THE EFFECTS OF FIRE SUPPRESSION TECHNIQUES ON BURNED REMAINS

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TABLE OF CONTENTS

LIST OF TABLES

Table **Page**

LIST OF FIGURES

Figure **Page**

ABSTRACT

THE EFFECTS OF FIRE SUPPRESSION TECHNIQUES ON BURNED REMAINS

by

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Fire, as a destructive force on soft and skeletal tissues, is used to cover-up criminal actions such as homicide. It is important to conduct actualistic experimentation to determine how fire modifies such tissues, as well as the observation and documentation of how the various additional taphonomic processes may alter human remains (e.g., human interaction, fire suppression, insect damage). Just as each fire is unique, each fire fatality should also be viewed as unique. This study lends support to that claim by presenting how various factors present at a fire scene may affect modification and associated characteristics observed on burned remains.

Results were obtained by experimentally burning four intact fleshed pig carcasses and treating each subject with a different fire suppression technique. Test one allow remains to naturally burn-out, with no method of fire suppression employed. Test two involved physical removal of the remains from the active fire event. Test three examined

the effects of using pressurized water with foam admixture from a fire truck. Test four examined effects of using a hand-held compressed air/dry-chemical portable fire extinguisher.

Results from this study will allow forensic anthropology practitioners to better discriminate between features caused by heat exposure and those caused by fire suppression techniques. In particular, this research will clarify the description and modification indicators that result from the two most common suppression techniques employed at modern fire scenes.

CHAPTER I
INTRODUCTION

Emergency service providers including police, fire, and ambulance personnel are often the first responders at the scene of a fire. However, at fire scenes where human fatalities are present, it is uncommon to encounter a forensic anthropologist in attendance assisting in the identification and recovery of burned human remains. First responders and medical examiners commonly undertake recovery, and coroners, medical examiners, or funeral home employees may also be employed for fire fatality recovery at the scene. This is unfortunate because 1) fire may consume a large portion of soft tissues and reduce the body to a partial skeletal state that may be difficult to identify for an individual lacking an osteological background (especially due to the surrounding scene having undergone similar thermal modification leading to a commingling of indistinguishable materials of burned fire debris; 2) contextual information regarding original location and positioning of the remains may not be documented; 3) specific factors of possible modification may go undetected (e.g., factors that alter the original anatomical positioning of the remains, contribute to bone loss and/or modify individual elements); and 4) burned remains may be damaged during recovery and transportation without documentation of the *in situ* position or additional postmortem alteration from handling. Specifically, fire suppression techniques, collection method, fire intensity, and fire duration all affect the fragmentation and preservation of human osteological material. The confounding factors noted above are relevant to the analysis of burned human remains by forensic anthropologists, and have recently been acknowledged in the literature (DeHaan 2006, Dirkmaat 2002, Dirkmaat and Adovasio 1997, Pope 2007, Pope and Smith 2004, Symes et al. 2008a, Symes et al. 2008b).

The question of what burned bones might reveal about the perimortem events that occur around the time of death (or burning) is a complex problem that requires both accurate identification of thermal damage to human remains, and reliable assessments of the context and associated variables that may cause additional taphonomic damage. However, there is a current lack of research examining the effects of situational or post-fire variables on burned bone. Specifically, little to no attention has been given directly to the effects that fire suppression techniques have on fragile burned bone.

This research will principally focus on two commonly used direct fire suppression techniques employed at fire scenes and their effects on bone. The direct fire suppression techniques investigated for this project include 1) pressurized water with a foam admixture, and 2) hand held compressed air/dry-chemical portable fire extinguishers. Two indirect methods of fire suppression, natural burn-out and active removal of remains from fire, will also be examined for potential taphonomic defects on burned remains. Analysis of the effects of these techniques on skeletal fragmentation, fracture, discoloration, and preservation, or completeness of skeletal elements at scene and post-transportation at laboratory, will be examined via the utilization of pig carcasses used to simulate the human body at fatal fire scenes.

Project Objectives and Research Goals

With consideration of the previously discussed variables, this research examines postmortem changes in burned remains through the effects of fire suppression and handling and movement of burned remains from a fire scene. The two distinctive types of direct fire suppression techniques examined are those of pressurized water with foam solution and a hand-held compressed air/dry-chemical portable fire extinguisher. In addition, the associated indirect effects of both natural burn-out, in which damage is exclusive to burning and active removal which involves handling and movement of burned bone from a fire scene, are examined for the postmortem taphonomic effects that each technique might produce on burned remains. Documenting the specific characteristics these fire suppression techniques produce on burned bone will allow for a better understanding of heat-related fractures from exposure during the fire and post-fire situational fractures related to fire suppression activities. Thus, documentation of specific characteristics or variables related to fire suppression and the fire scene overall is intended to provide a more thorough scientific foundation for assessments of trauma compared to heat exposure and post-fire situational fractures and taphonomic variables affecting fragile burned remains in the future.

The patterning and degree of skeletal alteration will be analyzed with reference to the following variables: 1) heat-related modification caused by fire, 2) post-fire modification caused by fire suppression techniques, and 3) post-fire modification caused by handling and transport. The ability to distinguish among heat-related, post-fire extinguishment, and post-fire handling/transport alteration is important for forensic anthropologists who are confronted with fragile and fragmentary burned bones. This research will provide practitioners a better understanding of the underlying mechanisms of skeletal alteration and possible characteristics associated with common fire suppression activities.

Challenges Associated with Burned Human Remains

Heat first acts on soft tissues that surround and protect bone. Exposure to heat causes the organic components of the soft tissues to dehydrate, contract, and then char. As the protective soft tissues burn away, the bone becomes exposed directly to heat and begins to undergo the process of pyrolysis, which is the chemical decomposition of organic materials from heat exposure (DeHaan 2002, Herrmann and Bennett 1999, Pope and Smith 2004). Once bone is exposed, the process of pyrolysis causes the decomposition of organic materials in bone, which gradually produces heat-related color changes associated with degradation of bone, deformation, shrinkage, fracturing, and fragmentation (Buikstra and Swegle 1989, Shipman et al. 1984). However, common activities at fire scenes have been shown to increase damage to burned bone in a variety of ways. Pope and Smith (2004) discuss falling debris, heat embrittlement (i.e., bone becoming brittle due to the effects of heat; thermal degeneration of skeletal properties), fire extinguishments, handling of the burned remains, and transport of the burned remains as typical fire scene events that damage bone. Furthermore, Pope (2007) reports that taphonomic changes within the fire environment, such as collapse of debris on the body, embrittlement from heat exposure, extinguishment with pressurized water hose, selective recovery of larger parts, and fragile remains, are shown to contribute to skeletal fragmentation. Additionally, dynamics of the burning environment including heat exposure, presence or absence of fire suppression methods, type of suppression methods used, and recovery of remains from the scene all contribute to damage of fragile burned bone (Herrmann and Bennett 1999, Pope and Smith 2004). Damage to bone as a result of the above factors is defined as situational or post-fire fractures (Herrmann and Bennett 1999, Pope and Smith 2004).

Historical Context - Previous Research - Court Driven Changes - Current Problems

Since the 1943 study by Wilton M. Krogman, regarding heat-induced alteration to both wet and dry bone, anthropologists have been interested in examining and understanding the effects of fire or heat modification on bone (Baby 1954, Bennett 1999, Binford 1963, Bohnert 2004, Bradtmiller and Buikstra 1984, Buikstra and Swegle 1989, Krogman 1949, Mayne Correia 1997, Pope and Smith 2004, Shipman et al. 1984, Stewart 1979, Thompson 2005, Webb and Snow 1945). Research of burned skeletal material has previously been synthesized in the literature based on type of data source (Maples 1997) and data-analysis methodology (Mayne 1990, Mayne Correia 1997). However, the most recent and comprehensive organization of burned bone research offers six interrelated categories of thermal modification research. The six categories, proposed by Symes et al. (2008a), are historical research, histological research, identification and visual classification, cremation studies, recovery and handling, and trauma interpretation.

Historical research includes examinations of cremated bone prior to the mid-1970's that are based within an archaeological perspective (e.g., Baby 1954, Binford 1963, 1972, Krogman 1943a, Krogman 1943b, Stewart 1979, and Webb and Snow 1945).

Histological research examines skeletal heat alteration at the histological or bone microstructure level (e.g., Bradtmiller and Buikstra 1984, Nelson 1992, and Stiner et al. 1995). Specifically, histological research examines the microscopic structures, such as vascular canals, lacunae, canaliculi, fine porosity, and spaces between mineral phase (Piekarski 1970) of skeletal material before and after thermal modification.

Identification and visual classification refers to studies focused on identifying thermally altered skeletal materials and the visual analysis of these changes in bone (e.g., Bass 1984, Buikstra and Swegle 1989, DeHaan 1997, DeHaan et al 1999, DeHaan and Nurbakhsh 2001, Delattre 2000, Dunlop 1978, Eckert et al. 1988, Gejvall 1969, Heglar 1984, Holland 1989, Mayne 1990, Mayne Correia 1997, Shipman et al. 1984, Stewart 1979, Thompson 2004, and Van Vark 1975).

Cremation studies is simply defined as including early and modern cremation studies (e.g., Bass and Jantz 2004, Owsley 1993, and Warren and Maples 1997).

Recovery and handling reports are those that address the recovery and preservation of skeletal remains through the use of modern archaeological protocols and procedures (e.g., Dirkmaat 2002, Dirkmaat and Adovasio 1997, Holland and Mann 1996, King and King 1989, Mayne Correia 1997, and Ubelaker et al. 1995).

Trauma interpretation addresses research focused on detecting and differentiating antemortem, perimortem, and postmortem trauma (i.e., blunt, sharp, or ballistic force) in heat-altered bone (e.g., de Gruchy and Rodgers 2002, Herrmann and Bennett 1999, Pope and Smith 2004, and Symes et al. 2002).

These six categories of thermal modification research were recently proposed with the aim of promoting consistent *Daubert*-compliant standards and terminology for research of thermal destruction of human remains (Symes et al. 2008a). *Daubert* compliance refers to scientific knowledge and standards of evidentiary reliability as established during courtroom litigation (*Daubert v. Merrell Dow Pharmaceuticals,* 509 US 579 1993) and has become increasingly important within the field of forensics through advancement of the associated disciplines. The admissibility of expert testimony, as well as the overall participation of experts within the litigation process, has changed considerably due to three court decisions. The first of these changes is that these new standards aid in defining who classifies as an expert and what the expectations are of these individuals. The second change, due to this closer examination of "experts", is that only those who qualify will be accepted as experts and allowed to practice in a court of law. Third, experts will be required to improve upon their qualifications and quality of testimony so that lawyers will utilize only qualified experts.

Frye v. United States (1923) addressed the admissibility of evidence and ruled that expert testimony must be based on sufficiently established and accepted scientific methods (*Frye v. United States,* 293 F. 1013; D.C. Cir. 1923*)*. The Frye standard holds that scientific technique must be generally accepted within the relevant scientific community. The Frye standard has since been outdated in various jurisdictions, including federal courts, by the Daubert ruling. *Daubert v. Merrell Dow Pharmaceuticals, Inc.* in 1993 regarded scientific testimony as a critical element of the proceedings and decided that the term "scientific" implied the utilization of certain methods and procedures (i.e., controlled and valid scientific methods) (*Daubert v. Merrell Dow Pharmaceuticals,* 509 US 579 1993). The Daubert opinion declares that the judge is to focus on methods and principles, not on the conclusions that they generate (Christensen and Crowder 2009). Thus, in order for scientific testimony to be offered during a trial, the judge must determine if the foundational validity and/or methodology underlying the testimony are sound (i.e., scientifically valid or methodologically suitable for application to the facts at issue) (Christensen and Crowder 2009, *Daubert v. Merrell Dow Pharmaceuticals,* 509 US 579 1993).

In the case of *General Electric Co. v. Joiner* in 1997, a legal suit filed in state court, the court ruled the expert testimony inadmissible because "it did not rise above subjective belief or unsupported speculation" (*General Electric Co. v. Joiner*, 522 US 136 1997). In other words, the court questioned whether existing scientific evidence could be generalized to address specific causal relationships. The court decided that district courts are not required to accept expert testimony connected only to existing data through unproven association made by the expert (*General Electric Co. v. Joiner*, 522 US 136 1997). Thus, experts must provide a clear methodological explanation of their opinion proffered and the data that it is based upon. Furthermore, courts have the ability to evaluate the acceptability of this linkage between methodology and conclusions (Christensen and Crowder 2009).

The case of *Kumho Tire Company v. Carmichael* (1999) expanded on the decisions of expert testimony that resulted from the Daubert case by broadening its application. In the Kumho case it was decided that the court's obligation to evaluate reliability and relevancy includes experts that are not scientists, yet base their testimony on "technical" and/or "specialized" knowledge, as well as on "skill or experience-based observations" (*Kumho Tire Co. v. Carmichael,* 526 US 137 1999). Overall, the Kumho decision places all types of expert testimony whether it be scientific, technical, or other specialized knowledge at the same level of scrutiny (Christensen and Crowder 2009).

The decisions from these cases were intended to ensure the reliability and relevance of scientific or technical testimony admitted as evidence in federal courts (Christensen and Crowder 2009). All three cases involve decisions on the admissibility of expert testimony. However, the Daubert case exists as the landmark of trial providing guidelines for the admissibility criteria for expert testimony, while both cases of Joiner and Kumho supplement and clarify the decisions in Daubert. Overall, since the 1993 Daubert ruling, the discipline of forensic anthropology has determined the need to critically reevaluate various techniques and methods employed during examinations, and furthermore the validity of the underlying scientific theories. Experts who possess the highest qualifications within their field, employ sound methodology, and adhere to the most up to date "best practices" as a result of these court rulings have increased the validity, reliability, and relevance of all expert testimony.

The validity, reliability, and relevance of "forensic practices underlying evidence introduced in criminal trials" has more recently been addressed since Daubert (Bohan 2010; p.564). Congress led the latest public examination of forensic practices in 2005 when they directed the National Academy of Sciences to examine the condition of forensic science in the United States, which operated under the project "Identifying the

Needs of the Forensic Science Community" (NAS 2009). As a result of this investigation of forensic practices, the NAS Committee released the report *Strengthening Forensic Science in the United States: A Path Forward* in 2009. Essentially, the NAS report articulates a need for systemic and scientific change or advancement within forensic science disciplines, as means to promote and manage reliability of the disciplines, enact standards, and assert the persistent employment of best practices (NAS 2009). For this reason, documented trauma analysis techniques should be employed systematically along with standardized collection, handling, and preservation methods.

Acknowledgement of the various factors of modification on burned remains is necessary for forensic anthropological reconstruction efforts of circumstances surrounding the victim's death and to also hold up to legal evidentiary standards (Bohnert 2004, Dirkmaat 2002, Eckert et al. 1988, Fairgrieve 2008, Galloway et al. 1990, Krogman 1943, Krogman 1949, Krogman and Iscan 1986, Stewart 1979, Symes et al. 2008a). Anthropological trauma analysis is commonly relied upon by those in the medicolegal community to assist in cause and manner of death determination, trauma sequencing (i.e., ante-, peri-, or postmortem), and the identification of tools potentially used in a crime (Symes et al. 2008a). These potential legal implications have led to scrutiny of trauma assessments within forensic anthropological reports (Symes at el. 2008b).

Focus of trauma analysis research has expanded from traditional trauma signatures (e.g., blunt force, sharp force, and ballistic trauma) to taphonomic signatures of skeletal modification due to heat exposure and thermal damage (Baby 1954, Binford

1963, Bohnert et al. 1997, Bratmiller and Buikstra 1984, Buikstra and Swegle 1989, de Gruchy and Rogers 2002, Herrmann and Bennett 1999, Krogman 1949, Mayne Correia 1997, Pope and Smith 2004, Shipman et al. 1984, Stewart 1979, Symes et al. 2008a, Thompson 2004, Thompson 2005, Webb and Snow 1945). Several recent studies present examinations of the effects that fire has on various bones, as well as how to distinguish heat fracturing from sharp force, blunt force, or projectile trauma (Calce and Rogers 2007, de Gruchy and Rogers 2002, Herrmann and Bennett 1999, Marciniak 2008, Pope and Smith 2004, Pope 2007, Symes et al. 2008a). Additionally, the differentiation between heat fractures and traumatically-induced fractures is a potentially problematic aspect of forensic analysis (Herrmann and Bennett 1999, Mayne 1990a, Mayne 1990b).

Purpose of the Project - Role of the Forensic Anthropologist - Implications for Analyzing Fire Suppression Effects in Burned Bone

One motivating factor leading to this research, problematic within the discipline, is that forensic anthropologists who analyze trauma on burned human remains generally are not involved in the initial recovery process and lack a detailed knowledge of the recovery context. Although forensic anthropologists are generally trained in aspects of archaeology and recognize the utility of taphonomic assessment (Ubelaker 1997), in most instances, anthropological analysis of deceased individuals involved in fatal fire scenes begin after field recovery and postmortem examinations by medicolegal authorities (Dirkmaat 2002). Furthermore, studies on the process of tissue destruction from heat and medicolegal analysis of the remaining biological materials by medical examiners or anthropologists has not received a considerable amount of attention (Pope 2007).

Three relatively discrete data collection phases typically exist during forensic investigations that involve human remains, including fatal fire victims. As outlined by Dirkmaat (1998, 2002) these phases are as follows: Level I occurs during the location, documentation, and recovery of the body at the scene, which is primarily focused on the association of the body to other physical evidence at the scene. Level II occurs during the postmortem examination, in which focus is directed primarily to soft tissues, and to a lesser extent the skeletal system. Level III occurs during the laboratory analysis, which is focused specifically on skeletal remains and includes the interpretation of the results.

Concerning these three levels of data collection, it is reasonable to conclude that the expertise and assistance of forensic anthropologists at fire scenes would maximize contextual and associational data collection, providing a more accurate event reconstruction and a greater ability to withstand courtroom scrutiny (Dirkmaat 2002). Eckert et al. (1988) provide general procedures necessary for forensic investigators to process cases of cremated or severely burned victims (Table 1).

Table 1: General Procedures in Cases of Cremated or Severely Burned Victims.

Procedure	Description of Procedure
1	Overcome the futility and lack of confidence felt by those conducting an examination of this type
2	Develop an approach to determine the cause and manner of death.
3	Determine what skeletal areas are missing.
4	Determine the presence of foreign objects by radiographic examination.
5	Determine sex, race, age, stature, evidence of previous illness, trauma, or pregnancy of decedent.
6	Determine variations in thermal trauma as well as recent mechanical trauma.
7	Determine the presence of dental evidence, examine it radiographically and document it photographically.
8	Determine toxicological and serological evidence.

Source: Eckert et al. 1988.

The sixth procedure described by Eckert et al. (1988) is to determine variations in thermal trauma as well as recent mechanical trauma. However, steps one through five could lead to further damage of the remains and further complicate the analysis of classic trauma, thermal modification, or post-fire situational fractures. Data necessary for the interpretation of context and association of the remains relative to other physical evidence and the scene may have been significantly disrupted or destroyed by incomplete scene documentation, improper recovery and transport methods, the postmortem evaluation, and during manipulation of the remains during the odontological examination (Dirkmaat 2002). DeHaan (2008) advises that thorough documentation of the fire scene and the burned remains prior to and during recovery is necessary because of the complex relationship between human remains and thermal reactions. Many factors can cause taphonomic modification of burned human remains, from the point where the individual undergoes the initial thermal trauma until the remains reach the forensic anthropologist for analysis, which often include damage from fire suppression techniques, cooling of the remains, and damage caused by recovery and transport activities.

Anthropological variables examined in cases of heat exposure to human remains include heat-related deformation, shrinkage, fracturing, color, warping, and delamination (DeHaan 2008, Dirkmaat 2002, Herrmann and Bennett 1999, McKinley and Roberts 1993, Pope and Smith 2004, Symes et al. 2008a). It is of interest to understand thermal modification and taphonomic effects of fatal fire scenes on skeletal elements due to the rates of civilian fire deaths in the United States. In 2008 alone, 3,320 civilian fire deaths were reported, with 2,755 of those deaths occurring in the home, 350 in highway vehicle fires, and 120 in non-residential structure fire (NFPA 2009). Furthermore, Dirkmaat (2002) asserts that fire investigation and forensic investigations of death require a multidisciplinary effort to provide the most informed and accurate interpretation of the events surrounding a death.

Relevant Variables Associated with Fire Fatalities

Fire produces observable and distinct burn patterns. When burned remains are discovered in a fire scene, according to DeHaan (2007) there are six significant questions that must be answered. Are the remains human? Who is the victim? What was the cause of death? What was the manner of death? Was the person alive and conscious at the time of the fire, and if so, why did they not escape? Was the death due to the fire or only associated with it? Several variables must first be addressed in order to understand and interpret thermal modification patterns on burned remains. Variables pertaining to the indiviual, such as age, sex, body positioning, and tissue shielding are briefly discussed below. Additionally, discussion of variables associated with the timing of injury (i.e., antemortem, perimortem, postmortem, and post-fire), environmental conditions, and burning within a criminal context follow.

The Individual

The first area of variables associated with fire fatalities that are addressed include those related to the individual. Characteristics of individual bodies influence burning, such as age, sex, weight, body size, and orientation of the body to the fire. Although each circumstance is unique, constants including thermal protective properties of the soft tissues surrounding bone, and the properties of fire produce predictable patterns in normal situations while abnormal patterns signal caution to the investigator (Smith et al. 2001).

Age and Sex

This factor is important because age influences bone structure, development, and composition. For example, the dense mineralization typical of healthy adult skeletal structures is lacking within young bone (Baker et al. 2005, Currey 2002, Scheuer and Black 2000). Young bone has been reported to have a higher rate of shrinkage in comparison to adult bone (Dunlop 2004). In addition to being fragile, (Baker et al. 2005, Currey 2002, Scheuer and Black 2000) young bone also lacks the cortical strength of mature bone, yet most diaphyses and epiphyses survive the fire as recognizable portions of the skeleton (Pope 2007). Furthermore, bone tissue taken from persons aged between infancy and young adulthood is less resilient to heat damage than mature bone due to young bone samples containing a larger proportion of newly synthesized bone in comparison to adult bone (Holden et al. 1995).

Skeletal elements of older adults decrease in density and strength in both cortical and trabecular composition, resulting in overall reduced bone mass (Browner et al. 1998, Ortner 2003, White and Folkens 2000). This increase in porosity (i.e., reduced density) of bone is a common component of the aging process and is referred to as osteoporosis (White and Folkens 2005). In respect to older adults, Christensen (2002) found that osteoporotic skeletal elements consistently displayed more discoloration and a greater degree of fragmentation than healthy skeletal elements. Thus, osteoporotic elements have been shown to have greater susceptibility to thermal damage than healthy bone.

The distribution of subcutaneous body fat differs between males and females. This sex-specific difference in body fat is a relavant variable because fat will melt in a fire, turning it to grease that will burn as a fuel source (DeHaan and Nurbakhsh 2001). As reported by the National Institutes of Health, on average, the range of body fat for adult males is 15-18% and for adult females it is 22-25%. According to the National Center for Health Statistics, the reported percentage of body fat for adults (persons 20 years and older) within the United States between the years 1999 and 2004 was 28.1% for males and 39.8% for females (Borrud et al. 2010). This variation in fat storage between males and females produces variation in thermal destruction of skeletal remains due to a greater amount of fat storage in females, thus females bring a greater amount of fuel to a fire (Holck 1986, Holden et al. 1995, DeHaan et al. 1999, DeHaan and Nurbakhsh 2001, Pope 2007). Holck (1986) examined both male and female ancient prehistoric cremated remains and found that female remains generally had the appearance of being burned at a higher 'grade' or temperature, compared to male remains. Holck (1986) inferred that this was a consequence of the greater distribution of stored fat on a female body.

Body Positioning and Tissue Shielding

Characteristic positioning of the body produced by fire and heat is referred to as the "pugilistic posture" due to the heating and shrinking of muscle fibers (Adelson 1955, Bass 1984, Pope 2007, Pope et al. 2004, Pope and Smith 2004, Spitz 1993). Depending on tissue depths and posturing of a body, exposure of some anatomical areas will increase while other anatomical areas will become shielded. Differential type of soft tissues and tissue depths surround bone, thickest being muscle. When bone is exposed, it undergoes heat-related color changes, and then shrinks and forms heat fractures (Pope 2007, Pope et al. 2004, Pope and Smith 2004). Recognition of this pattern aids in tracking the progression of bone destruction, even with extensively burned remains. Tracking thermal destruction may reveal subtle information, such as initial body position, thermal shielding, and differential thermal sources (Spitz and Fisher 1993), which are particularly of interest during evaluations of skeletal trauma and taphonomic modification (i.e., timing of injury).

Injury to living tissue that is caused by an external force or mechanism, albeit intentional or incidental, is refered to as trauma (Lovell 2008). Additionally, taphonomic modification, within the practice of forensic anthropology, refers to phenomenon that affect the remains throughout the duration between death and discovery (Ubelaker 1997). An important aspect of casework for anthropologists during examination of skeletal remains is to identify if skeletal trauma is present and determine when the trauma to the bone occured in relation to an individual's death (i.e., timing of trauma) (Buikstra and Ubelaker 1994, Komar and Buikstra 2008, SWGANTH 2010, Wieberg and Wescott 2008). Furthermore, within the present research, attention is given to postmortem and post-fire fractures (i.e., fractures that result from, as well as after, the fire), which differ from traumatic injury (i.e., antemortem or perimortem damage).

Timing of Injury

The second area of variables associated with fire fatalities that are addressed include those related to the timing of injury (i.e., antemortem, perimortem, postmortem, and post-fire).

Antemortem Injury

Antemortem trauma results from injury that occurs prior to an individual's death, which is evidenced by osteogenic reaction or healing (Dirkmaat et al. 2008, Galloway 1999, Ortner 2003, Sauer 1998, Smith et al. 2003, Spitz 1993, Stodder 2008, SWGANTH 2010, White and Folkens 2000, White and Folkens 2005, Wieberg and Wescott 2008). Features that indicate antemortem trauma include evidence of healing or healed fractures, development of a pseudarthrosis (i.e., if persistent movement occurs between two pieces of fractured bone a false joint may form), evidence of trauma-induced degenerative joint disease, infectious response, dental fractures with worn edges, and surgically implanted devices (Lovell 1997, SWGANTH 2010, White and Folkens 2005). Variables that affect the skeletal callous produced during healing include type ad thickness of the fractured bone, fracture completeness (i.e., single or comminuted), fixation or stabilization of the injury, duration of recovery, age and health of the individual, and general ability of the body to repair itself (Currey 2002, Galloway 1999, Ortner 2003, White and Folkens 2000, White and Folkens 2005). Calluses of healed bone are fragile, yet are able to survive thermal affects if partial or full mineralization of the structure has occurred (Galloway 1999, Ogden 2000, Pope 2007).

Perimortem Injury

Injury that occurs around the time of death (i.e., slightly before or slightly after) is referred to as perimortem trauma (Dirkmaat et al. 2008, Galloway 1999, Ortner 2003, Sauer 1998, Smith et al. 2003, Spitz 1993, Stodder 2008, SWGANTH 2010, White and Folkens 2000, White and Folkens 2005, Wieberg and Wescott 2008), which signifies the presences of grease and organic materials diagnostic of fresh bone properties (Pope 2007). Salient features of perimortem trauma include, but are not limited to, a lack of osteological activity (e.g., healing or infectious response), the presence of fresh bone fracture characteristics (e.g., plastic response) (Currey 2002, Galloway 1999), and the absence of dry bone fracture characteristics (e.g., angular fractures) (SWGANTH 2010).

Postmortem Fracture

Postmortem modification or damage to bone is defined as occurring after death, unassociated with the death event (Dirkmaat et al. 2008, Sauer 1998, Smith et al. 2003, Stodder 2008, SWGANTH 2010, Wieberg and Wescott 2008) and occur with dry bone that is void of tissues and grease (Pope 2007). Features associated with postmortem damage include, but are not limited to, differentially stained or recently exposed surfaces, lack of healing, and characteristics of the break that lack evidence of a plastic component (SWGANTH 2010). Postmortem heat-related fractures, typically observed in charred and calcined bone, only occur after bone has been directly exposed to heat (Pope 2007). Typically, fracture margins present similar coloration as the adjacent cortical surfaces, which indicate all surfaces during the fire event were exposed and burned (Pope 2007).

Post-Fire Fracture

Post-fire fractures, also called situational fractures (Herrmann and Bennett 1999), occur due to physical forces impacting the burned remains in the late stages of the fire event such as a result of the fire scene from fallen fire debris and/or influence of exstinguishment, or post-fire recovery (Pope 2007) . Pope and Smith (2004) reported that several typical fire scene events were shown to affect burned remains, including falling debris, heat embrittlement, fire extinguishment, handling, and transportation. Post-fire fractures often have fracture margins that are different and richer in color than that observed on the trabecular bone. This difference in thermal coloration between the external cortical bone and the fracture margin of post-fire fractures conveys that the lesser burned fracture margin was not directly exposed to heat, but fractured after the fire event in the absence of flame (Pope 2007). Thus, these fractures are not directly heat-induced (Herrmann and Bennett 1999).

Environmental

The third area of variables addressed are those related to environmental conditions of the fire scene. Humidity, temperature, and wind speed can all affect the temperature and duration of the fire (DeHaan 2002). Wind speed is most important of these variables because wind directly affects ventilation of the fire, leading to the increase or decrease of the fire itself (DeHaan 2002, DeHaan 2007). As presented by DeHaan (2007), no two fires are identical because both physical and thermal relationships, along with conditions, do not remain static throughout a fire.

Criminal Activity

Lastly, the fourth area of variables addressed in this section are those related to the act of burning within a criminal context. As previously stated, recognition of normal burn patterns in human bone relies on three diagnostic process signitures: body position and tissue shielding of bone, color change of burned skeletal material, and fracture biomechanics of burned bone (Symes et al. 2008a). The ability to recognize normal burn patterns allows for the identification of normal patterns versus deviations which may be as a result of criminal behavior, perimortem trauma, or additional factors.

The perpetrator may use fire in an attempt to destroy the body, to obliterate superficial features that potentially make victim identification possible (e.g., features of the face or fingerprints), or to hide evidence associated with death incident (DiMaio and DiMaio 2001, Dolinak et al. 2005, Symes et al. 2008). Due to the complexity of determining cause of death of burned individuals, Fanton et al. (2006) examined how victims of burning had died, including accident, homicide, or suicide, with the aim to determine manner of death and reports that criminal burning was above all a means for covering up homicide. Twelve observations of criminal burning were examined and distinguished between postmortem burning and burning alive subsequent to criminal immolation, in which nine cases were postmortem burning and only three cases were that of being burnt alive.

Thermal Effects to Human Remains

Destruction of tissues due to fire varies as a result of relative depth and protection within the body, varying thicknesses, moisture content, and organic content (Pope 2007). There are three main combustible components of the body (DeHaan 2001, Pope 2007). Skin and muscle will become dehydrated within a fire and burn if exposed to direct flame. Bone marrow and fat contained in the medullary cavities of long bones are not readily combustable, yet will add to the fuel of a fire. Fat is the best source of fuel on the body (Christensen 2002, DeHaan 2001).

The destruction of a wall of a building with various layers such as wallpaper, drywall, insulation, and the internal wood frame has been presented in the literature as a comparable illustration of the progressive destruction of soft tissue of the body. The layers of a wall, similar to the various layers of the body such as skin, fat, muscle, tendons and ligaments, cartilage and fibrocartilage will burn according to its unique material construction, relation and orientaition to heat, and will produce readable patterns that can be analysed (DeHaan 2006, Icove and DeHaan 2003, Pope 2007, Pope et al. 2004). The following section presents basic changes of the human body resulting from thermal modification (e.g., pugilistic posture), as well as, normal heat-related changes previously documented for tissues of the body including skin, fat, muscle, tendons, ligaments, cartilage, fibrocartilage, and bone.

Pugilistic Posture

The pugilistic posture is the natural repositioning of the body's posture due to thermal induced muscle shrinkage (Bohnert 2004, Spitz 1993), which is commonly observed on fire-death victims (Adelson 1955, Bass 1984). Heat exposure causes muscular proteins to coagulate and shrink forcing limbs to contract at the joints (Spitz 2006) with flexors usually overpowering extensors (Bohnert 2004, Pope 2007). Occurance of this joint flexion is prodominate on the hands, which may even cause dislocation of the wrist (Bohnert 2004, Symes et al. 1999). In addition to flexion of the extremities, the neck and back arch. Muscles of the neck and back are shorter than those in joints of the limbs, which leads to limited movement produced at the neck and back with a wide range of flexure in the limbs (Pope 2007). Due to alteration of anatomical position, arrangement of muscles, and strain on muscle and bone, the pugilistic posture greatly influences burning patterns (Smith et al. 2001). The absence of "posturing" is also important to note, as it may reflect that the body was restricted or confined (Bohnert 2004, Symes et al. 1999).

Skin

The external skin surface is the first layer of tissue of the body to experience effects of heat. Skin is characterized by superficial layers of collagen and protein, which are moisture-rich elastic tissues. Skin modified by heat will first appear waxy and glossy with an associated blistering (Pope 2007) with a leathery, hard consistency (Bohnert 2004). Heat will then cause tightening, shrinking, and splitting of the skin due to loss of fluid caused by heat (Bohnert 2004). Shrinkage of the soft tissues, specifically of the neck, may also cause protrusion of the tongue from an open mouth. This progression of heat modification is seen in accordance with progressive thermal damage color changes, or color banding, of reds, browns, and black char (Pope 2007). Skin shrinks and will then produce transverse, longitudinal, and stellate splits in the skin due to heat denaturalizing the organic and elastic structures and removing moisture (Pope 2007). In the occurrence of skin-splitting, underlying soft tissues of fat, fascia, tendons, ligaments, and muscle as well as bone will become exposed.

Fat

Fat will liquefy when directly exposed to heat by way of skin-splitting. As previously mentioned, fat provides fuel for a fire (DeHaan 2001). In order for liquefied, or rendered, body fat to burn as a fuel source, it must be absorbed by porous materials, such as clothing, carpet, furniture, flooring, or carbonized tissues (Christensen 2002, DeHaan 1997, DeHaan 2006, DeHaan et al. 1999, DeHaan and Nurbakhsh 2001, Pope 2007). Types of fat in the body include subcutaneous fat, visceral fat, and marrow contained in the medullary cavities of long bones.

Muscle

Muscles consist of proteins and are bulky, fibrous, and elastic, which burn as layered materials progressively and withdraw from bone shafts directionally by retracting from origins of heat (Pope 2007). Visually, heat will produce delineation of muscle fibers, charring of superficial layers, and coagulation of deeper muscles (Bohnert 2004, Pope 2007). The coagulation of muscle proteins, caused by heat exposure, physically shortens muscle fibers and produces permanent contraction (Spitz 1993, Spitz 2006). Whether deep or superficial, individual muscle size, thickness, shape, and orientation differ between muscles within the body (Pope 2007). Muscles of the head (e.g., the *temporalis* and *frontalis*) and chest (e.g., the *abdominal, obliques,* and *intercostals*) are flat-broad muscles that will expose bone gradually as they burn in thin layers from external to internal. Muscles of the neck (e.g., the *sternocleidomastoid* that permits flexion of the head), lower torso (e.g., the *obliquur externus*), arms (e.g., the *trapezius* that permits adduction of the shoulder), and legs (e.g., the *psoas major* and *iliacus* that permit flexion of the thigh) are thicker layered muscles that shrink, retracting along the shaft of the bone as they progressively burn in layers (Pope 2007). During the cooling process the body will become rigid and inflexible, which is due to the denaturation of the muscle proteins (Spitz 1993). The normal burn patterns observed for the body rely on these soft and skeletal tissue relationships. For example, thermal reduction of soft tissues and exposure of bone will occur at a quicker rate on areas with thin tendon, ligament, or muscle layers such as over flexible joint surfaces like those of the fingers compared to areas of thick, robust soft tissue layers that protect centrally located bone such as soft tissues of the thigh area that protects the femur (Pope 2007).

Tendons and Ligaments

Ligaments and tendons are flexible structures composed of dense fibrous connective tissue that bind together the musculoskeletal system and assist with pugilistic posturing (Martin et al. 1998, Pope 2007). The principle function of ligaments is to maintain correct bone and joint geometry by binding bones together and restricting the relative motions of bone (Martin et al. 1998). Tendons, composed of collagen, link muscle to the periosteal sheath that covers the outside of bone and transmit forces from muscle contractions through joints, which stabilize joints or produce motion (Martin et al. 1998). When tendons are exposed to heat, shortening occurs due to being composed primarily of collagen, which aids in the formation of the pugilistic posture (Pope 2007). Shortening of tendons in combination with that of muscle during heat exposure caused the extremities to reposition, significantly observed in flexion of the fingers, hand, and wrist.

Cartilage and Fibrocartilage

Cartilage and fibrocartilage are soft tissues within the body that protect bone during burning. Cartilage covers the joint surfaces of bones, is present in the ventral ends of ribs, and is a highly organic material that also makes up growth plates in the body

(Martin et al. 1998). Fibrocartilage is dense connective materials that is tough and elastic and occurs in intervertebral disks, the pubic symphysis, and in the body attachments of some tendons (Martin et al. 1998, Pope 2007). When these tissues undergo exposure to heat, dehydration and shrinkage occur, which may remain as charred brittle remnants on the articulation surfaces of bone and/or charred intervertebral discs (Pope 2007).

Bone

Heat-related changes to skeletal tissue, which is the primary analytical focus within this research, requires the presentation and explanation of the intricate interactions between bone and fire. Bone properties influence their reaction to processes that can alter the appearance of bone and related organic materials after death (Ubelaker 1997). First, in order to evaluate heat-related fractures of bone, the biomechanics and general fracture mechanics observed in unburned bone must be acknowledged. Second, the heat-related changes of bone color, structure/composition, and fracture production will be addressed.

Physical Structure of Bone - Biomechanics of Bone

It is important to acknowledge the basic structure and function of bone in order to understand heat-related skeletal change (Smith et al. 2003). For example, direct heat exposure to skeletal tissue progressively causes the thermochemical decomposition of organic materials and diminishes bone strength, which will differ in degree of impact depending on bone porosity and thickness (i.e., durability). Bone is a composite material of organic components within an inorganic matrix, which consists of fibrous protein and collagen that is stiffened by an extremely dense covering of calcium phosphate crystals (Currey 2002, Symes et al. 2008a). More specifically, the composition of bone includes collagen, water, and hydroxyapatite mineral, with proteoglycans and noncollagenous proteins (Martin et al. 1998).

Predominantly comprised of collagen that provides tensile strength, and hydroxyapatite crystals that provide compressive strength or hardness, bone is a resilient yet fragile structure (Smith and Peters 1996, Herrmann and Bennett 1999). There are two types of bone, trabecular (i.e., cancellous or spongy bone) and compact bone (Martin et al. 1998). Porous trabecular bone has a porosity of 75%-95% (i.e., the volume fraction of soft tissues) with a matrix of plates or struts called trabeculae and is present in cuboidal bones (e.g., vertebrae), flat bones, and in the ends of long bones (Martin et al. 1998). Dense compact or cortical bone has a porosity of 5%-10%, is present in long bones, and forms the cortex or outer shell of trabecular bone (Martin et al. 1998).

General Fracture Mechanics of Fresh Bone

To accurately perform trauma analysis, the ability to distinguish between fractures caused by manually induced trauma and fractures caused by heat is of primary necessity (Fairgrieve 2008). Basic beam theory defines fractures as caused by the application of a load to a given span that will develop where stress exceeds the tensile strength of the material (Currey 2002, Galloway 1999, Herrmann and Bennett 1999). Fracture type and degree is related to the energy absorbing capacity of the material or, in other words, the condition of the bone (Herrmann and Bennett 1999, Piekarski 1970).

Through documentation and interpretation of traumatic signatures, forensic anthropologists can infer details concerning the manner of death. Common traumatic events are classified by forensic anthropologists and pathologists as being the result of sharp, ballistic, or blunt forces (Berryman 1996, Herrmann and Bennett 1999, Knight 1991, Smith 1996, Symes 1996). Traditionally, sharp force trauma includes cutmarks, sawmarks, and stab wounds indicated by sharp margins, blade striae, kerf walls and sheering of cortical and cancellous bone surfaces (Bromage and Boyd 1984, Frayer and Bridgens 1985, Guilbeau 1989, Houck 1989, Symes 1992, Symes 1996). Ballistic trauma is evidenced by beveling, radiating fractures, concentric fractures, and often the presence of lead spatter provides confirmation (Di Maio 1985, Smith 1996, Smith et al. 1987). Blunt force trauma is commonly characterized by diverse fracture patterns and is often indicated by an impact point (Berryman 1996, Kress 1996, Mayne 1990a, Mayne 1990b, Porta 1996, Porta et al. 1996, Smith and Peters 1996). Unique skeletal attributes are generated by each of these forces. However, these traumatic signatures can be significantly distorted with exposure to heat (Herrmann and Bennett 1999). An understanding of these fracture types is required to identify and document thermal modification, which reveals thermal patterning and allows one to track the progression of bone destruction (Symes et al. 1999). In addition to understanding fracture types for thermal tracking, it is also important to understand the color gradients.

Heat-Related Colors Associated with Burned Bone

Pope et al. (2001) present four stages of color change: Stage I is the presentation of a heat line (white line or translucent bone) that represents the initial line of contact and heat destruction to bone. Stage II or the presence of a heat border (brown to white band of variable width) represents the location where organic material (collagen) is permanently altered and destroyed by heat, which distinguished it from green bone. This feature follows contours of the preceding heat line. Stage III or charred bone (black coloration of bone) occurs at the advanced stage of burning. Bone is thought to be directly in contact with fire and heat, hence the color resulting from a reduction atmosphere. Complete loss of organic material and moisture, which compromises the bone structure, resulting in tensile shrinkage fractures that run both parallel and perpendicular to the heat border. Stage IV or calcined bone (gray to white coloration of bone) occurs with post-organic destruction and modification of the bone mineral content (crystallization of hydroxyapatite in bone). Osseous structures in this last stage exhibit deformation and distortion along with heat-induced fractures and shrinkage.

Heat-Related Structural Changes to Bone

These heat-related color changes visually express the progressive thermal degradation of bone. Furthermore, the chemical properties of bone are altered and the structural integrity is impaired or lost when bone is exposed to high temperature (Symes et al. 2008) due to evaporation, organic degradation, and transformation of the inorganic matrix (Pope 2007). Stages of the heat modification process are currently described by the terms dehydration, decomposition, inversion, and fusion (Mayne Correia 1997, Thompson 2004, Symes et al. 2008a). These terms were introduced by Shipman et al. (1984) and are further supported by Mayne Correia (1997) (Table 2). Thompson (2004) revised the time intervals for stages of thermal modification presented by Mayne Correia (1997) and cautions that temperature is not a reliable variable for predicting these changes (Table 3). Also, Thompson (2004) suggests that the description of inversion given by Mayne Correia (1997) inaccurately characterizes the conversion of hydroxyapatite as normal for this stage within the thermal modification process. Thompson further notes that the four stages to date are highly theoretical and in themselves do not explain all the fundamental causal changes occurring within hard tissues and asserts that this complex process of organic and inorganic property degradation is not yet completely understood (Thompson 2005).

Table 2: Stages in the Process of Cremation.

Stage	**Histological Changes**	**Approximate Temperature Range(°C)**
Dehydration	Water removal (physisorbed and chemisorbed)	105-600
Decomposition	Removal of organic components	500-800
Inversion	Removal of carbonates Conversion of HAP → ß tricalcium phosphate	700-1100
Fusion	Melting of crystals	1,600+

Source: Data from Mayne Correia 1997, table 2.

Table 3: The Four Stages of Heat-induced Transformation in Bone.

Stage of Transformation	**Evidence**	**Existing Temperature Range (°C)**	**Revised Temperature Range (°C)**
Dehydration	Fracture patterns; weight loss	100-600	100-600
Decomposition	Color change; weight loss; reduction in mechanical strength; changes in porosity	500-600	300-800
Inversion	Increase in crystal size	700-1100	500-1100
Fusion	Increase in mechanical strength; reduction in dimensions; increase in crystal size; changes in porosity	1000+	700+

Source: Thompson 2004, table 1.

Heat-Related Fractures in Burned Bone

Heat-related fractures, similar to general fracturing of unburned bone, differ for the types of bone that undergo thermal modification based on differences in basic shape and primary cortical thickness (Pope, personal communication to BKC, 2009). Thus, it is necessary to briefly present the different bone shape found in the body and their characteristics. Based on shape, bone is classified as tabular, tubular, and short or cuboidal (Martin et al. 1998). Tabular bone or flat bones such as the scapula, iliac blades, and bones of the cranial vault consist usually of two thin cortical bone sheets separated by cancellous bone (Currey 2002). Tubular or long bones such as the humerus, radius, ulna, femur, tibia, fibula, metacarpals, and metatarsals are typically thick-walled and hollow with expanded ends that have cancellous bone underneath. Ribs are considered to be intermediate between tabular and tubular bones. Vertebrae are considered short bones or bones that are nearly the same size in all directions, due to the centra or vertebral body, which is approximately the same size in all directions. Thin cortices and the tendency to be completely filled with cancellous bone are two characteristics of short bones.

Heat exposure is a passive postmortem taphonomic agent, which deviates from fresh bone fracture production such as blunt force, sharp force, and ballistic trauma; injury to living tissue caused by impacting force. Heat causes bone to shrink and dehydrate due to pyrolyzation of the organic structures, which leaves the brittle inorganic structure of bone. Thermal modification to bone, which indicates sequence and extent of the pyrolysis of the bone's organic materials and inorganic alteration, occur progressivly from basic exposure through to heat-related discoloration and fracturing (Pope 2007).

Areas of primary bone exposure, in-line with uniform burning conditions, occur at locations of thin soft tissues that are first exposed; for example the superior crania and thin areas of the forehead, lateral mandible, and flexed joints. Heat induced fractures, commonly defined by location and direction of propagation, are classified by the terms of longitudinal, step, straight transverse, patina, splintering and delamination, burn-line fractures, and curved transverse (Herrmann and Bennett 1999, Pope 2007, Rockhold 1996, Symes et al. 2008a).

Longitudinal fractures trail along the long axis of bone and generally propagate with the grain (Binford 1963, Herrmann and Bennett 1999, Pope and Smith 2004, Rockhold 1996, Stewart 1979). However, a slight helical course may also be taken down the long axis of bone (Symes et al. 2001).

Transverse fractures, also referred to as step or straight transverse fractures, extend from the margin of longitudinal fractures transversely across the bone shaft (Binford 1963, Herrmann and Bennett 1999, Rockhold 1996, Stewart 1979). Step fractures refer specifically to fractures that also extend from the margin of longitudinal fractures transversely across the bone shaft, however these fractures extend through compact bone (Symes et al. 2001).

Crazing or patina fractures affect the outer layers of cortical bone and are typically observed in epiphyseal regions. A cracked and dehydrated form characterizes patina fractures, which are frequently associated to the surface appearance of an oil painting (Binford 1963, Herrmann and Bennett 1999, Pope 2007, Rockhold 1996, Stewart 1979).

Splintering and *delamination*, which is the splitting or separation into layers, occurs predominantly between the cortical and cancellous bone layers in epiphyseal regions (Binford 1963, Herrmann and Bennett 1999, Rockhold 1996, Stewart 1979). In other words, the cortical bone separates from the spongy bone or the inner and outer tables of cranial bones will separate (Pope 2007, Pope and Smith 2004, Symes et al. 2001).

Burn-line fractures follow along the line of burn exposure on bones and are characteristically observed at areas of interface between burned and unburned bone. This interface is referred to as the initial zone of pyrolysis and presents with burned bone anatomically followed first by fracture and second by unburned bone (Pope 2007, Pope and Smith 2004, Symes et al. 2001). The initial zone of pyrolysis refers to the fire transitional color change that follows along withdrawing soft tissues due to heat exposure, which produces variations of lighter or darker color in comparison to the color of fresh bone depending on grease saturation and/or dryness of cortical texture. Pope (2007) has shown that small, tensile heat-related superficial fractures in the external cortical bone occur during this transitory stage and may extend past the initial zone of pyrolysis slightly into unburned bone, however do not commonly progress through or radiate into unburned bone. These fractures may expand and deform further with heat exposure in the proceeding stages of charred and calcined bone, which are visually obvious to a great extent as bone continues to shrink and pull apart in calcined bone (Pope 2007). Charred and calcined bone is structurally weak and fragile, which can become separated from unburned segments of bone with movement or handling.

Curved tissue regression fractures, which are traditionally referred to as thumbnail fractures and may also be identified as curved transverse fractures, are typically grouped linearly down the long axis of a bone shaft and characteristically appear with a stacked arc formation across the grain of the bone and are strongly associated with cremations of fleshed remains due to reduction of the soft tissues during incineration (Binford 1963, Herrmann and Bennett 1999, Pope 2007, Rockhold 1996, Stewart 1979, Symes et al. 2001). As fleshed bone is heated the protective soft tissues and periosteum will shrink and burn off leaving cracks or soft tissue shrinkage lines in the heated bone (Pope 2007). Curved transverse fractures are considered to be products uniquely due to heat for the reason that they lack resemblance to trauma-attributed defects (Herrmann and Bennett 1999, Rockhold 1996).

Overview of Methods - Project Hypotheses

Experimental burning of four intact, fleshed pig *(Sus scrofa)* carcasses was conducted to specifically identify and compare the effects of direct and indirect fire suppression techniques on burned remains in an outdoor setting. This research examined how fire suppression methods further modify burned skeletal materials, and how these methods produce specific signatures on burned remains. Understanding these factors can aid in the identification of the causes underlying skeletal damage. The main goal of this project is to establish physical baselines for understanding how fire suppression activities and associated fatal fire scene variables might be expected to translate into the patterns produced on modern burned remains at the fire scene during suppression, recovery, and handling, as well as at the laboratory (after transportation from the scene) during anthropological analysis.

This project addresses four overarching components associated with burned remains and fatal fire scenes; 1) the expected thermal modification and additional damage to burned remains due to 2) active removal, 3) pressurized water, and 4) dry-chemical extinguishment. During experimentation and analysis of each test, three categories or scenes of modification are acknowledged: 1) the fire event, which includes heat exposure and heat-related changes of the soft tissues and bone; 2) the fatal fire scene, in which thermal coloration, fracture, fragmentation, and preservation of the burned remains at the fire site is assessed; and 3) the laboratory, which considers post-fire/secondary modification due to transportation and handling.

The first research component addresses how fleshed and intact remains change exclusively due to heat, which will document the progressive desrtuction of soft tissue layers and bone that aid in the understanding of basic thermal modification patterns observed during experimentation. It will establish the normal heat-related changes expected and the resulting burn patterns produced on soft tissues and bone for intact, fleshed remains of one pig.

The second research component addresses the overall impact to fragile burned remains by physically handling and moving fragile burned remains from the scene during the fire event. Is degree of thermal modification attained and overall skeletal damage similar or different from that reached during natural burn-out? Factors of interest that are specific to removal of remains during the active fire event include, but are not limited to, external force, modification due to handling prior to and after cooling of the remains, creation of an increased search area or secondary search area, and presence of heat affecting remains even after removal from flames.

The third research component addresses the overall impact to fragile burned remains from direct suppression by pressurized water and Class A foam. Is degree of thermal modification and overall skeletal damage similar or different from that reached during natural burn-out? Factors of interest that are specific to pressurized water fire suppression include moisture, pressure of the water and type of water stream employed (i.e., solid-stream and fog-stream), abrupt temperature change, chemical composition of foam admixture in water, and hose application (i.e., direct and indirect).

The forth research component addresses the overall impact to fragile burned remains from direct suppression by compressed-air/dry-chemical. Is degree of thermal modification and overall skeletal damage similar or different from that reached during natural burn-out? Factors of interest that are specific to dry-chemical fire suppression include pressure (i.e., external force) of compressed air and dry-chemical substance, chemcial composition of dry-chemical substance, and the act of smothering the fire, in comparison to cooling or wetting the fire.

It is hypothesized that burned remains extinguished by pressurized water versus a hand held ABC compressed-air/dry-chemical portable fire extinguisher will display differences in secondary modification (e.g., fragmentation and fractures) compared to burned remains allowed to cool naturally (i.e., no fire suppression technique employed). In other words, use of the direct fire suppression techniques of pressurized water and dry-chemical portable fire extinguishers will produce an increased amount or degree of skeletal damage in comparison to the indirect fire suppression techniques of allowing the fire to natrually burn-out or removing the burned remains from the active fire scene.

Additionally, it is hypothesized that preservation rates for the fragile burned remains will vary/differ between all four tests. Skeletal modification will be compared by pre-transportation (at fire site) and post-transportation (at laboratory) observations both between and within treatment groups (T1-T4 remains) in order to assess degree of transportation modification for all four tests.

Summary

It is of importance to fatal fire investigation and the analysis of burned remains to acknowledge one of the most common aspects of the scene, fire suppression techniques, and attempt to achieve a basic understanding of their potential to modify thermally altered soft tissues and skeletal materials. A broad summary of challenges and variables relevant to the analysis of burned remains has been outlined in this chapter. The following chapter outlines the experimental methodology employed, procedure of data collection, and statistical techniques utilized during data analysis for the current study.

Table 4: Summary of Experimental Tests.

Test	Subject	Materials	Burn Time	Fire Suppression
1: Control/ natural burn-out	Fleshed remains of one whole pig	200 lbs juniper ash split logs, 1/2 liter diesel fuel, half twin size mattress, large-scale fan	Hindrance of fire not set; flames absent at 4 hours and 45 min after ignition	None; fire allowed to follow natural course, remains allowed to cool naturally on the fire pit
2: Active removal	Fleshed remains of one whole pig	200 lbs juniper ash split logs, 1/2 liter diesel fuel, half twin size mattress, large-scale fan	4 hours	None; manually removed from the active fire scene, remains allowed to cool naturally
3: Pressurized	Fleshed remains of one whole pig	200 lbs juniper ash split logs, 1/2 liter diesel fuel, half twin size mattress, large-scale fan	4 hours	Pressurized water and 'First Strike' foam from hose of a brush truck
4: Dry-chemical	Fleshed remains of one whole pig	200 lbs juniper ash split logs, 1/2 liter diesel fuel, half twin size mattress, large-scale fan	4 hours	Twenty-pound hand-held (ABC) compressed air, dry- chemical fire extinguisher

Photographs of the remains were taken before, during, and after each treatment, as well as before and after handling of the remains in the field and in the laboratory. Photographs were taken with and without use of a flash, as use of the flash can affect the quality of photographs taken in the presence of fire, smoke, and steam (E. Pope, personal communication, 2009).

Materials

Four domestic pigs (*Sus scrofa*) were acquired for use in this research. Subjects were euthanized at the Seguin Animal Hospital in Seguin, Texas, using approved and standardized euthanizing agents (Euthasol: pentobarbital sodium and phenytoin sodium) according to Institutional Animal Care and Use Committee (IACUC) oversight and protocols. Texas State University-San Marcos (TSU) donated the two mattresses used during experimentation, which provided material for sufficient ignition of the remains during each test fire. Both mattresses consisted of 75% blended F/R (fire retardant) cotton felt, 25% synthetic polyurethane foam, and a metal spring unit. Bolt cutters and scissors were used to cut each of the mattresses in half. Additionally, microscopic analysis was conducted on the dentition of each pig with the Leica EZ4D Educational Stereomicroscope. Microscopic analysis of the dentition allowed for a more broad understanding of characteristics associated with heat-induced modification of remains.

Experiment and Procedure

Test one (T1): fleshed remains of the control pig were burned with no method of fire suppression employed and allowed to cool naturally. Test two (T2): fleshed remains were burned for four hours and then taken off of the fire and allowed to cool, which simulated conditions where firefighters hastily remove remains from the fire scene. The remains from T2 were used to evaluate the effects of the suppression techniques employed on the pressurized and dry-chemical pigs. The remains from T3 were burned for four hours and then extinguished using pressurized water extinguishment from a brush truck. The remains of T4 were burned for four hours and manually extinguished using a 20-pound hand-held (ABC) compressed air/dry-chemical fire extinguisher. Several variables were held as constant variables for each of the four tests: size of the fire and amount and type of fuel, size of the pig, placement of remains in relation to fire, duration of exposure, and condition of the bone (DeHaan 2002). In addition to these variables, the duration of the fire was held at a constant four hours for the active removal, pressurized, and dry-chemical test, the approximate time it takes for the majority of appendicular bones to be defleshed and fractured from heat (de Gruchy and Rogers 2002).

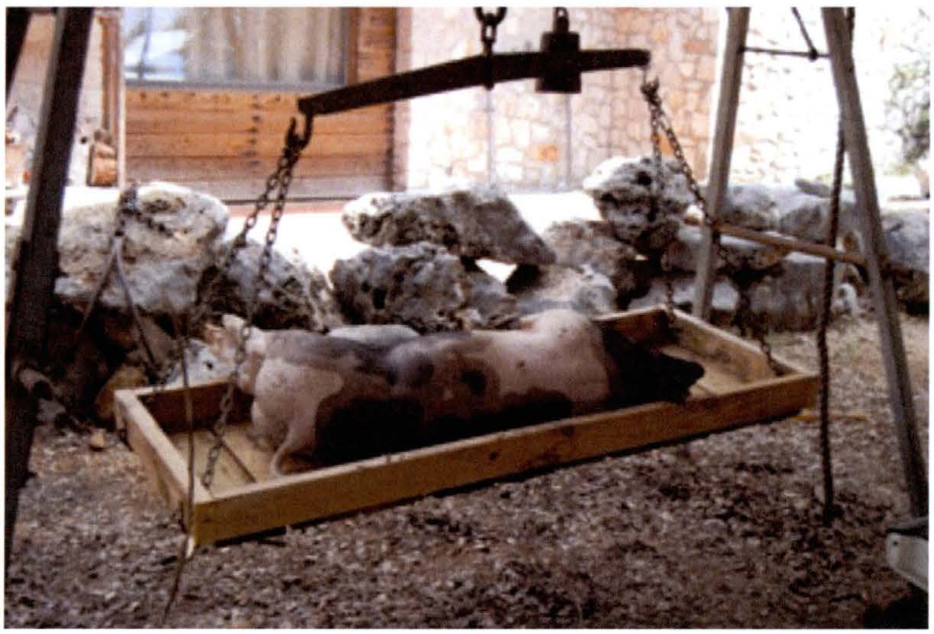
It has previously been suggested that burning bones which are fleshed will result in different fracture patterns than burning dry, degreased bones (Baby 1954, Binford 1963, Bohnert 2004, Herrmann and Bennett 1999, Pope and Smith 2004, Shipman et al. 1984, Stewart 1979, Ubelaker 1978). Additionally, the progression of thermal modification has been shown to differ between fleshed and defleshed bone due to the presence of soft tissues such as skin, fat, and muscle (i.e., tissue shielding) (Pope 2007). Thus, only fleshed remains were burned, examined, and compared in order to increase the reliability and comparative value of this study for forensic application.

A preliminary pig was burned for close to five hours prior to burning the four experimental tests. The preliminary test pig was burned in order to approximate and determine an appropriate burn duration for the active removal, pressurized, and dry-chemical tests. Additionally, this preliminary burn test allowed for the establishment of accompanying constant variables of interest; for example, equal amounts of wood required for each test to ensure sufficient thermal modification of both soft tissues and bone. Calcined skeletal elements were present during the preliminary burn test just prior to the four-hour time mark with a deficiency of flames approaching the five-hour time mark. However, the remains of T1/Natural Burn-Out test were not limited by a standard duration burn since it functioned as the experimental control of this research. The three additional tests (T2-T4) were limited by a standard duration burn, which maintained a four-hour time limit on burning for each of the three pigs.

For each test/fire, 200 pounds of juniper ash (*Juniperus ashei*) split logs were used for fuel and placed inside a cinderblock square with rounded edges; each aligned cinderblock wall of the fire pit measured five feet by four feet nine and one-half inches wide with a height of 15 inches (Figure 1). All split logs used for experimentation were cut and allowed to dry-out several weeks before experimentation began. Decreasing the woods moisture content was necessary for proper ignition, since heating the organic layers to high temperatures needed for ignition will be hindered by moisture (NWCG 2001). Juniper ash was used in each fire due to availability and its high combustibility (i.e., its ability to burn and quickly ignite).

(Figure 1) Set-up of outside fire pit with split logs.

Each whole pig was weighed before experimentation with a large scale (Figure 2) and then placed on top of a rigid one-forth inch metal grate. Prior to ignition the grate was located on a metal stand situated north of the fire pit (Figure 3). An outside fire pit was employed in view of the fact that suspicion commonly arises when bodies are discovered in unfamiliar outdoor places (Fanton et al. 2006).



(Figure 2) Large scale used to weight each pig.

(Figure 3) Metal grate positioned next to fire pit holding pig prior to ignition.

Several factors affect the rate at which wood ignites, burns, and decomposes (NFPA 2009), of which the factor of ignition size is included. A small ignition source, for example, one paper towel and a handheld lighter, contains less energy and will generate a longer ignition time; the process of ignition will occur more rapidly with the use of an accelerant. Accordingly, one-half liter (16 fluid ounces) of diesel fuel was poured directly on the juniper ash logs placed in the fire pit to promote a timely ignition. It has previously been demonstrated that gasoline-fueled flames and flames produced from wood are indistinguishable in their average maximum flame temperature (DeHaan and Nurbakhsh 2001). Each test fire within the pit was ignited through use of one paper towel and a small handheld lighter. Directly after ignition of each fire, half of a twin size mattress was placed on top of the burning wood within the fire pit (Figure 4).

(Figure 4) Half of a twin size mattress being placed on fire pit after ignition.

Lastly, the remains of the pig and supporting metal grate were placed on top of the mattress segment within the fire pit. The fire experimentation protocol employed during this research was developed for the present study in conjunction with Dr. Elayne Pope (personal communication, 2009). Additionally, a large-scale fan was placed next to the fire pit and remained in operation during each test. Utilization of the fan was to insure airflow and help disperse smoke and steam from the fire for clear pictures to be taken during documentation of all four tests. The fan remained two feet from the west wall of the fire pit for the full duration of each test.

Each set of remains were allowed to cool overnight after burning, with processing at the burn site commencing the following day. The soft tissue of each pig was removed by hand using plastic gloves, a medical scalpel, metal tweezers, and one pair of small metal scissors. All bodies were allowed to decompose overnight so that insects could aid in the removal of all soft tissues. Total removal of soft tissues was accomplished over the course of one week for each pig. Each set of remains was carefully examined through visual assessment with the aid of a hand lens during and after soft tissue removal.

Care was taken in the retrieval, handling, transport and storage of the burned remains. De Gruchy and Rogers (2002) recommend the following method of packing and storage, which was employed in this research. Larger fragments were packed in a box with at least 2.5 centimeters of paper towel between each fragment. Smaller fragments were packed in and separated by paper towels before sealing them in sandwich bags. All fragments were sprayed with Aqua Net© hairspray to preserve their form. In addition, post-fire fractures caused by movement and handling were evaluated by comparing photographs taken of the burned remains at the burn site with photographs taken of the remains after they had been transported to the Grady Early Forensic Anthropology

Research Laboratory (GEFARL), Texas State University-San Marcos.

Limitations

The weather conditions (humidity, temperature, barometric pressure, and wind speed) and temperature of the pig were recorded during each test for purposes of reproducibility and also because humidity, temperature, and wind speed can all affect the temperature and duration of the fire (DeHaan 2002). Weather data were not collected from a weather station near the burn area, but were collected from www.weather.com directly before each test fire was ignited (Appendix A).

Difference in sex (male vs. female) was not considered to produce significant variation in thermal modification among the four experimental pigs. Due to the young age of each pig, sexually dimorphic characteristics had not yet developed due to the pigs not yet becoming physiologically mature. The sex and age of each test pig was recorded prior to experimentation for purposes of reproducibility and also due to reports that sex and age have been shown to produce variation in the thermal destruction of skeletal remains (Christensen 2001, DeHaan and Nurbakhsh 2001). However, Gaillard et al. (1992) found that no sexual dimorphism in growth rate could be detected between two weeks and six months in *Sus scrofa*, which is contrary to the expectation for a dimorphic and polygynous mammal like the wild boar. The weight recorded for the four test pigs ranges from the lowest recorded weight of 103 pounds to the highest recorded weight of 135 pounds (Table 5; Figures 5-8), which is comparable to adult human remains. Based on weight, in order of lightest to heaviest the pigs are ranked T2 (female), T4 (male), T1 (female), T3 (male).

The age of each pig was approximately three months (Table 5) and further ensured that each test pig had a healthy skeleton of similar growth and maturation stage prior to experimentation. With all four experimental pigs having an age of approximately three months, these younger specimens would initially be more active with respect to heat-treatment (Holden et al. 1995).

Table 5: Demographic Data for Experimental Pigs.

Pig Number:	**1**	**2**	**3**	**4**
Sex:	Female	Female	Male	Male
Age:	3 months	3 months	3 months	3 months
Weight:	115 lbs.	103 lbs	135 lbs	108 lbs
Length:	47 in.	39 in.	46 in.	43 in.
Width:	13 in.	7 in.	13 in.	12 in.

(Figure 5) Active Removal pig (T2) positioned on grate at start of experimentation.

(Figure 6) Dry-Chemical pig (T4) positioned on grate at start of experimentation.

(Figure 7) Pressurized pig (T3) positioned on grate at start of experimentation.

(Figure 8) Natural Burn-Out pig (T1) positioned on grate at start of experimentation.

Due to scheduling requirements, the porcine subjects attained for this research were retrieved on two separate days; two pigs were collected on each pick-up day. This manner of pick-up, in addition to the high temperatures (range: 97°-99° F or 36.11°-37.22° C; average: 97.5° F or 36.39° C) experienced in Texas during experimentation, made it necessary to place two of the experimental pigs on ice over night. The remains of the active removal and dry-chemical pigs were placed on ice to slow decomposition and placed outside in the heat before burning on the morning of their test in order to reach ambient temperature and regain a similar temperature as that recorded for the control pig and the pressurized pig, which had not been placed on ice. This was necessary as difference in body temperature and state of decomposition could produce variation between thermal modifications produced on the experimental remains (Anderson and VanLaerhoven 1996, Campobasso et al. 2001, Catts and Goff 1992).

To mimic realistic characteristics of a fatal fire scene, the use of a fire engine was requested in order to conduct the experimental test focused on fire suppression in the form of pressurized water from a fire hose. However, a fire engine was not available for use at the scheduled time of T3 the pressurized water test. Therefore, a brush truck was employed during the pressurized test (Figure 9). A brush truck is a small fire truck outfitted for the suppression of wild land fires (PHWC 2007).

(Figure 9) Brush truck used during Pressurized treatment.

The primary attack line from a fire engine for a house or vehicle fire is a 1 ¾" attack hose (NFPA 2009). The standard operating water pressure for a 1 ¾" attack hose (classified attack lines directly discharge water from the hose onto a fire without going through another pump) attached to a fire engine is on average between 100-120 pounds per square inch (psi) (K. Bell, personal communication, November, 2009, NFPA 2009). A 1 ¾" attack hose can deliver between 140 and 200 gallons per minute (gpm) and may be used with both smooth-bore and fog-stream nozzles. Nozzles are required on the discharge end of attack lines, which gives the fire stream its shape and direction.

Smooth-bore nozzles produce straight streams that are solid columns of water. Fog-stream nozzles are able to separate and disperse the water to form fine droplets, which aid in heat absorption (NFPA 2009), and are also able of producing straight streams. During Pressurized experimentation, the brush truck attack hose was equipped with a fog-stream nozzle. The diesel motor brush truck utilized during experimentation deviates in capability from a fire engine due to standard operating water pressure, which is 70-80 psi with a gpm range of 10 to 50 (D. Smith and K. Bell, personal communication, January 26, 2010, NFPA 2009).

During the pressurized water test (T3), chemical "First Strike" Class A foam was unexpectedly applied during fire suppression by the brush truck due to standard fire extinguishment protocol. "First Strike" Class A foam is a synthetic fire fighting foam concentrate specifically formulated for all Class A applications such as structural fires, forestry and wild land fires, landfill fires, and tire fires. The special chemical balance in First Strike reduces the surface tension of water, greatly increasing the penetrating and wetting abilities of the water, thus making the water supply five times more effective than untreated water. First Strike is biodegradable, non-toxic, non-corrosive, and not harmful to the environment (usfoam 2009). The chemical components of First Strike foam are water, a proprietary mixture of synthetic detergents, 1,2 Propanediol, (2-Methoxymethylethoxy) Propanol, and a proprietary mixture of corrosion inhibitors (FMS600 2004). The recommended application rate for wild land attack with use of an aspirated hand line nozzle is 0.3%, (usfoam 2009), which was the application rate used during the pressurized test. However, the recommended application rate for a structural attack with use of a non-aspirated hand line nozzle is 0.5% (usfoam 2009), which would be used for a structural or vehicular fire.

Experimental Research with Non-Human Remains

The use of pig remains has become a widely accepted practice in forensic research as a substitute for human cadavers (Anderson and VanLaerhoven 1996, DeHaan 1997, DeHaan et al. 1999, DeHaan and Nurbakhsh 2001, de Gruchy and Rogers 2002, Goff 1993, Herrmann and Bennett 1999, Marciniak 2009, Wieberg and Wescott 2008). The obvious ideal research material, human bodies, are generally not obtainable in large numbers, thus studies that use human bodies customarily have had only one replicate (Anderson and VanLaerhoven 1996, Rodriguez and Bass 1983, Rodriguez and Bass 1985). The validity of baseline data obtained from nonhuman models has been of frequent concern (Anderson and VanLaerhoven 1996, Campobasso et al. 2001, Catts and Goff 1992, Micozzi 1991, Pope 2007). However, pigs have similar gut fauna in comparison to humans due to being them being omnivorous, as well as being relatively hairless and possessing skin similar to that of human skin (Anderson and VanLaerhoven 1996, Campobasso et al. 2001). Also, putrefaction of a pig has been shown to proceed approximately at the same rate as a human body of the same weight (Campobasso et al. 2001). Furthermore, court trial cases have questioned the validity of information deduced from nonhuman studies to human bodies (Catts and Goff 1992). In order for nonhuman studies to withstand courtroom scrutiny, the animal model must similarly pattern the decomposition of a human corpse, be obtained easily, be inexpensive, and maintain public acceptance. The most acceptable animal model, used frequently in decomposition studies, is the domestic pig (Catts and Goff 1992).

Methods

Data Collection

Degree of thermal damage was scored on each bone of all four pigs twice; first at the burn site and then at the Grady Early Forensic Anthropology Research Laboratory (GEFARL). The bones scored for each of the four test pigs included bones of the crania (frontal, parietal, occipital, sagittal, zygomatic, palate, maxilla, nasal, and premaxilla), the mandible, and the vertebrae (cervical = 7, thoracic = 15, lumbar = 7, sacral = 4, and caudal = 20-23). Additionally, bones present on both the right and left sides of each set of remains and were scored include the clavicle, scapula, ribs (15 right, 15 left) humerus, ulna, radius, carpals, metacarpals, phalanges, os coxa (ilium, ischium, and pubis), femur, patella, tibia, fibula, tarsals, metatarsals, phalanges, and dentition (5 right, 5 left).

Coding Protocol

The general coding scale (Appendix B) used to score thermal damage of each bone is as follows: 0, absent, unable to score thermal modification; 1, present, no heat-related damage; 2, heat-related color change only; 3, 0-25% fracture or fragmentation; 4, 26-50% fracture or fragmentation; 5, 51-75% fracture or fragmentation; 6, 76-100% fracture or fragmentation; 7, absent, post-fire fracture due to thermal damage (Table 6). The general coding scale was employed during inventory of the ilium. However, due to the atypical shape of the porcine ilium, a measurement must be taken from the most superior portion of the iliac crest to the most superior portion of the acetabulum (Figure

10). The general coding scale is also used when coding the ribs. Each rib was divided in to four sections: external sternal extremity, external vertebral extremity, internal sternal extremity, and internal vertebral extremity. For example, if no fracture or fragmentation is present on the internal portion of the rib, the rib will receive a score of 1, 2, 3, or 4 (scores less than 50%), depending on the magnitude of trauma present on the external surface of the rib.

(Figure 10) Iliac measurement taken during coding.

Table 6: General Coding Scale Used During Data Collection.

Inventory Codes	**Description**
0	Absent - Unable to score thermal modification
1	Present - No thermal damage
2	Color change only
3	0-25% Fracture/Fragmentation
4	26-50% Fracture/Fragmentation
5	51-75% Fracture/Fragmentation
6	76-100% Fracture/Fragmentation
7	No Longer Present - Due to Thermal Damage

The vertebral coding scale (Appendix C) used is as follows: 0, absent, unable to score thermal modification; 1, present, no thermal damage; 2, heat-related color change only; 3, superior portion of spinous process fracture or fragmentation; 4, majority of spinous process fracture or fragmentation; 5, all spinous process fracture or fragmentation; 6, ≥ 50% of vertebral body fracture or fragmentation; 7, absent, post-fire fracture due to thermal damage (Table 7).

Table 7: Vertebral Coding Scale Used During Data Collection.

Inventory Codes	Description
0	Absent - Unable to score thermal modification
1	Present - No thermal damage
2	Color change only
3	Superior portion of spinous process fracture/fragmentation
4	Majority of spinous process fracture/fragmentation
5	All spinous process fracture/fragmentation
6	≥50% of Vertebral Body Fracture/Fragmentation
7	No Longer Present - Due to Thermal Damage

Visual Observations

The heat-related changes were first evaluated for the control remains (T1) to establish an expected/normal pattern of thermal modification prior to analyzing fire suppression technique characteristics. Further examination was performed on the secondary post-fire fractures caused by the fire suppression treatments through first-hand visual analysis and photographic documentation taken during fire site analyses (Appendix D) and macroscopic comparative analyses at the Grady Early Forensic Anthropology Research Laboratory (GEFARL). Specific variables of interest during analysis included bone fracture type, size, and color scored for each bone (Appendix E) at both research venues (fire site and laboratory).

The first of these characteristics, fracture type, was classified using the seven currently accepted thermal fracture categories: longitudinal, step, transverse, patina, splintering and delamination, curved transverse, and burn line fractures (Binford 1963, Buikstra and Swegle 1989, Herrmann and Bennett 1999, Rockhold 1996, Shipman et al. 1984, Stewart 1979, Symes et al. 2001, Symes et al. 2008). Fracture size referred to the length, width, and depth of each fracture. Fracture color refers to both the external and internal color present on the fractured bone, as well as the color of the fracture edge (Pope 2007). Fracture color is of particular diagnostic interest due to its ability to aid in distinguishing between traumatic and burn-related fractures, specifically on the cranium (Pope and Smith 2004).

Statistical Analysis

All statistical analyses were performed by using SPSS software (Statistical Package for Social Sciences; SPSS 2010, Version 19). Once all data for each test had been collected at the burn site (pre-transport) and the laboratory (post-transport), then descriptive statistics were run for the thermal modification present during data collection at the fire site for each set of remains and the thermal modification present during data collection at the laboratory on each set of remains. A broad understanding of the differences and similarities between the fire site scored and laboratory scored thermal modification was attained through comparing both sets of collected thermal modification data.

Two independent-samples Kruskal-Wallis test were conducted to compare the degrees of skeletal modification observed and recorded for the four different test subjects. The first compared skeletal modification scores recorded during fire site analysis for all four tests, in order to analyze the effect of fire suppression and manipulation of the remains at the fire scene. In other words, differences in degree of thermal modification and secondary fractures observed at the fire site were evaluated between the four test subjects. The second independent-samples Kruskal-Wallis test compared skeletal modification scores recorded during laboratory analysis for all four test, in order to analyze the effect of transportation and handling. Thus, this test allowed for the evaluation of preservation rates between the four test subjects through comparison of thermal modification and secondary fractures observed after transportation. For both independent-samples Kruskal-Wallis tests, the null hypothesis is that the distributions (medians) of skeletal modification scores no not differ between the four tests. Accordingly, the alternate hypothesis is that the distributions (medians) of skeletal modification scores show a significant difference between the four tests.

A paired-samples t-test was conducted for each of the four test subjects, which compared each set of fire site recorded scores and laboratory recorded scores of skeletal modification according to test subject. Thus, the fire site or pre-transport skeletal modification scores for each test subjects were tested against the corresponding laboratory or post-transport skeletal modification scores. In other words, the four paired-samples t-tests were employed to examine the differences between fire site and laboratory scores of skeletal modification per individual test subject. For each paired-samples t-test the null hypothesis is that the average of the differences between the paired observations of fire site scores and laboratory scores is zero. Accordingly, the alternative hypothesis is that there is a significant difference between means for the paired observations of fire site scores and laboratory scores.

CHAPTER III
RESULTS

Visual Analysis/Observations

The information presented is based on direct observation of the progressive destruction of protective soft tissue layers around bone and, furthermore, on bone during an outdoor wood fire.

Natural Burn-Out (T1)

T1/Natural Burn-Out test (control) established the baseline heat-related changes to soft tissues and bone prior to analyzing the possible fire suppression characteristics. Remains from T1 started showing heat-related changes during the fire event with leakage of fluid from the snout, discoloration and blistering of the skin, the ears becoming singed, and protrusion of the tongue at approximately 5 minutes after ignition (Figure 11). Once the soft tissue began to char, calcify, and flake along the posterior body, muscle contraction occurred at the shoulders and thighs, which began by adduction of the right forelimb at approximately 23 minutes after ignition (Figure 12). Arching of the neck also occurred due to muscle contraction. In association with the muscle contraction of the limbs, flexion occurred at the joints in both the left and right fore limbs (at the elbows and wrists) and hind limbs (at the knees and ankles). Flexion at the joints, in addition to heat, created skin splits in these areas, which exposed underlying soft tissues and bone.

Bone exposure that occurred during the first four hours of the Natural Burn-Out test is presented in Table 8 (see *Appendix D* for fire site scores/data). All burned material remained located within the fire pit interior area during the T1 fire event.

(Figure 11) T1 remains during fire, approximately 17 minutes after ignition. Early heat-related changes are shown (i.e., leakage of fluid from snout, discoloration and blistering of skin, ears becoming singed, and appearance of slight tongue protrusion).

(Figure 12) T1 remains during fire, approximately 23 minutes after ignition. Soft tissues of the posterior and lateral body charred and beginning to flake, muscle contraction and adduction of the right forelimb.

Table 8: Skeletal Observations Recorded During T1/Natural Burn-Out Test.

T1: Natural Burn-Out	**Observations During Burning**
Vault	Occipital exposed and charred along superior arch.
Mandible	No bone exposure.
Dentition	Maxillary and mandibular anterior teeth blackened.
Scapulae	Left and right scapulae exposed and charred along medial blade.
Vertebrae	Caudal vertebrae exposed and calcined.
Ribs	Left and right ribs exposed and charred along lateral-posterior shaft. Heat-related fractures present on right rib shafts.
Innominate	Right iliac blade exposed, blackened, and charred along lateral iliac crest (both anterior and posterior).
Long Bones	Left distal tibia and fibula exposed laterally and blackened; Right distal tibia and fibula exposed laterally and blackened with right fibula charred laterally; Lateral portions of left metatarsals #4 and #5 exposed, blackened, and charred; Right metatarsals #3, #4, and #5 exposed laterally with metatarsal #3 blackened.

At the four-hour point during the fire event (the standard duration set for T2, T3, and T4 taken from time of ignition/placement of remains on fire pit) remains from T1 (Figure 13) presented muscle contraction of all four limbs with bone exposure of the left hind limb at the ankle and muscle delineation (e.g., right hindlimb) (Figure 14). Heat-related changes to soft tissue were greatest along the posterior body with calcined soft tissues and bone exposure, coloration, charring, and calcination. The neck remained arched with superior exposure of the ventral surface and the ventral plane slightly angled. Thermal modification to remains is consistent with all observations recorded during fire event. All material from burned remains was located within the interior of the fire pit area.

(Figure 13) Remains from Natural Burn-Out test at four-hour point during fire event on metal grate. Thermal discoloration of soft tissues along the anterior midline shown, discoloration exemplifies how the elevated spatial relationship between body and fire can affect burn patterning. No direct or radiant heat reached the midline, thus no heat-related damage.

(Figure 14) Muscle contraction of the hindlimbs of T1 remains during fire event. Left hindlimb presents muscle deliniation and advanced limb flexion with bone exposure at the ankle joint (i.e., location of distal tibia and fibula articulation with proximal metatarsals).

Visually, no further heat-related changes were identified the following morning in addition to those observed and recorded during the fire event (Figure 15). However, muscle contraction achieved by heat during the fire event appeared slightly relaxed the following morning as the arching of the neck decreased and hind limbs fell with position being lower towards the metal grate. All material from burned remains remained located within the interior of the fire pit area.

(Figure 15) Remains from Natural Burn-Out test the morning after burn event.

During analysis of T1 burned skeletal material at the fire site, longitudinal and transverse fractures were present with blackened and charred cortical and trabecular bone (i.e., similar heat-related coloration at fracture margins) and jagged fracture edges (Figure 16). Heat-related color difference also observed between cortical and trabecular bone at the fracture margins.

(Figure 16) T1 ribs showing sharp and jagged fracture edges. Top of photo: rib with white calcined cortical bone at fracture edge and blackened trabecular bone.

T1 remains during laboratory analysis, after transportation, were greasy in appearance and texture (Figure 17). Mold in the colors of white, black, and mustard yellow observed on the skeletal remains of T1 in the laboratory (Figure 18). Longitudinal and transverse fractures present (Figure 19) with no color differentiation at the fracture margins (i.e., fracture margins showing heat-related color change both exterior and interior) and jagged fracture edges. Small superficial striations observed on cortical bone of left and right lateral mandibular body running superior-inferior and slightly curved anterior-posterior (Figure 20). Modification observed, scored, and recorded during laboratory analysis of T1 skeletal remains is presented in Table 9 (see *Appendix E* for laboratory scores/data).

(Figure 17) T1 remains at laboratory appeared greasy, shown on crania.

(Figure 18) Vertebrae (T14, T15, L1-L6, S1, and S2) of T1 shown with white, black, and yellow mold during laboratory analysis.

(Figure 19) Rib of T1 with longitudinal and transverse fractures in cortical bone of external rib surface.

(Figure 20) Curved superficial striations present on lateral mandibular body.

Table 9: Skeletal Observations Recorded During Post-Transport Analysis of Natural Burn-Out/T1 Remains at Laboratory.

T1: Natural Burn-Out	**Observations at Laboratory**
Crania	No thermal modification observed on palate, maxilla, nasal, or premaxilla bones of crania. Frontal, sagittal, and zygomatic bones of crania blackened, with both right and left frontal and parietal bones charred. Thermal fracturing of right and left parietal bones. Occipital blackened, charred (14 mm from midline), and fractured along superior crest.
Mandible	No visible signs of thermal coloration on mandible. Possible curved tissue regression fractures present on left and right anterior portions of the lateral mandibular body.
Dentition	Anterior dentition (i.e., left and right maxillary incisors #1, #2, #3, and first premolar; left and right mandibular incisors #1, #2, #3, and first premolar) blackened due to direct heat exposure during fire event.
Scapulae	Right scapula charred with fragmentation along dorsal border/medial border (0-25%), recovery damage along blade exterior cranially, and calcined along blade exterior caudally. Left scapula was charred, fractures and fragmented along exterior of blade (0-25%).
Vertebrae	No thermal coloration on Cervical 1-7. First thoracic (T1) blackened (i.e., thermal coloration only). Thoracic 2-6 blackened, charred, and superior spinous process fracture/fragmentation. Thoracic 7-9 blackened and charred with majority of spinous process fractured and fragmented. Thoracic 10, 14, and 15 blackened, charred, and fragmented, spinous processes absent due to thermal modification and >50% of vertebral bodies fractured/fragmented. Thoracic 11-13 blackened and charred with spinous process absent. Lumbar 1-2 blackened and charred with spinous process absent. Lumbar 3-6 blackened and charred with majority of spinous process fractured and fragmented. Seventh lumbar absent, not result of fire. First sacral (S1) blackened, charred, and fragmented with 100% of spinous process fractured/fragmented on left side and >50% of vertebral body fractured and fragmented on right side. Second sacral blackened, charred, and fragmented with >50% of vertebral body fractured and fragmented on left side with right side no longer present due to thermal modification. Sacral 3, 4, and all caudal vertebrae absent due to thermal modification.

Table 9-Continued: Skeletal Observations Recorded During Post-Transport Analysis of Natural Burn-Out/T1 Remains at Laboratory.	
Ribs	No thermal coloration on left ribs 1-5 and right ribs 1-3. Left ribs 6-9 and right ribs 4-8 blackened (i.e., thermal coloration only). Remaining left ribs (10-15) charred along lateral portion of shaft with longitudinal fractures and delamination. Remaining right ribs (9-15) blackened and charred medial to lateral with heat-related transverse and longitudinal fractures along rib shaft, delamination, and complete heat-related fragmentation with charred and calcined fracture margins.
Os Coxa	Left ilium charred along blade crest, both anterior and posterior, and calcined at superior-lateral margin. Right ilium charred along blade crest, both anterior and posterior. Left and right ilium fractured/ fragmented 51-75%. Left and right pubic symphyses blackened and charred (0-25% fracture/fragmentation). No thermal coloration on left and right ischium.
Long Bones	Left humerus, ulna, radius, carpals, metacarpals and phalanges blackened (i.e., thermal coloration only). Right humerus, ulna, radius, carpals, metacarpals and phalanges blackened (i.e., thermal coloration only). Left femur, patella, tibia, fibula, tarsals, metatarsals and phalanges blackened (i.e., thermal coloration only). Right patella blackened (i.e., thermal coloration only). Right femur, fibula, and tarsals blackened, charred, and thermal fracturing (0-25%). Right tibia and metatarsals blackened, charred, and thermal fracturing (26-50%) with blackened, charred, and thermal fractured phalanges (51-75%).

Active Removal (T2)

Remains from T2/Active Removal test started showing heat-related changes during the fire event with discoloration and blistering of the skin, ears becoming singed, and leakage of fluid from snout. Once the soft tissue began to char, calcify, and flake along the posterior body, muscle contraction occurred at the shoulders and thighs, which was first observed by adduction of the left hind limb and flexion at the ankle joint with underlying bone exposure at approximately 37 minutes on after ignition (Figure 21). Arching of the neck also occurred due to muscle contraction. In association with the muscle contraction of the limbs, flexion occurred at the wrist joints of both the forelimbs and the ankle joints of both hind limbs. Flexion at the joints, in addition to heat, created skin splits in these areas, which exposed underlying soft tissues and/or bone (Figure 22). Bone exposure that occurred during the first four hours of the Active Removal test is presented in Table 10 (see *Appendix D* for fire site scores/data). All burned material remained located within the fire pit interior area during the T2 fire event.

(Figure 21) T2 remains showing muscle contraction at the shoulders and thighs with adduction of limbs at the joints.

(Figure 22) Flexion of all four limbs observed with associated skin-splitting and exposure of underlying soft tissues and bone of the left hindlimb.

Table 10: Skeletal Observations Recorded During T2/Active Removal Test.

T2: Active Removal	Observations During Burning
Crania	Superior and posterior occipital exposed, charred, and calcined along superior arch.
Mandible	No bone exposure.
Dentition	Maxillary and mandibular anterior teeth blackened.
Scapulae	Left and right scapulae exposed and charred along medial blade.
Vertebrae	Caudal vertebrae exposed and completely calcined or ash.
Ribs	Left and right ribs exposed and charred along lateral-posterior shaft.
Os Coxa	No bone exposure.
Long Bones	Left distal tibia and proximal-lateral metatarsals exposed.

Prior to treatment, at the four-hour point during the fire event, remains from T2 (Figure 23) presented muscle contraction of all four limbs. However, the left hindlimb was extended and stretched downwards with no exposure of underlying tissues at the joints. Heat-related changes to soft tissue were greatest along the posterior body with calcined soft tissues and bone exposure, coloration, charring, and calcination. The neck remained arched with superior exposure of the ventral surface and the ventral plane slightly angled. The overall thermal modification to remains is consistent with the observations recorded during fire event. All material from burned remains was located within the interior of the fire pit area.

(Figure 23) Remains from Active Removal test prior to treatment at four hours on metal grate.

During treatment, at four hours after ignition of the fire, remains of T2 with the metal grate were abruptly moved from on top of the fire and relocated to a secondary position approximately 20 feet from the fire pit. In route to the secondary location, charred and calcined pieces of the burned soft tissue and bone were seen fragmenting, became detached, and dropped to the ground. The remains continued to radiate heat after being relocated to the secondary fire scene position (no active method was employed to lower the degree or intensity of heat present in the burned remains of T2).

After treatment (i.e., active removal from the fire pit/primary fire scene location), subsequent to the four-hour mark, fragments of charred and calcined soft tissue and bone were found detached from the body and dispersed under the metal stand at the secondary fire scene location (Figure 24). General appearance of remains at the secondary location presented no significant changes compared to that observed prior to active removal (Figure 25).

(Figure 24) Fragments of burned T2 remains located on the ground at the secondary fire scene location of the body.

(Figure 25) Left lateral view of T2 remains after active removal from the fire pit.

Upon closer inspection during analysis of skeletal material at the fire site, differences in fracture characteristics were observed. A portion of bone fractures presented no color differentiation at the fracture margins (i.e., fracture margins showing heat-related color change both exterior and interior (Figure 26). A portion of fractures also presented contrasting coloration between the external cortical bone and the internal fracture margin (Figure 27).

(Figure 26) Similar coloration of the fracture margin and adjacent cortical surfaces.

(Figure 27) Color difference observed between the charred cortical and trabecular bone and that of the unburned fracture margin.

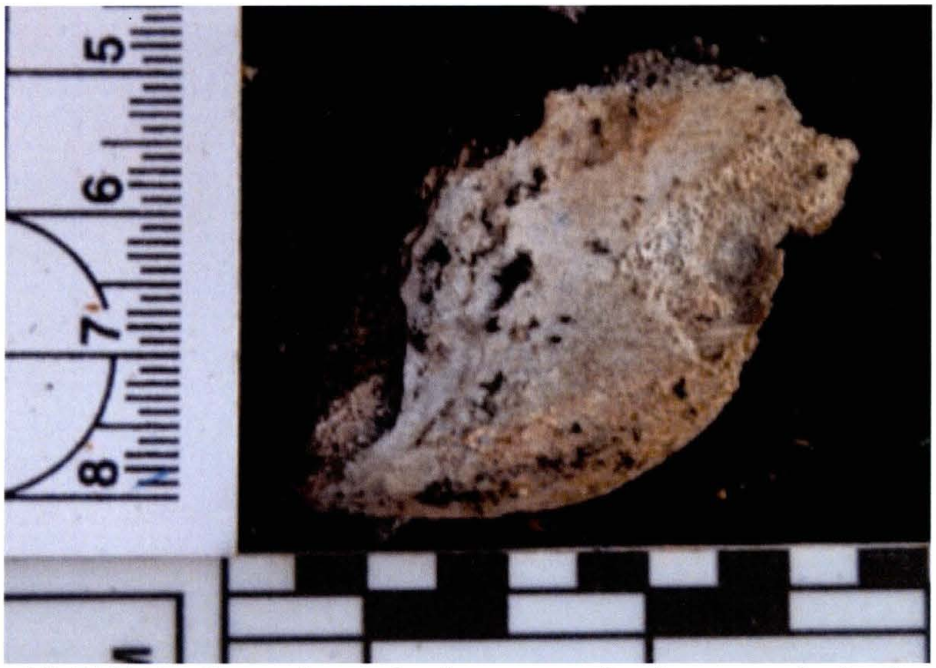
Additionally, during analysis of T2 burned skeletal material at the fire site, several recovered skeletal fragments presented a unique blue discoloration the day after the burn event (Figures 28, 29).

(Figure 28) Blue discoloration of T2/Active Removal scapulae fragments at fire site.

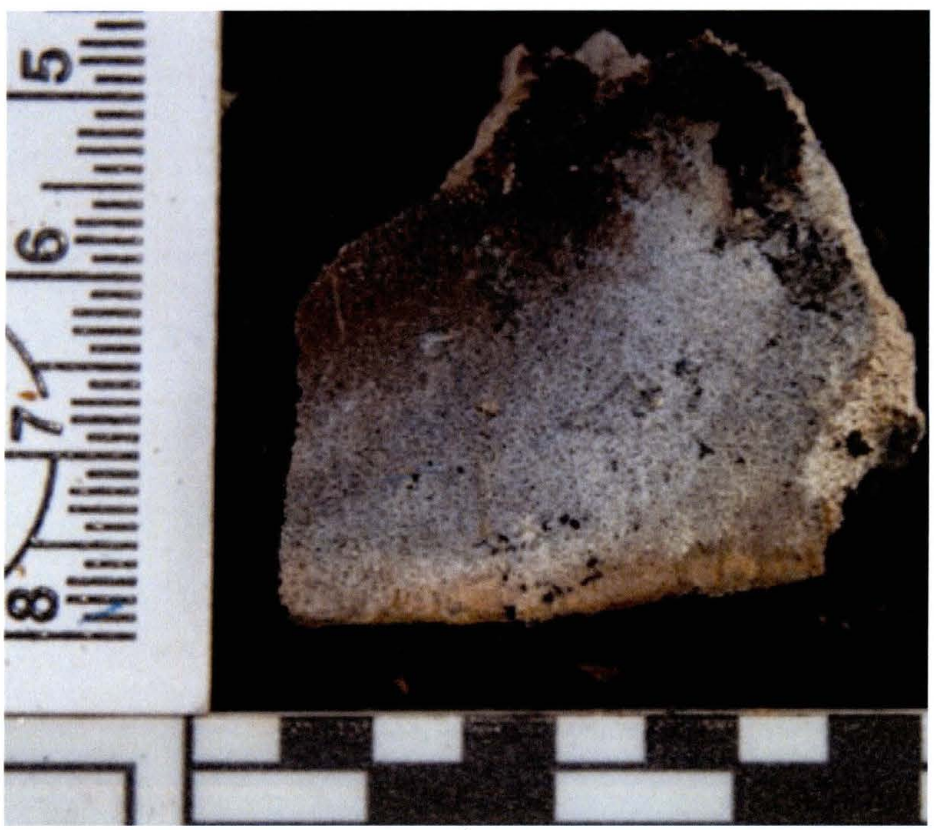
(Figure 29) Blue discoloration of T2/Active Removal scapulae fragments at fire site.

During laboratory analysis, a line of slight blue discoloration was observed on the occipital bone along the border between the superior calcined portion and the interior charred portion (Figure 30). However, the blue discoloration of scapular fragments observed at the fire site was no longer present during laboratory analysis (Figures 31, 32, 33). Fractures presented blackened and charred cortical and trabecular bone (i.e., similar heat-related coloration at fracture margins) and jagged fracture edges. Color difference also observed between heat-related color change of cortical bone and unburned trabecular bone at the fracture margins (Figure 34). Skeletal elements of T2 remains also showed a decrease in skeletal tissue (Figure 35). Also, on T2 remains during laboratory analysis (i.e., after transportation), small superficial striations observed on cortical bone of left and right lateral mandibular body running superior-inferior and slightly curved anterior-posterior (Figure 36). Modification observed, scored, and recorded during laboratory analysis of T1 skeletal remains is presented in Table 11 (see *Appendix E* for laboratory scores/data).

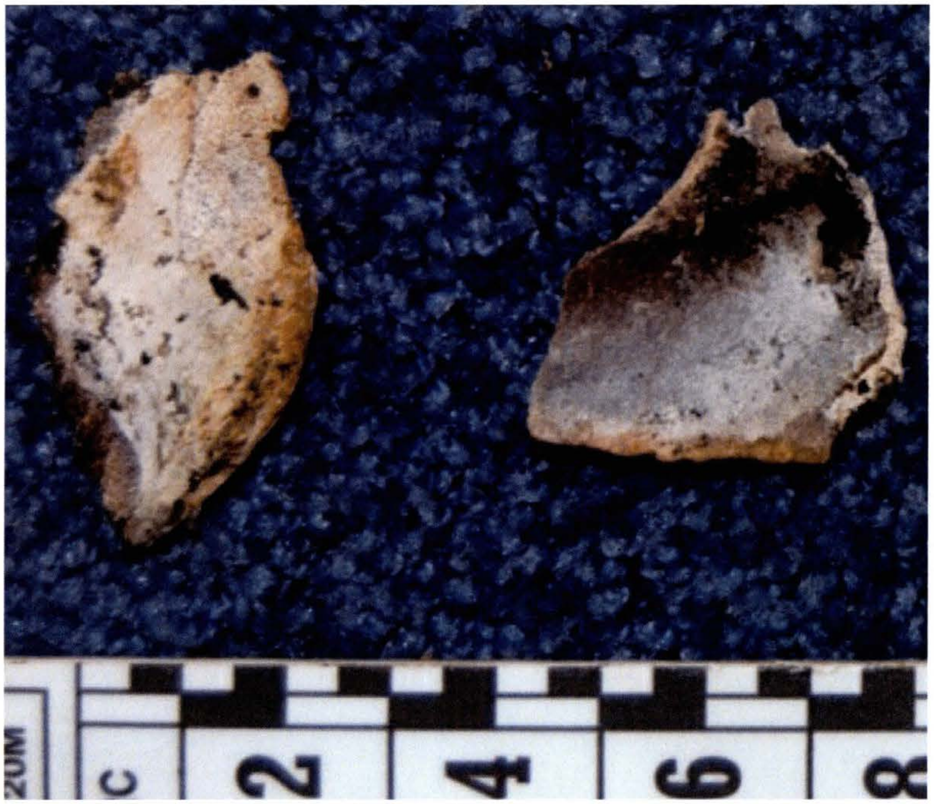
(Figure 30) Blue line of discoloration present on occipital of T2, located at the calcine border between the white and blackened bone.



(Figure 31) T2/Active Removal scapulae fragment at fire site one week after burn event showing lack of previously observed blue discoloration.



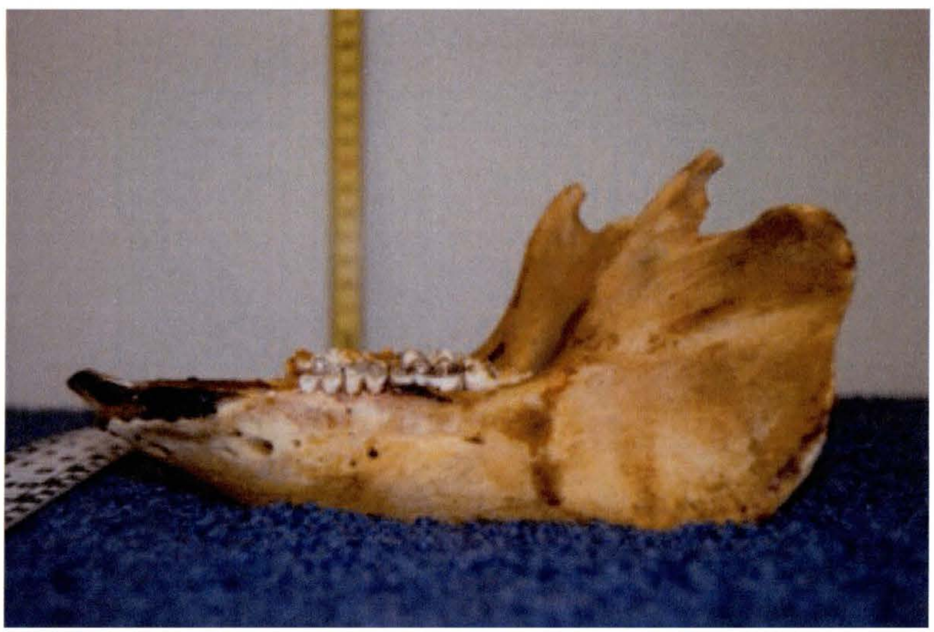
(Figure 32) T2/Active Removal scapulae fragment at fire site one week after burn event showing lack of previously observed blue discoloration.



(Figure 33) T2/Active Removal scapulae fragments at laboratory showing lack of previously observed blue discoloration.

(Figure 34) T2 remains showing sharp and jagged fracture edge with color difference between heat-altered cortical bone and unburned trabecular bone.

(Figure 35) Decrease of skeletal tissue on T2 remains.



(Figure 36) Curved superficial striations present on lateral mandibular body.

Table 11: Skeletal Observations Recorded During Post-Transport Analysis of Active Removal/T2 Remains at Laboratory.

T2: Active Removal	**Observations at Laboratory**
Crania	No thermal modification observed on palate, maxilla, nasal, and premaxilla bones of the crania. Thermal coloration on sagittal and zygomatic bones. Frontal and occipital blackened, charred, and thermally fractured/fragmented (0-25%). Parietals blackened, charred, and thermally fractured/fragmented (51-75%). Occipital blackened, charred, and thermally fractured/fragmented (76-100%) and blackened area of superior crest and extends 62 mm from midline.
Mandible	No visible signs of thermal coloration on mandible. Possible curved tissue regression fractures present on left and right anterior portions of the lateral mandibular body. *Dermestes damage on left and right mandibular condyles.
Dentition	The anterior dentition (i.e., left and right maxillary incisors #1, #2, #3, and canine; left and right mandibular incisors #1, #2, #3, and canine) blackened and fractured (0-25%) due to direct heat exposure during fire event. No thermal coloration on first premolars.
Scapulae	Left and right scapulae charred with fragmentation along dorsal border/medial border (51-75%).
Vertebrae	Cervical 1 and 2 blackened. No thermal coloration on Cervical 3-6. Cervical 7 through thoracic 6 blackened, charred, and superior spinous process fracture/fragmentation. Thoracic 7 and 8 blackened and charred with majority of spinous process fractured and fragmented. Thoracic 9-14 blackened, charred, and superior spinous process fracture/fragmentation. Thoracic 15 through lumbar 3 blackened and charred with majority of spinous process fractured and fragmented. Lumbar 4-7 blackened and charred with spinous process absent. First sacral (S1) blackened (i.e., thermal coloration only). Second sacral (S2) blackened, charred, and superior spinous process fracture/fragmentation. Third sacral (S3) blackened and charred with majority of spinous process fractured and fragmented. Fourth sacral (S4) and all caudal vertebrae absent due to thermal modification.

Table 11-Continued: Skeletal Observations Recorded During Post-Transport Analysis of Active Removal/T2 Remains at Laboratory.	
Ribs	No thermal coloration on first three ribs of the left and right side. Right ribs 4-6 blackened (i.e., thermal coloration only). Left rib 4 and right ribs 7-8 blackened, charred and fragmented (0-25%). Left ribs 5-6 and right ribs 9-11 blackened, charred and fragmented (26-50%). Left ribs 7-10 and right ribs 12-13 blackened, charred and fragmented (51-75%). Left ribs 11-15 and right ribs 14-15 blackened, charred and fragmented (76-100%).
Os Coxa	Left and right ilium blackened and charred (0-25% fracture/ fragmentation). Left and right ischium and pubis blackened and charred.
Long Bones	No thermal coloration on left radius and right radius, ulna, and phalanges of the forelimb. Left and right humerus, carpals, and metacarpals blackened. Left and right femur, patella, tibia, fibula, tarsals, metatarsals, and phalanges blackened. Left ulna and phalanges of the forelimb blackened, charred, and thermal fracturing (0-25%).

Pressurized (T3)

Remains from T3/Pressurized test started showing heat-related changes during the fire event with leakage of fluid from the snout, discoloration and blistering of the skin, the ears becoming singed, and protrusion of the tongue. Once the soft tissue began to char, calcify, and flake along the posterior body, muscle contraction occurred at the shoulders and thighs, which was observed by adduction of the limbs and flexion of the left and right forelimbs at the wrists and the ankle joint of the right hindlimb (Figure 37). Arching of the neck also occurred due to muscle contraction. Flexion at the joints of the right hind limb, in addition to heat, created skin splits in these areas, which exposed underlying soft tissues and bone (Figure 38). Bone exposure that occurred during the first four hours of the Pressurized test is presented in Table 12 (see *Appendix D* for fire site scores/data). All burned material remained located within the fire pit interior area during the T3 fire event.

(Figure 37) Flexion of T3 remains during fire event.

(Figure 38) Exposure of underlying soft tissue and bone of T3 right hindlimb.

Table 12: Skeletal Observations Recorded During T3/Pressurized Test.

T3: Pressurized	Observations During Burning
Crania	Occipital exposed and charred along superior arch.
Mandible	No bone exposure.
Dentition	Maxillary and mandibular anterior teeth blackened.
Scapulae	Left and right scapulae exposed and charred along medial blade.
Vertebrae	Caudal vertebrae exposed and completely calcined or ash.
Ribs	Left and right ribs exposed and charred along lateral-posterior shaft.
Os Coxa	Right and left iliac blade exposed with blackened and charred soft tissue still present along lateral iliac crest, both anterior and posterior.
Long Bones	Right tibia and fibula exposed, blackened on distal, anterior, and lateral portions; Right metatarsals charred laterally; Right patella exposed on anterior side with lateral portion blackened and still greasy; Right proximal phalanges of hind limb exposed and blackened.

Prior to treatment, at the four-hour point during the fire event, remains from T3 (Figure 39) presented muscle contraction of all four limbs. Heat-related changes to soft tissue were greatest along the posterior body with calcined soft tissues and bone exposure, coloration, charring, and calcination. The neck remained arched with superior exposure of the ventral surface and the ventral plane slightly angled. Overall thermal modification to remains is consistent with the observations recorded during fire event. All material from burned remains was located within the interior of the fire pit area.

(Figure 39) Remains from Pressurized test prior to treatment at four hours on metal grate.

During treatment, at four hours after ignition of the fire, remains from T3 underwent direct application of pressurized water with foam admixture. Initial application started to the left of the remains and only employed pressurized water (Figure 40). Foam solution was activated and made direct contact with the burned remains while the fire hose was positioned to the left of the remains and directed towards right side of body (Figure 41). Pressurized water was also applied directly on the burning wood located in the interior of the fire pit, which produced steam (Figure 42). During treatment, fragile charred and calcined soft tissues and bone were displaced, removed from body, and/or scattered (Figure 43), as well as, unburned soft tissues (e.g., the muscles of the left shoulder) (Figure 44).

(Figure 40) Pressurized water directly applied to left side of T3 remains.

(Figure 41) Activation of foam solution during treatment of T3 remains.

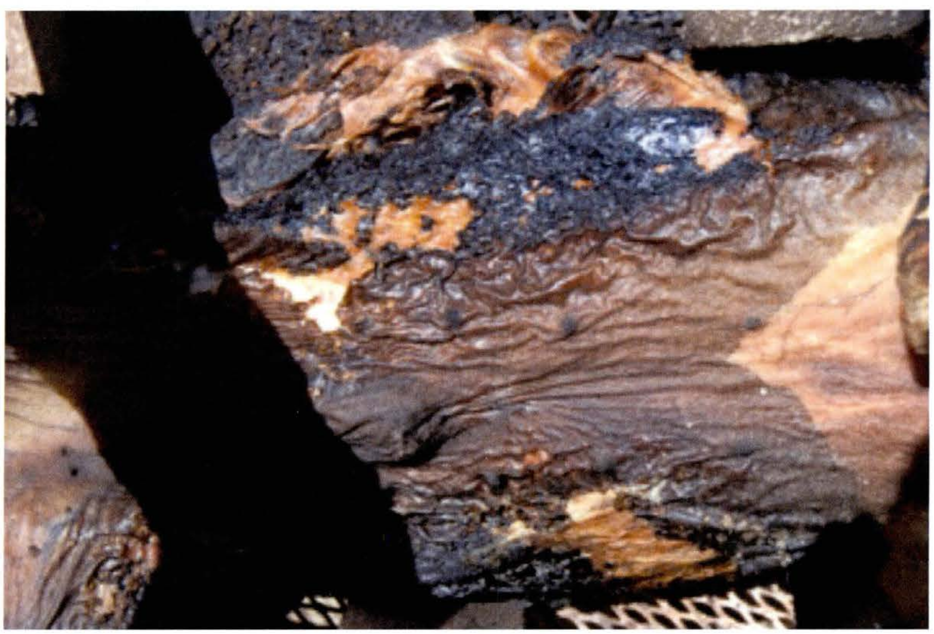
(Figure 42) Steam shown in fire pit due to direct application of pressurized water on burning wood.

(Figure 43) Underlying and/or unburned soft tissues and bone exposed with fragile, charred and calcined remains displaced, removed from body, and/or scattered during treatment with pressurized water.

(Figure 44) Left shoulder muscles of T3 remains showing displacement of unburned tissues during treatment of pressurized water.

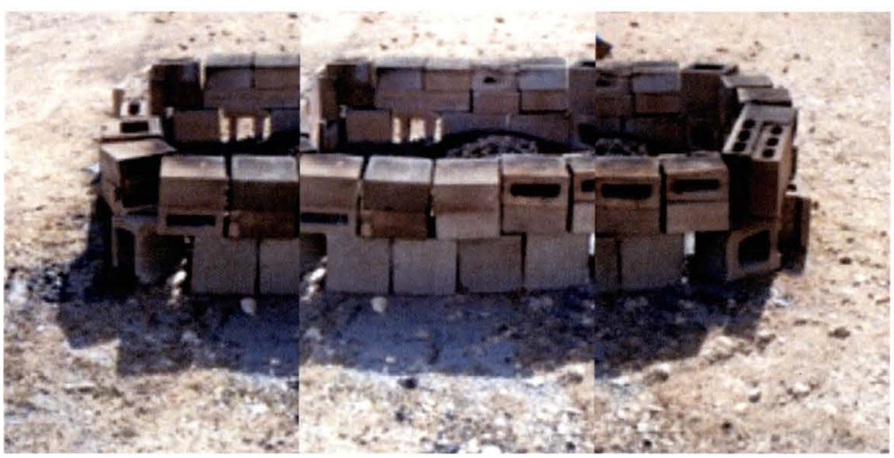
After treatment of the pressurized water and foam solution, but subsequent to the four-hour mark, remains from T3 were wet (Figure 45) and appeared leathery (Figure 46) with visible displacement of unburned soft tissues (Figure 47). After treatment had finished, water and foam solution were pooled around the fire pit parameter corresponding with the right side of T3 remains (Figure 48). Fragments of burned T3 remains and burned wood from the fire were located within and around the parameter of the fire pit after treatment had concluded. Even though fragile remains were displaced during treatment, shortly after treatment had stopped, fragments of charred and calcined material were detached from the body and gathered around on top of the metal grate (Figure 49). In other words, charred remains attached to the body increased in fragility, became further fragmented, separated from the body, and collected on the metal grate (Figure 50).

(Figure 45) After treatment, the charred and unburned T3 remains were wet.



(Figure 46) T3 remains after treatment appeared leathery. Viewing the soft tissues on the ventral torso, unburned skin is wrinkled with unburned underlying tissues exposed through openings of displaced charred soft tissues.

(Figure 47) View of left shoulder after treatment with pressurized water, which shows displaced soft tissues.

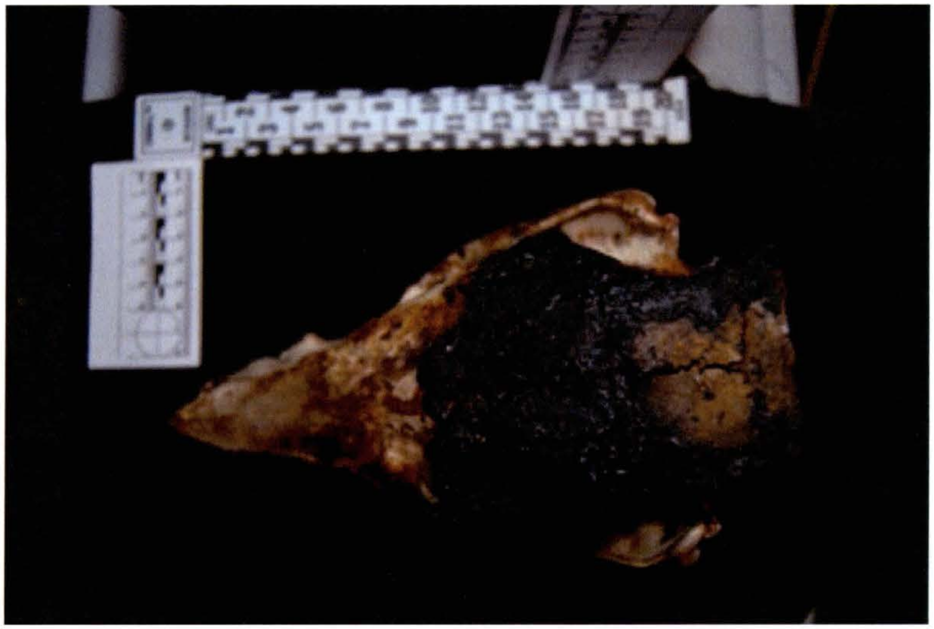


(Figure 48) Pooled water and foam solution located around exterior parameter of fire pit (wall to the right side of T3 remains) with fragments of charred and calcined materials (i.e., fragments of T3 remains and fire wood).

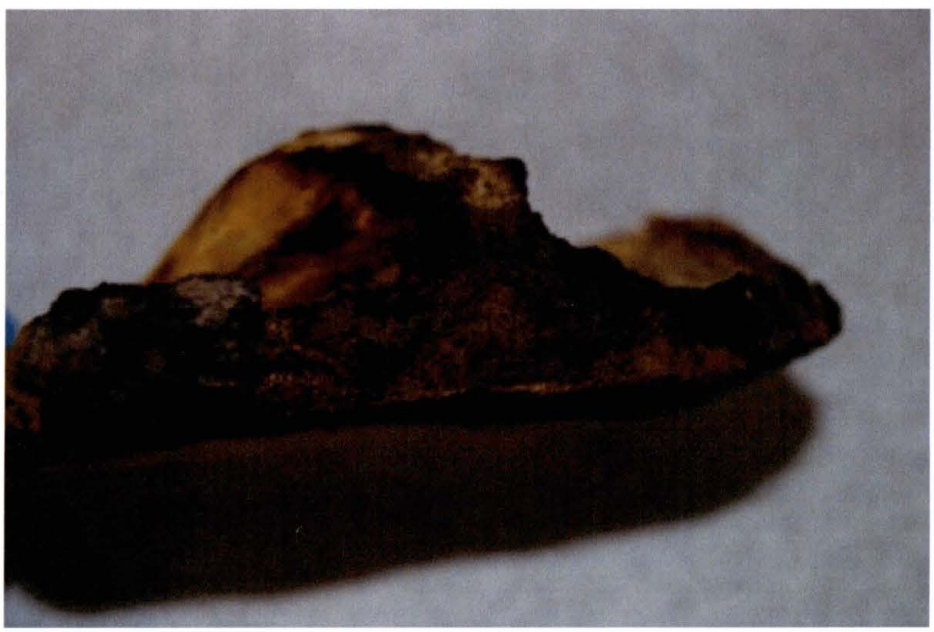
(Figure 49) Pieces of charred and calcined soft tissues detached from body of T3 after treatment with pressurized water and foam solution.

(Figure 50) Fragile, charred remains of T3 separated from body and collected on metal grate after treatment with pressurized water and foam solution.

During analysis of T3 skeletal material at the fire site, white, calcine bone prior to treatment, was observed to have brown coloration after treatment on areas such as the superior/medial portion of parietal bones and medial portion of superior arch on occipital cranial bone (Figure 51). Fracture edges/margins also appeared rounded in some cases such as on the right scapula along superior angle (Figure 52). Additionally, during analysis of T3 burned skeletal material at the fire site, several recovered skeletal elements presented a unique green discoloration the day after the burn event (see *Appendix F* for photos of green discoloration observed on T3 remains at the fire site).



(Figure 51) Brown coloration present on superior/medial portion of parietal bones, as well as, superior/posterior/medial portion of superior occipital arch.



(Figure 52) Rounded fracture edges/fracture margins observed on T3 remains, superior angle of right scapula shown.

T3 remains during laboratory analysis (i.e., after transportation), fractures presented blackened and charred cortical and trabecular bone (i.e., similar heat-related coloration at fracture margins) and jagged fracture edges. Color difference also observed between heat-related color change of cortical bone and unburned trabecular bone at the fracture margins (Figures 53, 54, 55). Small superficial striations observed on cortical bone of left and right lateral mandibular body running superior-inferior and slightly curved anterior-posterior (Figure 56). Modification observed, scored, and recorded during laboratory analysis of T1 skeletal remains is presented in Table 13 (see *Appendix E* for laboratory scores/data).

(Figure 53) Post-fire/transportation fracture with color difference at fracture margin.

(Figure 54) Posterior view of T3 crania showing post-fire/transportation fracture with color difference at fracture margin.

(Figure 55) T3 rib showing post-fire/transportation fracture with color difference at fracture margin.

(Figure 56) Curved superficial striations present on lateral mandibular body.

Table 13: Skeletal Observations Recorded During Post-Transport Analysis of Pressurized/T3 Remains at Laboratory.

T3: Pressurized	Observations at Laboratory
Crania	No thermal modification observed on palate, maxilla, nasal, premaxilla, and occipital bones of crania. Frontal, sagittal, and zygomatic bones of crania blackened with both right and left frontal bones charred and fractured/fragmented (0-25%). Parietal and occipital bones blackened, charred and fractured/fragmented along superior crest of occipital(26-50%).
Mandible	No visible signs of thermal coloration on mandible. Possible curved tissue regression fractures present on left and right anterior portions of the lateral mandibular body.
Dentition	Maxillary left first incisor and first premolar blackened due to direct heat exposure during fire event. Maxillary right first and second incisors blackened due to direct heat exposure during fire event. Maxillary right third incisor and canine blackened and fractured (0-25%) due to direct heat exposure during fire event. Left and right mandibular incisors (1, 2, and 3), canines, and first premolars blackened and fractured (0-25%) due to direct heat exposure during fire event.

Table 13-Continued: Skeletal Observations Recorded During Post-Transport Analysis of Pressurized/T3 Remains at Laboratory.	
Scapulae	Right scapula charred and fractured/fragmented (0-25%) along dorsal border/medial border and calcined along blade exterior caudally. Left scapula blackened and charred with fracture/ fragmentation along exterior of blade (0-25%).
Vertebrae	No thermal coloration on Cervical 1-6. Cervical 7 through thoracic 9 blackened, charred, and superior spinous process fracture/ fragmentation Thoracic 10 through lumbar 6 blackened and charred with majority of spinous process fractured and fragmented. Seventh lumbar (L7) absent, not result of fire. First sacral (S1) blackened (i.e., thermal modification only). Second sacral (S2) blackened, charred, and superior spinous process fracture/fragmentation. Third sacral (S3) blackened and charred with majority of spinous process fractured and fragmented. Fourth sacral (S4) and all caudal vertebrae blackened, charred, and fragmented (spinous processes absent due to thermal modification and >50% of vertebral bodies fractured/fragmented).
Ribs	No thermal coloration on left ribs 1-5. Left ribs 6-15 blackened . No thermal coloration on right ribs 1-4. Right rib 5 blackened, charred and fragmented (26-50%). Right ribs 6-15 blackened.
Os Coxa	Right ilium, ischium, and pubis blackened and charred. Left ischium and pubis blackened and charred. Left ilium blackened and charred (26-50% fracture/fragmentation).
Long Bones	Right humerus, ulna, radius, carpals, and phalanges blackened. Right metacarpals blackened, charred, and thermal fracturing (0-25%). Left humerus, ulna, radius, carpals, metacarpals, and phalanges blackened. Right patella, tarsals, metatarsals, and phalanges blackened. Right femur, tibia, and fibula blackened, charred, and thermal fracturing (0-25%). Left femur, patella, tibia, fibula, tarsals, metatarsals, and phalanges blackened.

Dry-Chemical (T4)

Remains from T4/Dry-Chemical test started showing heat-related changes during the fire event with discoloration and blistering of the skin, ears becoming singed, and leakage of fluid from snout. Once the soft tissue began to char, calcify, and flake along the posterior body, muscle contraction occurred at the shoulders and thighs, which was observed by adduction of the limbs (Figure 57). Arching of the neck also occurred due to muscle contraction. In association with the muscle contraction of the limbs, flexion occurred at the joints of both the left and right forelimbs at the wrists and the right hind limb at the knee and ankle (Figure 58). Flexion at the joints, in addition to heat, created skin splits in these areas, which exposed underlying soft tissues and bone. Bone exposure that occurred during the first four hours of the Dry-Chemical test is presented in Table 14 (see *Appendix D* for fire site scores/data). All burned material remained located within the fire pit interior area during the T1 fire event.

(Figure 57) Muscle contraction observed at the shoulders and thighs of T4 remains, showing flexion of both forelimbs.

(Figure 58) Limb flexion as shown on T4 remains.

Table 14: Skeletal Observations Recorded During Dry-Chemical Test.

T4: Dry-Chemical	Observations During Burning
Crania	Occipital exposed and charred along superior arch.
Mandible	No bone exposure.
Dentition	Maxillary and mandibular anterior teeth blackened.
Scapulae	Left and right scapulae exposed and charred along medial blade.
Vertebrae	No bone exposure (due to body positioning); Caudal vertebrae present with charred soft tissues.
Ribs	Left and right ribs exposed and charred along lateral-posterior shaft.
Os Coxa	Right iliac blade exposed and blackened along lateral iliac crest, both anterior and posterior.
Long Bones	Distal tibia and fibula exposed.

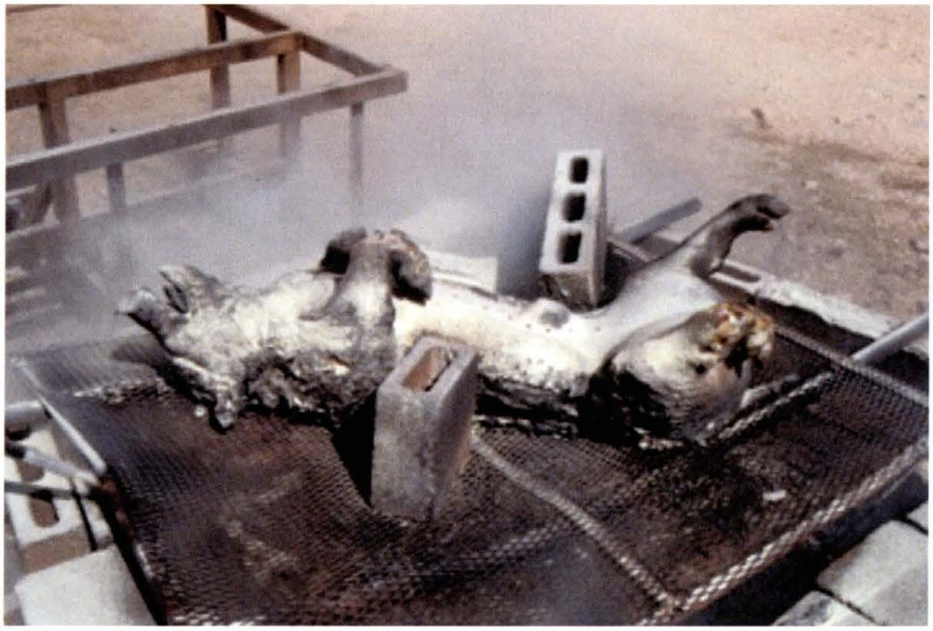
Prior to treatment, at the four-hour point during the fire event, remains from T4 (Figure 59) presented muscle contraction of all four limbs. However, the left hindlimb was extended and lacked skin splitting or exposure of underlying tissues at the joints. Heat-related changes to soft tissue were greatest along the posterior body with calcined soft tissues and bone exposure, coloration, charring, and calcination. The neck remained arched with superior exposure of the ventral surface and the ventral plane slightly angled. The overall thermal modification to remains is consistent with the observations recorded during fire event. All material from burned remains was located within the interior of the fire pit area.

(Figure 59) Remains from Dry-Chemical test prior to treatment at four hours on metal grate. Also, the expected soft tissue color progression is present: unburned (tan), to pink, red, brown, black, gray and white (calcined).

During treatment, at four hours after ignition of the fire, remains from T4 were suppressed using a hand-held compressed air and dry chemical fire extinguisher positioned to the right of the remains (Figure 60). Direct observation of T4 remains was not permitted during treatment due to the nature of this suppression method because the dry chemical created an opaque cloud around the remains during treatment.

(Figure 60) T4 remains during treatment with a hand-held compressed air and dry chemical fire extinguisher.

After treatment, subsequent to the four-hour mark, the exterior of T4 burned remains were covered in white chemical powder (Figure 61), which caused black charred tissues to appear calcined due to the white color of the dry chemical coating (Figure 62). White powder also settled within skin splits and exposed joints. Fragmentation of remains after treatment appeared to increase further with no additional external force or human manipulation applied (Figure 63). Fragments of burned skeletal materials in differing stages of heat-related color change/degradation remained on metal grate after removal of the body (Figure 64). In other words, T4 remains were greatly fractured and fragmented post-fire (Figure 65). All material from burned remains remained located within the interior of the fire pit area.



(Figure 61) T4 remains coated with white/yellow dry chemical after treatment.

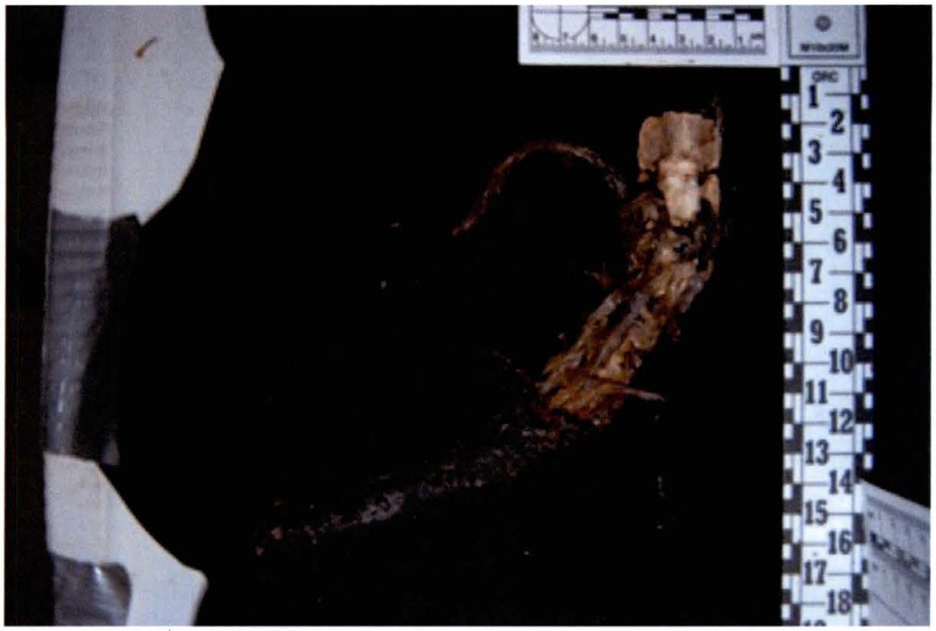
(Figure 62) Example of charred tissues (black) coated with white/yellow dry chemical shown by the left side of T4 remains.

(Figure 63) Increased fragmentation of T4 remains after treatment.

(Figure 64) Burned fragments of T4 bone located on the metal grate after the body was removed showing various/differing stages of heat-related coloration and degradation.

(Figure 65) T4 remains appeared to have the greatest amount of secondary/situational/ post-fire fragmentation at the fire site. (Top: Large amount of burned and fragmented T4 remains left on the metal grate after removal of the body. Bottom: T4 scapula shows fracture and fragmentation characteristics consistent with the causes of heat-related degradation and movement.

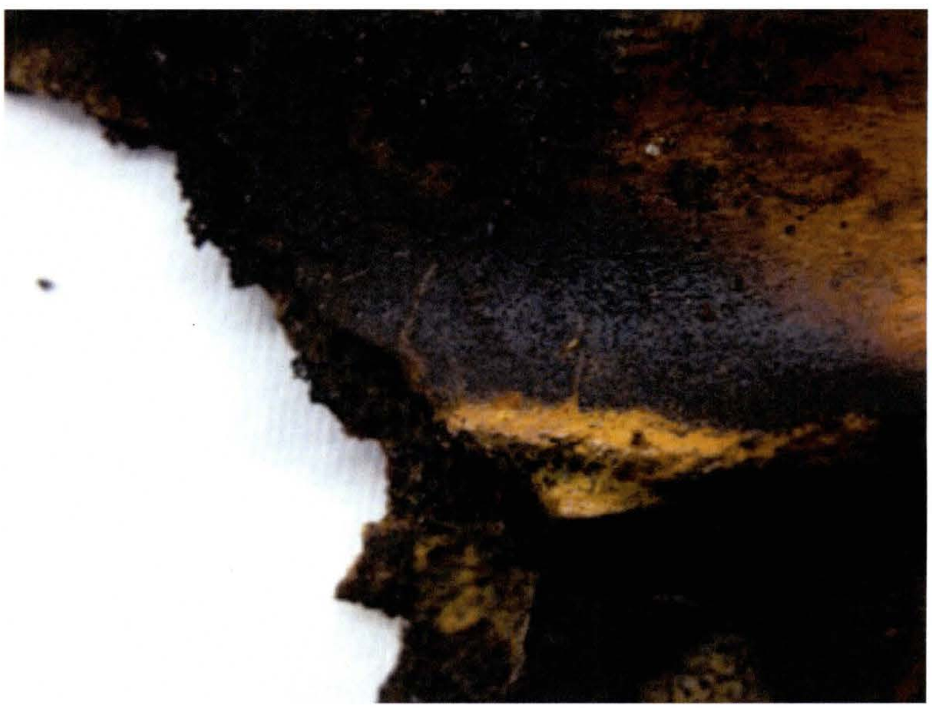
At the fire site, the tail of T4 (i.e., all caudal vertebra and associated soft tissues) appeared intact with slight blackening of external soft tissue (Figure 66). Fractures presented blackened and charred cortical and trabecular bone (i.e., similar heat-related coloration at fracture margins) and jagged fracture edges. Color difference also observed between heat-related color change of cortical bone and unburned trabecular bone at the fracture margins.



(Figure 66) Tail of T4 intact post-fire.

Mold present on remains of T4 at laboratory, which was yellow, green, white, and black in color (Figure 67). Charred periosteum appeared dried-out with cracks exposing unburned underlying bone (Figure 68). T4 remains during laboratory analysis (i.e., after transportation) showed external cortical bone charred with unburned internal trabecular bone with jagged fracture edge (Figures 69, 70, 71, 72).

(Figure 67) Yellow, green, white, and black mold present on T4 remains during laboratory analysis.



(Figure 68) Example of cracked, charred periosteum shown on scapula.

(Figure 69) Sternal end of T4 rib with jagged fracture edge.

(Figure 70) Internal surface of rib from Dry-Chemical remains showing the jagged fracture edge observed during laboratory analysis.

(Figure 71) Internal surface of rib from Dry-Chemical remains showing the jagged fracture edge observed during laboratory analysis.

(Figure 72) Close-up of T4 rib showing blackened cortical bone and an unburned fracture edge.

Charred and calcined bone had noticeable decrease of skeletal tissues, mostly observed on cortical bone (Figure 73). This decrease of skeletal tissues was associated with small channels running through bone and additional fragmentation (Figures 74, 75). Small superficial striations observed on cortical bone of left and right lateral mandibular body running superior-inferior and slightly curved anterior-posterior (Figure 76). Modification observed, scored, and recorded during laboratory analysis of T1 skeletal remains is presented in Table 15 (see *Appendix E* for laboratory scores/data).

(Figure 73) Example of decrease in skeletal tissues observed.

(Figure 74) Additional fragmentation of bone with decrease of skeletal tissue observed on T4 innominate at the location between the inferior pubic ramus and the ischial ramus.

(Figure 75) Close-up of inferior pubic ramus. Posterior view close-up at border of obturator foramen on the inferior pubic ramus.

(Figure 76) Curved superficial striations present on lateral mandibular body.

Table 15: Skeletal Observations Recorded During Post-Transport Analysis of Dry-Chemical/T4 Remains at Laboratory.

T4: Dry-Chemical	Observations at Laboratory
Crania	No thermal modification observed on occipital and palate of the crania. Sagittal, zygomatic, maxilla, nasal, and premaxilla blackened. Frontal and parietal bones blackened, charred, and fractured/ fragmented (0-25%). Occipital blackened, charred, and fractured/ fragmented (26-50%) with left portion of superior crest calcined.
Mandible	Mandibular body blackened. No visible signs of thermal coloration on left or right ramus. Possible curved tissue regression fractures present on left and right anterior portions of the lateral mandibular body.
Dentition	No thermal coloration on left mandibular first premolar and right maxillary second incisor. Left maxillary first incisor, third incisor, first premolar and mandibular canine blackened due to direct heat exposure during fire event. Right maxillary third incisor, first premolar, and mandibular first premolar blackened due to direct heat exposure during fire event. Left maxillary second incisor, mandibular first incisor, and second incisor blackened and fractured (0-25%). Right maxillary first incisor, canine, mandibular first incisor, second incisor, and canine blackened and fractured (0-25%).

Table 15-Continued: Skeletal Observations Recorded During Post-Transport Analysis of Dry-Chemical/T4 Remains at Laboratory.	
Scapulae	Left blackened, charred, and fragmented along dorsal border/medial border (51-75%). Right blackened and charred with fracture/ fragmentation along exterior of blade (0-25%).
Vertebrae	No thermal coloration on Cervical 1-5. Cervical 6 through thoracic 5 blackened, charred, and superior spinous process fracture/ fragmentation. Thoracic 6-12 blackened and charred with majority of spinous process fractured and fragmented. Thoracic 13-15 blackened, charred, and fragmented (spinous processes absent due to thermal modification). Lumbar 1-6 blackened and charred with majority of spinous process fractured and fragmented. Seventh lumbar (L7) absent, not result of fire. Sacral 1-4 and caudal vertebrae (12 present) blackened.
Ribs	No thermal coloration on left ribs 1-3 and right ribs 1-4. Left ribs 4-6 and right ribs 5-13 blackened (i.e., thermal coloration only). Right ribs 14-15 blackened, charred and fragmented (0-25%). Left ribs 7-9 blackened, charred and fragmented (26-50%). Left ribs 10-13 blackened, charred and fragmented (51-75%). Left ribs 14-15 blackened, charred and fragmented (76-100%).
Os Coxa	Left and right ilium, ischium, and pubis blackened and charred.
Long Bones	Left radius and carpals blackened. Left humerus, ulna, metacarpals, and phalanges blackened, charred, and thermal fracturing (0-25%). No visible signs of thermal coloration on right carpals, metacarpals, and phalanges. Right humerus, ulna, and radius blackened (i.e., thermal coloration only). No visible signs of thermal coloration on left and right femur, patella, tibia, fibula, tarsals, metatarsals, and phalanges.

Laboratory Comparison

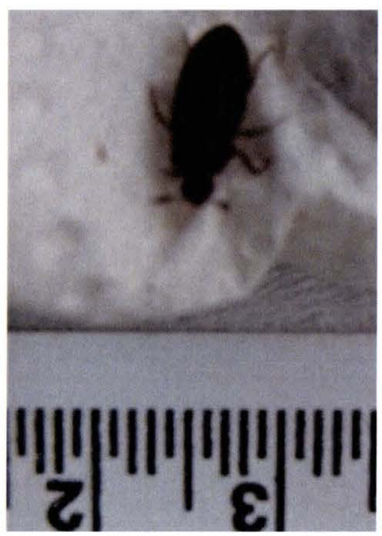
During laboratory analysis, each set of remains began to show a decrease in tissue around the articular surfaces with a "chewed-on" appearance, as well as, the development of channels running through bone on nearly all skeletal elements (e.g., the lateral mandible shown in Figure 77), while more extreme occurances observed were located along the superior arch of the occipital bone on all crania (Figure 78). Most of this modification however was limited to the cortical bone of skeletal elements (e.g., the proximal end of long bone shown in Figure 79). These channels were accompanied by small tan elongated particles/material, small tan smooth living larvae (similar in appearance to blow-fly larve), and living larve that was brown in color with hairy exoskeletons (Figure 80). Late in my laboratory analysis small black beetles (Figure 81) appeared in areas occupied by the living larvae.

(Figure 77) Observed channel developed on lateral mandible. [Left photo: Left lateral mandible of T4/Dry-Chemical remains. Right photo: Close-up of damage to left lateral mandible]

(Figure 78) Example of observed channels developed on superior arch of occipital bone of crania, photo shown of T2/Active Removal remains.

(Figure 79) Example of reduced cortical bone observed, shown on long bone of T4/ Dry-Chemical remains.

(Figure 80) Example of bug found within the transportation boxes and on each set of remains during laboratory analysis.



(Figure 81) Example of small black beetles observed on remains during laboratory analysis.

Due to this association, the observed modification and related living larvae were compared to known examples of entomological/insect modification on human bone in the literature, which failed to produce an answer as to what type of damage had occurred.

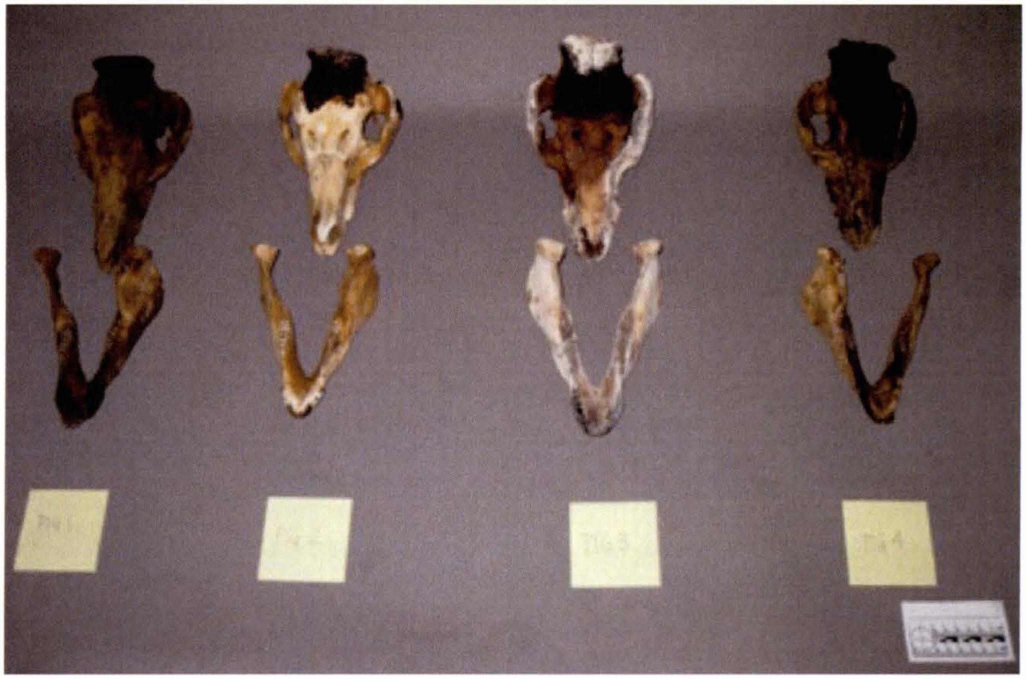
However, the trace characteristics observed during this research appeared to be visually consistent with trace characteristics discovered on fossil bone/dinosaur skeleton presented by Britt et al. (2008), which were produced by dermestid beetles. In order to verify that the observed skeletal tissue loss exhibited characteristics of *Dermestes* damage, Dr. B. Britt analyzed photographic evidence of the bone loss observed during this research. Britt concluded that classic *Dermestes* damage was exhibited on the bones, which were attacked due to their greasy condition at preferred foraging sites on articular surfaces of thin edges. In addition to the comparison of trace characteristics on bone, Dr. Britt identified classic examples of dermestid frass (i.e., the tan, elongated frass) and the presence of dermestes larval casts (i.e., the brown, hairy exoskeletons) from several instar classes, "and (the presence of) what appear to be live larvae pretty much seals the case that you have dermestid damaged bones" (B. Britt, personal communication, 2009). A detailed description of trace characteristics for Dermestid Beetles on bone is given in Table 16 (Britt et al. 2008).

Table 16: Description of trace characters for dermestid beetles on bone.

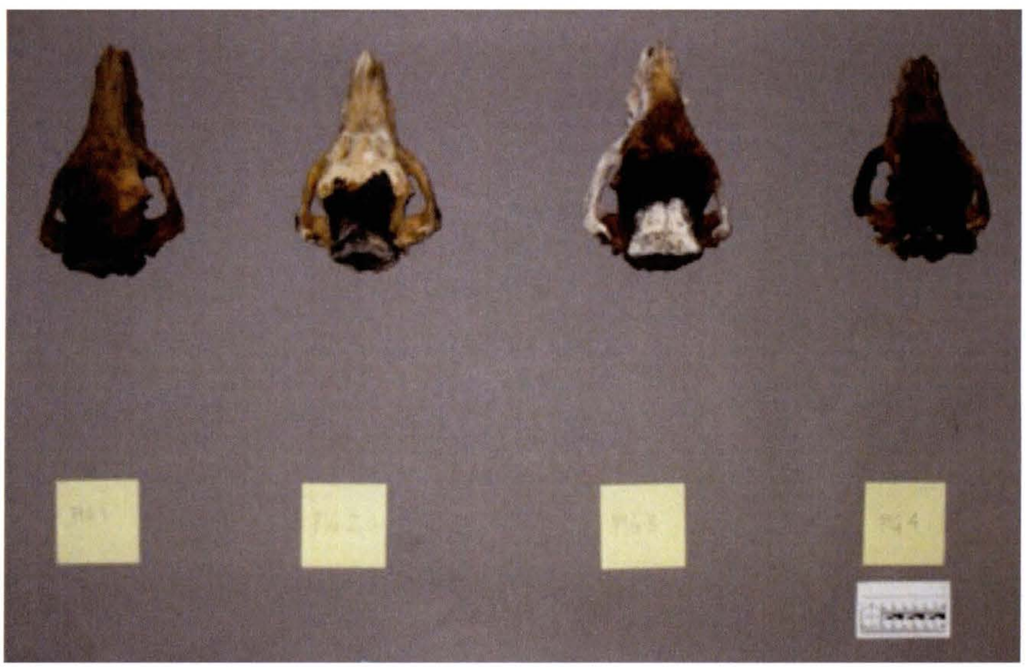
Character	Dermestid Beetle
Bone affected	Articular, trabecular
Pit/bore diameter (mm)	1.5 5 pit/bore 3.5-5.2, pupation
Pit/bore outline	Elliptical to round
Pit pattern	None, irregular rows
Surface loss	0 to minor, usually none
Composite pits?	No
Bore	Yes
Furrow	Yes, width of larvae
Pupation chamber	Superficial ovoid or flask-shaped chamber
Mandible (= single or double (parallel) mandible marks)	Symmetrical, 2-3 apical teeth in Dermestes, or medially concave cusp. 2 in D maculates set 170 µm apart

*Table adapted from Britt et al. 2008 (Table 3, p 67).

Additionally, the crania and scapulae for each set of remains were directly comparied to one another in order to standarize the identification and comprehension of laboratory results. The cranial comparison shows the broad range of modification differences observed between the four sets of test remains (Figures 82, 83, 84, 85). T1 shows the most complete crania, followed in descending order by T3, T4, and the least complete T2. While T4 presents the greatest amount of blackened area on the crania, the crania of T2 shows the least amount of preserved bone. The crania and mandible of T2 is also the lightest of the four in overall color and has the greatest decrease of skeletal tissue. Furthermore, the crania and mandible of T3 are both coated by a whtie, mold-like substance.



(Figure 82) Superior-anterior view of cranial (and mandibular) comparison of T1, T2, T3, and T4 in laboratory.



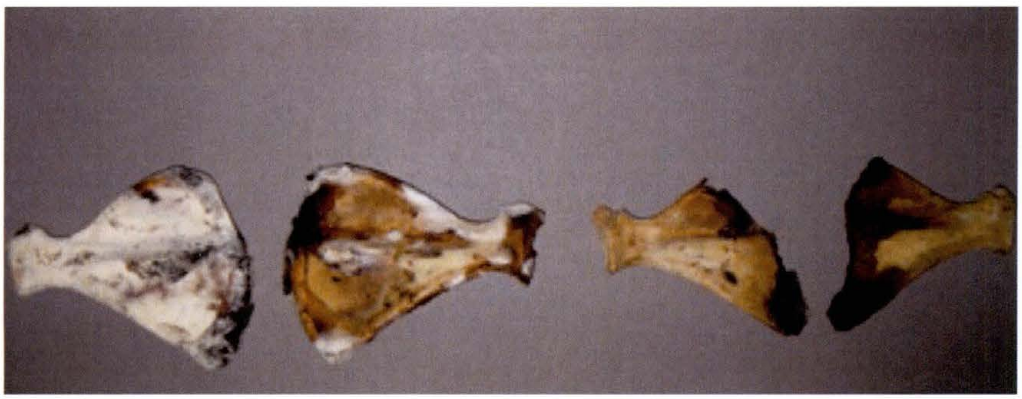
(Figure 83) Superior view of cranial comparison of T1, T2, T3, and T4 in laboratory.

(Figure 84) Posterior view of T1 (left) and T2 (right) crania in laboratory.

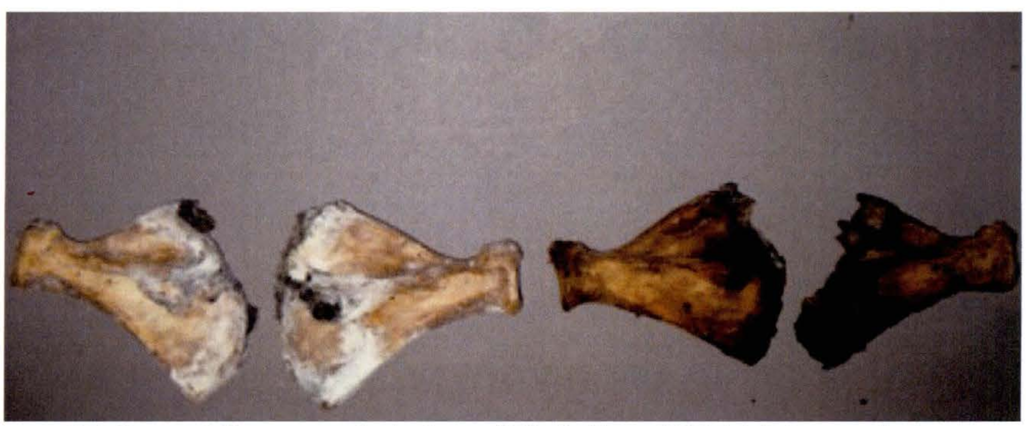
(Figure 85) Posterior view of T3 (left) and T4 (right) crania in laboratory.

The scapulae comparison also shows the broad range of modification differences observed between the four sets of test remains (Figures 86, 87, 88). Scapulae of T1 and T3 present greater preservation and more complete skeletal elements than T2 and/or T4 remains. Scapulae of T4 present the greatest area of blackened bone out of all four sets of remains. However, scapulae of T2, while less blackened, have the least amount of preserved bone. T1 shows the most complete left and right scapulae, followed in descending order by T3, T4, and the least complete T2. Furthermore, scapulae of T1 and T3 are all coated by a whtie, mold-like substance.

(Figure 86) Lateral, posterior view of scapulae comparison between T1, T2, T3, and T4 in laboratory (cranial border directed superiorly in image).



(Figure 87) Lateral, posterior view of T1 (left) and T2 (right) scapulae in laboratory (caudal border directed superiorly in image).



(Figure 88) Lateral (i.e., posterior) view of T3 (left) and T4 (right) scapula in laboratory (caudal border directed superiorly in image).

Statistical Analysis

Descriptive Statistics

Descriptive statistics were first run on the large amount of data collected on thermal modification present on all four test subjects at the fire site. Descriptive statistics based on thermal modification scores recorded at the fire site for all four experimental tests are presented in Table 17.

Table 17: Descriptive Statistics On Recorded Fire Site Data.

Test	N	Score		Fire Site Score					
		Min	Max	Sum	Mean	SD	Variance	Skewness Statistic	Skewness Std. Error
Natural Burn-Out	182	0	7	496	2.73	1.65	2.73	0.74	0.18
Active Removal	182	1	7	539	2.96	1.50	2.24	0.69	0.18
Pressurized	182	0	7	441	2.42	1.24	1.54	0.68	0.18
Dry-Chemical	182	0	6	447	2.46	1.32	1.75	0.41	0.18

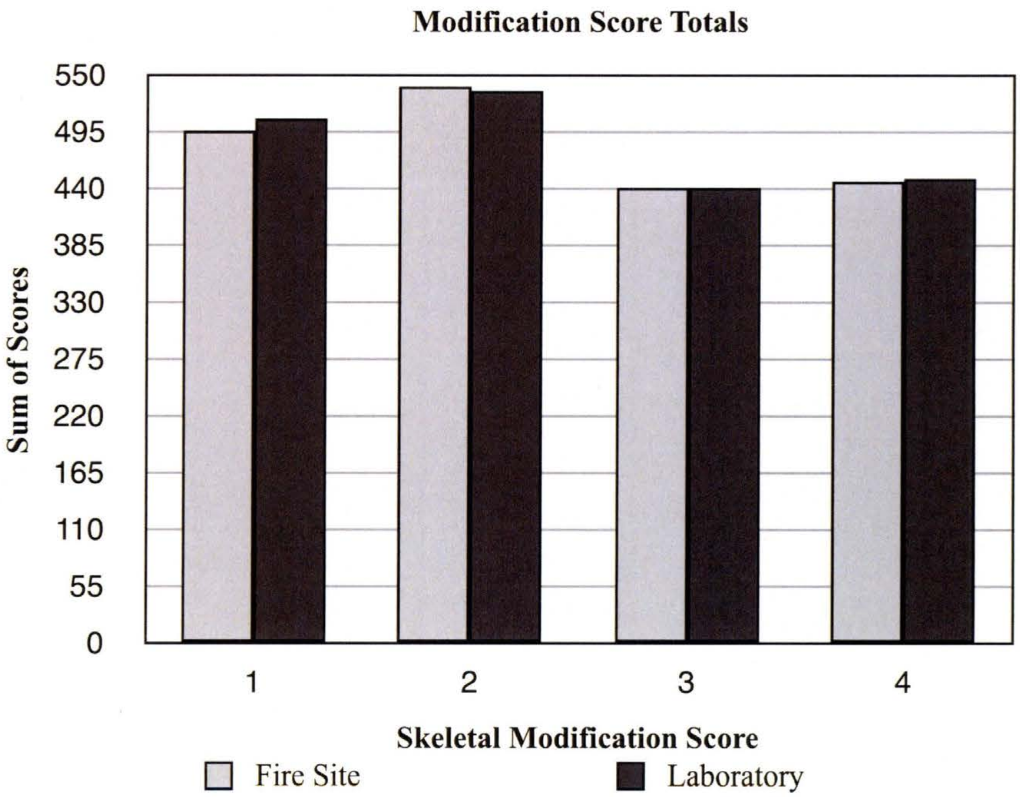
The descriptive statistics on fire site collected data (Table 17) indicate Active Removal remains underwent the greatest skeletal modification of the four tests, as shown by the sum of Active Removal modifcation scores of 539 (M=2.96, SD=1.5). Natural Burn-Out remains with a sum modification score of 496 (M=2.73, SD=1.65) show the next largest recorded modification nscore followed by that of Dry-Chemical remains with a sum of 447 (M=2.46, SD=1.32). Pressurized remains underwent the least skeletal modification of the four tests, as shown by the sum of Pressurized modification scores of 441 (M=2.42, SD=1.24). Comparison of the skeletal modification scores recorded at the fire site between all four tests show a difference in sum score, seperating the indirect and direct suppression treatment groups. The indirect suppression groups of Natural Burn-Out and Active Removal showed greater thermal modification to skeletal material than the direct suppression groups of Pressurized and Dry-Chemical skeletal remains. Descriptive statistics based on thermal modification scores recorded at the laboratory for all four experimental tests are presented in Table 18.

Table 18: Descriptive Statistics On Recorded Laboratory Data.

Test	**N**	**Score**		**Laboratory Score**					
		Min	Max	Sum	Mean	SD	Variance	Skewness Statistic	Skewness Std. Error
Natural Burn-Out	182	0	7	508	2.79	1.75	3.06	0.76	0.18
Active Removal	182	1	7	535	2.94	1.52	2.30	0.66	0.18
Pressurized	182	0	6	441	2.42	1.20	1.45	0.43	0.18
Dry-Chemical	182	0	6	450	2.47	1.32	1.74	0.39	0.18

The descriptive statistics on laboratory collected data (Table 18) indicate Active Removal remains underwent the greatest skeletal modification of the four tests, as shown by the sum of Active Removal modifcation scores of 535 (M=2.94, SD=1.52). Natural Burn-Out remains with a sum modification score of 508 (M=2.79, SD=1.75) show the next largest recorded modification nscore followed by that of Dry-Chemical remains with a sum of 450 (M=2.47, SD=1.32). Pressurized remains underwent the least skeletal modification of the four tests, as shown by the sum of Pressurized modification scores of 441 (M=2.42, SD=1.20). Comparison of the skeletal modification scores recorded at the laboratory between all four tests show a difference in sum score, seperating the indirect and direct suppression treatment groups. The indirect suppression groups of Natural

Burn-Out and Active Removal showed greater thermal modification to skeletal material than the direct suppression groups of Pressurized and Dry-Chemical skeletal remains. Additionally, the sum modification scores for all four tests were diagrammed in order to visually compare the overall skeletal modification recorded at the fire site and laboratory between all four test remains (Figure 89).



(Figure 89) Fire site and laboratory modification score totals for all four test remains; comparison of pre-transport and post-transport recorded scores for each test.

Independent-Samples Kruskal-Wallis Test

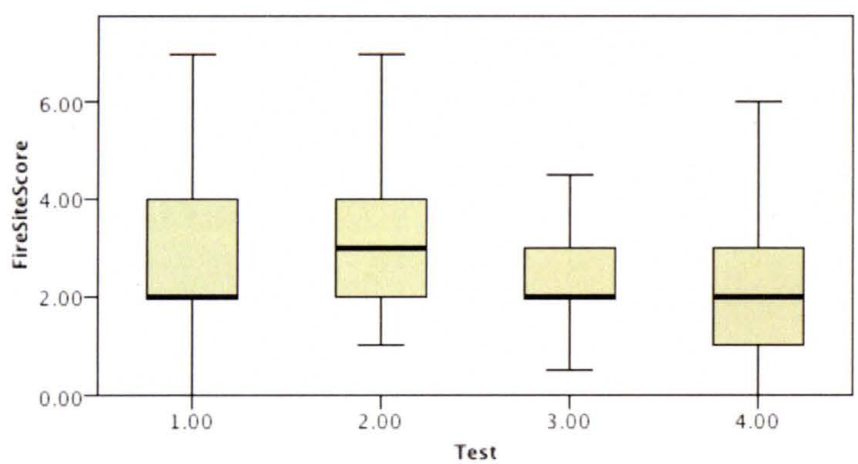
The first independent-samples Kruskal-Wallis test was calculated on the scores recorded during fire site analysis of skeletal modification for each test pig. The fire site scores mean rank for each test is as follows: Natural Burn-Out = 366.15, Active Removal = 408.49, Pressurized = 340.64, and Dry-Chemical = 342.73. The results of the first

Kruskal-Wallis test were significant (H=12.90, 3 d.f., P=.005), indicating there is a significant difference between mean scores of fire site scored skeletal modification for the four groups (Table 19; Figure 90). The second independent-samples Kruskal-Wallis test was calculated on the scores recorded during laboratory analysis of skeletal modification for each test pig. The laboratory scores mean rank for each test is as follows: Natural Burn-Out = 368.21, Active Removal = 403.12, Pressurized = 341.77, and Dry-Chemical = 344.90. The results of the second Kruskal-Wallis test were significant (H=10.39, 3 d.f., P=.016), indicating there is a significant difference between mean scores of laboratory scored skeletal modification for the four groups (Table 20; Figure 91).

Table 19: Kruskal-Wallis Summary for Fire Site Scored Skeletal Modification.

Null Hypothesis	Test	Total N	Test Statistic	Degrees of Freedom	Asymtotic Sig. (2-sided test)	Decision
The distribution of FireSiteScore is the same across categories of Test.	Independent-Samples Kruskal-Wallis Test	728	12.901	3	.005	Reject the null hypothesis.

(Asymptotic significances are displayed. The significance level is .05. The test statistic is adjusted for ties.)

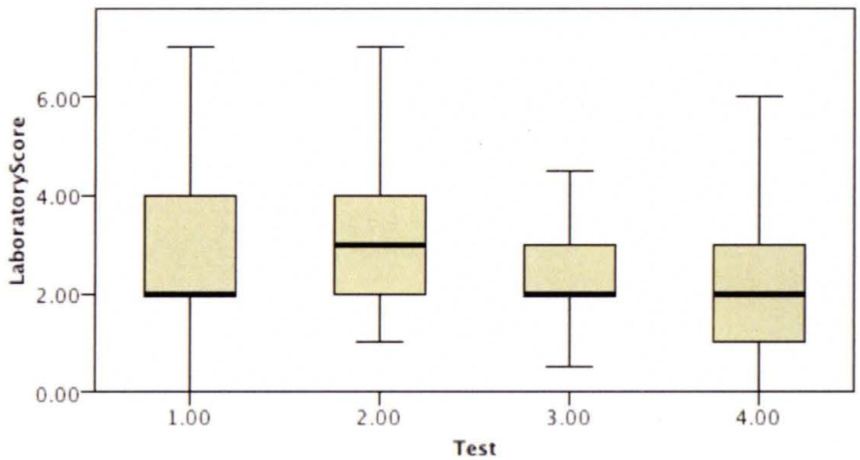


(Figure 90) Independent-Samples Kruskal-Wallis Test: group distribution and fire site scored skeletal modification.

Table 20: Kruskal-Wallis Summary for Laboratory Scored Skeletal Modification.

Null Hypothesis	Test	Total N	Test Statistic	Degrees of Freedom	Asymtotic Sig. (2-sided test)	Decision
The distribution of LaboratoryScore is the same across categories of Test.	Independent-Samples Kruskal-Wallis Test	728	10.392	3	.016	Reject the null hypothesis.

(Asymptotic significances are displayed. The significance level is .05. The test statistic is adjusted for ties.)



(Figure 91) Independent-Samples Kruskal-Wallis Test: group distribution and laboratory scored skeletal modification.

Paired-Samples t-Test

Natural Burn-Out: A paired-sample t-test was used to test the null hypothesis that the average of the differences in scored modification of skeletal elements between the fire site and the laboratory (i.e., pre-transport and post-transport scores) for Natural Burn-Out remains was zero (Table 21). There was a significant difference in the scores for pre-transport skeletal modification (M=2.73, SD=1.65) and post-transport skeletal modification (M=2.79, SD=1.75) for Natural Burn-Out remains; t(181)=±1.653, p= −3.57. Thus, at the a=0.05 level of significance, there exists enough evidence to reject the null hypothesis and conclude that there is a difference in the mean skeletal modification score recorded on the Natural Burn-Out remains for the two data collection locations (i.e., fire site and laboratory).

Table 21: Paired-samples t-test Results for Effect of Transportation on Natural Burn-Out Remains.

Natural Burn-Out: Paired Samples Statistics and Correlations						
	Mean	N	Std. Deviation	Std. Error Mean	Correlation	Sig.
Pre-Transport	2.73	182	1.65	0.12	0.99	0.00
Post-Transport	2.79	182	1.75	0.13		

Natural Burn-Out: Paired Samples Test								
	Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference		t	df	Sig. (2-tailed)
				Lower	Upper			
Pre-Transport - Post-Transport	-0.07	0.25	0.02	-0.10	-0.03	-3.57	181	0.00

Active Removal: A paired-sample t-test was used to test the null hypothesis that the average of the differences in scored modification of skeletal elements between the fire site and the laboratory (i.e., pre-transport and post-transport scores) for Active Removal remains was zero (Table 22). There was not a significant difference in the scores for pre-transport skeletal modification (M=2.96, SD=1.50) and post-transport skeletal modification (M=2.94, SD=1.52) for Active Removal remains; $t(181)=\pm1.653$, $p= 1.16$. Thus, at the a=0.05 level of significance, the null hypothesis is accepted, concluding no difference in the mean skeletal modification score recorded on the Active Removal remains for the two data collection locations (i.e., fire site and laboratory).

Table 22: Paired-samples t-test Results for Effect of Transportation on Active Removal Remains.

Active Removal: Paired Samples Statistics and Correlations						
	Mean	N	Std. Deviation	Std. Error Mean	Correlation	Sig.
Pre-Transport	2.96	182	1.50	0.11	0.99	0.00
Post-Transport	2.94	182	1.52	0.11		

Active Removal: Paired Samples Test								
	Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference		t	df	Sig. (2-tailed)
				Lower	Upper			
Pre-Transport - Post-Transport	0.02	0.26	0.02	-0.02	0.06	1.16	181	0.25

Pressurized: A paired-sample t-test was used to test the null hypothesis that the average of the differences in scored modification of skeletal elements between the fire site and the laboratory (i.e., pre-transport and post-transport scores) for Pressurized remains was zero (Table 23). There was not a significant difference in the scores for pre-transport skeletal modification (M=2.42, SD=1.24) and post-transport skeletal modification (M=2.42, SD=1.20) for Pressurized remains; t(181)=±1.653, p= 0.00. Thus, at the a=0.05 level of significance, the null hypothesis is accepted, concluding no difference in the mean skeletal modification score recorded on the Pressurized remains for the two data collection locations (i.e., fire site and laboratory).

Table 23: Paired-samples t-test Results for Effect of Transportation on Pressurized Remains.

Pressurized: Paired Samples Statistics and Correlations						
	Mean	N	Std. Deviation	Std. Error Mean	Correlation	Sig.
Pre-Transport	2.42	182	1.24	0.09	0.99	0.00
Post-Transport	2.42	182	1.20	0.09		

Pressurized: Paired Samples Test								
	Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference		t	df	Sig. (2-tailed)
				Lower	Upper			
Pre-Transport - Post-Transport	0.00	0.15	0.01	-0.02	0.02	0.00	181	1.00

Dry-Chemical: A paired-sample t-test was used to test the null hypothesis that the average of the differences in scored modification of skeletal elements between the fire site and the laboratory (i.e., pre-transport and post-transport scores) for Dry-Chemical remains was zero (Table 24). There was not a significant difference in the scores for pre-transport skeletal modification (M=2.46, SD=1.32) and post-transport skeletal modification (M=2.47, SD=1.32) for Dry-Chemical remains; t(181)=±1.653, p= −1.00. Thus, at the a=0.05 level of significance, the null hypothesis is accepted, concluding no difference in the mean skeletal modification score recorded on the Dry-Chemical remains for the two data collection locations (i.e., fire site and laboratory).

Table 24: Paired-samples t-test Results for Effect of Transportation on Dry-Chemical Remains.

Dry-Chemical: Paired Samples Statistics and Correlations						
	Mean	N	Std. Deviation	Std. Error Mean	Correlation	Sig.
Pre-Transport	2.46	182	1.32	0.10	0.99	0.00
Post-Transport	2.47	182	1.32	0.10		

Dry-Chemical: Paired Samples Test								
	Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference		t	df	Sig. (2-tailed)
				Lower	Upper			
Pre-Transport - Post-Transport	-0.02	0.22	0.02	-0.05	0.02	-1.00	181	0.32

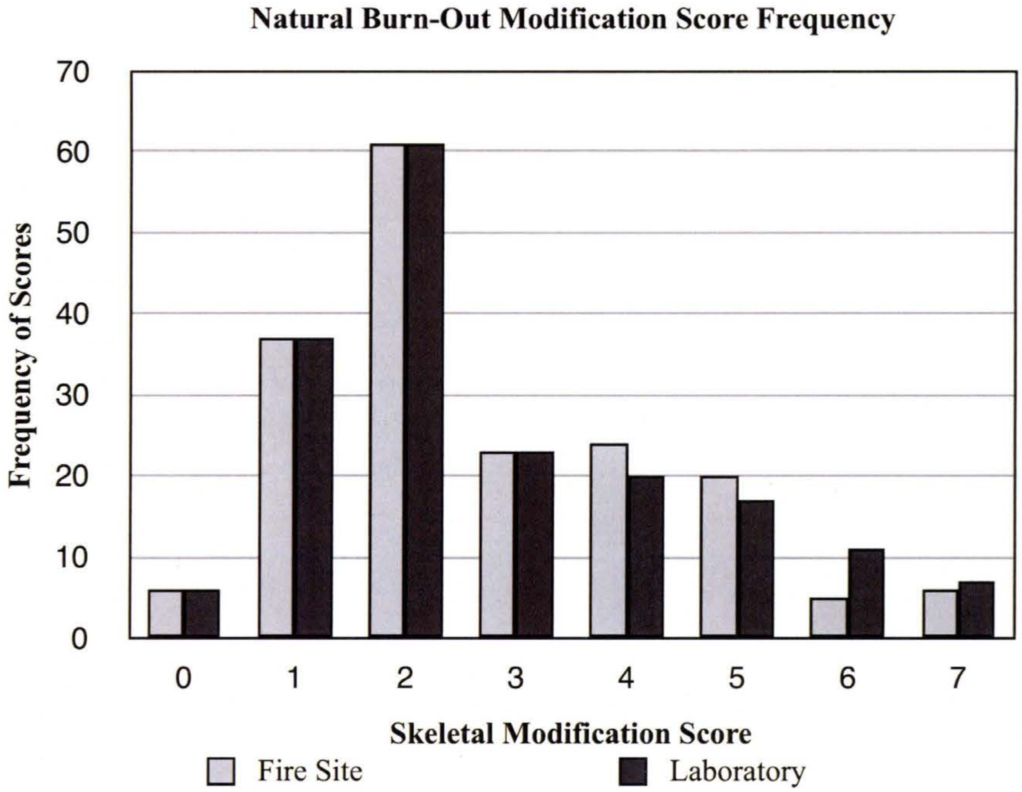
Histograms and Frequency Analysis

After analysis of observed characteristics and statistical data, the individual frequency of skeletal modification scores collected for each pig at the fire site and at the laboratory were diagrammed. The distribution of skeletal modification scores for Natural Burn-Out remains (Table 25; Figure 92) shows that scores of 0, 1, 2, and 3 did not differ between collection at the fire site and collection at the laboratory. The lack of observable change on skeletal elements with no thermal damage, color change only, of the least amount of fracture and fragmentation due to thermal modification suggests that handling and transportation did not affect the condition or completeness of remains scored 0, 1, 2, or 3. However, the frequency of scores 4, 5, 6, and 7 differed between collection at the fire site and collection at the laboratory, which suggests that the skeletal elements that reached a greater degree of thermal modification were affected by transportation or handling. Furthermore, a trend in the difference is present from the fire site to the laboratory; a decrease of four for elements scored 4, a decrease of three for elements scored 5, and an increase of six for elements scored 6. Thus, the degree of affect observed for transportation and handling on the Natural Burn-Out remains increased directly with higher scores or progressively greater thermal modification.

Table 25: Frequency of Thermal Modification Scores Collected for Natural Burn-Out.

Natural Burn-Out: Frequency of Scores		
Score	Fire Site	Laboratory
0	6	6
1	37	37
2	61	61
3	23	23
4*	24	20
5*	20	17
6*	5	11
7*	6	7

*indicates change in score between the two data collection locations



(Figure 92) Frequency of Natural Burn-Out skeletal modification scores recorded at fire site and at laboratory.

The distribution of skeletal modification scores for Active Removal remains (Table 26; Figure 93) shows that scores of 0, 3, 4, 5, 6, and 7 did not differ between collection at the fire site and collection at the laboratory. The lack of observable change on skeletal elements with various degrees of thermal fracturing and fragmentation suggests that transportation and handling after the fire event did not affect the condition or completeness of the fragile remains scored 3, 4, 5, 6, or 7. This lack of affect on higher scored skeletal elements due to transportation and handling may suggests that removing the remains from the fire or moving the remains while still high in temperature at the fire scene affects the condition or completeness of the skeletal material, similar to that produced exclusively by transportation and handling of the remains after the fire event.

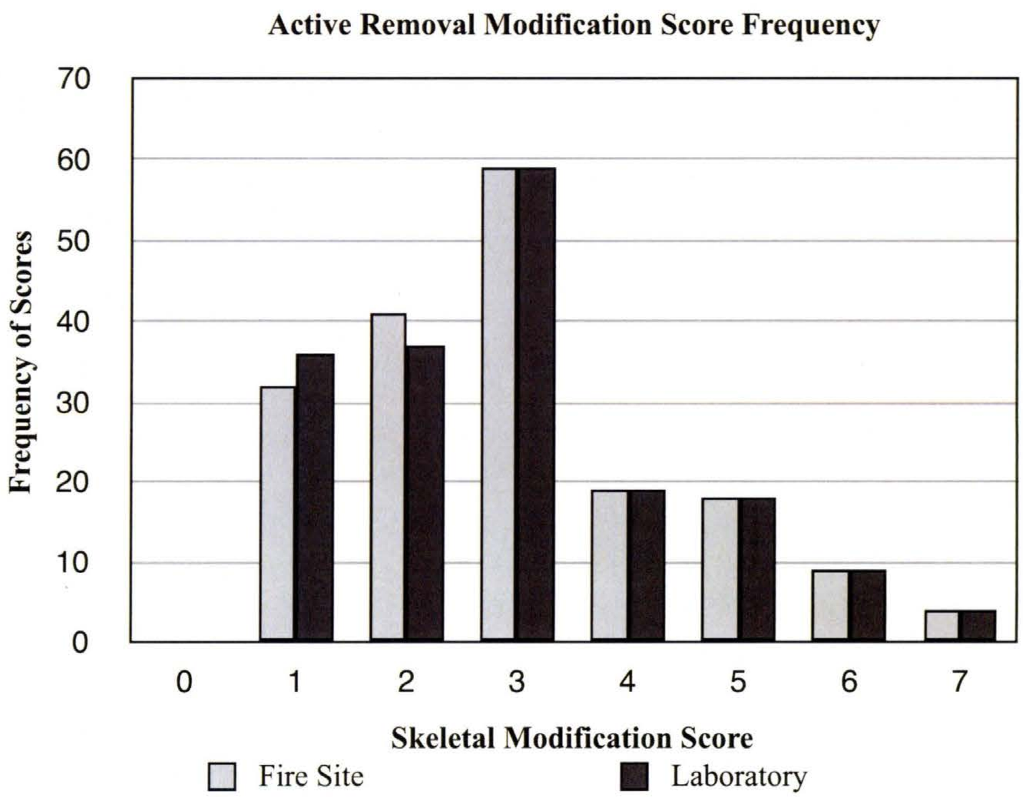
However, the frequency of scores 1 and 2 differed between collection at the fire site and collection at the laboratory, which suggests a difference in the condition or completeness of skeletal elements observed with no thermal damage or with color change only in-between the fire site and laboratory analysis. More specifically, the frequency of skeletal elements that lacked heat-induced alteration increased by four, after transportation, from the fire site to the laboratory. Also, the frequency of skeletal elements that presented with only heat-induced color change decreased by four, after transportation, from the fire site to the laboratory. However, the suggested disappearance of heat-induced color change for several Active Removal skeletal elements is most likely due to the insect activity observed. According to Dr. Britt, the dermestid beetles identified on the remains were attracted to greasy areas of bone with thin edges (B. Britt, personal communication, 2009). Accordingly, skeletal elements scored with the least amount of thermal modification (i.e., color change only) were able to maintain their greasy condition, yet their structural integrity had been compromised. This leads me to believe that such elements were preferred foraging sites for the *Dermestes* in this particular case, which resulted in an underrepresentation of thermal modification due to insect removal of skeletal tissues with heat-induced alteration.

It should be mentioned that all expected skeletal elements were present for Active Removal remains during both fire site and laboratory analysis. Active Removal remains were the only set of remains out of the four tests that presented with all expected skeletal elements. More specifically, the presence of a seventh lumbar vertebra was confirmed for Active Removal remains, whereas the Natural Burn-Out, Pressurized, and Dry-Chemical remains all naturally lacked a seventh lumbar vertebrae. According to Akers and Denbow 2008, the seventh lumbar vertebra is not consistently present in domestic pigs.

Table 26: Frequency of Thermal Modification Scores Collected for Active Removal.

Active Removal: Frequency of Scores		
Score	Fire Site	Laboratory
0	0	0
1*	32	36
2*	41	37
3	59	59
4	19	19
5	18	18
6	9	9
7	4	4

*indicates change in score between the two data collection locations



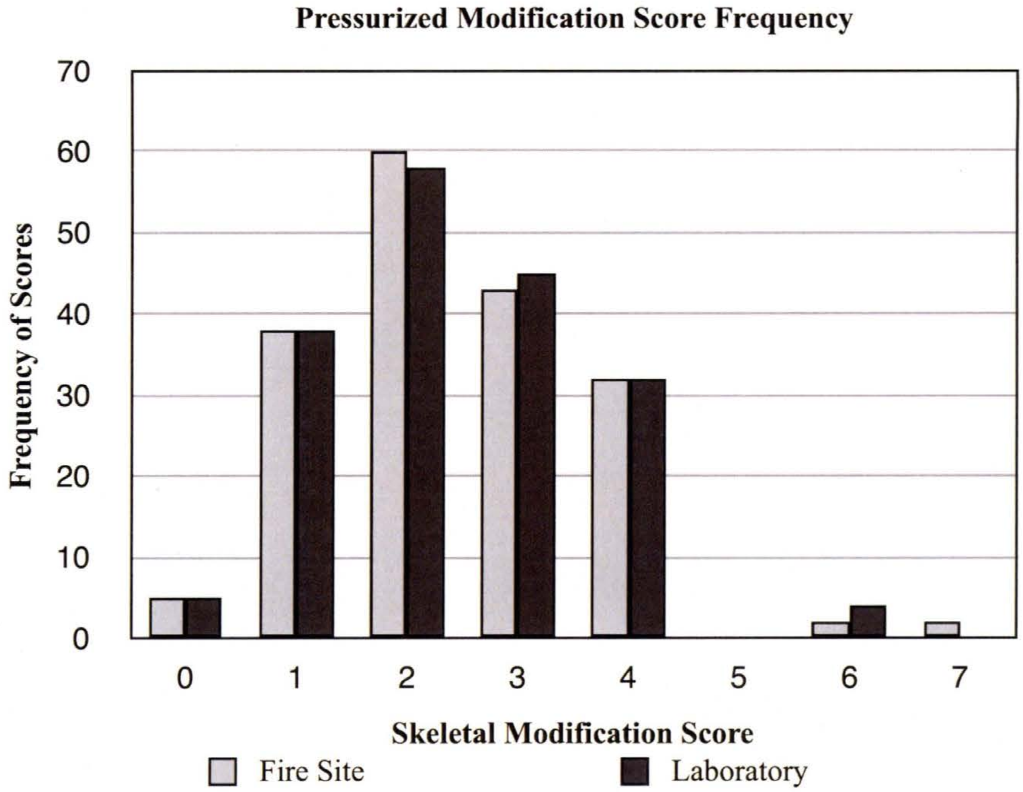
(Figure 93) Frequency of Active Removal skeletal modification scores recorded at fire site and at laboratory.

The distribution of skeletal modification scores for Pressurized remains (Table 27; Figure 94) shows that scores of 0, 1, 4, and 5 did not differ between collection at the fire site and collection at the laboratory. The lack of observable change on skeletal elements that had no thermal modification suggests that the Pressurized suppression technique did not affect unburned bone. However, the frequency of scores 2, 3, 6, and 7 differed between collection at the fire site and collection at the laboratory. The frequency difference for scores 2 and 3 may indicate that suppression with pressurized water and foam slightly increased the fragility of the burned remains after employment. The slight increase of skeletal damage, suggested by the change in frequency for scores 2 and 3, may also merely be an effect of transportation and handling of burned remains after the fire event.

Table 27: Frequency of Thermal Modification Scores Collected for Pressurized.

Pressurized: Frequency of Scores		
Score	Fire Site	Laboratory
0	5	5
1	38	38
2*	60	58
3*	43	45
4	32	32
5	0	0
6*	2	4
7*	2	0

*indicates change in score between the two data collection locations



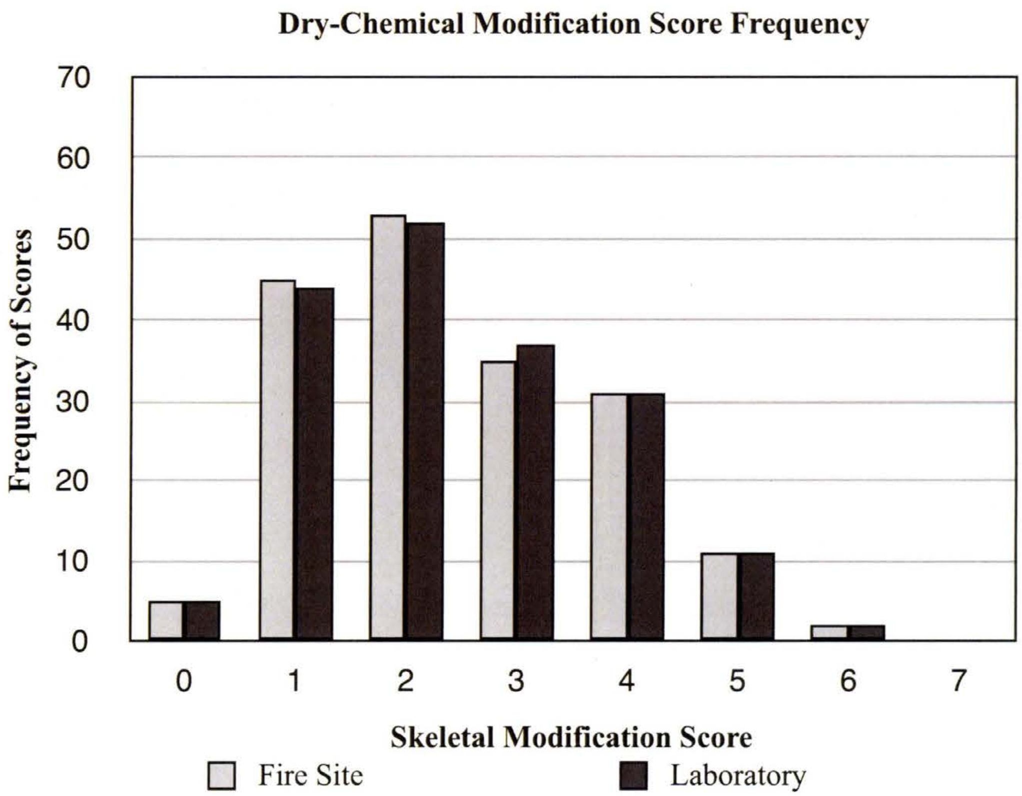
(Figure 94) Frequency of Pressurized skeletal modification scores recorded at fire site and at laboratory.

The distribution of skeletal modification scores for Dry-Chemical remains (Table 28; Figure 95) shows that scores of 0, 4, 5, 6, and 7 did not differ between collection at the fire site and collection at the laboratory. This lack of affect on higher scored skeletal elements after transportation and handling may suggests that dry-chemical suppression affects the condition or completeness of the skeletal remains, similar to that produced exclusively by transportation and handling of the remains after the fire event. However, the frequency of scores 1, 2, and 3 differed between collection at the fire site and collection at the laboratory, which may indicate that suppression with dry-chemical slightly increased the fragility of the burned remains after employment. The slight increase of skeletal damage, however, may also merely be an effect of transportation and handling of burned remains after the fire event.

Table 28: Frequency of Thermal Modification Scores Collected for Dry-Chemical.

Dry-Chemical: Frequency of Scores		
Score	Fire Site	Laboratory
0	5	5
1*	45	44
2*	53	52
3*	35	37
4	31	31
5	11	11
6	2	2
7	0	0

*indicates change in score between the two data collection locations



(Figure 95) Frequency of T4/Dry-Chemical skeletal modification scores recorded at fire site and at laboratory.

According to the results presented in this chapter, skeletal modification such as heat-related and non heat-related coloration, fracture characteristics, and preservation differed between the four sets of remains. The observed and statistically analyzed skeletal modification of T1, T2, T3, and T4 remains will be discussed in detail within the following chapter.

CHAPTER IV
DISCUSSION

The primary goal of this research is to document the taphonomic processes and associated effects of common fire suppression techniques on burned remains (i.e., taphonomic changes to burned bone) through examination, observation, and statistical analysis. The research was conducted in order to develop a more thorough scientific foundation for assessments of trauma (vs. heat exposure and post-fire situational fractures) and taphonomic variables affecting fragile burned remains through documentation of specific characteristics or variables. The results obtained provide a preliminary assessment of taphonomic characteristics from the fire scene to the laboratory related to variables of fire suppression and the fatal fire scene. This taphonomic assessment can be useful when anthropological analysis of burned remains is conducted within the laboratory setting without contextual information from the scene.

As shown in the previous chapter, the observed skeletal modification of the burned remains varied between four treatments. The four treatments included allowing for natural burn-out of the remains, actively removing remains from the fire, applying pressurized water and foam, and employing dry-chemical fire suppression. The range of modification observed during experimentation and/or analysis, in conjunction to statistical results obtained, will be discussed in association with three overarching modification contexts acknowledged specifically for this research: 1) the fire event, 2) the fatal fire scene, and 3) the laboratory. More specifically, modification of the remains varied in accordance to several spatial and temporal contexts, which within this research are broadly categorized by the following five interrelated fields: 1) heat-related, 2) associated activities of fire suppression, 3) transportation, 4) analysis (handling) within the laboratory, and 5) natural processes.

In this study, the following research questions were posed with regard to burned remains and fire suppression techniques:

1. What common factors present at a modern fatal fire scene may produce post-fire taphonomic modification to burned skeletal material?

2. How are burned remains further modified at the fatal fire scene by suppression activities, in addition to heat-related alteration? More specifically, regarding the two common fire suppression techniques of (a) pressurized water and (b) dry chemical, do suppression activities produce specific signatures on burned remains?

3. Does condition and completeness (i.e., preservation rate) of burned skeletal remains vary between the fatal fire scene and the laboratory? Additionally, if significant variance in preservation is found, how might condition and completeness of burned skeletal material show correlation to the fire suppression techniques employed during the fire event?

To observe, document, and examine the effects of fire suppression techniques on burned remains (i.e., postmortem changes to burned bone), four intact, fleshed pig carcasses were burned, employing techniques of indirect or direct fire suppression, scoring skeletal modification as well as condition of the remains at the fire site and at the laboratory after transportation, and comparing the recorded data between and within each set of T1 through T4 remains. Statistical analysis was designed to: (1) compare skeletal modification recorded for the burned remains of each test at the fire site, at the laboratory, and between fire site and laboratory analysis, (2) effectively analyze the possible skeletal modification difference at the fire site between remains allowed to naturally burn-out or were actively removed from the fire and remains that were extinguished with direct fire suppression, (3) effectively analyze the possible skeletal modification difference at the laboratory between remains allowed to naturally burn-out or were actively removed from the fire and remains that were extinguished with direct fire suppression, and to (4) compare and decide if the degree of skeletal modification is significantly different after transportation for each set of test remains.

However, in order to answer the questions posed, observation and documentation of heat-related patterns on porcine soft and skeletal tissues were first and foremost necessary. During observation of each fire event, I documented characteristics of fire-related (thermal) modification to the remains (soft tissue modification, bone exposure, and bone modification).

Fire Event – Heat-Related Modification

The study subject remains display similar heat-related modification to soft tissues consistent with that of fleshed, intact human remains exposed to fire (Bohnert 2004, Christensen 2002, DeHaan 1997, DeHaan 2006, DeHaan et al. 1999, DeHaan and Nurbakhsh 2001, Pope 2007, Pope et al. 2004, Spitz 1993, Spitz 2006, Smith et al. 2001, Symes et al. 1999). During each of the four fires, fluid was seen leaking from the snout, the ears became singed, and the skin underwent thermal discoloration and blistering. As the soft tissues charred, calcified, and began to flake along the posterior body (the anatomical plane positioned closest to the fire), the thermal modification continued to progress with muscle contraction of the shoulders, thighs, and neck. Muscle contraction was further observed by adduction of the limbs, increased arching of the neck and flexion at limb joints. The combination of heat exposure and associated muscle contraction further modified the remains by inducing skin splitting, which exposed the underlying soft tissues and skeletal materials. In addition to this observed heat-related pattern, T1 and T3 remains appeared to show protrusion of the tongue, as well as the eyes of the T2 pig changing in appearance to a cloudy gray/white color. The experimental burning performed by Pope (2007) on human remains also documents these expected heat-related changes during early exposure to heat sources as swelling and protrusion of the tongue, exposure of the eyes to heat due to heat causing eyelids to shrink, and the eyes changing color to a cloudy blue, gray, or white due to the coagulation of the proteins and organic materials of the eyes caused by heat.

The classic repositioning of the body's posture in to the pugilistic posture observed on human fire fatalities was observed on all four sets of remains. Posturing of the remains has been described in the literature with some contradiction as to when and why muscle contraction occurs. Specifically, Spitz (1993) and Fairgrieve (2007) describe for example, that flexion into the pugilistic posture occurs during the cooling process. However, arching of the neck observed during experimentation became relaxed/

weakened after the remains cooled. This agrees with the notion that muscle shortening during burning causes flexion into the pugilistic posture, and does not occur during the cooling process (DiMaio and DiMaio 2001, Dolinak et al. 2005, Pope 2007).

The patterned bone exposure observed during the fire on all four sets of remains is consistent with the expected primary areas of bone exposure for fleshed, intact human remains exposed to fire for a long duration. Expected areas of primary bone exposure depend on the proximity and position of remains in relation to the fire, which includes the heat-related posturing (pugilistic posture) that occurs (Symes et al. 1999).

Areas of bone exposure observed during all four fires include the occipital bone (superior arch), anterior dentition (maxillary and mandibular), scapulae (dorsal blade), rib shafts (lateral-posterior), distal tibia, and distal fibula. Additional areas of common bone exposure observed during the fire events include the caudal vertebrae (T1, T2, T3), ilium (blade and crest) (T1, T3, T4), and metatarsals (T1, T2, T3). The right patella and proximal hind limb phalanges of T3 remains were also visibly exposed during the fire event. That is to say, bone exposure occurred at areas closest to the fire (e.g., posterior crania, posterior scapulae, lateral-posterior rib shafts) and areas of thin soft tissues (e.g., superior crania, anterior of flexed joints). Upon further inspection of the burned remains at the laboratory, the observed areas of heat-related change to bone correspond to the expected sites of bone exposure for human remains presented by Pope (2007). (See *Appendix G* for details on observed changes in the pugilistic posture, heat-related changes in the soft tissues, and the expected sites of bone exposure during research compared to that presented by Pope (2007).)

Fatal Fire Scene

Numerous influential factors in addition to fire are present at a fatal fire scene that may potentially modify burned biological material post-fire, many of which are brought on by activities of fire suppression. Due to the significant difference observed in degree of skeletal modification scores during fire site analysis of the burned remains, the following discussion of suppression will be addressed accordingly. The four tests were separated between direct or indirect suppression technique due to the method of application. Possible variables of interest or influential factors specific to the different suppression activities addressed will be presented below.

Indirect and Direct Fire Suppression Techniques

Specific to fire suppression techniques, which are of primary concern in this research, distinction is made between indirect and direct application. Common indirect suppression activities include natural burn-out of the fire and remains, as well as, physical removal of the remains from the active fire event/scene. Furthermore, although the remains of both indirect suppression tests (T1 and T2) underwent gradual cooling, T1 remains were moved after cooling and T2 remains were moved before cooling occurred. Common direct suppression activities include pressurized water with foam solution, as well as compressed air/dry-chemical compounds. Direct suppression of the fire and remains abruptly stopped heat transfer between the fire and the remains, as T3 remains were quickly cooled and the T4 remains were smothered. Regardless of this separation between indirect and direct suppression techniques, the four general fire extinguishment methods underlying all suppression techniques include: 1) cooling of the burning material, 2) exclusion of oxygen from the fire environment, 3) removal of fuel from the fire, and 4) interruption of the chemical reaction with a flame inhibitor (NFPA 2009b). Possible suppression variables leading to a substantial deviation in skeletal modification on burned remains, therefore, can broadly be reviewed under these four general methods.

Indirect Suppression

The remains of T1/Natural Burn-Out test showed greatest heat-related modification along the posterior body with muscle contraction of all four limbs and arching of the neck at the four hour mark after ignition of the fire. The next morning, no additional heat-related changes were visually identified, yet muscle contraction achieved during the fire event appeared relaxed. The remains of T2/Active Removal test, prior to removal, also showed greatest heat-related modification along the posterior body with muscle contraction of all four limbs and arching of the neck at the four hour mark after ignition.

Two main differences observed at the fire site between the two indirect suppression tests include: location of cooling and temperature of the remains during movement at the fire scene. Natural Burn-Out remains were allowed to cool at a gradual rate while located on the fire pit without the presence of external forces/pressures and were removed from the fire pit after the remains had completely cooled. Active Removal remains were removed from the primary location prior to completion of cooling and gradually cooled after being relocated to the secondary scene area. Therefore, the remains continued to be in a heated state during removal/movement from the fire pit.

Direct Suppression

The remains of T3/Pressurized test and T4/Dry-Chemical test presented with similar heat-induced alteration to soft and skeletal tissues in comparison with Natural Burn-Out and Active Removal remains. For example, Pressurized and Dry-Chemical remains both showed greatest heat-related modification along the posterior body with muscle contraction of the limbs and arching of the neck at the four hour mark after ignition, prior to suppression. However, both Pressurized and Dry-Chemical remains displayed an increase in tissue fragility directly after fire suppression, which was not observed on Natural Burn-Out or Active Removal remains. An understanding of extinguishing agents reveals two additional similarities exclusive to the T3 and T4 conditions: the abrupt reduction of heat and the active prevention of rekindling.

The taphonomic variable of pressurized water (and foam) may displace or project burned remains due to the pressure and abrupt temperature difference of a cold-water stream, especially if a straight stream is employed and/or direct contact is made with the remains (Pope 2007). While the difference of temperature between burning remains and a cold-water stream is valid, the application of water alone is know to produce a rapid decrease in temperature, especially when a foam concentrate is mixed with the water.

The cooling effect produced by the application of water to a fire (or to the remains within a fire) may increase tissue shrinkage of heated muscle during suppression. In other words, if muscles are at a higher temperature than the water applied during suppression, the heated muscles may retract further and expose a greater amount of unburned skeletal material. This cooling effect produced by water is not limited to the water's temperature.

Water quickly converts from liquid into steam when applied to a fire, which will absorb great quantities of heat in the process. This reduction of heat from the combustion process will allow the fuel to cool below its ignition temperature and as a result will stop the fire from burning (NFPA 2009b). Thus, with steam production and water absorption, cooling of the burning material will take place with the application of water, while the degree of cooling may differ due to the water's temperature.

The use of water as an extinguishing agent is increased in effectiveness by combining a foam concentrate with water, resulting in a reduction of the surface tension of water and allowing the water to penetrate dense materials. Consequently, an increase in heat absorption and water contact with unburned fuel is produced by the foam mixture and prevents ignition (NFPA 2009b). Firefighting foam is generally used to fight multiple types of fires and to also prevent ignition of materials in close proximity that could become involved in a fire. The specific use of Class A firefighting foam is intended to fight fires involving ordinary combustible materials (e.g., wood, paper, textiles) and is also effective on organic materials (e.g., hay or straw). Particularly, Class A foam is effective for protecting buildings in rural areas during forest and/or brush fires when water supplies are limited (NFPA 2009b).

Pope (2007) also reported that the suppression technique of pressurized water extinguishment will wash away a portion of superficial soot along with fragile pieces of charred tissues. Due to this information, it is possible that the pressurized water and foam solution could have led to a false decrease in the modification scoring conducted at the fire site on T3 remains. However, further examination of pressurized water and foam fire suppression would be necessary to explore this possibility.

In comparison to direct suppression of pressurized water and foam, the second direct suppression technique examined is that of dry chemical fire extinguishers. Dry chemical fire extinguishers deliver a stream of very finely ground particles into a fire and differ in their chemical compounds, thus producing extinguishers of varying capabilities and characteristics (NFPA 2009b). Dry chemical extinguishing agents work in two ways to suppress a fire: dry chemicals interrupt the chemical chain reactions that occur as part of the combustion process, and the finely ground particles are allowed to absorb large quantities of heat due to their tremendous surface area.

In specific relevance to the present study, multipurpose dry chemical fire extinguishers are rated to fight Class A, B, and C fires and will produce a crust over class A combustible fuels to prevent rekindling. The compound of Ammonium Phosphate, the only dry chemical extinguishing agent that is rated as suitable for use on Class A fires, is used as the primary dry chemical extinguishing agent in fire extinguishers rated from Class A, B, and C fires (NFPA 2009b). Multipurpose dry chemical extinguishing agents are also treated with additional chemicals in order to help maintain an even flow during use, as well as, additional additives that prevent the absorption of moisture known to cause packing or caking and interfere with the extinguisher's discharge.

Spatial Distribution

The distribution of remains at the fire site provides a preliminary understanding of how suppression activities at the fire scene influence burned remains. The size and dimensions of the search area differed between the four tests; however, this division was not made between indirect and direct fire suppression techniques. The difference in distribution of burned biological materials in regards to search area can be separated by remains that were confined within the interior of the fire pit (Natural Burn-Out/T1 and Dry-Chemical/T4), and remains that were located within, as well as, outside of the fire pit (Active Removal/T2 and Pressurized/T3). Even though the pressurized water increased dispersal of the burned material to the exterior of the fire pit, the area of scatter observed for T3 remains was more confined compared to that of the T2/Active Removal remains.

Regarding scatter and search area, and as a result completeness of element recovery, removal of the burned remains from the active fire provided the greatest dispersal area of burned biological material. Suppression by pressurized water and foam solution also increased dispersal of the burned remains. However, burned biological material was only dispersed within and around the primary location (i.e., the fire pit), while the scatter of burned materials produced by active removal created additional dispersal not limited in proximity to the primary location of the fire pit. Dispersal of Natural Burn-Out/T1 and Dry-Chemical/T4 remains was limited to the interior fire pit.

Heat-Related Modification to Bone

The four stages of heat-related color change associated with burned bone (Pope et al. 2001) were observed on all four sets of remains analyzed during this study. Each set of remains presented with the expected alteration to structural integrity and organic degradation of bone when exposed to high temperatures (Pope 2007, Symes et al. 2008) apparent by the visible color change and increased fragility observed during experimentation and analysis. Also, the expected heat-induced fractures of longitudinal, step, straight transverse, patina, splintering and delamination, burn-line fractures, and curved transverse (Herrmann and Bennett 1999, Pope 2007, Rockhold 1996, Symes et al. 2008a) were all identified on the skeletal material analyzed during this study.

Preservation

Within taphonomic analysis, evaluating skeletal tissue preservation consists of two analytical components: completeness and condition (Marean 1991). Completeness and condition of skeletal tissues during fire site analysis were assessed individually through examination of each skeletal element at the time modification scoring was conducted. Once all fire site modification scoring had been recorded for each skeletal element of all four sets of remains, statistical analysis was employed. The descriptive statistics on fire site scores showed a possible division in modification severity between indirect suppression and direct suppression remains. A comparison of the mean ranks of fire site skeletal modification scores by test subject showed there was a statistically significant difference between the different fire suppression techniques. Furthermore, due to the difference in score distribution between the fire site modification recorded for each test subject, it appears that employment of direct suppression techniques hindered thermal effects to the remains at the fire site.

Laboratory

Preservation

Completeness of skeletal tissues during laboratory examination was assessed individually through examination of each skeletal element at the time modification error is quite possible in experimental research, such as the present study, I believe the decrease in modification score for T2 remains can be attributed to the natural process of insect alteration that obscured visually identifiable characteristics of thermal modification to the bone and also, that removed a significant amount of compromised skeletal tissue.

Condition of the skeletal remains for T1, which were analyzed using a two-tailed paired-samples t-test, showed a statistically significant difference between the modification scored at the fire site and the modification scored at the laboratory. Furthermore, directionality of this significance indicates that the fire site score of T1 remains is lower than the laboratory score for T1 remains. This difference was expected as transportation and handling of fragile burned remains can produce an increase in skeletal damage. It is interesting to note, the comparison of modification scores between the fire site and laboratory collected data that were run independently between each of the four tests, was only found to be significant for the T1 remains. It is likely that due to the lack of external skeletal modification factors at the fire scene (i.e., lack of disturbance) the majority of fracture and fragmentation experienced by the T1 remains occurred during or after removal from the scene. In other words, while transportation and handling of the Natural Burn-Out remains may have induced a greater amount of fracture and/or fragmentation, it is also a possibility that the degree of post-fire modification was not increased, yet simply occurred at a later period.

A direct comparison was possible between the completeness and condition of skeletal elements from all four test at the location of laboratory analysis. Through comparison of all four crania (Figures 99-102), the cranium of T1 appears to be the most complete followed by the T3 cranium, T4 cranium, and the least complete cranium of T2. During direct comparison of scapulae within the laboratory (Figures 103-105), the T1 scapulae were found to have the greatest degree of completeness followed by scapulae of T3. The scapulae of T4 shows a noticeably greater degree of fragmentation than that presented by T1 or T3, however the T2 scapulae show a significantly lower degree of skeletal completeness than that of T1, T3, and T4. The crania and scapulae from all four sets of remains were chosen for this comparison due to the overall significant amount of thermal modification present, as well as, a limited amount of additional modification produced by natural processes that occurred after fire site analysis.

Natural Occurrence of Obscuring Processes

Two influential obscuring processes were observed during laboratory analysis of the burned remains, each of which varied by test. The first obscuring process identified was that of mold. T1 remains had white, black, and mustard yellow mold, T2 remains lacked any visual characteristics of mold, T3 remains were covered by a white mold-like substance with small black circular patches of mold spores, and T4 remains presented the greatest range of mold variation including yellow, green, white, and black mold. The degree of mold on the remains at the laboratory thus ranged (most to least obscuring) from the lack of mold on T2 remains, various colors of limited mold on T4 remains, light superficial covering on the majority of T3 remains, to the thick and layered coating of mold on T1 remains.

According to Ubelaker (1991, 1997), a blackening of bones resulting from fungus can simulate burning characteristics on bone. Black mold on the T1, T3, and T4 remains during lab analysis did in fact resemble heat-related color change, which may have led to an increase or false identification of thermal modification during lab analysis. In my opinion, the white chalky mold-like substance that also presented on T1, T3, and T4 remains further simulated burned characteristics (i.e., calcine bone) much like that of the black mold. Furthermore, the addition colors of mold (yellow and green) may have possibly hindered identification of thermal modification during lab analysis by covering or concealing visible characteristics indicative of heat-related modification.

By looking at the overall mold damage present on the remains, the lack of mold on T2 remains is an outlier. This lack of mold seems to be evident due to the severe degree of skeletal tissue loss that occurred between fire site analysis and laboratory analysis. The skeletal tissue loss observed on all four sets of remains was the second obscuring process identified during laboratory analysis.

The progressive decrease of skeletal tissue varied between tests in both identifiable characteristics and degree of tissue loss. Overall characteristics of this tissue loss includes the production of pits and furrows that mainly impacted trabecular bone at the articular surfaces, as well as circular-edged borings into spongy bone. Furthermore, the progressive loss of skeletal tissue observed was associated with the presence of tan, elongated pieces of material (similar in appearance to small wood chippings), small brown hairy casings, and live larvae.

Additionally, the living larvae and adult beetles removed/collected from the remains during laboratory analysis were visually compared to various members of the family Dermestidae. Upon visual inspection, both the living larvae and beetle bodies matched in appearance to the 'skin beetle' (*Dermestes maculates*). Distinct patterns produced by the hairs (i.e., setae) on the body of the skin beetle, the serrated edge and small spine located at the tip of the elytra that are characteristics of this species and the appearance of freshly deposited skin beetle frass (Byrd and Castner 2009), all of which aided in identification. It is of interest to note, that the larvae of *Dermestes maculates* are known to generally remain associated with decomposing tissues for several months.

Unique/Additional Coloration

The first inconsistent coloration that appeared on the burned remains analyzed during this research was the blue tint apparent on T2/Active Removal remains observed at the fire scene and the laboratory. The blue color observed on several T2/Active Removal scapulae fragments at the fire scene faded over the course of several weeks, progressing from blue to gray and then to white. Blue discoloration of burned remains is stated as being particularly associated with calcined bone and is most prevalent when the bone becomes wet due to water or being in a moist environment (Pope 2007), which aligns with the observed and recorded data for the present study. It is also interesting to note that the blue coloration observed on the scapulae fragments were at areas of calcined bone, thus showing an association between blue coloration due to moisture and calcined bone. The scapulae fragments exposed to moisture at the fire site lost their blue tint over time as the bone dried-out, which left the bones a gray color and further, with drying of the calcined fragments, white in color.

As seen in Appendix A, the Active Removal test was the only burn event in which it rained, with humidity at 31% and barometric pressure measured at 30.02 inches (in mercury). Blue coloration only present during laboratory analysis was also observed on the occipital of T2 at the calcine border located between the white and the blackened bone. This blue line at the calcine border observed in the laboratory once the remains had began drying-out further supports that the T2 remains were affected by the moisture present during the fire event, as moisture on burned remains was observed to produce a blue line at the calcine border once remains dried after the fire event (Pope 2007).

The second inconsistent coloration that appeared on the burned remains analyzed during this research was the green tint observed on T3/Pressurized remains recognized at the fire scene. The areas of green coloration observed at the fire site on soft tissues directly attached to the T3/Pressurized skeletal remains include the palate (Figure 111), posterior-distal innominate on cartilage of the left acetabulum (Figure 112), cartilage of the right distal humerus (Figure 113), right carpals, metacarpals, phalanges (Figure 114), right distal femur (Figure 115), externior blade of the left scapulae (Figure 116), proximal and distal ends of the left radius and ulna (Figure 117), left carpals, metacarpals, phalanges (Figure 118), proximal and distal ends of the left tibia and fibula (Figure 119), and the left tarsals, metatarsals, phalanges (Figure 120) (See *Appendix F* for photographic examples).

The apparent green coloration observed on Pressurized remains at the fire site however, was no longer present at the time of laboratory analysis. This disappearance of green coloration indicated the presence of an unidentified reaction or variable acting on the Pressurized remains, such as a chemical reaction or bacterial infection. Additionally, the brown coloration of calcine skeletal elements directly after Pressurized suppression could not be identified during laboratory analysis.

A survey of the literature provided little in means of previous documentation for the occurrence of green discoloration observed on burned remains. Dunlop (1978) investigated discoloration in cremated bone (specifically the colors of pink, green, and yellow) and concluded that metal in the form of iron caused the green discoloration noted, which presented at the location of bone to metal contact. However, it should be stressed that the green discoloration investigated by Dunlop (1978) was conducted through the examination of cremains cremated more than 1300 years ago, thus the discoloration is assumed to have been observed on burned skeletal material that lacked the presence of soft tissues. Furthermore, the green discoloration observed during the present research faded in less than a month, unlike that of the discoloration examined by Dunlop (1978).

In order to explore the possible cause of the color green observed during the present study, I considered four interrelated fields known to produce discoloration to soft and/or hard human tissues: 1) diet, 2) drug/medication, 3) chemical compounds, and 4) bacteria/infection. An example of a dietary factor known to cause staining of bone is the red color produced at the ends of long bones in individuals who consume the plant Madder (Hall 2005). However, since all four pigs were acquired from the same farm, housed together, and of the same age, it is assumed that a significant difference in diet did not exist between the four pigs.

Drugs known to produce discoloration to bone include tetracycline, minocycline, and chlortetracycline, which are common tetracycline antibiotics) that bind to bone and teeth and are isolated from various species of Streptomyces (Riviere and Papich 2009). Tetracycline is associated to the discoloration of developing teeth and bones with yellow to brown or green to gray pigmentation (Guillot et al. 2010). Minocycline is commonly associated with skin and tooth discoloration (Somayazula and Rogers 2010); however, it has also been shown to induce blue-green discoloration of bone (McCleskey et al. 2004). Despite the possibility that tetracycline or minocycline could have been given to the T3 pig while alive, the most probable drug of the three discussed is chlortetracycline. Chlortetracycline is a common additive fed to promote growth in calves, pigs, and poultry (Blood et al. 2006) and has been observed to induce a reversible green bone discoloration in growing pigs (Guillot et al. 2010). However, any growth additive that may have been fed to the T3 pig would have also been introduced to the remaining three pigs used during experimentation, thus producing similar unique pigmentation of the remains.

A chemical possibility is that of nickel compounds, which easily dissolve in water and have a green color (ATSDR 2003). Most nickel is commonly used to make stainless steel (Lide 2004). However, the only metal introduced during experimentation was that of the metal grate used during each of the four fire events. A second chemical possibility is the Class A foam employed at the start of T3 suppression, which may have had an effect on the green discoloration observed. The possibility that Class A foam could be connected, directly or indirectly, to the green coloration is a possible modification variable that is exclusive to Pressurized remains.

Bacteria known to produce green discoloration of soft tissues includes *Pseudomonas* bacteria (Kraft 1992), which is commonly found in soil and water (Levison 2008). Soft tissue infections caused by *Pseudomonas* effect tissues in muscle, tendons, ligaments, fat, and skin (Levison 2008). The green water soluble pigment produced by *Pseudomonas* is associated with growth of the bacteria. This association between bacterial growth and green pigmentation provides one possible line of reasoning for why the green observed on the soft tissues of T3 remains faded with time and eventually dissolved in entirety. Furthermore, the areas of observed green discoloration on the T3 remains show an association to areas where water was seen to pool (e.g., at the joints of limbs with flexion and exposure of underlying soft tissues). Due to the areas of green discoloration, it was first thought that the foam admixture present with the pressurized water may have produced a chemical reaction. However, the limited contact of that the foam had with the remains was confined to the left side of T3 remains and the green discoloration observed presented predominantly on skeletal elements and soft tissues of the right side. It is possible that the chemical compounds hindered the growth of *Pseudomonas* bacteria on the left side of the remains, which accounts for the majority of green tint being observed on skeletal elements of the right side. For this line of reasoning to possibly be correct, the bacteria would have had to be introduced on the remains from the water applied during treatment of the T3 remains. It seems likely that the use of a brush truck during experimentation may have contributed in the production of green discoloration to the T3 remains. Unlike fire engines that receive water from hydrants or an alternative water source, small brush trucks are equipped with a water tank that typically carries 200 to 300 gallons of water. As presented above, a tank full of sitting water is consistent to the common environment of such bacteria. Additionally, it is interesting to note that *Pseudomonas* is known to easily populate at areas of compromised tissue (e.g., this type of infection is common in burn patients).

Overall, these results demonstrate how different types of fire suppression techniques may modify fragile burned remains during treatment, recovery, and laboratory analysis. These results emphasize the importance of taphonomic experimentation regarding scene specific variables and strongly support the suggestion of utilizing forensic anthropologists at the scene of a fatal fire for recovery, analysis, and transportation, if possible.

Limitations

Some limitations within this research were found. First, the use of a brush truck instead of a fire engine during the T3 treatment may set constraints on the validity of this study's application to fatal fire cases in which a fire engine was used for suppression. The higher water pressure of a fire engine would most likely produce greater secondary fractures and fragmentation in comparison to the secondary fractures and fragmentation produced by the brush truck used during the pressurized test. Furthermore, the increased water pressure from a fire engine may have produced different results of spatial distribution of the burned remains in comparison to that observed with employment of a brush truck. Second, the method of soft tissue removal employed during this research was found to increase the time period needed for soft tissue removal, thus leading to a prolonged stay of the burned remains at the fire site before the possibility of transportation to the laboratory. The abundant amount of maggots and additional insects brought about from this method of soft tissue removal used, also has been shown in the previous discussion of obscuring processes to likely produce increased post-fire modification, and even removal of heat-related modification characteristics.

A third possible limitation to this research is the small sample size, which was constrained by both financial and time factors. While the sample size of test subjects was small (N=4), the amount of skeletal elements analyzed for each test subject at both the fire site and the laboratory was large (n=182). However, the possible limitation of this research is the small subject size that directly implicates a small number of experimental burns. This limited number of experimental fires may be problematic due to the complex nature of fires, being that no two fires are identical (DeHaan 2007). Physical and thermal relationships, in addition to environmental and material conditions, remain active and are subject to fluctuation throughout the fire.

Also, since a fire will show distinct differences based on confinement (wild land fires compared to structural fires), which in turn calls for different suppression techniques, it is possible that the effects of fire suppression to burned remains will differ based on confinement. Accordingly, validity of the present research aligns with open fire situations to a greater degree than to confined fire situations.

Furthermore, due to the limited area available for the experimental fires, as well as the attempt to control variables associated with each fire, all four experimental fires were conducted at the same location. Use of the same location for each fire did not allow for the collection of scattered skeletal materials after each test, as commingling of the skeletal elements may have occurred. It is unlikely, yet possible, that collection of the scattered material after each test could have produced differences within the results.

CHAPTER V
CONCLUSION

The primary question posed within this research was how common fire suppression techniques or typical activities present at modern fatal fire scenes are observed to further modify burned skeletal material. By comparing the differences in modification scores for all four test subjects between the fire site and the laboratory, several effects of transportation and handling were found in relation to degree of thermal modification. First, the modification of Natural Burn-Out remains was observed to increase directly with higher scores or progressively greater thermal modification. Second, removing the remains from the fire or moving the remains while still high in temperature at the fire scene may cause similar modification to the skeletal remains as that produced by transportation and handling of the remains exclusively after the fire event. Third, the suppression techniques of pressurized water and foam and dry-chemical may have caused a slight increase in fragility of the skeletal remains after employment of pressurized water.

Evaluation of possible effects caused by both indirect and direct fire suppression methods were of interest in this study. Indirect suppression techniques evaluated were those of Natural Burn-Out and Active Removal, while direct suppression techniques evaluated were pressurized water with foam admixture and hand-held compressed air and dry-chemical. Specific to Natural Burn-Out, the increase in fracture or fragmentation of the remains after transportation is most likely due to the lack of disturbance at the fire scene. Thus, the degree of post-fire modification was not actually increased compared to the other three tests, but merely occurred at a later time after removal from the fire scene.

Through comparison of score distribution and mean ranks for fire site and laboratory scores, it appears that both direct suppression techniques hindered thermal effects to the skeletal remains while producing a possible increase in tissue fragility directly after suppression. The Pressurized remains specifically, underwent displacement of fragile burned material during suppression, and the pressurized water was observed to remove a portion of superficial soot along with fragile pieces of charred tissues. Thus, overall, the fire suppression technique of pressurized water may have caused a false decrease in degree of heat-induced damage on the burned remains.

Additionally, two obscuring processes and two unique discolorations were observed on the burned remains. The two obscuring processes consist of mold and insect activity, each of which varied by test. Mold appeared in colors of white, black, green, and mustard yellow, all of which may have masked characteristics of heat-induced modification on the remains. The insect activity or *Dermestes* damage to the burned skeletal material resulted in bone loss, which increased skeletal damage and caused an underrepresentation of thermal modification during skeletal analysis by removing a large amount of compromised skeletal tissue. The two unique discolorations observed consist of blue and green. The blue tint, apparent on Active Removal remains, was shown to have been produced by the environmental condition of moisture during the fire event. The second discoloration observed was the green tint of the soft tissues on Pressurized remains, which most likely was produced by bacteria introduced through the water used for suppression.

Dispersal of Natural Burn-Out and Dry-Chemical remains was limited to the interior fire pit. Pressurized remains were dispersed directly around the fire pit in relation to the direction of the water stream. Dispersal of Active Removal remains extended beyond the area of the fire pit (i.e., within and around the pit) in direct relation to the area of relocation as seen by the trail of scattered burned material between the fire pit and the secondary fire scene location for the remains, as well as an increased amount of burned material scattered on the ground at the secondary location for the remains at the fire scene.

This difference in spatial distribution of burned remains at the fire site is important for forensic anthropologists that may be called to a fatal fire scene as it could increase the rate of recovery for burned biological materials. Thus, physical removal of remains from the active fire produced the greatest dispersal area of burned biological material compared to natural burn-out, pressurized water, and dry chemical extinguishment during this research. However, I suspect that remains modified to a greater degree by fire could produce a different outcome (i.e., pressurized might cause greater dispersal or majority of active removal handling modification could mostly occur at the moment the body is picked-up from its primary location).

An understanding of this expected spatial distribution of burned remains at the fatal fire scene supports the recommendations of 1) the utilization of forensic anthropologists during scene activities (i.e., search, recovery, etc.), and 2) that contact between individuals at the scene and the burned remains present should be limited exclusively to those trained in archaeological methods. Furthermore, the application of archaeological search methodology has been shown to increase the recovery rate of burned biological material and associated artifacts in fatal fire scenes (Olson 2009). This is also evident by the percentage of skeletal element completeness recorded for each set of remains at the laboratory (i.e., T1/Natural Burn-Out remains were the most complete and T2/Active Removal remains were the least complete).

Implications

Due to fire being used to cover-up criminal actions (e.g., homicide) and the destructive power that fire has on soft and skeletal tissues, it is important to conduct actualistic experimentation to determine how fire modifies such tissues, as well as the observation and documentation of how the various additional taphonomic processes may alter human remains (e.g., human interaction, fire suppression, insect damage). This will enhance the ability to accurately distinguish between and identify various types of modification typical on burned human remains in a laboratory setting.

The finding that employment of different suppression techniques changes the scatter patterns of the burned remains may lead to improved rates of skeletal recovery at the fatal fire scene. Furthermore, the natural obscuring process of dermestid foraging observed on the skeletal remains of test subjects shows that taphonomic processes are capable of removing heat-induced modification characteristics on bone.

Just as each fire is unique, each fire fatality should also be viewed as unique. This research supports that claim by showing how various factors present at a fire scene may affect modification and associated characteristics observed on burned remains. For example, external pressure from suppression techniques affects scatter and enlarges the extent of the search area. Also, it seems that direct application of fire suppression techniques may hinder heat-induced modification to the remains, which may increase survivability of skeletal elements. However, without acknowledgment or experimental support backing this finding, inaccurate conclusions may be reached during fire fatality investigations since it manifests as variation to the expected degree of thermal modification. Additionally, the bacterial factor of the water employed during pressurized fire suppression, thought to be the cause of the unexpected green coloration to the burned remains observed during this study, further illuminates the idea that each fire fatality is unique. This finding also supports the stance that knowledge of specific fire suppression variables may be critical in understanding modification characteristics of burned remains.

Overall, the results of this study have been found to be consistent as well as inconsistent with previous research, which validates the importance of experimental research. Furthermore, in an effort to strengthen courtroom testimony of fire fatality analyses, the particular experimental research presented here provides an additional source of information regarding the effects and associated skeletal characteristics produced at a fatal fire scene.

Future Research

It would be beneficial to further examine if greatest completeness of skeletal elements (i.e., least fragmentation) was due to the fact that the remains were not moved from the fire pit/metal grate until they had cooled.

Thompson (2005) reported that the amount of heat-induced dimensional change recorded will be influenced by the length of time after removal from the heating source. This shows that heat-related change is still occurring to skeletal material even after removal of the remains from the active fire environment/heat. Thus, the modification of burned skeletal material cannot easily be separated by cause and is a very complex process involving numerous interrelated variables that influence/play with one another. Thompson (2005) showed that the size of burned skeletal elements gradually decreased over time after the heating event. The further reduction of bone size after removal from heat thus necessitates further experimental research of burned remains.

Upon completion of this research, several additional questions were brought to light, such as the effects of chemicals associated with modern and common fire suppression techniques on the microstructure of burned skeletal material (is the structure or strength of bone compromised?); dermestes modification to bone (compared between unburned and burned bone); and whether it is possible to detect thermal modification of bone if additional taphonomic processes (e.g., *Dermestes* damage) removes thermal modification indicators.

Previous research (Olson 2009) has shown that recovery of significant material at the fire scene increases with the aid of osteologists/forensic anthropologists at the scene.

Could/would the recovery rate also increase if information about the suppression technique(s) employed was provided? Also, could providing this information decrease the recovery time at the fire scene?

It is obvious that the factors intrinsic to bone (i.e., size, shape, density) are altered by extrinsic factors of the fatal fire scene, such as heat and exposure to flame. However, regarding the taphonomic modification and preservation over time and/or across location of burned skeletal remains from modern fatal fire scenes, a complicated and intertwined system of factors is apparent. This research has shown the magnitude of possible modification variables, temporally and spatially, that may have a relation to burned remains from the fire scene through to laboratory analysis. The intrinsic variables of bone and corresponding visual characteristics that aid in the analysis of burned skeletal material from a modern fatal fire scene have been addressed and may further our current understanding of the various operating processes that influence the overall state of such skeletal elements.

By using correct packaging procedures of the burned remains for transportation was shown to limit the modification caused by transportation and handling after recovery from the fire site. The implications of using these packaging protocols include improving trauma analysis as well as assessments of cause and manner of death. Furthermore, it is supported by this research that analyses of burned remains could be improved with the help of an osteologist on site for search and recovery, use of archaeological methods during recovery, and the use of an interdisciplinary scope during the fatal fire scene investigation.

APPENDIX A

WEATHER DATA AND PIG TEMPERATURE FOR BURN EVENTS

Table 1: Recorded Weather Conditions and Pig Temperature for Natural Burn-Out.

Test:	**Natural Burn-Out**
Date:	7.17.2009
time:	12:07 p.m.
Weather:	Fair
Temp:	97° F, feels like 102° F
UV Index:	Very high
Wind Speed:	6 m.p.h.
Wind Direction:	From East
Humidity:	39%
Pressure:	30.05 in
Dew Point:	N/A
Visibility:	N/A
Pig temperature	
Before fire:	103° F
4 HOUR MARK:	160° F

Table 2: Recorded Weather Conditions and Pig Temperature for Active Removal.

Test:	**Active Removal**	
Date:	7.18.2009	
time:	1.01 p.m.	3:07 p.m.
Weather:	Sunny	Partly Cloudy
Temp:	96° F, feels like 98° F	99° F, feels like 102° F
UV Index:	N/A	High
Wind Speed:	Calm	6 m.p.h.
Wind Direction:	N/A	From East
Humidity:	33%	31%
Pressure:	30.08 in	30.02 in
Dew Point:	N/A	N/A
Visibility:	N/A	N/A
*3:19 p.m. Rain (light sprinkle & heavy downpour)		
Pig temperature		
Before fire:	75° F	
after Fire:	130° F	

Table 3: Recorded Weather Conditions and Pig Temperature for Pressurized.

Test:	**Pressurized**
Date:	7.27.2009
time:	12:07 p.m.
Weather:	Sunny
Temp:	97° F, feels like 99° F
UV Index:	Extreme
Wind Speed:	13 m.p.h., gusting to 22 m.p.h.
Wind Direction:	South-Southwest
Humidity:	34%
Pressure:	29.96 in
Dew Point:	69° F
Visibility:	10.0 miles
Pig temperature	
Before fire:	100° F
after Fire:	155° F

Table 4: Recorded Weather Conditions and Pig Temperature for Dry-Chemical.

Test:	**Dry-Chemical**
Date:	7.28.2009
time:	12:07 p.m.
Weather:	Sunny
Temp:	97° F, feels like 100° F
UV Index:	Very high
Wind Speed:	12 m.p.h., gusting to 24 m.p.h.
Wind Direction:	South-Southwest
Humidity:	36%
Pressure:	29.89 in
Dew Point:	N/A
Visibility:	N/A
Pig temperature	
Before fire:	100° F
after Fire:	

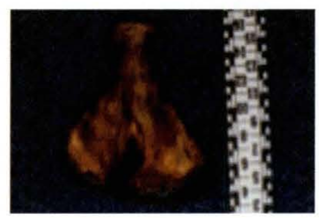
APPENDIX B

VISUAL ATLAS OF GENERAL CODING SCALE

Inventory/Code: General - 1
View: Macroscopic
Definition: Present with no thermal modification observed.
Photo Description: Right ulna.

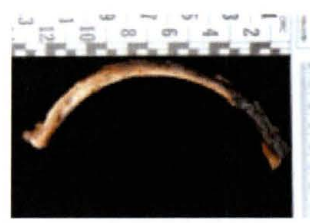
Inventory/Code: General - 2
View: Macroscopic
Definition: Heat-related color change only.
Photo Description: Anterior mandibular dentition.

Inventory/Code: General - 3
View: Macroscopic
Definition: 0-25% of element fractured or fragmented.
Photo Description: Left scapula.



Inventory/Code: General - 4
View: Macroscopic
Definition: 26-50% of element fractured or fragmented.
Photo Description: Left humerus, radius, and ulna.

Inventory/Code: General - 5
View: Macroscopic
Definition: 51-75% of element fractured or fragmented.
Photo Description: Superior view left rib.



Inventory/Code: General - 6
View: Macroscopic
Definition: 76-100% of element fracture or fragmented.
Photo Description: Blade of scapula.

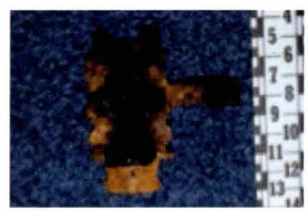
APPENDIX C

VISUAL ATLAS OF VERTEBRAL CODING SCALE

Inventory/Code: Vertebral - 1
View: Macroscopic
Definition: Present with no thermal modification observed.
Photo Description: Atlas of T2.

Inventory/Code: Vertebral - 2
View: Macroscopic
Definition: Heat-related color change only.
Photo Description: Thoracic vertebrae 2, 3, and 4.

Inventory/Code: Vertebral - 3
View: Macroscopic
Definition: Superior segment of spinous process fractured or fragmented.
Photo Description: Thoracic vertebrae.



Inventory/Code: Vertebral - 4
View: Macroscopic
Definition: Majority of spinous process fractured or fragmented.
Photo Description: Thoracic vertebrae.

Inventory/Code: Vertebral - 5
View: Macroscopic
Definition: Entirety of spinous process fractured or fragmented.
Photo Description: Sacral vertebrae.

Inventory/Code: Vertebral - 6
View: Macroscopic
Definition: 50-100% of vertebral body fractured or fragmented.
Photo Description: Sacral vertebrae.

APPENDIX D

FIRE SITE DATA

		Natural Burn-Out				Active Removal				Pressurized				Dry-Chemical			
		Left		Right		Left		Right		Left		Right		Left		Right	
Frontal		2		2		3		3		3		3		3		3	
Parietal		3		3		5		5		4		4		3		3	
Occipital		2		2		3		3		1		1		1		2	
Sagittal		2		2		2		2		2		2		2		2	
Zygomatic		2		2		2		2		2		2		2		2	
Palate		1		1		1		1		1		1		1		1	
Maxilla		1		1		1		1		1		1		2		2	
Nasal		1		1		1		1		1		1		2		2	
Interparietal		3		3		6		6		4		4		4		4	
Premaxilla		1		1		1		1		1		1		2		2	
Mandibular Body		1		1		1		1		1		1		2		2	
Mandibular Ramus		1		1		1		1		1		1		1		1	
Maxillary Dentition	Mandibular Dentition	2	2	2	2	3	3	3	3	2	3	3	3	3	3	3	3
i1	i1	2	2	2	2	3	3	3	3	2	3	2	3	2	3	3	3
i2	i2	2	2	2	2	3	3	3	3	1	3	2	3	3	3	1	3
i3	i3	2	2	2	2	3	3	3	3	0	3	3	3	2	0	2	0
c	c	0	0	0	0	3	3	3	3	0	3	3	3	0	2	3	3
pm1	pm1	2	2	2	2	1	1	1	1	2	3	0	3	2	1	2	2
Cervical Vertebra 1		1		1		1		1		1		1		1		1	
Cervical Vertebra 2		1		1		1		1		1		1		1		1	
Cervical Vertebra 3		1		1		2		2		1		1		1		1	
Cervical Vertebra 4		1		1		2		2		1		1		1		1	
Cervical Vertebra 5		1		1		2		2		1		1		1		1	
Cervical Vertebra 6		1		1		2		2		1		1		1		1	

Cervical Vertebra 7	1	1	3	3	3	3	3	3
Thoracic Vertebra 1	2	2	3	3	3	3	3	3
Thoracic Vertebra 2	3	3	3	3	3	3	3	3
Thoracic Vertebra 3	3	3	3	3	3	3	3	3
Thoracic Vertebra 4	3	3	3	3	3	3	3	3
Thoracic Vertebra 5	3	3	3	3	3	3	3	3
Thoracic Vertebra 6	3	3	3	3	3	3	4	4
Thoracic Vertebra 7	4	4	4	4	3	3	4	4
Thoracic Vertebra 8	4	4	4	4	3	3	4	4
Thoracic Vertebra 9	4	4	3	3	3	3	4	4
Thoracic Vertebra 10	5	5	3	3	4	4	4	4
Thoracic Vertebra 11	5	5	3	3	4	4	4	4
Thoracic Vertebra 12	4	4	3	3	4	4	4	4
Thoracic Vertebra 13	4	4	3	3	4	4	5	5
Thoracic Vertebra 14	5	5	3	3	4	4	5	5
Thoracic Vertebra 15	5	5	4	4	4	4	5	5
Lumbar Vertebra 1	5	5	4	4	4	4	4	4
Lumbar Vertebra 2	5	5	4	4	4	4	4	4
Lumbar Vertebra 3	4	4	4	4	4	4	4	4
Lumbar Vertebra 4	4	4	5	5	4	4	4	4
Lumbar Vertebra 5	4	4	5	5	4	4	4	4
Lumbar Vertebra 6	4	4	5	5	4	4	4	4
Lumbar Vertebra 7	0	0	5	5	0	0	0	0
Sacral Vertebra 1	5	5	2	2	2	2	2	2
Sacral Vertebra 2	6	6	3	3	3	3	2	2
Sacral Vertebra 3	7	7	4	4	4	4	2	2
Sacral Vertebra 4	7	7	7	7	6	6	2	2
Caudal Vertebrae	7	7	7	7	7	7	2	2
Rib 1	1	1	1	1	1	1	1	1
Rib 2	1	1	1	1	1	1	1	1
Rib 3	1	1	1	1	1	1	1	1
Rib 4	1	2	3	2	1	1	2	1
Rib 5	1	2	4	2	1	4	2	2

Rib 6	2	2	4	2	2	2	2	2
Rib 7	2	2	5	3	2	2	4	2
Rib 8	2	2	5	3	2	2	4	2
Rib 9	2	3	5	4	2	2	4	2
Rib 10	2	4	5	4	2	2	5	2
Rib 11	3	5	6	4	2	2	5	2
Rib 12	4	5	6	5	2	2	5	2
Rib 13	4	6	6	5	2	2	5	2
Rib 14	4	6	6	6	2	2	6	3
Rib 15	5	6	6	6	2	2	6	3
Clavicle	1	1	1	1	1	1	1	1
Scapula	3	3	5	5	3	3	5	3
Humerus	2	2	2	2	2	2	3	2
Ulna	2	2	3	1	2	2	3	2
Radius	2	2	1	1	2	2	2	2
Carpals	2	2	2	2	2	2	2	1
Metacarpals	2	2	2	2	2	3	3	1
Phalanges (forelimb)	2	2	3	1	2	2	3	1
Ilium	5	5	3	3	4	2	2	2
Ischium	2	1	2	2	2	2	2	2
Pubis	3	3	2	2	2	2	2	2
Femur	2	3	2	2	2	2	1	1
Patella	2	2	2	2	2	2	1	1
Tibia	2	4	2	2	2	2	1	1
Fibula	2	3	2	2	2	3	1	1
Tarsals	2	3	2	2	2	2	1	1
Metatarsals	2	4	2	2	2	2	1	1
Phalanges (hindlimb)	2	5	2	2	2	2	1	1

APPENDIX E

LABORATORY DATA

	Natural Burn-Out		Active Removal		Pressurized		Dry-Chemical	
	Left	Right	Left	Right	Left	Right	Left	Right
Frontal	2	2	3	3	3	3	3	3
Parietal	3	3	5	5	4	4	3	3
Occipital	2	2	3	3	1	1	1	1
Sagittal	2	2	2	2	2	2	2	2
Zygomatic	2	2	2	2	2	2	2	2
Palate	1	1	1	1	1	1	1	1
Maxilla	1	1	1	1	1	1	2	2
Nasal	1	1	1	1	1	1	2	2
Interparietal	3	3	6	6	4	4	4	4
Premaxilla	1	1	1	1	1	1	2	2
Mandibular Body	1	1	1	1	1	1	2	2
Mandibular Ramus	1	1	1	1	1	1	1	1

		Natural Burn-Out				Active Removal				Pressurized				Dry-Chemical			
		Left		Right		Left		Right		Left		Right		Left		Right	
Maxillary Dentition	Mandibular Dentition	2	2	2	2	3	3	3	3	2	3	3	3	3	3	3	3
i1	i1	2	2	2	2	3	3	3	3	2	3	2	3	2	3	3	3
i2	i2	2	2	2	2	3	3	3	3	1	3	2	3	3	3	1	3
i3	i3	2	2	2	2	3	3	3	3	0	3	3	3	2	0	2	0
c	c	0	0	0	0	3	3	3	3	0	3	3	3	0	2	3	3
pm1	pm1	2	2	2	2	1	1	1	1	2	3	0	3	2	1	2	2

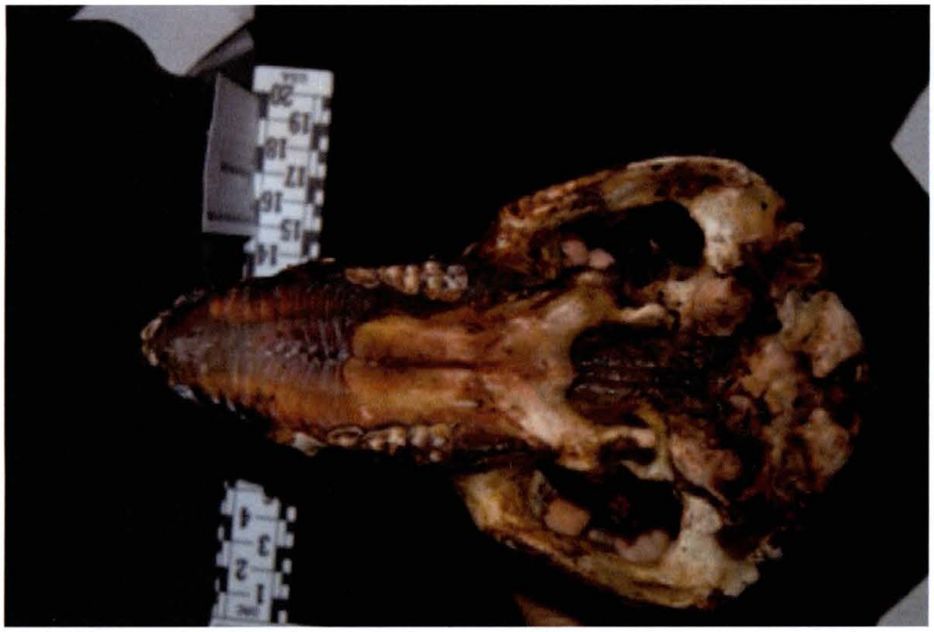
	Natural Burn-Out		Active Removal		Pressurized		Dry-Chemical	
	Left	Right	Left	Right	Left	Right	Left	Right
Cervical Vertebra 1	1	1	2	2	1	1	1	1
Cervical Vertebra 2	1	1	2	2	1	1	1	1
Cervical Vertebra 3	1	1	1	1	1	1	1	1
Cervical Vertebra 4	1	1	1	1	1	1	1	1
Cervical Vertebra 5	1	1	1	1	1	1	1	1
Cervical Vertebra 6	1	1	1	1	1	1	3	3

Cervical Vertebra 7	1	1	3	3	3	3	3	3
Thoracic Vertebra 1	2	2	3	3	3	3	3	3
Thoracic Vertebra 2	3	3	3	3	3	3	3	3
Thoracic Vertebra 3	3	3	3	3	3	3	3	3
Thoracic Vertebra 4	3	3	3	3	3	3	3	3
Thoracic Vertebra 5	3	3	3	3	3	3	3	3
Thoracic Vertebra 6	3	3	3	3	3	3	4	4
Thoracic Vertebra 7	4	4	4	4	3	3	4	4
Thoracic Vertebra 8	4	4	4	4	3	3	4	4
Thoracic Vertebra 9	4	4	3	3	3	3	4	4
Thoracic Vertebra 10	6	6	3	3	4	4	4	4
Thoracic Vertebra 11	5	5	3	3	4	4	4	4
Thoracic Vertebra 12	5	5	3	3	4	4	4	4
Thoracic Vertebra 13	5	5	3	3	4	4	5	5
Thoracic Vertebra 14	6	6	3	3	4	4	5	5
Thoracic Vertebra 15	6	6	4	4	4	4	5	5
Lumbar Vertebra 1	5	5	4	4	4	4	4	4
Lumbar Vertebra 2	5	5	4	4	4	4	4	4
Lumbar Vertebra 3	4	4	4	4	4	4	4	4
Lumbar Vertebra 4	4	4	5	5	4	4	4	4
Lumbar Vertebra 5	4	4	5	5	4	4	4	4
Lumbar Vertebra 6	4	4	5	5	4	4	4	4
Lumbar Vertebra 7	0	0	5	5	0	0	0	0
Sacral Vertebra 1	5	6	2	2	2	2	2	2
Sacral Vertebra 2	6	7	3	3	3	3	2	2
Sacral Vertebra 3	7	7	4	4	4	4	2	2
Sacral Vertebra 4	7	7	7	7	6	6	2	2
Caudal Vertebrae	7	7	7	7	6	6	2	2
Rib 1	1	1	1	1	1	1	1	1
Rib 2	1	1	1	1	1	1	1	1
Rib 3	1	1	1	1	1	1	1	1
Rib 4	1	2	3	2	1	1	2	1
Rib 5	1	2	4	2	1	4	2	2

Rib 6	2	2	4	2	2	2	2	2
Rib 7	2	2	5	3	2	2	4	2
Rib 8	2	2	5	3	2	2	4	2
Rib 9	2	3	5	4	2	2	4	2
Rib 10	2	4	5	4	2	2	5	2
Rib 11	3	5	6	4	2	2	5	2
Rib 12	4	5	6	5	2	2	5	2
Rib 13	4	6	6	5	2	2	5	2
Rib 14	4	6	6	6	2	2	6	3
Rib 15	5	6	6	6	2	2	6	3
Clavicle	1	1	1	1	1	1	1	1
Scapula	3	3	5	5	3	3	5	3
Humerus	2	2	2	2	2	2	3	2
Ulna	2	2	3	1	2	2	3	2
Radius	2	2	1	1	2	2	2	2
Carpals	2	2	2	2	2	2	2	1
Metacarpals	2	2	2	2	2	3	3	1
Phalanges (forelimb)	2	2	3	1	2	2	3	1
Ilium	5	5	3	3	4	2	2	2
Ischium	2	1	2	2	2	2	2	2
Pubis	3	3	2	2	2	2	2	2
Femur	2	3	2	2	2	3	1	1
Patella	2	2	2	2	2	2	1	1
Tibia	2	4	2	2	2	3	1	1
Fibula	2	3	2	2	2	3	1	1
Tarsals	2	3	2	2	2	2	1	1
Metatarsals	2	4	2	2	2	2	1	1
Phalanges (hindlimb)	2	5	2	2	2	2	1	1

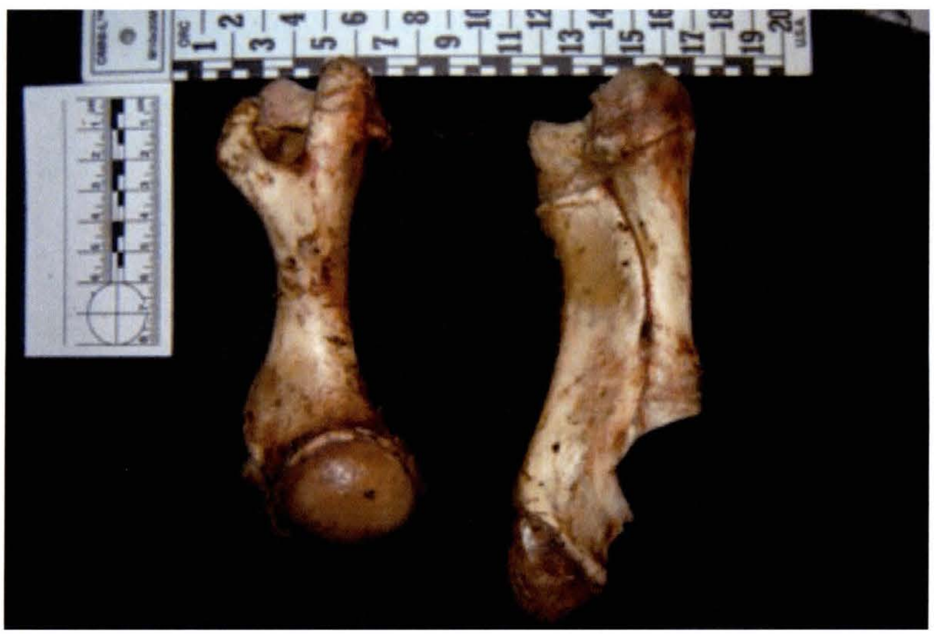
APPENDIX F

VISUAL LOG OF GREEN COLORATION ON T3/PRESSURIZED REMAINS OBSERVED DURING ANALYSIS AT THE FIRE SITE



(Figure 96) The hard palate (i.e., soft tissue covering the palatal plate of the maxilla).

(Figure 97) Acetabular labrum and articular surface soft tissues of the acetabulum.



(Figure 98) Soft tissue of right distal radius.

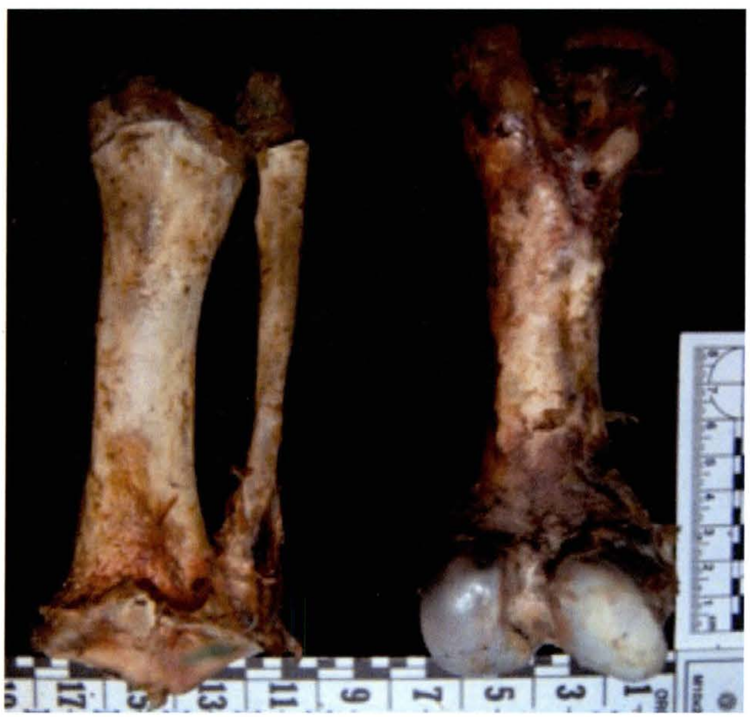
(Figure 99) Soft tissues of the right carpals, metacarpals, and phalanges.

(Figure 100) Soft tissue of right distal femur.

(Figure 101) Soft tissue on exterior blade of left scapula.

(Figure 102) Proximal and distal ends of left radius and ulna.

(Figure 103) Soft tissues of the left carpals, metacarpals, and phalanges.



(Figure 104) Proximal and distal ends of left tibia and fibula.

(Figure 105) Soft tissues of the left tarsals, metatarsals, and phalanges.

APPENDIX G

OBSERVED POSTURING AND BONE EXPOSURE OF PIG REMAINS COMPARED TO EXPECTED CHANGES IN THE PUGILISTIC POSTURE AND SITES OF BONE EXPOSURE FOR HUMAN REMAINS

Area of Body	**Pugilistic Posture**	**Observed Sites of Bone Exposure**	**Pope 2007 Site of Bone Exposure**
Head		Frontal, sagittal, zygomatic, parietal, occipital (along superior arch), and anterior dentition. Possible curved tissue regression fractures on anterior portions of the lateral mandibular body (i.e., sides of the jaw).	Earliest exposure to areas of the forehead and vault. Followed by areas of the nose, brow ridge, upper cheeks (zygomatics), mandible, and anterior teeth. P.179, P.186
Hand and Wrist	Fingers flex	Dorsal surface of phalanges.	Dorsal surface of phalanges. P. 308
	Hand flexes	Dorsal surfaces of metacarpals and phalanges.	Dorsal surfaces of the metacarpals and phalanges. P. 308
	Wrist flexes	Dorsal surfaces of metacarpals and phalanges.	Dorsal surfaces of the phalanges, metacarpals, carpals. P.308
Lower Arm (Radius and Ulna)	Flexure of the wrist	Distal radius and ulna.	Distal radius and ulna. P.319
	Elbow flexes	--	Proximal radius and ulna. P. 319
Upper Arm (Humerus)	Elbow flexes	Distal humerus.	Distal humerus (primary site). P.338
	Muscles burn	--	Deltoid tuberosity. P.338
	Shoulder flexes	Proximal humerus.	Proximal humerus (secondary site). P.338

Area of Body	**Pugilistic Posture**	**Observed Sites of Bone Exposure**	**Pope 2007 Site of Bone Exposure**
Foot and Ankle	Toes flex and curl	Dorsal surfaces of phalanges (proximal).	Dorsal surfaces of phalanges and joints. P.360
	Foot flexes and arches	Dorsal surfaces of metatarsals (proximal-lateral).	Dorsal surfaces of the metatarsals and tarsals. P.360
	Ankle plantar flexion	Dorsal surfaces of metatarsals, distal tibia.	Dorsal surfaces of the metatarsals, tarsals, distal tibia. P.360
Lower Leg (Tibia and Fibula)	Ankle flexes	Distal tibia and distal fibula (anterior-lateral).	Distal tibia, fibula. P.372
	Anterior exposure	Anterior crest of tibia.	Anterior crest of the tibia. P. 372
	Knee flexes	Proximal and anterior tibia, patella (anterior-lateral).	Proximal and anterior tibia. P. 372
Upper Leg (Femur)	Knee flexes	Distal femur.	Distal femur. P.398
	Muscles burn	Shaft of femur.	Femoral shaft. P.398
	Hip flexes	Proximal femur at greater trochanter.	Proximal femur at the greater trochanter. P.398
Upper Torso (anterior portion)	Organ exposure	--	Lungs. P.418
	Anterior exposure	Lateral ribs.	Lateral and anterior ribs. P.418
	Anterior exposure	Lateral ribs.	Ribs, clavicle, sternum. P.418
Upper Torso (posterior portion)	Posterior exposure	Scapular spine (acromion process) and dorsal border (superior border, superior angle, medial border).	Scapular spine and acromion process. P.422
	Posterior exposure	Spinous processes of vertebrae.	Spinous processes of vertebrae. P.422
Lower Torso and Pelvis	Anterior exposure	Iliac crests of ilium.	Iliac crests. P.431
	Anterior exposure	Pubic symphyses of pubis.	Pubic symphysis. P.431

Area of Body	**Pugilistic Posture**	**Observed Sites of Bone Exposure**	**Pope 2007 Site of Bone Exposure**
	Posterior exposure	Spinous processes of lumbar vertebrae and dorsal surfaces of caudal vertebrae.	Spinous processes of lumbar. P.431

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VITA

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