, mitre saw, and bow saw were all visible and easily identifiable, even in a fractured state.

Figure 4.7 Samples burned at 600°C for 1 hour.

700°C

The samples that were burned at 700°C for one hour were all completely calcined (white in color) and very fragile (Figure 4.8). All of the samples were highly fractured and broke if moved or shifted. Complete fractures and patina fracturing was present on most of the samples. The saw marks made with the crosscut saw, mitre saw, and bow saw were all visible and easily identifiable, even in a fractured state.
Figure 4.8 Chainsaw complete cut burned at 700°C for 1 hour. Scale is in cm.

**Shrinkage Data**

Maximum kerf width measurements for experimental and control samples were taken one time for each false start kerf for the mitre saw and crosscut saw. Maximum scratch width measurements for experimental and control samples were taken one time for each false start scratch mark for the bow saw, mitre saw, and crosscut saw. All of the width measurements for each respective type of cut and saw were averaged using Microsoft Excel. These averages were compared to determine if shrinkage or warping played a role in changing or altering the saw mark characteristics. The results are as follows (Tables 4.1-4.8):
Examination of false start scratch width made with the crosscut saw showed a progressive decrease in scratch width average when moving from 200°C to 700°C (Table 4.1). The largest difference in width average was from the control sample average (1.532 mm) to the average of samples burned at 200°C for three hours (0.695 mm). The width continued to decrease and at 700°C the width average was 0.486 mm, which is a decrease of 68%.

<table>
<thead>
<tr>
<th>Temperature</th>
<th>Scratch Width Average (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>200°C for 1 Hour</td>
<td>1.059</td>
</tr>
<tr>
<td>200°C for 2 Hours</td>
<td>1.059</td>
</tr>
<tr>
<td>200°C for 3 Hours</td>
<td>0.695</td>
</tr>
<tr>
<td>200°C for 4 Hours</td>
<td>0.869</td>
</tr>
<tr>
<td>400 °C for 1 hour</td>
<td>0.346</td>
</tr>
<tr>
<td>500 °C for 1 hour</td>
<td>0.412</td>
</tr>
<tr>
<td>600 °C for 1 hour</td>
<td>0.428</td>
</tr>
<tr>
<td>700°C for 1 hour</td>
<td>0.468</td>
</tr>
</tbody>
</table>

The false start kerf width averages created with the crosscut saw were closely grouped. The control sample kerf width average measured at 1.443 mm which is in the same range as the other false start kerf width average samples that were burned at different temperatures (Table 4.2). These width averages do not differ greatly, much like the false start scratch width average created with the crosscut saw.
Table 4.2 Average kerf width for false start kerf with crosscut saw (mm).

<table>
<thead>
<tr>
<th>Temperature</th>
<th>Kerf Width (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>200°C for 1 Hour</td>
<td>1.631</td>
</tr>
<tr>
<td>200°C for 2 Hours</td>
<td>1.708</td>
</tr>
<tr>
<td>200°C for 3 Hours</td>
<td>1.394</td>
</tr>
<tr>
<td>200°C for 4 Hours</td>
<td>1.541</td>
</tr>
<tr>
<td>400 °C for 1 hour</td>
<td>1.578</td>
</tr>
<tr>
<td>500 °C for 1 hour</td>
<td>1.502</td>
</tr>
<tr>
<td>600 °C for 1 hour</td>
<td>1.554</td>
</tr>
<tr>
<td>700°C for 1 hour</td>
<td>1.637</td>
</tr>
</tbody>
</table>

There was a large decrease in striation width average of complete cuts made with the crosscut saw (Table 4.3). The control samples average striation width was 0.658 with the largest difference in average size being between the samples from 200°C for two hours (0.706 mm) and 200°C for three hours (0.497 mm). Overall, there was a decrease of the striation width average of 44% from the control sample average (0.658 mm) to the sample average burned at 700°C for one hour (0.360 mm).

Table 4.3 Average striation width for complete cuts with crosscut saw (mm).

<table>
<thead>
<tr>
<th>Temperature</th>
<th>Striation Width (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>200°C for 1 Hour</td>
<td>0.620</td>
</tr>
<tr>
<td>200°C for 2 Hours</td>
<td>0.706</td>
</tr>
<tr>
<td>200°C for 3 Hours</td>
<td>0.497</td>
</tr>
</tbody>
</table>
The width averages of false start scratches made with the mitre saw (Table 4.4) did fluctuate, but not as much as the false start scratch averages made with the crosscut saw (Table 4.1). The control sample widths averaged 0.941 mm, which is close to the other average kerf widths, but shows a slight decreasing kerf width until the average rose for samples from the 700°C one hour group.

<table>
<thead>
<tr>
<th>Temperature/Cure Time</th>
<th>Average Kerf Width (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>200°C for 1 Hour</td>
<td>0.772</td>
</tr>
<tr>
<td>200°C for 2 Hours</td>
<td>0.809</td>
</tr>
<tr>
<td>200°C for 3 Hours</td>
<td>0.840</td>
</tr>
<tr>
<td>200°C for 4 Hours</td>
<td>0.771</td>
</tr>
<tr>
<td>400 °C for 1 hour</td>
<td>0.662</td>
</tr>
<tr>
<td>500 °C for 1 hour</td>
<td>0.688</td>
</tr>
<tr>
<td>600 °C for 1 hour</td>
<td>0.676</td>
</tr>
<tr>
<td>700 °C for 1 hour</td>
<td>0.894</td>
</tr>
</tbody>
</table>

Table 4.4 Average kerf width for false start scratch with mitre saw (mm).
Some of the false start kerf width averages made with the mitre saw are grouped together; however, these averages are scattered with no real pattern to reflect if any shrinkage is taking place (Table 4.5). The control sample average for this group measured 0.774 mm and the sample average burned at 700°C for one hour (1.115 mm) have the largest kerf of the whole group. Warping could have taken place here by pulling the kerf walls apart, thus making the kerf widths wider.

<table>
<thead>
<tr>
<th>Temperature</th>
<th>Average Kerf Width (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>200°C for 1 Hour</td>
<td>0.832</td>
</tr>
<tr>
<td>200°C for 2 Hours</td>
<td>0.879</td>
</tr>
<tr>
<td>200°C for 3 Hours</td>
<td>1.034</td>
</tr>
<tr>
<td>200°C for 4 Hours</td>
<td>0.848</td>
</tr>
<tr>
<td>400°C for 1 hour</td>
<td>0.933</td>
</tr>
<tr>
<td>500°C for 1 hour</td>
<td>1.048</td>
</tr>
<tr>
<td>600°C for 1 hour</td>
<td>0.914</td>
</tr>
<tr>
<td>700°C for 1 hour</td>
<td>1.115</td>
</tr>
</tbody>
</table>

The average striation widths for complete cuts made with the mitre saw (Table 4.6) are grouped together however there was a slight increase from the control sample average (0.674 mm) to the sample average burned at 200°C for four hours (0.900 mm). Overall, these width averages are fairly consistent with the possibility of slight shrinkage.
Table 4.6 Average striation width for complete cuts with mitre saw (mm).

<table>
<thead>
<tr>
<th>Temperature</th>
<th>Striation Width (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>200°C for 1 Hour</td>
<td>0.723</td>
</tr>
<tr>
<td>200°C for 2 Hours</td>
<td>0.509</td>
</tr>
<tr>
<td>200°C for 3 Hours</td>
<td>0.794</td>
</tr>
<tr>
<td>200°C for 4 Hours</td>
<td>0.900</td>
</tr>
<tr>
<td>400 °C for 1 hour</td>
<td>0.649</td>
</tr>
<tr>
<td>500 °C for 1 hour</td>
<td>0.688</td>
</tr>
<tr>
<td>600 °C for 1 hour</td>
<td>0.708</td>
</tr>
<tr>
<td>700 °C for 1 hour</td>
<td>0.514</td>
</tr>
</tbody>
</table>

Much like the false start kerf width averages made with the mitre saw, the false start scratch width averages made with the bow saw are fairly consistent (Table 4.7). The only outlier was the samples that were burned at 200°C for one hour (1.127 mm) which differs from the control sample average (0.665 mm) significantly. If the outlier is omitted, then the average widths show a slight decrease, but then a rise with the samples burned at 700°C for one hour (0.620 mm). However, the sample average burned at 700°C for one hour do not differ significantly from the control sample average (0.665 mm).

Table 4.7 Average kerf width for false start scratch with bow saw (mm).

<table>
<thead>
<tr>
<th>Temperature</th>
<th>Kerf Width (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>200°C for 1 Hour</td>
<td>1.127</td>
</tr>
<tr>
<td>200°C for 2 Hours</td>
<td>0.753</td>
</tr>
<tr>
<td>Temperature</td>
<td>Average Kerf Width (mm)</td>
</tr>
<tr>
<td>-------------</td>
<td>------------------------</td>
</tr>
<tr>
<td>200°C for 3 Hours</td>
<td>0.475</td>
</tr>
<tr>
<td>200°C for 4 Hours</td>
<td>0.544</td>
</tr>
<tr>
<td>400 °C for 1 hour</td>
<td>0.611</td>
</tr>
<tr>
<td>500 °C for 1 hour</td>
<td>0.454</td>
</tr>
<tr>
<td>600 °C for 1 hour</td>
<td>0.518</td>
</tr>
<tr>
<td>700 °C for 1 hour</td>
<td>0.620</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>False Start Kerf Profile Shapes</th>
</tr>
</thead>
<tbody>
<tr>
<td>False start kerf profile shape A classification is considered to be kerfs that are created with fine-toothed saws and serrated knives. The mitre saw used in this research is considered a fine-toothed saw. These types of kerfs can be classified by the rounded floor and corners, which was seen in most of the mitre false start samples in this research. The</td>
</tr>
</tbody>
</table>
average kerf width for kerf profile shape A as defined by Symes (1992) is 0.762 mm to 1.016 mm. The average kerf widths for samples in this research fall within this range, this includes samples that have been burned for one hour at 700°C.

False start kerf profile shapes with a B classification are kerfs that are created using a rip or chisel saw. These types of false start kerfs have a flat or concave floor. This was exhibited in some of the samples, even though a rip saw was not used in this study. This could be normal variation or thermal alteration could have altered the appearance of the false start kerf.

False start kerf profile shapes with a C classification are ones that are made with crosscut saws. These false start kerfs exhibit convex or truncated floors, with pointed or non-rounded corners. The average kerf width that should be seen as stated by Symes (1992) is 1.143 mm to 2.286 mm. In this research all of the false start kerfs created with the crosscut saw fall within this range. The kerfs in this research do not exceed 1.708 mm, thus not reaching the maximum average kerf width as stated by Symes (1992). Thus, it would appear that thermal alteration did not affect the average kerf width. Most of the false start kerfs created with the crosscut saw in this study were classified as Class C.

All false start kerf profile shapes, experimental and control samples, were blindly examined and identified into Class A, B, C, or D. Tables 4.9 and 4.10 outline this analysis. Each false start kerf profile was given a sample number before being examined to avoid knowledge of the type of saw that created the kerf. The profile shapes were studied along with the classification chart from Symes (1992) and recorded.
Overall, 93% of the false start kerf profile shapes were classified into the correct class as outlined in Symes (1992). The false start kerf profile shape samples that were burned (Tables 4.9-4.10) did not differ from the control sample profile shapes (Table 4.9-4.10) when class was examined, thus thermal alteration does not affect this saw mark characteristic.

<table>
<thead>
<tr>
<th>Table 4.9 False start kerf profile shapes for crosscut saw.</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
</tr>
<tr>
<td>Control sample</td>
</tr>
<tr>
<td>Sample 1</td>
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<tr>
<td>Sample 2</td>
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<tr>
<td>Sample 3</td>
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<tr>
<td>Sample 4</td>
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<td>Sample 5</td>
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<td>Sample 6</td>
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<td>Sample 7</td>
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<tr>
<td>Sample 8</td>
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<tr>
<td>Sample 9</td>
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<tr>
<td>Sample 10</td>
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</tbody>
</table>

<table>
<thead>
<tr>
<th>Table 4.10 False start kerf profile shapes for mitre saw.</th>
</tr>
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<tbody>
<tr>
<td></td>
</tr>
<tr>
<td>Control sample</td>
</tr>
<tr>
<td>Sample 1</td>
</tr>
<tr>
<td>Sample 2</td>
</tr>
<tr>
<td>Sample 3</td>
</tr>
</tbody>
</table>
Tooth width can be calculated by using the formulae in Formula 2.1 described in Symes (1992). In this research tooth islands were not common enough to be used to reliably calculate tooth width, thus the calculation for tooth width without islands was used. The average false start kerf width for the crosscut saw and mitre saw (Tables 4.2 and 4.5) were used. Each average false start kerf width, which was calculated for assessing shrinkage in the previous section, was placed into the formula below, calculating the tooth width.

For kerfs with no islands, the formula is:

\[
\frac{\text{Greatest kerf width}}{2} \leq \text{tooth width}
\]
### Table 4.11 Tooth width calculations for false start kerfs with the crosscut saw.

<table>
<thead>
<tr>
<th>Temperature</th>
<th>Tooth Width Calculation</th>
</tr>
</thead>
<tbody>
<tr>
<td>200°C for 1 hour</td>
<td>$1.631/2 = 0.816$</td>
</tr>
<tr>
<td>200°C for 2 hours</td>
<td>$1.708/2 = 0.854$</td>
</tr>
<tr>
<td>200°C for 3 hours</td>
<td>$1.394/2 = 0.697$</td>
</tr>
<tr>
<td>200°C for 4 hours</td>
<td>$1.541/2 = 0.771$</td>
</tr>
<tr>
<td>400°C for 1 hour</td>
<td>$1.578/2 = 0.789$</td>
</tr>
<tr>
<td>500°C for 1 hour</td>
<td>$1.502/2 = 0.751$</td>
</tr>
<tr>
<td>600°C for 1 hour</td>
<td>$1.554/2 = 0.777$</td>
</tr>
<tr>
<td>700°C for 1 hour</td>
<td>$1.637/2 = 0.819$</td>
</tr>
</tbody>
</table>

### Table 4.12 Tooth width calculations for false start kerfs with the mitre saw.

<table>
<thead>
<tr>
<th>Temperature</th>
<th>Tooth Width Calculation</th>
</tr>
</thead>
<tbody>
<tr>
<td>200°C for 1 hour</td>
<td>$0.832/2 = 0.416$</td>
</tr>
<tr>
<td>200°C for 2 hours</td>
<td>$0.879/2 = 0.439$</td>
</tr>
<tr>
<td>200°C for 3 hours</td>
<td>$1.034/2 = 0.517$</td>
</tr>
<tr>
<td>200°C for 4 hours</td>
<td>$0.848/2 = 0.424$</td>
</tr>
<tr>
<td>400°C for 1 hour</td>
<td>$0.933/2 = 0.467$</td>
</tr>
<tr>
<td>500°C for 1 hour</td>
<td>$1.048/2 = 0.524$</td>
</tr>
<tr>
<td>600°C for 1 hour</td>
<td>$0.914/2 = 0.457$</td>
</tr>
<tr>
<td>700°C for 1 hour</td>
<td>$1.115/2 = 0.558$</td>
</tr>
</tbody>
</table>
The tooth width of the crosscut saw is 1 mm across. All of the false start kerfs created with the crosscut saw in this research are less than or equal to the tooth width as set out in the formula created by Symes (1992).

The tooth width for the mitre saw is 0.700 mm across. Again, all of the false start kerfs in this research that were created by the mitre saw are less than or equal to the tooth width, that is specified in the formula created by Symes (1992).

**Analysis of Chainsaw False Start Kerfs and Complete Cuts**

False start kerfs and complete cuts made with the chainsaw were examined macroscopically. The false start kerfs consisted of a large (approximately 10 mm wide) cuts with relatively straight borders with no striations present. These marks are quite distinct and easily identifiable when the bone is completely intact or with very minimal fracturing (Figures 4.9-4.12). When fracturing became extensive (in the 600ºC to 700ºC samples), false start kerfs were difficult to distinguish. There was a high degree of fracturing and breakage at 700ºC, which made reconstruction and identification of the false start kerfs much more difficult.
Figure 4.9. Chainsaw false start kerf at 200°C for 3 hours. Scale is in cm.

Figure 4.10. Chainsaw false start kerf at 500°C for 1 hour. Scale is in cm.
Figure 4.11. Chainsaw false start kerf at 700°C for 1 hour. Scale is in cm.

Figure 4.12. Chainsaw false start kerf control. Scale is in cm.
Complete cuts consisted of irregularly shaped ends of bones where the power of the chainsaw broke most of the bone in two rather than sawing completely through it. These marks could possibly be distinguished if a chainsaw was suspected, but these marks may also appear as fractures or broken bones. When fracturing due to heat became extensive (600°C to 700°C), these complete cuts were very difficult to distinguish and would be difficult to separate from other fractures and breaks due to other causes, such as thermal alteration (Figure 4.13-4.15). Overall, false start kerfs made with the chainsaw were easier to distinguish than complete cuts, especially with a high amount of fracturing due to thermal alteration present.

![Figure 4.13 Chainsaw complete cut at 500°C for 1 hour. Scale is in cm.](image)
Figure 4.14. Chainsaw complete cut at 700°C for 1 hour. Scale is in cm.
Figure 4.15. Chainsaw complete cut control. Scale is in cm.

Other Saw Mark Characteristics

Kerf Flare

Kerf flare can be seen on one end of the kerf floor and indicates the end of the blade where the handle is present. This area expresses the increased movement of the flexible blade as it enters and exits the kerf. The other end of the kerf floor will not show kerf flare, due to the stability of the opposite end of the blade (Symes et al. 2010). Kerf flare was seen in many of the false start kerf and false start scratch samples (Figure 4.16). This feature did not change and was not obliterated by the bones being thermally altered.
Thus, this characteristic does not disappear when small bone samples, used in this research, were thermally altered.

**Figure 4.16. Kerf flare from sample burned at 200°C for 3 hours.**

**Blade Drift**

In some instances in this research blade drift was seen, however, many times the false start kerfs were too deep for blade drift to be seen, see chapter 2. However, when blade drift was seen it did not appear to be altered by the bone being thermally altered (Figure 4.17). These marks did not appear to be obliterated or visually affected by thermal alteration.
Figure 4.17 Blade drift: Crosscut saw false start scratch burned at 200°C for 4 hours.

Overall, some of the saw mark characteristics in this research were changed by thermal alteration, shrinkage and warping, while other characteristics in this research were not changed by thermal alteration, false start kerf profile classification, blade drift, and kerf flare.
CHAPTER 5: DISCUSSION

Visual Identification

When examined macroscopically the saw marks present on the thermally altered samples were visible without a microscope. These marks (false start scratches, false start kerfs, and complete cuts) could be distinguished from one another due to the depth or lack of depth between false start scratches and false start kerfs and the absence of a kerf accompanying stations on a completely cut end of the bone with or without the presence of a breakaway spur and notch for complete cuts. At all temperatures and time durations the saw marks were not obliterated, even when there was a high degree of fracturing. The only exception to this was the chainsaw false start kerfs and complete cuts, due to the high degree of fracturing in the higher temperatures (500°C to 700°C). Due to the lack of striations created by the chain and the power of the saw to break part of the bone rather than cut through the entire shaft, when these samples fractured it would have been difficult to discern if a chainsaw had been used to cut the bone or if the bone had only fractured.

Shrinkage

As discussed in Chapter 2 shrinkage affects bones that have been burned. This can affect measurements taken of saw mark characteristics, such as false start kerf width and complete cut striations.

False start scratch width made with the crosscut saw showed a progressive decrease when moving from 200°C to 700°C (Table 4.1). The largest difference in width was from the control (1.532 mm) to the samples burned at 200°C for three hours (0.695
The width continued to decrease, and at 700°C the width was 0.486 mm, which is a decrease of 68%. The high shrinkage percentage could be due to the kerf walls being pulled together as shrinkage affects the bone. In this case it appears that saw mark characteristic measurements would not be affected until the bones have been burned at 200°C for more than two hours. In this case if the temperature increases above 200°C, then the measurements would be affected and the results of the saw mark examination could be incorrect.

The false start kerf widths created with the crosscut saw were closely grouped. The control sample kerf width was 1.443 mm, which is in the same range as the other false start kerf width samples that were burned at different temperatures (Table 4.2). These widths do not differ greatly, much like the false start scratches created with the crosscut saw. With this specific mark and saw it appears as if shrinkage does not affect the kerf width. This could possibly be due to the shallowness of the false start scratches and possibly the kerfs being too shallow for shrinkage to affect this type of mark. The average width measurements say the relatively close to each other, thus not affecting the identifying saw mark characteristic measurements. In this case the data, along with other characteristic examinations, would be able to accurately identify the type of saw that created the mark.

There was a large decrease in striation width of complete cuts made with the crosscut saw (Table 4.3). The control samples average striation width was 0.658 mm with the largest difference in size being between the samples from 200°C for two hours (0.706 mm) and 200°C for three hours (0.497 mm). Overall, there was a decrease of the striation
width of 44% from the control (0.658 mm) to the samples burned at 700ºC for one hour (0.360 mm). These data show that shrinkage does affect these complete cut marks made with this crosscut saw. Thus, it would be inappropriate to rely on measurements taken of the striations on bones that are burned above 200ºC. Using these measurements could provide misleading information and could lead to the wrong conclusions being drawn about what type of saw created the marks.

The widths of false start scratches made with the mitre saw (Table 4.4) do fluctuate, but not as much as the false start scratches made with the crosscut saw (Table 4.1). The control sample widths averaged 0.941 mm, which is close to the other average kerf widths, but show a slight decreasing kerf width until the average rose for samples from the 700ºC at one hour group. This group could have been affected by shrinkage, but with the rise of the kerf widths in samples burned at 700ºC at one hour it is misleading. The widening of the kerf could be due to warping, pulling the walls away from one another. The loss of organic material could also play a factor in the widening of the kerf width. This type of saw mark could be affected by shrinkage and thus caution must be used when assessing and measuring saw mark characteristics in bones that have been burned in a forensic case.

Some of the false start kerf widths made with the mitre saw did fluctuate; however, these are scattered with no real pattern to reflect if any shrinkage is taking place (Table 4.5). The control sample for this group measured 0.774 mm and the samples burned at 700ºC for one hour (1.115 mm) have the largest kerfs of the whole group. Overall, it appears that shrinkage has not affected this group, thus one could rely on
measurements taken from these marks, and in addition data from other saw mark
caracteristics, in a forensic case. The false start kerf width measurements created using a
mitre saw could provide useful, helpful, and possibly accurate information.

The average striation widths for complete cuts made with the mitre saw (Table
4.6) are around the same range. There is a slight increase in average width measurement
from the control sample (0.674 mm) to the sampled burned at 200ºC for four hours (0.900
mm). Overall, these widths are fairly consistent with the possibility of slight shrinkage.

Much like the false start kerf widths made with the mitre saw, the false start
scratch widths made with the bow saw are fairly consistent (Table 4.7). The only outlier
here are the samples that were burned at 200ºC for one hour (1.127 mm) which differs
from the control sample (0.665 mm) significantly. If the outlier is omitted then the widths
show a slight decrease, but then a rise with the samples burned at 700ºC for one hour
(0.620 mm). However, the samples burned at 700ºC for one hour do not differ greatly
from the control samples (0.665 mm). It appears in this case that shrinkage does not
affect the false start scratch width. These data could be reliable and could be used to help
identify what type of saw created the mark. This statement is further backed up by the
fact that the average control sample width and the average width of the sampled burned at
700ºC for one hour are so similar.

**False Start Kerf Profile Shape Classification**

Overall, 93% of the false start kerf samples were classified into the correct profile
shape class as outlined in Symes (1992). The samples that were burned (Tables 4.10-
4.25) did not differ from the control samples (Table 4.9) when profile shape was examined. Thus, thermal alteration does not affect the false start kerf profile shape classification. Figure 5.1 shows an excellent example of a false start kerf profile shape with an A classification with the #1 alteration. Figure 5.2 shows an example of a class C kerf profile shape, with the convex or truncated floors, with pointed or non-rounded corners.

![Figure 5.1 False start kerf created by mitre saw burned at 500°C for 1 hour.](image-url)
Figure 5.2 False start kerf created by crosscut saw burned at 400°C for 1 hour.

**Tooth Width**

The tooth width of the crosscut saw is 1 mm across. All of the false start kerfs created with the crosscut saw are within the less than or equal to range set out in the formula created by Symes (1992). Thus, thermal alteration did not affect the false start kerf widths enough to make these measurements fall out of the parameters. If shrinkage did play a part in altering the false start kerfs, the kerfs would have become smaller and thus still would have fallen within the “less than or equal to the tooth width” parameter.

The tooth width for the mitre saw is 0.700 mm across. Again, all of the false start kerfs in this research that were created by the mitre saw fall within the less than or equal to range that is specified in the formula created by Symes (1992). The same is true for the mitre saw as for the crosscut saw. The false start kerfs are within the “less than or equal
to the tooth width” parameter, but shrinkage still could have affected the false start kerf widths.

Other Saw Mark Characteristics

In addition, kerf flare and blade drift were examined. Both of these features appear to not have been affected or obliterated by thermal alteration due to the presence of the features. Kerf flare can be seen on one end of the kerf floor and indicates the end of the blade where the handle is present. This area expresses the increased movement of the flexible blade back and forth as it enters and exits the kerf. The other end of the kerf floor will not show kerf flare, due to the stability of the opposite end of the blade (Symes et al. 2010). Thus, only one side of the kerf will exhibit kerf flare and was discernable in this research. There were examples of kerf flare in every temperature range and at every time duration. Even if there was a great deal of fragmentation and fracturing and if reconstruction was possible, kerf flare could been seen in some of the samples. Thermal alteration did not appear to affect the appearance or identification of kerf flare.

Blade drift is produced when a new tooth enters the kerf, causing the blade to move. This results in a drift that resembles a figure eight pattern. The drift pattern is most visible at the beginning or end of a cut in a tubular bone. Once the blade has become immersed in the material, most of this drift is suppressed. There were a few instances in this research where blade drift was observed. There is a very distinct figure eight pattern where there are two wide areas with a narrow area in between those wise areas. This feature did not appear to be changed or obliterated by thermal alteration. However, with
bones that are fragmented and highly fractured this may be a feature that could not be easily identified.

The author hypothesized that the higher the temperature and the longer the duration of bone burning, the greater the obliterator effect would be on the saw mark characteristics. This hypothesis is not rejected, because while in some cases thermal alteration did modify the saw mark characteristic measurements and in some cases thermal alteration did not alter the measurements. Some of the saw marks were affected by shrinkage, while others were not. The maximum kerf width seemed to not be affected by thermal alteration, because once calculations were performed the kerf width was less than or equal to the tooth width. False start kerf class classification was not affected by thermal alteration, because the control samples and the research samples fell within the correct classes. The chainsaw samples were affected most by the thermal alteration, because of the obliterator effects of heat fracturing. Overall, the evidence in this study shows that thermal alteration at temperatures ranging from 200°C (burning for one to four hours) to 700°C (burning for one hour) does affect the saw marks and changes the dimensions of the saw mark greatly enough for it to possibly effect the outcome of identifying the saw that created the marks, when measuring techniques are accompanied by other saw mark characteristic examinations.
CHAPTER 6: CONCLUSION

Research Conclusions

When examined macroscopically the saw marks present on the thermally altered samples could be seen by the naked eye. These marks (false start scratches, false start kerfs, and complete cuts) could be distinguished from one another. At all temperatures and time durations the saw marks were not obliterated, even when there was a high degree of fracturing. The only exception to this pattern was the chainsaw false start kerfs and complete cuts, because of the pre-thermal alteration fracturing and the heat-related fracturing. The fracturing made it difficult to determine with certainty that the marks were created with a chainsaw and not due to fracturing pre- or post-burning.

Some of the saw marks were affected by shrinkage, while others were not. The maximum kerf width seemed to not be affected by thermal alteration, because once calculations were performed the kerf width was less than or equal to the tooth width. False start kerf class classification was not affected by thermal alteration, because the control samples and the research samples fell within the correct classes. Overall, this study shows that temperatures ranging from 200ºC (burning for one to four hours) to 700ºC (burning for one hour) do affect saw marks and change the dimensions of the saw mark, though shrinkage and warping, significantly enough for it to effect the outcome of identifying the saw that created the marks. In forensic cases, this research can be helpful in determining if the saw marks on burned remains are a reliable source of information.
Future Research

There are several points of further research that could be conducted on this topic. A broader range of temperatures could be employed, such as, burning samples at 400°C for two or three hours. Shorter time periods could also be explored, such as burning samples at 500°C for 20 or 30 minutes. Smaller temperature ranges could be researched as well, for example increasing by increments of 20°C instead of 100°C.

One of the pitfalls of this study was using convection heat instead of an actual flame, which would be more consistent with a forensic case. Similar research could be conducted using a controlled fire and attempting to control the temperature range. This could be done by placing samples closer or further away from the center of the flames, thus creating different temperature ranges within the same fire. Samples could be arranged in concentric circles, like a bulls-eye, where the desired temperature reading is.

This research design could be replicated using larger sample sizes to obtain more data on whether shrinkage or warping is affecting the saw marks and at what temperature those changes can be distinguished, which would shed light on how exactly shrinkage is affecting the saw mark characteristics. Larger bones, rather than small samples, could be used to obtain data more closely related to a forensic case, since in a forensic case there will be large, as well as, small pieces of bone. An intact specimen could be used, rather than already dismembered metapodials, thus allowing the researcher to dismember the specimen themselves, which would be more relevant to a forensic case.

Blade drift and kerf flare measurements could also be examined. These measurements could be affected by shrinkage and change once burned. There are many
other saw mark characteristics that were not examined in this study, such as, the direction of blade stroke and progress, harmonics, and tooth scratches, and how those marks are affected by thermal alteration. Also, the effects thermal alteration has on breakaway spurs and breakaway notches could be examined.

Different types of saws could be used to expand this research. There are many other types of saws that were not used in this research with different numbers of teeth per inch, tooth widths, etc. More power saws could be incorporated for a greater variety of data. Only a chainsaw was used here, but the effects of thermal alteration on saw mark characteristics of a reciprocating saw or band saw would be helpful in forensic cases as well.

In addition, more extensive blind research could be conducted, using subjects other than the current author. Each stage could be expanded by adding the element of novice and expert opinions on each saw mark appearance and how those change after thermal alteration has taken place.

This research will provide more information when examining saw marks on burned remains in a forensic case. When examined macroscopically the saw marks present on the thermally altered samples could be seen by the naked eye and could be distinguished from one another. At all temperatures and time durations the saw marks were not obliterated, even when there was a high degree of fracturing. The only exception to this pattern was the chainsaw false start kerfs and complete cuts, because of the pre-thermal alteration fracturing and the heat-related fracturing. Overall, this study shows that temperatures ranging from 200°C (burning for one to four hours) to 700°C (burning for
one hour) do affect saw marks and change the dimensions of the saw mark, though
shrinkage and warping, significantly enough for it to effect the outcome of identifying the
saw that created the marks.
BIBLIOGRAPHY


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