THE ESTIMATION OF BIOLOGICAL PROFILE

FROM UNPROCESSED HUMAN

CREMATED REMAINS

THESIS

Presented to the Graduate Council of
Texas State University-San Marcos
in Partial Fulfillment of
the Requirements

for the Degree

Master of ARTS

By

Teresa Gotay Nugent, B.A.

San Marcos, Texas
December 2010

THE ESTIMATION OF BIOLOGICAL PROFILE

FROM UNPROCESSED HUMAN

CREMATED REMAINS

Committee Members Approved:

____
Elizabeth M. Erhart, Chair

____
Laura C. Fulginiti

____
Steven A. Symes

____
M. Katherine Spradley

Approved:

____
J. Michael Willoughby
Dean of the Graduate College

DEDICATION

Para el amor de mi vida, el que me adora siempre, no sólo cuando le conviene. Te dedico este trabajo porque te lo mereces por cuidarme durante estos últimos dos años y por creer en mí mientras yo luchaba recientemente y en otros años-lejanos ya-cuando luché contra otros desafíos. Quiero agradecerte todo lo que has hecho por mí y por nuestra pequeña familia. Aunque con frequencia estemos lejos el uno del otro o de nuestro hogar, vivimos juntos en mi corazón. (¡Soy Nugent-hasta la muerte!)

ACKNOWLEDGEMENTS

I am grateful to so many people who probably do not even realize that they contributed to this process. Now that this is through, I will make sure they all know how much I appreciate them. In particular, I could not have done it without the influence of those who believe in my abilities and my passion for this field and nurture my heart and mind by meeting my curiosity with patience and generosity.

Also, I would like to go ahead and thank you (whoever you are) even if you were not around when I prepared, collected the data, wrestled with the data, or finally released it into the wild. Consider this preemptive thanks for any opportunities (big or small) that may arise from your reading this work including casual nerd sessions, future employ and dreams come true…

GRACIAS.

This manuscript was (finally) submitted on 9 July 2010.

TABLE OF CONTENTS

Page

ACKNOWLEDGEMENTS v

LIST OF TABLES ix

LIST OF FIGURES xi

ABSTRACT xiii

CHAPTER I 1

I. INTRODUCTION 1

Prior Studies 2

Experimental cremation research and forensic anthropology 3

Commercial cremains research 3

Current Study 5

II. MATERIALS AND METHODS 7

Materials 7

Sample and data 7

Methods 9

Inventory 9

Completeness scoring procedure 15

Estimation of Biological Profile 18

Sex estimation 18

Age-at-death estimation.. 21

Ancestry estimation 22

Descriptive Statistics... 23

III RESULTS 24

Preservation of Elements.. 24

Bone preservation frequency and degree of preservation 24

Standards versus amended completeness scoring system 28

Macroscopic Observations 29

Cranial 32

Postcranial.. 35

Biological Profile 38

Sex estimation 38

Cranial based sex estimation.. 39

Pelvic based sex estimation.. 42

Postcranial metric sex estimation 44

Age-at-death estimation.. 46

Ancestry estimation 49

Summary 53

IV DISCUSSION... 56

Preservation 57

Overall characteristics 57

Color signatures... 58

Calcination 60
Evidence of Normal Burn Patterns 61
"The myth of flesh." 61
Trabecular or cortical? 62
Tissue shielding 64
Burned bone fractures and biomechanical signatures 66
Body position 69
Biological Profile 71
Sex estimation 72
Age-at-death estimation 75
Ancestry estimation 79
V. CONCLUSION 83
APPENDIX A: DATA COLLECTION SHEETS I-IV FOR UNPROCESSED CREMAINS 88
APPENDIX B: KEYS FOR DATA COLLECTION SHEETS I-IV 93
APPENDIX C: BIOLOGICAL PROFILE SCORES 98
APPENDIX D: RAW DATA 103
REFERENCES 112

LIST OF TABLES

Table Page

1a. Cranial elements analyzed in current study 14

1b. Postcranial elements analyzed in current study 14

2. Completeness score frequency for all elements (N=19) 25

3. *Standards* scale completeness score frequency distribution (N=19) 26

4. Amended scale completeness score frequency distribution (N=19) 27

5. Completeness score frequency distributions for scored sample 28

6. Comparison of sex estimation methods (N=19) 38

7. Cranial sex estimate classification rates (N=19) 39

8. Distribution of amended scale completeness scores with classification rates for cranial sex estimation morphology 40

9. Pelvic sex estimate classification rates (N=19) 42

10. Distribution of amended scale completeness scores and classification rates for pelvic sex estimation morphology 43

11. Postcranial metric sex estimate classification rates (N=19) 44

12. Distribution of amended scale completeness scores for postcranial measurements for sex estimation 46

13. Age-at-death estimate classification rates (N=19) 46

14. Distribution of amended scale completeness scores and classification rates for pelvic age-at-death estimation morphology 47

15. Scored nonmetric traits and ancestry estimation results (N=19) 51

16. Final estimated versus actual age-at-death, sex, and ancestry (N=19)........ 55

Tables in Appendices:

CA. All sex estimation methods results and comparison (N=19)........................ 98

CB. Cranial morphology observations for sex estimation (N=19)....................... 99

CC. Pelvic morphology observations for sex estimation (N=19)....................... 100

CD. Metric analyses with sectioning points (mm) and classification rates for sex Estimation (N=19).. 101

CE. All age-at-death estimation methods results and comparison (N=19) 102

DA. Combined *Standards* Cranial Inventory.. 104

DB. Frequency of *Standards* Scores – Cranial.. 105

DC. Combined Amended Cranial Inventory... 106

DD. Frequency of Amended Scores – Cranial.. 107

DE. Combined *Standards* Postcranial Inventory.. 108

DF. Frequency of *Standards* Scores – Postcranial.. 109

DG. Combined Amended Postcranial Inventory 110

DH. Frequency of Amended Scores – Postcranial 111

LIST OF FIGURES

Figure **Page**

1. Sample specimen 11

2. Tools used for sorting and analysis 12

3. Left auricular surface fragments 19

4. Completeness score frequency distributions 29

    4a. Cranial 29

    4b. Postcranial 29

5. Comparison of associated “ash” color of cremains 31

6. Bone fragments 31

7. Bone fragments and “ash” 31

8. Miscellaneous cremation artifacts 32

9. Curled calcined cranial fragments 33

10. Left and right parietal bone fragments showing delamination and cranial sutures 33

11. Cranial fragments with autopsy cut marks 34

12. Comparison of proximal femur preservation 37

    12a. Posterior view 37

    12b. Anterior view 37

12c. Isolated femoral head ... 37
13. Mastoid process-male ... 41
14. Hook-like nuchal crest-male ... 41
15. Supraorbital margin-female ... 41
16. Auricular surface and greater sciatic notch-female, age 58 ... 43
17. Humeral epicondylar breadth-male ... 45
18. Pubic symphyses ... 48
18a. Male-age 42 ... 48
18b. Male-age 84 ... 48
19. Poorly preserved auricular surface fragment-age 70, male ... 48
20. Degenerative marginal lipping of lumbar vertebrae-age 71, male ... 49
21. Frequency of nonmetric trait observations for ancestry estimation (N=19) ... 51
22. Nonmetric traits ANS and INA ... 52
23. Nonmetric traits SPS and partial NBC ... 52
24. Nonmetric traits ANS, INA, and (approximated) NAS ... 52

THE ESTIMATION OF BIOLOGICAL PROFILE

FROM UNPROCESSED HUMAN

CREMATED REMAINS

by

Teresa Gotay Nugent, B.A.

Texas State University-San Marcos

December 2010

SUPERVISING PROFESSOR: ELIZABETH ERHART

Despite the recent increase in studies that involve the experimental burning of human remains and analysis of heat-induced change both taphonomic and traumatic, research focused on the analysis of thoroughly cremated or calcined bone is rare. The intent of the current study is to add to the existing literature and augment methodologies for the interpretation of severely burned fragmentary remains such as those from mass fatality contexts in which explosions or fire destroy the traditional means for identification. Earlier

commercial cremains research focused on mechanically pulverized or processed cremains, post-cremation weights, differences between sexes and molecular composition. In contrast, this research studies human remains cremated in a commercial crematory retort without pulverization that yielded observations of recognizable skeletal elements that survived the firing process. Therefore, this commercial cremains research can be better applied to forensic fire contexts.

The unprocessed cremains of 19 individuals were carefully inventoried and analyzed macroscopically. This study focused on the skeletal elements that lend themselves to the determination of biological profile (e.g. mastoid process, supraorbital ridge, greater sciatic notch) and included the degree of preservation of such elements. A 5-point completeness scoring system was developed to better reflect the variable preservation throughout the sample. Estimates of sex, age-at-death and ancestry were made when preservation permitted. However, the marked destruction of the facial skeleton did not allow for the observation of nonmetric traits necessary for ancestry estimation and the estimation of stature was beyond the scope of the current study. Sex was estimated correctly in 88% of the 18 cases in which preservation allowed for an estimate. Age-at-death estimation was correct in only 68% of the 16 cases for which the survival of the auricular surface and pubic symphyses allowed for the generation of an age range.

The successful application of traditional anthropological techniques such as auricular surface aging and metric sexing of the postcranial skeleton, to the calcined remains in the current study demonstrates that valuable information can still be gleaned from a human body that has undergone sustained exposure to temperatures exceeding 870˚C(1600˚F). These findings are encouraging because they suggest that the concept of burned beyond recognition is a myth rather than the inevitable result of fire acting upon human remains.

CHAPTER I

INTRODUCTION

Forensic anthropologists are skeletal biologists well versed in the recognition, recovery and interpretation of human skeletal remains. However, forensic anthropologists are not typically among the investigators present at fatal fire scenes. Forensic anthropologists have used their specialized skills to recover and successfully identify human remains several weeks and even years after a fire event in which law enforcement personnel had already recovered remains (Bass 1984). For instance, sound forensic archaeological techniques applied to a 22 year old crime scene yielded 420 identifiable burned bone fragments from which the minimum number of individuals (MNI), sex, and age-at-death were estimated (Dirkmaat 2002). In another case, Owsley (1993) positively identified the severely fragmented and calcined remains of a homicide victim 7 years after his death based on unusual morphology of the frontal crest.

Integral to the process of human identification is the development of a biological profile, which consists of estimates of the age-at-death, sex, ancestry and stature suggested from the analysis of skeletal remains. Cases that involve extreme fragmentation of bone, such as fatal fire contexts, transportation accidents and clandestine cremations present some of the most difficult

Severely burned or calcined human remains, can offer diagnostic possibilities with regard to sex and age in addition to individualizing characteristics and evidence of antemortem injuries and pathology (Bohnert et al. 1998).

The highly fragmentary nature of cremains from commercial crematoria may mimic those encountered in mass fatalities such as, aircraft crashes, train wrecks, multiple vehicle collisions, and explosions, in which fragments are often commingled and spread over a large area, and may also resemble forensic contexts such as a fire intended to destroy human remains in the hopes of concealing the identity of the victim and associated evidence of a crime in a tended fire (Fairgrieve 2007). However, burning is an inefficient way to completely dispose of human remains. Although many people imagine that a human body turns to ashes in a commercial crematory retort, cremated remains or “cremains” are actually burned skeletal remains that have been mechanically processed into tiny fragments suitable for scattering or inurnment. Research has proven that several skeletal elements survive exposure to extreme heat and remain recognizable as human (Stewart 1979; Bohnert et al.1998; Klepinger 2006).

Prior studies

Cremation studies have appeared in the forensic anthropology literature since the early days of the discipline and have their roots in archaeology (Baby 1954; Stewart 1979; Symes et al. 2008).

Experimental cremation research and forensic anthropology

Since the 1940's anthropologists have conducted experimental research on burned animal bone and archaeological and modern human bone (Baby 1954; Binford 1972; Thurman and Willmore 1980; Webb and Snow 1981; Buikstra and Swegle 1989) in order to understand details about the fire event such as the maximum temperature, extent of contact with the flames, the condition of the body prior to burning (fleshed vs. dry) and the position of the body during the fire event from the differential burning. Other experimental research included laboratory studies using SEM inspection and X-ray diffraction to determine heat-related shrinkage in burnt animal bone (Shipman et al. 1984), and infra-red spectroscopy to better understand the recrystallization and subsequent fragmentation in archaeological and experimentally burned animal bone (Stiner et al.1995). More recently, Bohnert et al. (1998) observed the commercial cremation of 15 human bodies and documented the chronology of heat related changes and temperature in 10 minute increments. Pope (2007) burned 30 bodies in various fire environments and documented the influence of the relationship between soft tissue and bone upon normal burn patterns.

Commercial cremains research

The increased use of cremation over burial as the preferred method of final disposition for many Americans has caused an increase in the number of occasions that forensic anthropologists are called upon to analyze commercially cremated remains (Murray and Rose 1993; Warren and Maples 1997; Murad

1998). According to the Cremation Association of North America (CANA) (2008) the percentage of all recorded deaths in America that were cremated increased by nearly 10% from 17.13% in 1990 to 26.19% in 2000 and the projection for 2010 is 39.03% and expected to increase to 58.89% by 2025 (CANA Final 2006 Statistics 2008).

Commercial cremains have been analyzed in the context of the inappropriate disposal of mortuary remains, including investigation of the disputed identity of remains and commingling using macroscopic observation and radiographs (Murray and Rose 1993; Kennedy 1996), and in examinations of deliberate contamination of cremains with nonhuman materials or animal bones using elemental analysis (Brooks et al. 2006). Variation in cremains weights has also been the subject of analyses in the pursuit of detectable sexual dimorphism or other potential identifying parameters in cremated remains (Warren and Maples1997; Bass and Jantz 2004).

Researchers have also focused on developing statistical methods for sex estimation using bones burned in commercial crematoria. Gejvall (1970) compared prehistoric cremains to bone cremated in an older and newer commercial crematory and developed statistical methods for sex estimation using a series of measurements of cortical wall thickness from the cranial vault, humerus, femur, and radius based on the presence of thinner cortical walls in females versus males. Van Vark (1975, 1996) developed multivariate statistical methods to aid in the estimation of sex and ancestry from cremated remains to determine the degree of shrinkage based on the measurements of the mandibular ramus region, second cervical vertebra (axis), proximal humerus, proximal radius, proximal ulna, calcaneus and patella, and cortical thickness measurements (similar to those developed by Gejvall) that were taken before and after burning in a commercial crematorium.

Current Study

This paper presents the results of a morphoscopic analysis of unprocessed human cremated remains from commercial crematoria with a focus on the preservation of specific skeletal elements and landmarks, and the potential for the estimation of sex, age, and ancestry from calcined fragmentary remains. The goal of this study is to maximize the amount of information that can be gleaned from fragmentary remains in order to increase the likelihood of accurate estimations of the biological profile for forensic anthropologists working with burned human remains. The current study will augment the existing literature and methodologies and provide investigators with important information on the quality of the remains that they can expect to encounter in contexts in which thermal destruction and extreme fragmentation dominate the condition of the remains.

During commercial cremation a body undergoes constant heat exposure, 1-2 hours in duration, at temperatures between 950˚C – 1100˚C (1800˚F-2100˚F), in an oxygen rich environment as opposed to the typical fluctuations in heat and intensity found in most fires (DeHaan 2007). Although cremation oven temperatures are similar to those reached in house fires and vehicle fires, the variables of fuel and influence of fire suppression techniques are minimized or absent completely in the crematory context (Bohnert et al. 1998). In spite of these differences bones in a commercial crematorium may best resemble real fire conditions (DeHaan 2007). Therefore, it seems justified to apply the observations of commercially cremated remains to the forensically significant effects of fire (Bohnert et al. 1998). Additionally, the commercial crematory conditions minimize the effects of confounding variables such as non-human debris that are encountered in field studies and fatal fire scenes that can mimic human remains.

CHAPTER II

MATERIALS AND METHODS

Materials

Sample and data

Eighteen commercially cremated specimens from the William M. Bass Donated Skeletal Collection at the Forensic Anthropology Center at the University of Tennessee at Knoxville were evaluated in order to assess biological profile over a nine-day period from June 16, 2009 – June 26, 2009. The William M. Bass Donated Skeletal Collection contains over 650 known individuals who either preregistered during life to donate their bodies or were donated by their families or a medical examiner (www.utk.edu: 2005). Individuals that are potentially or positively infected with diseases such as MRSA (methicillin-resistant *Staphylococcus aureus*) or hepatitis are considered ineligible for natural decomposition studies at the Forensic Anthropology Center's outdoor anthropological research facility (Rebecca Wilson pers. comm.). Due to the risks of exposure from infectious agents, such individuals are cremated prior to donation.

The cremated remains, or cremains, of 27 individuals are housed at the William M. Bass Donated Skeletal Collection. Of these cremated remains, nine are mechanically pulverized and eighteen are unprocessed. For the purposes of this study, the analysis was limited to the unprocessed cremated remains (N=18). The sample (N=18) consisted of known individuals whose age, sex, and ancestry were recorded prior to cremation. The cremations in this collection were all conducted in a standard crematory setting at temperatures between 870ºC-982ºC (1600ºF-1800ºF) for similar duration for approximately 2-3 hours (Bass and Jantz 2004). The cremated remains of each individual are contained in separate boxes, each measuring .762m x .3048m x .2286m with a volume of .053094m^3. Each box is labeled with a University of Tennessee Identification Number (UTID No.) that includes the individual’s age, sex, and ancestry.

On January 23, 2010, a commercially cremated specimen from the Donated Skeletal Collection of the Forensic Anthropology Center at Texas State University-San Marcos (FACTS) was added to the sample. The Willed Body Donation Program at FACTS also declines donations of individuals who have infectious diseases, this particular individual tested positive for tuberculosis (M. Katherine Spradley pers. comm.). The unprocessed cremated remains of this individual arrived at the FACTS facility double bagged in four separate boxes, each measuring .2286m x .1778m x .1143m with a volume of .004645m^3. This additional specimen (N=1) was analyzed at the Texas State Grady Earl Forensic Anthropology Research Laboratory (GEFARL) in San Marcos, TX, using the methods described for the other specimens.

To ensure a blind analysis of the sample and reduce bias, the University of Tennessee Forensic Anthropology Center lab personnel and Texas State Department of Anthropology staff concealed the demographic information or name on each box label before data were collected. However, the UTID and FACTS numbers remained visible and were recorded in each case in order to minimize confusion and maintain consistency between this study and the records of the skeletal collection. Both the University of Tennessee Forensic Anthropology Center and the Forensic Anthropology Center at Texas State have records for each donated individual and the known sex, age at death, and ancestry data were revealed to the investigator only after the initial data collection and analysis were completed.

Methods

Inventory

The contents of each of the 19 boxes of unprocessed human cremated remains were inventoried in order to determine the degree and frequency of preservation of skeletal elements that are useful in creating a biological profile. Biological profile in this study included sex, age-at-death and ancestry. The estimation of stature was beyond the scope of the current study due to time limitations and the extreme fragmentation and marked heat related deformation of the skeletal material.

Each box was examined individually so as not to commingle the remains or confuse their origin. Prior to opening the box, the UTID number or FACTS number was written on a dry erase board. A photograph of the open box and the dry erase board was taken to identify each specimen. All cremains were photographed with the same digital camera (Canon A2000 ISO). In the event that the cremated remains were in another container within the box such as a bag, the inner container was photographed before and after the author opened it. The initial photograph with the individual identification number simplified organization of the digital photographs at each day's end and ensured that photographs were not confused between boxes. The initial I.D. photograph of each box also provided a valuable record of the overall condition of the undisturbed cremains (Fig. 1).

Due to the fragmentary nature of burned remains, the inventory procedures in this study were modeled after the inventory procedures for relatively complete skeletons found in Buikstra and Ubelaker's (1994) *Standards for Data Collection From Human Skeletal Remains* (hereafter "*Standards"). * Data collection sheets (Appendix A) were developed after the *Standards* "*Inventory recording form for complete skeletons*" (Chapter 2: Attachment 1) and "*Inventory recording form for commingled remains and isolated bones*" (Chapter 2: Attachment 2). The author developed cranial and postcranial unprocessed cremains inventories in which the side and percent completeness of each bone could be recorded. Space was also provided for recording degenerative changes, skeletal age markers, or pathology observed on the selected bones during the inventory.

FIG. 1—*Sample specimen. Reveals typical preservation and curation of cremains.*

All identifiable pelvic, cranial, mandibular, and select postcranial bones chosen for inclusion in this study were separated from the remainder of the fragments based on the presence of recognizable landmarks and overall appearance. Large fragments and other recognizable elements located near the surface were the first to be removed and placed in trays provided by the Forensic Anthropology Centers at Tennessee and Texas State. Any non-osseous materials found among the cremains, such as staples and coffin hardware, metal rivets and buttons, and surgical appliances were also removed from the box and kept separate from the cremains. Then the remaining bone fragments and “ash” were carefully sorted in order to expose additional fragments that were relevant to this study.

In addition to manual sorting, a combination of tools (Fig. 2) was used to sort through the cremains- these include a 3-inch bamboo paddle brush, and a 1-inch long-bristle paintbrush. As fragments of skeletal elements were found and removed from the box, each was cleaned of residual ash with the use of the 1-inch paintbrush or a smaller #6 paintbrush (Fig. 2). Soft, fine-bristled paintbrushes were used to expose the fine details of individual fragments for photography while minimizing additional damage to the cremains. A 4X magnifying hand lens (Fig. 2) was also used to examine the fragments; particularly in order to see features on the pubic symphyses and auricular surfaces.

FIG. 2—*Tools. Shows tools used for sorting and analysis: (a) paintbrushes; (b) hand lens; (c) clear ruler*

Care was taken to conduct the sorting process without compounding the existing level of fragmentation. Identifiable fragments were divided into three groups (cranial fragments, pelvic and vertebral fragments, and remaining postcranial fragments) and placed on separate trays to expedite the inventory process. The elements were not laid out in anatomical position; instead each element was held together by hand in order to approximate completeness and examined on its own. Tables 1*a* and 1*b* show the cranial and postcranial bones that were included in the "unprocessed cremains inventories", respectively. These elements were selected for inclusion in the inventory based on their utility as potential indicators of sex, age-at-death and ancestry. The presence or absence of the features/landmarks listed for each bone in the tables was often the basis for identification of the burned fragments. For instance, when a fragment was encountered that included the trochlea of the distal humerus, this fragment would be extracted from the box of cremains, sided, and recorded on the inventory sheet in the blank marked "distal humerus". Conversely, a fragment that included an olecranon process of the proximal ulna would not be separated from the cremains nor recorded in the inventory because the ulna was not included in the inventory developed for this study.

Table 1a—*Cranial elements analyzed in current study.*

BONE	FEATURE(S)/LANDMARK(S)
Frontal	Supraorbital ridges, frontal crest, temporal lines, frontal sinus, glabellar region, coronal suture
Parietal	Meningeal grooves, parietal striae, sagittal suture
Occipital	Occipital condyles, cruciform eminence, foramen magnum, interosseous crest, nuchal area, lambdoidal suture
Temporal	Petrous portion, mastoid process, squamosal suture, mandibular fossa, EAM
Zygomatic	Frontal and temporal processes, zygomaticofrontal suture
Maxilla	Maxillary sinus, alveolar, palatine, and frontal processes, nasal aperture
Mandible	Mandibular condyle, mental eminence, gonial angle, ramus, alveolus

Table 1b—*Postcranial elements analyzed in current study*.

BONE	FEATURE(S)/LANDMARKS
Clavicle	
Humerus	Proximal and Distal Epiphyses (humeral head, medial and lateral epicondyles, olecranon fossa, trochlea)
Os Coxae	
Ilium	Iliac Crest
Ischium	Ischiopubic Ramus, Ischial Tuberosity
Pubis	Pubic Symphysis
Acetabulum	
Auricular Surface	Preauricular sulcus, Retroauricular Area, Apex
Femur	Proximal and Distal Epiphyses (femoral head, femoral neck, greater and lesser trochanters, lateral and medial condyles, patellar surface)
Patella	Lateral and Medial Articular Facets
Tibia	Proximal and Distal Epiphyses (lateral and medial condyles, intercondylar fossa)
Vertebrae	Cervical, Thoracic, Lumbar (Vertebral bodies, spinous processes)

Additional data collection sheets (Appendix A) were developed for the recording of standardized pelvic and cranial characteristics used to estimate sex, age-at-death, and ancestry. These biological profile data collection sheets were modeled after the "*Adult sex/age recording form*" in Buikstra and Ubelaker (1994: Chapter 3: Attachment 11) and Hefner (2007). A key for each data sheet was developed to clarify the definitions and scoring systems used in order to facilitate the use of the data sheets in this and subsequent research (Appendix B).

Completeness scoring procedure

The unprocessed cremains inventory incorporated the fragmentary remains inventory procedure described in Buikstra and Ubelaker (1994:7). Once an element was identified and sided, the completeness was determined and recorded using the following scale:

blank = missing
1 = > 75% present = complete
2 = 25% - 75% present = partial
3 = < 25% present = poor

The completeness scores are designed to reflect the "information value" of individual skeletal elements in archaeological investigations into demography, pathology, and genetic relationships (Buikstra and Ubelaker 1994).

Buikstra and Ubelaker (1994:6) state that a bone or designated section of a bone is defined as complete, "when the majority of the element is present and available for observation of diagnostic features". In this study, complete bones were scored as "1", while a score of "2" or partial indicated "a reduced potential for attribute observation". A score of "3" indicated that all the fragments combined represent less than 25% of the whole bone or “badly eroded or very incomplete materials”. In the *Standards* scale, the temporomandibular joint surfaces are scored separately from the temporal bone and mandible. In this study the fused cranial bones (frontal, occipital, maxilla, and mandible) were sided in order to more accurately reflect the overall preservation of the skull and more readily explain why certain observations are restricted to one side of the skull.

For the purposes of this study, in addition to the *Standards* scale, an amended scale with additional values was developed to more accurately reflect the completeness of each element. This amended scale was based on the *Standards* scale (Buikstra and Ubelaker 1994) and includes two additional levels of completeness. Each element was scored with both the *Standards* scale and the following amended 5-point scale:

blank = missing
1 = >75% present = complete
2 = 50% - 74% present = mostly complete
3 = 25% - 49% present = partial
4 = 11% - 24% present = mostly poor
5 = < 10% present = poor

When using both scales, the determination of the percent complete was based on two factors: the presence or absence of an element and its degree of preservation. The degree of preservation describes: (a) how much of an element survived the cremation process; (b) the presence or absence of skeletal landmarks; and (c) the potential for correct side identification. As in the *Standards* scale, complete bones are scored as “1”. However, the amended scale differs from the *Standards* scale in the scoring of partially complete elements and includes three different scores: “2”, ”3”, and ”4” to reflect 11% - 75% complete and a score of “5” to indicate < 10% present or poor preservation.

In the amended scale, identifiable elements that remained complete (> 75% present) after the cremation process and could be sided are scored as “1”. Identifiable elements that were mostly complete (50% – 75% present) are scored as “2”. Identifiable elements for which less than half remained (25% - 49% present) were considered partial and scored as “3”. Elements that were identifiable but mostly poorly preserved (10% - 24% present) were scored as “4”. Both isolated and multiple fragments with little or no informative landmarks that could not be sided were scored as “5”. All fragments that were identifiable based on the presence of certain landmarks but could not be sided were recorded on the inventory as “side unknown”.

Prior to conducting this inventory, it was assumed that all skeletal materials would be present and accounted for with minimal or no commingling of individuals leading to an MNI of one for each cremation. Additionally, intentional commingling is against the law in most states (Murad 1998). This assumption was challenged in two instances when extraneous skeletal elements were found in the cremains indicating commingling with another individual. Fragments from a previous cremation(s) may have been overlooked by crematory staff and remained in the retort during the cremation of another individual.

Estimation of Biological Profile

In order to determine whether or not a biological profile of sex, age-at-death, and ancestry could be estimated from observations of the elements that preserved, different combinations of the following age, sex, and ancestry techniques were applied to each specimen as preservation allowed:

Sex estimation

Sex estimation was based on observations of the fragmentary os coxae, because the pelvis is the most reliable and accurate indicator for discrete traits due to the marked sexual dimorphism from pubescent growth changes and the anatomical requirements of childbearing (SWGANTH draft-unpublished, Phenice 1969, France 1998). When possible, the ischium, acetabulum, and auricular surface were held together for observation in order to approximate anatomical completeness (Fig. 3).

The ventral arc, subpubic concavity, and ischiopubic ramus ridge of the subpubic region of the *os coxae* were scored using the scale for sex determination in Buikstra and Ubelaker (1994:16):

blank = Unobservable
1 = Female
2 = Ambiguous
3 = Male

A score of “1” indicated the presence of a ventral arc, a defined subpubic concavity, and a ridge on the ischiopubic ramus; conversely a score of “3” indicated the absence of a ventral arc and subpubic concavity and a flat and broad ischiopubic ramus (Phenice 1969). A score of “2” indicated ambiguity in the expression of the criteria (Buikstra and Ubelaker 1994).

FIG. 3—*Left auricular surface fragments. Shows greater sciatic notch and preauricular sulcus. (28-06D-Female, 59 years old)*

Fragments of the greater sciatic notch were used for sex estimation because it is markedly sexually dimorphic and often preserves better than the pubic region because it is more resistant to postmortem damage (Walker 2005). The greater sciatic notch was also scored on a scale from 1-5 as described in Buikstra and Ubelaker (1994:18), where “1” indicates the broadest and shallowest extreme, which represents typical female morphology and a score of

“5” represents an extremely narrow and U-shaped greater sciatic notch, which is more common in males (Walker 2005). Additionally, the presence or absence of the preauricular sulcus was also recorded when observable (Buikstra and Ubelaker 1994).

Using sliding calipers, humeral head diameter, humerus epicondylar breadth, femoral head diameter, femur bicondylar breadth, and tibia bicondylar breadth were measured due to their potential utility as sex indicators (Dwight 1905; Spradley and Jantz 2003). The measurements were compared to univariate sex estimation sectioning points with classification rates of between 82-90% (Spradley and Jantz 2003). Observations of robusticity and rugosity at muscle attachment sites on the elements included in the unprocessed cremains inventory were also noted.

The size and shape of the following cranial features: mastoid process, brow ridge and glabellar region, supraorbital margin, supraorbital ridge, mental eminence, and nuchal area of occipital, were recorded and scored using the 5-point scale in Buikstra and Ubelaker (1994:20), where “1” indicates minimal expression of the specific cranial morphology, which coincide with more gracile or typically female features and a “5” indicates maximal expression and coincides with robusticity and large overall size typical of male individuals.

Once all of the above observations were made and recorded, the scores for each individual were combined and the individual was assigned to one of the following categories (Buikstra and Ubelaker 1994):

Undetermined Sex. Insufficient data are available for sex determination (-).
Female. There is little doubt that the structures represent a female (F).
Probable Female. The structures are more likely female than male (F?).
Ambiguous Sex. Sexually diagnostic features are ambiguous (?).
Probable Male. The structures are more likely male than female (M?).
Male. There is little doubt that the structures represent a male (M).

Age-at-death estimation

The auricular surface was analyzed using the technique developed by Lovejoy et al. (1985). The presence or absence and degree of the following characteristics were noted: grain and density, porosity, billowing, striae, retroauricular activity, and transverse organization. Due to poor preservation of the pubis, pubic symphyseal aging was limited to only one third of the individuals. The presence or absence of the following features were noted: delimitation of lower and upper extremity, ridge and furrow system, depression of symphyseal face, definition or erosion of the symphyseal rim, marginal lipping, and separation of the pubic tubercle (Suchey and Katz 1998). Extensive close-up photographs were taken of each auricular surface and pubic symphyseal the data fragments, for assignment of each individual to the appropriate age-at-death range after collection process.

Fusion of the iliac crest was also used for age-at-death estimation, where complete fusion indicates an adult individual over the age of 17 years (Webb and Suchey 1985). In addition, the overall absence of epiphyseal lines, evidence of pathology and surgical intervention, degenerative changes in the vertebral column (grouped into cervical, thoracic, and lumbar) and/or joint surfaces, and the presence of edentulous maxillary and mandibular fragments were also taken into consideration when estimating age-at-death in this study.

Once all age-related changes were recorded, each element was assigned to the corresponding age-at-death range, using the techniques listed above. The age ranges for each of the elements of one individual were combined into a broad age range for that individual. In some cases, an additional narrow age range was developed based on auricular surface aging.

Ancestry estimation

Nonmetric cranial traits as defined by Hefner (2007) were used to estimate ancestry. Only a limited number of these traits were observable after the heat related destruction of the thin layer of soft tissue over the facial skeleton and underlying facial bones (Bohnert et al. 1998) due to reduced tissue shielding (Symes et al. 2008). The nonmetric traits recorded in the current study included: anterior nasal spine (ANS) inferior nasal aperture morphology (INA), nasal bone contour (NBC), nasal aperture shape (NAS), posterior zygomatic tubercle (ZT), and supranasal suture (SPS). When poor preservation and fragmentation rendered these traits unobservable, such traits were not scored. Traits such as NAS were observed only after reconstruction of the cranial feature to approximate the shape.

Descriptive Statistics

Descriptive statistic and frequency analyses were run on the unprocessed cremains inventories for both of the completeness scales using PASW 18.0 statistical package in order to determine: (a) which skeletal elements that provide information for age-at-death, sex, and ancestry survived cremation; (b) whether or not there was consistency of preservation of particular elements from one cremation to the next; and (c) whether or not the amended scale actually influenced the results of the current study.

A frequency analysis was run to assess the number of cases in which an element preserved sufficiently to receive a score. An element was included in this count when one or both sides of the element were scored; if both sides of a single element were scored, the observation was still counted as one.

Two additional frequency analyses were performed in order to determine the distribution for each completeness score from the 3-point *Standards* scale and the 5-point amended scale for each skeletal element observed. If both sides of the element were scored, the author took an average score and rounded down to the nearest whole number in order to more accurately reflect the higher completeness level observed. When only one side of an element was scored or the side of the element remained unknown this score was used in the final calculation. Another frequency analysis was performed on the total completeness scores for the entire sample in order to compare the distribution of the completeness scores between the *Standards* scale and the amended scale.

CHAPTER III

RESULTS

Preservation of Elements

The results of this study indicate that it is possible to estimate parts of the biological profile from macroscopic observations of unprocessed human cremated remains depending on the preservation of specific elements. Although the commercial cremation process resulted in thermal destruction and associated fragmentation of the skeleton, sufficient osteological material preserved for successful sex and age-at-death estimation. However, preservation was insufficient for ancestry estimation.

Bone preservation frequency and degree of preservation

Table 2 presents the incidence of identifiable elements for the entire sample (N=19). The category *valid* indicates the total number of cases in which an element was recognizable enough to receive a completeness score. The category *missing* indicates that the element did not receive a score because the preservation of the element was too poor. Based on these data, the cranial vault bones, proximal femur, proximal and distal humerus, ischium and patella were scored most often while the clavicles and gonial angle of the mandible were scored least often. The mental eminence of the mandible was the only feature that did not receive a score.

Table 2—*Completeness score frequency for all elements (N=19).*

Cranial	Frontal	Parietal	Occipital	Occipital Condyle	Temporal	Zygomatic
Valid	19	19	19	6	19	13
Missing	0	0	0	13	0	6

Cranial Cont.	Maxilla	Mandible	Mandibular Condyle	Mental Eminence	Gonial Angle	Clavicle
Valid	12	16	14	0	4	4
Missing	7	3	5	19	15	15

	Proximal Humerus	Distal Humerus	Ilium	Ischium	Pubis	Auricular Surface
Valid	18	18	9	17	8	12
Missing	1	1	10	2	11	7

	Acetabulum	Proximal Femur	Distal Femur	Patella	Proximal Tibia	Distal Tibia
Valid	17	19	17	18	11	10
Missing	2	0	2	1	8	9

Elements that scored a “2” within the *Standards* scale dominated the cremains inventory (Table 3). However, a score of “2” on the *Standards* scale represented elements that ranged from 26% to 74% complete, which made the score too broad and underrepresented the variation in preservation, which necessitated the amended scale (Table 4). In these Tables, *Fq* is the number of times in the entire sample (N=19) that an element received a specific score and *valid %* represents the distribution of the scores.

Table 3— *Standards scale completeness score frequency distribution (N=19).*

Score	Frontal		Parietal		Occipital		Occipital Condyle		Temporal	
	Fq	%	Fq	%	Fq	%	Fq	%	Fq	%
1	1	5.3	2	10.5	1	5.3	1	16.7	1	5.3
2	13	68.4	13	68.4	14	73.7	5	83.3	11	57.9
3	5	26.3	4	21.1	4	21.1			7	36.8

Score	Zygomatic		Maxilla		Mandible		Mandibular Condyle		Gonial Angle		Clavicle	
	Fq	%	Fq	%	Fq	%	Fq	%	Fq	%	Fq	%
1	1	7.7			1	6.3	10	71.4	2	50.0		
2	9	69.2	3	25.0	5	31.3	4	28.6	1	25.0	2	50.0
3	3	23.1	9	75.0	10	62.5			1	25.0	2	50.0

Score	Proximal Humerus		Distal Humerus		Ilium		Ischium		Pubis		Auricular Surface	
	Fq	%	Fq	%	Fq	%	Fq	%	Fq	%	Fq	%
1	2	11.1	2	11.1	1	11.1	2	11.8			1	8.3
2	10	55.6	8	44.4	4	44.4	12	70.6	3	50.0	11	91.7
3	6	33.3	8	44.4	4	44.4	3	17.6	5	50.0		

Score	Acetabulum		Proximal Femur		Distal Femur		Patella		Proximal Tibia		Distal Tibia	
	Fq	%	Fq	%	Fq	%	Fq	%	Fq	%	Fq	%
1	4	23.5					8	44.4				
2	7	41.2	13	72.2	6	35.3	8	44.4	4	36.4	6	60.0
3	6	35.3	5	27.8	11	64.7	2	11.1	7	63.6	4	40.0

% = valid percent (of the elements that received a score); Fq = frequency
Note: The mental eminence and gonial angle of the mandible were omitted because of their poor preservation and minimal information value; The percentages may be one decimal place above or below 100% in some cases due to the rounding SPSS round the number to one decimal.

Table 4—*Amended scale completeness score frequency distribution (N=19).*

Score	Frontal		Parietal		Occipital		Occipital Condyle		Temporal	
	Fq	%	Fq	%	Fq	%	Fq	%	Fq	%
1	1	5.3	2	10.5			1	16.7	1	5.3
2	2	10.5	3	15.8	5	26.3	3	50.0	3	15.8
3	4	21.1	5	26.3	6	31.6	1	16.7	5	26.3
4	7	36.8	5	26.3	4	21.1	1	16.7	6	31.6
5	5	26.3	4	21.1	4	21.1			4	21.1

Score	Zygomatic		Maxilla		Mandible		Mandibular Condyle		Gonial Angle		Clavicle	
	Fq	%	Fq	%	Fq	%	Fq	%	Fq	%	Fq	%
1	1	7.7					9	64.3	1	25.0		
2	5	38.5			1	6.3	4	28.6			2	50.0
3	2	15.4	1	8.3	2	12.5	1	7.1	2	50.0		
4	2	15.4	2	16.7	4	25.0						
5	3	23.1	9	75.0	9	56.3			1	25.0	2	50.0

Score	Proximal Humerus		Distal Humerus		Ilium		Ischium		Pubis		Auricular Surface	
	Fq	%	Fq	%	Fq	%	Fq	%	Fq	%	Fq	%
1	1	5.6	1	5.6	1	11.1	1	5.9			1	8.3
2	2	11.1	3	16.7			2	11.8	2	25.0		
3	5	27.8	2	11.1	2	22.2	6	35.3			2	16.7
4	6	33.3	6	33.3	3	33.3	5	29.4	2	25.0	9	75.0
5	4	22.2	6	33.3	3	33.3	3	17.6	4	50.0		

Score	Acetabulum		Proximal Femur		Distal Femur		Patella		Proximal Tibia		Distal Tibia	
	Fq	%	Fq	%	Fq	%	Fq	%	Fq	%	Fq	%
1	2	11.8					7	38.9				
2	3	17.6	2	10.5	2	11.8	2	11.1	1	9.1		
3	4	23.5	6	31.6	1	5.9	6	33.3			3	30.0
4	3	17.6	6	31.6	3	17.6	2	11.1	3	27.3	4	40.0
5	5	29.4	5	26.3	11	64.7	1	5.6	7	63.6	3	40.0

% = valid percent (of the elements that received a score); Fq = frequency
Note: The mental eminence and gonial angle of the mandible were omitted because of their poor preservation and minimal information value; The percentages may be one decimal place above or below 100% in some cases due to the rounding SPSS round the number to one decimal.

Table 5 illustrates the completeness score frequencies for the entire scored sample for both scales. Although a score of “1” represents > 75% complete in both scales, the amended scale has a percent frequency of 9% while the *Standards* scale has a percent frequency of 13%. This discrepancy is due to the additional scores in the amended scale and their influence on the average score for each element, which brought the overall amended score up or down compared to the *Standards* score.

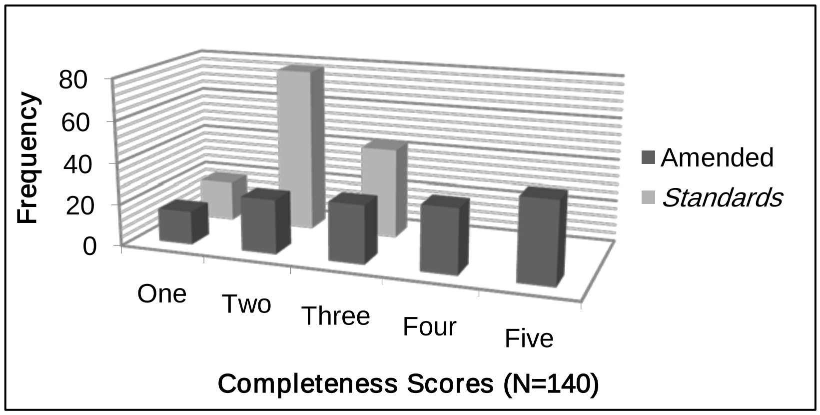
Table 5—*Completeness score frequency distributions for scored sample.*

Standards Scale	> 75%	25%-75%		<25%	
Frequency of Completeness	13%	54%		33%	
Amended Scale	> 75%	50%-74%	25%-49%	11%-25%	1%-10%
Frequency of Completeness	9%	15%	21%	26%	29%

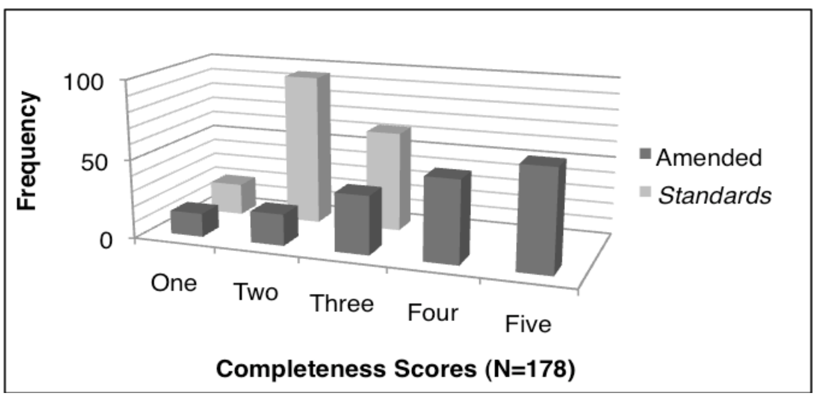
Based on the frequency analyses and statistical data there was no obvious consistency in the overall degree of preservation of particular elements from one cremation to the next. Exceptions are the mandibular condyle and patella, which exhibited high degrees of preservation in the majority of cases. The degree and frequency of preservation of skeletal elements that provide information for the estimation of biological profile will be addressed in detail later in this chapter.

Standards versus amended completeness scoring system

The amended scale did influence the results of the current study by providing more detailed assessments of the preservation of elements and reflecting the variation in the degree of preservation in the sample. The double bar graphs in Figures 4a and 4b depict the frequency distributions of both completeness scores for the cranial and postcranial inventories, respectively, for comparison.



4a. Cranial



4b. Postcranial

FIG. 4a and 4b— *Completeness score frequency distributions.* Figure 4a *Shows the frequency distributions of cranial completeness scores for both scales for all scored elements (N=140); Figure* 4b *Shows the frequency distributions of postcranial completeness scores for both scales for all scored elements (N=178).*

Macroscopic Observations

The overall appearance and color of the fragments and the associated matrix of “ash” and minute bone fragments was consistent in 18 of the 19 boxes examined. The contents of each box appeared grey in color overall with fragments representing the gradations between black and white. The color was never completely uniform across all the cremains within a box; the fragments ranged in color from white calcined bone, to charcoal grey bone, with occasional fragments of blue-gray, blue, pink, and green.

The color of the associated ash in case 28-06D was a salmon pink color rather than grey encountered in the other 18 boxes. Figure 5 compares the color of the associated ash from cases 28-06D and 67-07D, which typifies the rest of the sample. However, the identifiable fragments from case 28-06D (Fig. 6) were consistent with the bone fragments in 67-07D (Fig. 7) and the remainder of the sample.

The overall composition of the cremains was consistent from case to case. Each box contained larger recognizable bony fragments and smaller bone fragments, some of which were better classified as bone dust. Cremation artifacts (Warren and Schultz 2002) including medical (staples, ligates, and orthopedic devices) dental (metallic crowns and bridgework) and mortuary (staples from cremation containers) varieties were also found among the cremains (Fig. 8).

Fig. 5—*Comparison of associated "ash" color of cremains. (28-06D on left 67-07D on right)*

FIG. 6— *Bone fragments. (case 28-06D)*

FIG. 7— *Bone fragments and "ash". (case 67-07D)*

FIG. 8—*Miscellaneous cremation artifacts.*

Cranial

The overall appearance of the cranial fragments was more consistent from one case to another than the postcranial fragments. Cranial fragments were often either completely calcined or in the process of delamination and displayed both of these characteristics within the same set of cremains. The calcined fragments appeared bright white, markedly thin, and curled as in Figure 9. During the sorting process, the consistency of the calcined fragments was similar to fine china and when the fragments came into contact with one another they sounded as though they were made of glass or porcelain.

In the fragments undergoing delamination, both the inner and outer tables were preserved but were visibly coming apart, exposing the underlying diploe (Fig. 10). A bubbly texture and pink staining was also found on the endocranial surfaces of some fragments across the different cases. In some cases, the mandibular fragments and teeth were blue in appearance.

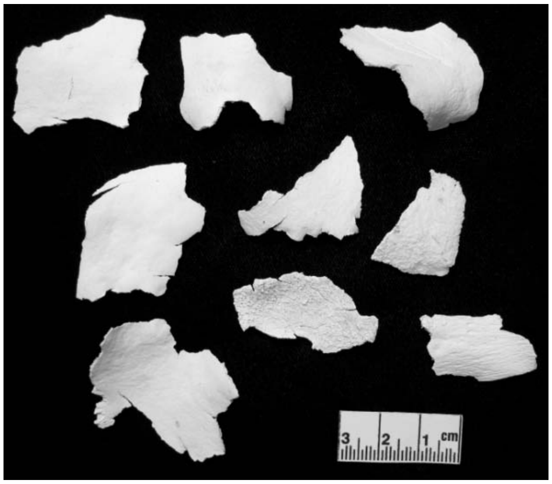


FIG. 9—*Curved calcined cranial fragments. (55-09D-female, age 70)*

FIG. 10—*Left and right parietal bone fragments showing delamination and cranial sutures. (28-06D-female, age 59)*

Cranial fragments were identifiable although the thermal alteration to the bone changed the shape. The presence of sutures (both open and fused), vessel markings (such as meningeal grooves), and muscle attachment sites (such as temporal lines) were observable and assisted in the identification and scoring of the completeness of the cranial vault bones. In some cases, due to the delamination and subsequent destruction of diagnostic features combined with the absence of sutures due to the friable nature of some of the cremains, a specific bone and side identification was not possible. In such cases, to reflect the poor preservation and low informative value the cranial bones were scored as “3” in the *Standards* scale and as “5” in the amended scale.

The cranial fragments were similarly friable from one case to the next. However, in case 77-05D in particular, the remains crumbled apart at the slightest touch; the outer table and inner tables would separate, and the projections that make up the cranial sutures broke off from the rest of the fragment. In contrast, in case 21-05D (Fig. 11), preservation allowed for the observation of autopsy cuts on the frontal bone, parietals, and occipital bone fragments, in addition to extensive retention of the integrity of the inner and outer tables without much delamination.

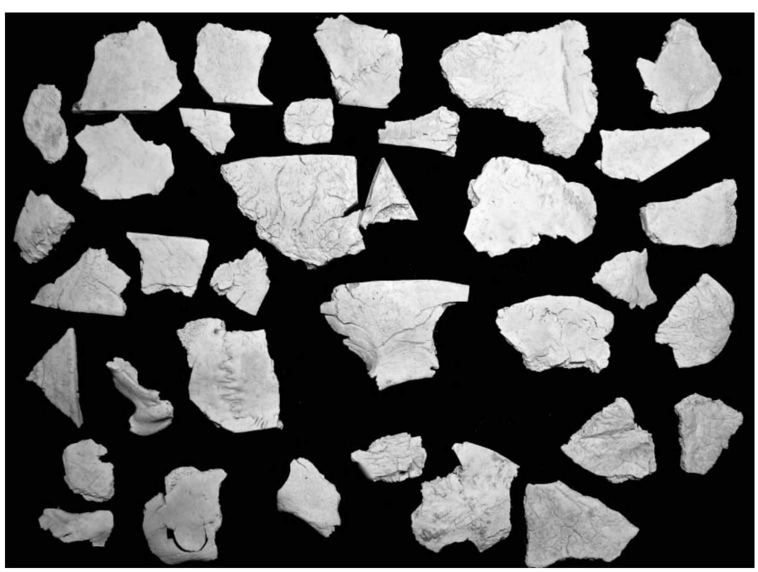


FIG. 11—*Cranial fragments with autopsy cut marks. (21-05D-male, age 51)*

As reported in Table 2, the cranial vault bones (frontal, parietals, occipital, and temporal) were scored more often than the other bones in the cranium and mandible. The bones of the facial skeleton were poorly preserved overall. The intact petrous portion of the temporal bone preserved on both sides in 13 out of the 19 cases (and on one side in another 4 cases) often with a mandibular fossa fragment, even in the absence of identifiable temporal squama. The frontal crest was found intact in 6 cases and a styloid process was found in 2 cases and evidence of a mandibular torus was found in one case.

Postcranial

The overall appearance and preservation of the postcranial fragments was more variable from one case to another than the cranial fragments. Postcranial fragments were either completely calcined similar to the cranial fragments, appearing warped and white in color, or in varying stages of thermal alteration, appearing various shades of grey and blue-gray in color. Additionally, multiple colorful fragments in shades of pink, blue, and neon green were observed in multiple boxes. Some postcranial fragments also displayed the bubbly surface and pink staining found on the internal surface of the cranial vault fragments

Long bones shared a similar preservation pattern from case to case. The proximal and distal epiphyses and metaphyses preserved to varying degrees while the diaphyses fragmented extensively. Most shaft fragments were broken on both the horizontal and vertical axes, which yielded large irregular cross sections of bone. Epiphyseal preservation allowed for certain postcranial measurements to be taken that contributed to the estimation of sex for the biological profile and are discussed in detail later in this chapter.

The proximal femur was scored in all 19 cases and a femoral head diameter was taken in 12 cases yielding a total of 17 measurements. However, there was wide variation in preservation within the scored proximal femurs, as can be seen by comparing the mostly complete (> 75%) proximal femur from case 15-03D (Figs. 12a and 12b) with the poorly preserved (<10%) isolated femoral head from case 70-04D (Fig. 12c). In contrast, the distal femur when scored, was less than 25% complete 58% of the time according to the *Standards* scale (Table 3) and 82% of the time according to the amended scale (Table 4), indicating a lower rate of preservation overall.

Of the frequently scored distal humerus, the trochlea preserved the most, the olecranon fossa preserved occasionally and the epicondyles were mostly absent. The trochleae were often isolated and the distal metaphyses rarely preserved. Therefore, the distal epicondylar breadth was only measured in 4 out of the 18 cases yielding a total of 4 measurements. Humeral head diameter was taken in 8 of the 18 cases yielding a total of 11 measurements.

12a. 12b. 12c.

FIGS. 12a,12b, and 12c—*Comparison of proximal femur preservation. Figure* 12a*. shows posterior while Figure* 12b*. shows anterior view of 15-03D. Figure* 12c*. shows the proximal femur (isolated femoral head only) of 70-04D.*

Biological Profile

Sex Estimation

Sex was estimated for 18 of the 19 individuals in the sample using a combination of observations of cranial morphology, pelvic morphology and postcranial metric analysis (See Appendix C). In all observations, both unambiguous and probable estimates of sex that were classified correctly were summed to give a total number of correct sex estimates.

A comparison of the sex estimation methods used in this study found metric analysis of the postcrania and pelvic morphology to be most reliable (Table 6). Using a combination of all of the methods, sex estimation was correct in 16 cases (8 male-8 female) out of the 18 cases (See Appendix C, Table CA). Twelve cases out of these 16 cases were classified unambiguously. Interestingly, all of the correctly classified males were unambiguously estimated, while 4 of the correctly classified females were probable estimates. One individual (case 21-05D) was misclassified as female and 1 individual (case 43-05D-male) was estimated as ambiguous or sex unknown.

Table 6 – Comparison of sex estimation methods (N=19).

Method	No. Cases	No. Correct	% Correct
Metric (Postcranial)	14	13	93
Pelvic	8	7	88
Cranial	15	11	73

Cranial based sex estimation. Table 7 illustrates the classification rates for sex estimation derived from observations of cranial morphology (Figs. 13-15) (See also Appendix C, Table CB). Of the 8 nuchal crests, 6 were scored correctly, including 1 probable classification, while 2 were assigned the wrong sex. Of the 9 mastoid processes, 8 were scored correctly, including 3 probable classifications, and the remaining case was classified as ambiguous. Five of the 10 cases in which supraorbital margins were classified correctly included 4 probable classifications, while misclassifications consisted of 3 ambiguous individuals and 2 incorrect probable sex estimates. Of the 2 cases in which glabella was scored, 1 remained ambiguous while the other was scored correctly.

Table 7—*Cranial sex estimate classification rates (N=19).*

Skeletal Feature	Total Cases Scored	No. Correct	% Correct
Nuchal Crest	8	6	75
Mastoid Process	9	8	89
Supraorbital Margin	10	5	50
Glabella	2	1	50

The features used in cranial based sex estimation were not given completeness scores. Rather, the skeletal element the feature is associated with was scored. For instance, the completeness score for the frontal bone was applied to the supraorbital margin and glabella, the occipital score was applied to the nuchal crest, and the temporal score was applied to the mastoid process (with the exception of one case in which the mastoid process was isolated from surrounding bone). The distribution of the amended scale completeness scores of cranial features used to correctly estimate sex and the classification rates for each score are presented in Table 8.

Table 8 – *Distribution of amended scale completeness scores with classification rates for cranial sex estimation morphology.*

Skeletal Element	Feature	No. Correct	Amended Completeness Score				
			1	2	3	4	5
Occipital	Nuchal Crest	6		2	1	2	1
Temporal	Mastoid Process	8		3	2	2	1
Frontal	Supraorbital Margin	5	1	1	2	1	
	Glabella	1		1			
	Totals:	20	1	7	5	5	2
	Percent Correct		5%	35%	25%	25%	10%

FIG. 13—*Mastoid process-male. (09-05D)*

FIG. 14—*Hook-like nuchal crest-male. (62-03D)*

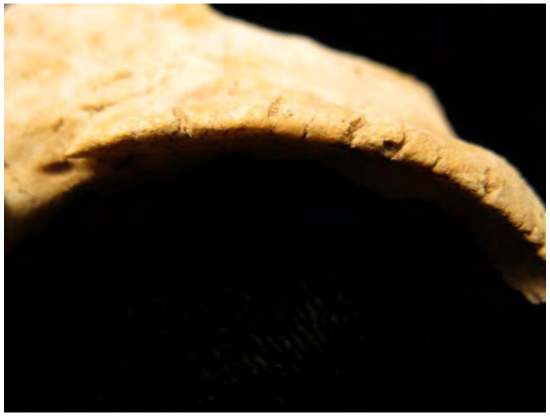


FIG. 15—*Supraorbital margin-female. (53-09D)*

Pelvic based sex estimation. Table 9 illustrates the classification rates for sex estimation based on observations of pelvic morphology (Fig. 16) (See also Appendix C, Table CC). Of the 3 ventral arcs, 2 were classified correctly and 1 was ambiguous. Six of the 7 greater sciatic notches were classified correctly, including 1 probable sex estimate and one was unambiguously misclassified. yielding an 86% classification rate. Every case in which the subpubic concavity (N=2), ischiopubic ramus ridge (N=3), and preauricular sulci (N=3) received a score was correctly scored as male or female, yielding a 100% classification rate.

Table 9 – *Pelvic sex estimate classification rates (N=19).*

Skeletal Feature	Total Cases Scored	No. Correct	% Correct
Greater Sciatic Notch	7	6	86
Ischiopubic Ramus Ridge	3	3	100
Preauricular Sulcus	3	3	100
Subpubic Concavity	2	2	100
Ventral Arc	3	2	67

Pelvic features were also scored based on the score of the associated bone. Table 10 shows the distribution of amended completeness scores for pelvic morphology used to correctly estimate sex and the classification rates for each score. The pubis completeness score was applied to the ischiopubic ramus ridge, subpubic concavity and ventral arc. In the case of the greater sciatic notch, the auricular surface preservation score was applied to the greater sciatic notch because 5 of the 7 greater sciatic notch fragments preserved joined with the auricular surface, one preserved with a fragment of the dense bone of the iliac pillar, and the remaining greater sciatic notch fragment was isolated.

Table 10 – *Distribution of amended scale completeness scores and classification rates for pelvic sex estimation morphology.*

			Amended Completeness Score				
Skeletal Element	Feature	No. Correct	1	2	3	4	5
Pubis	Ventral Arc	2		1			1
	Subpubic Concavity	2				2	
	Ischiopubic Ramus Ridge	3		1		2	
Auricular Surface	Greater Sciatic Notch	7	1		2	4	
	Preauricular Sulcus	3	1		2		
	Totals	17	2	2	4	8	1
	Percent Correct		12%	12%	23%	47%	6%

FIG. 16—*Auricular surface and greater sciatic notch-female, age 58. Note preauricular sulcus (53-09D).*

Postcranial metric sex estimation. Table 11 shows classification rates for postcranial metric sex estimation. Preservation allowed the taking of measurements (Fig. 17) in 14 of the 19 individuals in the sample and yielded 13 correct sex classifications. These measurements are shown with the sectioning points and classification rates developed for sex estimation of American Whites (Spradley and Jantz 2003) in Appendix C, Table CD). Due to the shrinkage associated with thermally altered bone, if any measurement was equal to or above the sectioning point, the individual was automatically classified as a male. For example, case 15-03 was correctly classified as male based on a humeral head measurement that was 3mm above the sectioning point (83% classification rate) although based on observations of the supraorbital margin alone this individual was classified as a possible female.

Table 11 – *Postcranial metric sex estimate classification rates (N=19).*

Postcranial Measurement	Total Cases Measured	No. Correct	% Correct
Humeral Head Diameter	8	6	75
Femoral Head Diameter	12	9	75
Distal Femoral Epicondylar Breadth	2	1	50
Humeral Epicondylar Breadth	4	1	25
Tibia Proximal Bicondylar Breadth	1	1	100

FIG. 17—Humeral epicondylar breadth-male. (09-05D)

The skeletal features that were measured for metric based sex estimation were not given completeness scores independently. The epiphyses and joint surfaces were assigned the completeness score of the associated bone. For instance, the humeral head diameter and femoral head diameters were scored as part of the proximal humerus and proximal femur, respectively. Table 12 shows the distribution of amended completeness scores for pelvic measurements used to correctly estimate sex.

Table 12 – *Distribution of amended scale completeness scores for postcranial measurements for sex estimation.*

			Amended Completeness Score				
Skeletal Element	Feature	No. Correct	1	2	3	4	5
Proximal Femur	Head Diameter	9		1	1	6	1
Proximal Humerus	Head Diameter	6	2	2	2		
Distal Femur	Epicondylar Breadth	1				1	
Distal Humerus	Epicondylar Breadth	1	1				
Proximal Tibia	Bicondylar Breadth	1			1		
	Totals	18	3	3	4	7	1
	Percent Correct		17%	17%	22%	39%	5%

Age-at-death estimation

Age-at-death estimations were possible for 16 of the 19 individuals in the sample. Out of the 16 age-at-death estimates, 3 cases (74-04D, 33-05D, and 77-05D) were given an age-at-death of 17+ years because the only morphological age indicator that survived cremation for observation was the iliac crest of the os coxae. The iliac crest was observable in 9 cases, but in each case gave a vague adult age-at-death estimate. The remaining 13 estimates were based on 18 observations of fragmentary auricular surfaces from 11 cases and 8 observations of fragmentary pubic symphyses from 7 cases. Table 13 contains classification rates for both age-at-death estimation methods.

Table 13 – Age-at-death estimate classification rates (N=19).

Method	No. Cases	No. Correct	% Correct
Auricular Surface	11	10	91
Pubic Symphyseal	7	5	71

The auricular surface was assigned a completeness score independent of the ilium on which it is located, while the completeness score of the pubic symphysis was borrowed from the completeness score of the pubis. Table 14 shows the distribution of amended scale completeness scores for pelvic age-at-death morphology. The retroauricular area and apex of the auricular surface were absent in most cases and the superior and inferior demiface seldom preserved in their entirety. Pubic symphyseal and auricular surface aging were limited by preservation and observations were made within these limitations yielding broad age ranges (See Appendix C, Table CE). Figures 18a and 18b demonstrate variation in age and preservation of pubic symphyses from 2 different cases. The auricular surfaces in Figure 3 and Figure 16 were well preserved in contrast with the poorly preserved auricular surface in Figure 19.

Table 14 – *Distribution of amended scale completeness scores and classification rates for pelvic age-at-death estimation morphology.*

Skeletal Element	Feature	No. Correct	Amended Completeness Score				
			1	2	3	4	5
Auricular Surface	Auricular Surface	10	1		2	7	
Pubis	Pubic Symphysis	5		1		1	3
	Total	15	1	1	2	8	3
	Percent Correct		7%	7%	13%	53%	20%

Age-at-death assessment also incorporated other evidence of age-related degeneration such as bony lipping on vertebral margins shown in Figure 20. Marginal lipping of vertebral bodies and joint surfaces was observed in 74% of the cases (n=14) in the current study. Orthopedic devices and skeletal evidence of surgical intervention were encountered in 4 cases (D01-2010, 09-05D, 70-07D, and 43-05D) and also taken into consideration in age-at-death estimation.

18a

18b.

FIGS. 18a and 18b—*Pubic symphyses. Figure* 18a*. Male-age 42.(67-07D) Figure* 18b*. Male-age 84. (43-05D)*

FIG. 19—*Poorly preserved auricular surface fragment–age 70, male. (16-03D)*

FIG. 20—*Degenerative marginal lipping of lumbar vertebrae-age 71, male. (70-04D)*

Ancestry estimation

Ancestry estimation for the individuals in this study was the most difficult assessment of the biological profile. The poor preservation of the facial skeleton resulted in the observation of only six nonmetric or morphoscopic traits out of the 14 traits defined by Hefner (2007). The nonmetric traits recorded in the current study included: anterior nasal spine (ANS) inferior nasal aperture morphology (INA), nasal bone contour (NBC), nasal aperture shape (NAS), posterior zygomatic tubercle (ZT), and supranasal suture (SPS). Figure 22 shows the frequency distribution for each of these observed traits across the 8 cases in which they were scored. Hefner (2007) warns of the fragility and high potential for perimortem or postmortem damage to the inferior nasal region and suggests that observations of damaged morphology be excluded from analyses. However, in this study, the ANS scores were assigned and given the minimum score appropriate based on the existing spine. Although Hefner (2007) recommends against such methods, all possible observations of surviving morphology (including approximations) were recorded even if the area sustained postmortem damage in order to reflect the extent of preservation and potential for ancestry estimation from thermally altered and fragmented remains. Figures 22-24 show examples of the preservation of nonmetric traits observed in this sample.

Tentative ancestry assessments (Table 15) were based on the frequency distributions for ANS, INA, and NBC in four populations (African, American Indian, Asian, and European) published by Hefner (2009). The observations of traits NAS, ZT, and SPS (Hefner 2007) were recorded but not used in the estimation of ancestry. Based on evidence that nonmetric traits are correlated, the combination of multiple traits results in more robust ancestry estimation (Hefner 2007, 2009). However, the highest number of observable nonmetric traits for ancestry estimation in this study was recorded in case D01-2010, which only had 3 traits (ANS, INA, and NBC), all of which were discordant (Table 12). Of the remaining 7 cases, 4 cases had two observable traits and 3 cases had only a single observable trait. Overall, ancestry was estimated correctly in only 2 out of the 8 cases (25% correct). However, it is important to recognize that nonmetric traits cannot be attributed to any single ancestral group (Hefner 2009).

Table 15 – *Scored nonmetric traits and ancestry estimation results (N=19).*

Case No.	ANS	INA	NAS	ZT	NBC	SPS	Estimated Ancestry	Actual Ancestry
70-04D		c. 2					(AFR)	W
74-04D	2	4					(EUR)	W
67-07D	3	2	1				(EUR/AFR)	W
53-09D				1	1	1	(AI)	W
77-05D	1	3					(ASI)	W
55-09D		4					(EUR)	W
43-05D	3				0	1	(AFR/EUR)	W
D01-2010	2 or 3	3					(ASI/EUR/AFR)	B

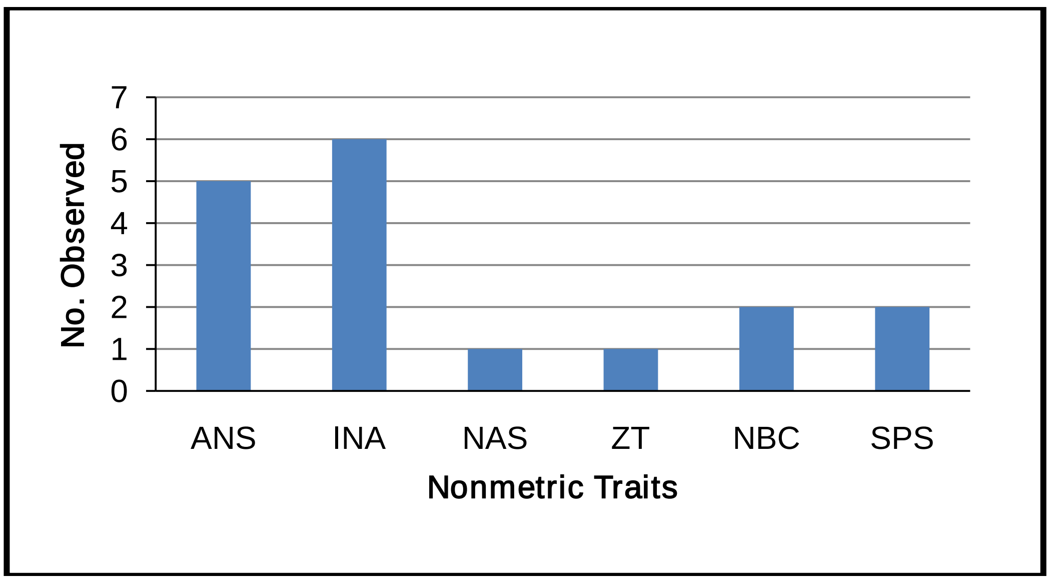


FIG. 21—*Frequency of nonmetric trait observations for ancestry estimation (N=19).*

FIG. 22—*Nonmteric traits ANS and INA. (43-05D)*

FIG. 23—*Nonmetric traits SPS and partial NBC. (53-09D)*

FIG. 24—*Nonmetrtic traits ANS, INA, and (approximated) NAS. (67-07D)*

Summary

The results of this study indicate that when the elements necessary for the development of the biological profile survive cremation, sex and age-at-death can be estimated from macroscopic observations of unprocessed human cremated remains. Although the commercial cremation process resulted in thermal destruction and associated fragmentation of the skeleton, sufficient osteological material preserved for successful sex and age-at-death estimation while the highly limited preservation of nonmetric cranial traits rendered ancestry estimation inconclusive.

The amended scale did influence the results of the current study by providing more detailed assessments of the preservation of elements and reflecting the variation in the degree of preservation in the sample. The overall appearance and color of the fragments and the associated matrix of “ash” and minute bone fragments was consistent in 18 of the 19 boxes examined. Based on the frequency analyses and statistical data there was no obvious consistency in the overall degree of preservation of particular elements from one cremation to the next.

Classification rates were calculated for sex (Table 7, 9 and 11), age-at-death (Table 13), and ancestry estimation based on macroscopic observations of the skeletal features that provide information for the estimation of biological profile that preserved. The final estimated versus actual sex, age-at-death and ancestry results are summarized in Table 16. Sex was estimated correctly in 16 of the 18 cases in which preservation allowed for an estimate. In particular, sex was estimated correctly in 100% of cases in which the auricular surface and pubis preserved to allow the preauricular sulcus, greater sciatic notch and subpubic concavity to be scored and in 89% of cases in which the mastoid process of the temporal survived. Postcranial metrics were applied for sex estimation and yielded 93% correct classification rate. The proximal femur (N=12) and proximal humerus (N=8) survived the most, however individually the femoral head diameter and humeral head diameter had a classification rate of only 75%.

Age-at-death estimation was correct in 91% of cases in which the auricular surface preserved (N=11) while pubic symphyseal aging was correct in only 71% of cases in which the pubis preserved (N=7). Ancestry estimation was too disparate for a success rate to be determined based on the poor preservation of nonmetric traits of the facial skeleton.

Table 16—*Final estimated versus actual age-at-death, sex, and ancestry (N=19).*

Case No.	Actual Sex	Estimated Sex	Actual Age	Estimated Age	Actual Ancestry	Estimated Ancestry
70-04D	M	M	71	45-60+	W	(AFR)
74-04D	F	F	74	17+	W	(EUR)
28-06D	F	F	59	45-59	W	-
15-03D	M	M	68	45-86	W	-
67-07D	M	M	42	27-66	W	(EUR/AFR)
09-05D	M	M	75	50-59	W	-
70-07D	F	F?	101	-	W	-
21-05D	M	F?	51	-	W	-
16-03D	M	M	70	45-60+	W	-
62-03D	M	M	82	45-66	W	-
33-05D	F	F?	91	17+	W	-
33-04D	M	M	65	45-60+	W	-
53-09D	F	F	58	50-86	W	(AI)
10-04D	F	F	52	45-59	W	-
55-05D	M	-	53	45-60+	W	-
77-05D	F	F	74	17+	W	(ASIAN)
55-09D	F	F	70	-	W	(EUR)
43-05D	M	?	84	34-86	W	(AFR/EUR)
D01-2010	M	M	75	60-86	B	(ASI/EUR/AFR

CHAPTER IV

DISCUSSION

The purpose of the current study was to assess the retention of skeletal features critical for the estimation of a biological profile on unprocessed commercially cremated human remains, which may have applications in analyses of fragmentary remains encountered in mass fatality or human rights contexts. Data from this study suggest that age-at-death and sex can be estimated from cremated remains based on the survivability of specific elements from the cranial and postcranial skeleton. However, attempts at ancestry estimation were ruled inconclusive and stature estimation was not attempted as it was beyond the scope of the current study. Before discussing estimation of the biological profile, it is necessary to discuss the various factors that affect the preservation of commercially cremated bone and the burn patterns that lead to the differential survival of skeletal elements in cremains.

Preservation

Overall characteristics

The overall condition of the cremains in this study fit some of the previous classifications of complete body cremation. The complete lack of soft tissue, the high degree of fragmentation, the presence of warping, shrinkage and delamination and the light grey to white coloration of the fragments fit the criteria for complete cremation set forth by Baby (1954) and Crow and Glassman (1996) as a Baby Type 1 and CGS level #5, respectively. However, the sample does not meet the criteria for complete cremation as proposed by Eckert et al. (1988) that refers to alleged cases in which “only ashes remain” after burning; rather, it consists of recognizable bone fragments in a matrix of ash and minute flakes of bone and is better classified as Eckert et al. Type 2 or incomplete cremation.

The post cremation survival of anatomically recognizable skeletal elements is consistent with earlier commercial cremains studies (Stewart 1979; Eckert 1981; Bass 1984; Heglar 1984; McKinley 1989; Warren and Maples 1997; Bohnert et al. 1998; Murad 1998; Klepinger 2006). Despite the overwhelming interest in burned remains in the last 25 years, the current study is unique in that it focuses on the documentation of existing characteristics in calcined bone and the potential for biological profile estimation from unprocessed cremains.

The amended completeness scoring scale developed to document the information value of individual skeletal elements provided a more detailed account of the differential preservation of the elements included in the current study. The existing 3-point *Standards* scale was found to under represent the variation in preservation among the cremains including the following: how much of an element survived cremation, the presence or absence of skeletal landmarks and the potential for correct side identification. The 5-point amended scale more accurately reflected the low incidence of well-preserved fragments and the high incidence of fragments that were poorly preserved compared to the *Standards* scale.

Fragments that scored a 4 or 5 in the amended score were found to contribute to accurate sex and age-at-death estimation in multiple cases. The division of the <25% complete or “3” score from the Standards scale into smaller categories of 1-10% “5” and 11-24% or “4” illustrates that diagnostic features often survive on the most poorly preserved fragments. Therefore, in mass fatality investigations in which human remains have undergone extensive fragmentation it is important to recover even the smallest pieces of bone because they may represent information that is vital to the estimation of parts of the biological profile.

Color signatures

The appearance of the bones in the current sample differed from those described in early cremation studies that claimed temperatures above 700˚C always yield bones that are bright white in color (Herrmann 1977). The bright white endpoint color, synonymous with complete cremation, was expected to be found consistently throughout the entire sample because each case was burned under standard commercial crematory procedures with average minimum temperatures of 870°C (1600°F). However, there were differences in color within and among the individual sets of remains. The color variation in the current sample suggests that other variables beyond the temperature of the fire or heat source affect bone color.

Experimental burned bone research has demonstrated that color changes in bone are more complex than earlier believed and may or may not equate with the temperature of the fire (Shipman et al. 1984; Walker and Miller 2005; Brickley 2007). In fact, recent studies have shown that multiple colors can be found throughout the burned remains of a single individual (Heglar 1984; Brickley 2007); and the full spectra of heat related color change can be found on a single bone (Symes et al. 2008). The variable coloration on a single bone can provide a wealth of information when interpreted with an understanding of the dynamic nature of normal burn patterns and the associated changes in the structural composition of bone.

Some colors observed in the current study fell outside the range of blue-grey to white previously recorded for commercial cremains (Holden et al.1995; Schultz et al. 2008). Various fragments from different bones exhibited staining or were entirely pink, bright green, or salmon colored. The presence of such anomalies suggests that the temperatures either varied throughout the retort or were not high enough for complete calcination (Schultz et al. 2008). Dunlop (1978) proposed that the introduction of metals into the cremation environment might explain this phenomenon, which he termed “traffic light discoloration” [pink, yellow, and green in color]; the recovery of metallic cremation artifacts from the cremains in this study supports Dunlop's explanation.

Finally, color is a function of the decomposition of the organic component of the bone matrix and is not a precise indicator of temperature in itself (Shipman et al. 1984; Walker and Miller 2005). The color of burned bone is affected more by the duration of the heat exposure, the amount of available oxygen and tissue shielding than the temperature of the fire (Mayne Correia and Beattie 2002; Symes et al. 2008; Walker and Miller 2005).

Calcination

In order to interpret burned remains it is necessary to understand the material or physical properties of bone; the size, shape and configuration, or structural properties of bone; and the underlying molecular composition of bone (Gozna 1982). Bone is a composite (biphasic) material (Currey 2002) comprised of organic (collagen), mineral (calcium hydroxyapatite), and water components. Collagen is a protein that makes up 90% of the organic content of bone and provides elasticity and tensile strength; inorganic calcium hydroxyapatite crystals are embedded within the collagen fibrils and provide rigidity and compressive strength (Herrmann and Bennett 1999; Nielsen-Marsh et al. 2000). The resultant matrix makes the skeleton both strong and flexible at once, while the mineral content gives bone its brittleness (Gozna 1982).

When bone is exposed to heat, it loses its moisture content through dehydration and the protein in the organic matrix burns off as the hydroxyapatite crystals enlarge and recrystallize (Shipman et al. 1984; Stiner et al. 1995). Mayne (1990) abbreviated the 4-stage process of dehydration decomposition inversion and fusion of cremation as “the DDIF process”. Calcination is the terminal stage of the DDIF process and refers to the loss of the organic phase and the inorganic mineral crystalline structure that remains (DeHaan 2007, 2008). When the organic material is totally lost, completely calcined bone appears white in color (Holden et al. 1995).

In addition to changes in color, recrystallization also changes the structural integrity of bone and in particular its dimensions (warping and shrinkage) and friability (fracture, fragmentation). When bone is heated, it becomes considerably more brittle and fragile than unburned bone with increasing temperature and molecular modification (Forbes 1941; Stiner et al. 1995; Klepinger 2006; Brickley 2007). As a human body burns, due to the unique material and structural properties of the skeleton, bone will behave in predictable ways as it is exposed to heat (Christensen 2002; Pope 2007; Symes et al. 2008) particularly as bone relates to overlying soft tissue.

Evidence of Normal Burn Patterns

“The myth of flesh”

In the introduction of <u>Forensic Taphonomy: The Postmortem Fate of Human Remains,</u> Haglund and Sorg (1997) discuss a bias that influences the analysis of human remains in which the investigator treats skeletal remains as though the soft tissues that surrounded them in life never existed – the myth of flesh. This myth of flesh must be abandoned and the relationship between bone and overlying soft tissue must be understood in order to interpret burned human remains effectively. The type of bone, trabecular or cortical and the location of the bone as related to tissue depth are the two most important variables in understanding the differential preservation of burned human remains.

Trabecular or cortical?

In addition to being a biphasic material, bone can be divided into two distinct types: trabecular and cortical. Trabecular and cortical bone are identical in molecular composition and lamellar organization with similar porosity; they differ in the amount of solid matter relative to the size and number of spaces within the tissue (Warwick and Williams 1973; White 1991). Trabecular or cancellous bone is significantly more porous than cortical bone; trabeculae (bony spicules) are randomly organized with ample space in between resembling a sponge, which is why trabecular bone is also referred to as spongy bone. Conversely, cortical or compact bone is made up predominantly of highly organized dense bone that is tightly packed together and oriented parallel to the long axis of the bone (Ortner 2003); thus, cortical bone is more brittle than trabecular bone (Gozna 1982).

Trabecular bone is primarily located in the metaphyses and epiphyses at the ends of long bones and also found to make up the bulk of the flat bones of the pelvis and cranium, and the vertebral body centra (White 1991). A thin layer of cortical bone protects the underlying trabecular bone at the ends of long bones, while the diaphyses or long bone shafts consist of dense cortical bone that protect the marrow chamber deep within the bone (Currey 2002). Another significant difference in structure is that cortical bone contains Haversian systems or complex networks of cellular structures and vessels that nourish the bone, while trabecular bone simply nourishes itself through diffusion from the surrounding marrow tissue (Warwick and Williams 1973; Ortner 2003).

The preferential preservation of epiphyses and trabecular regions of the skeleton throughout the sample in the current study reflects the structural integrity of trabecular bone and its ability to withstand dehydration and recrystallization better than cortical bone. The retention of the overall shape of trabecular bone over cortical bone was observed in casework by Symes et al. (2008), in commercial cremation research by Gejvall (1970) and Warren and Maples (1997) and in experimental burn research by Pope (2007).

In the current study, the trabecular organization of the mandibular condyle and mastoid process allowed for their preservation in 14 cases and 9 cases, respectively. Additionally, the trabecular structures of the proximal femur and vertebral centra preserved despite the destruction of the overlying cortical bone. Although overlooked in the literature, the articular cartilage overlying the joint surfaces of long bones and the cartilaginous intervertebral discs likely provide additional protection to the epiphyses and vertebral bodies. This could be due to the predominantly nonvascular composition of both cartilage and trabecular bone tissue[s] (Warwick and Williams 1973). Also, the fact that external cortical bone is exposed to direct heat earlier than underlying trabeculae and undergoes thermal modification first and for the longest duration may also contribute to the observed differential preservation. How deeply a bone is encased in soft tissue including muscle, ligaments, tendons, or organs is a measure of the protection said tissue will provide when exposed to a heat source; this is known as tissue shielding.

Tissue shielding

Tissue shielding appears to manifest itself in two ways, fixed and flexion. In the current study, fixed shielding refers to skeletal elements that experience tissue shielding as a result of their fixed location within the human body. Examples of skeletal elements affected by fixed shielding are the auricular surface and acetabulum of the os coxae and the proximal femur. These elements are protected by their location deep within the pelvic region including the large buttock muscles along their posterior aspect. In contrast, flexion shielding is the consequence of the pugilistic posture the human body assumes during the burning process. As a body burns, the liquid components of soft tissues evaporate, which leads to shrinkage of muscle fibers and contraction of ligaments and muscles (Bass 1984; DeHaan 2007; Pope 2007; Symes et al. 2008; Ubelaker 2009). This contraction results in the simultaneous heightened exposure and heightened protection of joint surfaces. The differential preservation observed across a burned body and even within a single articulation site is a direct result of the pugilistic posture and the associated changes in body position and tissue shielding in concert with the structural components of trabecular and cortical bone that dictate where the bone will fail (Gozna 1982; Mayne 1990; Pope 2007).

The burn pattern observed in the proximal and distal ends of the humerus is a result of a combination of fixed and flexion tissue shielding. The preservation of the isolated humeral head in this sample is consistent with normal burn patterns as the shoulder joint is exposed when it flexes as the assumption of the pugilistic posture advances (Pope 2007). In 6 out of the 18 times the distal humerus was scored, it was over 25% complete (using the amended scale). The differential preservation of the distal humerus observed in this study is consistent with the pugilistic flexion that provides increased tissue shielding of the antecubital region of the elbow and renders the posterior aspect of the articular surface more vulnerable to thermal destruction. Therefore, of the anterior skeletal features of the distal humerus, the trochlea preserved the most often followed by the coronoid fossa and radial fossa, respectively. In contrast, the posterior aspect of the distal humerus exhibited more delamination and fractures than the anterior aspect, although the olecranon fossa preserved in many cases, which probably reflects protection afforded by fixed shielding from the articulation of the olecranon process of the proximal ulna with the distal humerus.

The popliteal region of the knee, should exhibit preservation similar to that described above for the elbow joint because they are both hinge joints. Therefore, the posterior aspect of both the distal femur and proximal tibia should preserve well due to flexion shielding. However, the proximal tibia was scored under 25% complete in 10 of the 11 cases in which it preserved, according to the amended scale. This is likely due to the thinness of the overlying soft tissue of the anterior aspect of the tibia, which would cause early exposure of the cortical bone. The distal femur fared only slightly better, and was scored under 25% complete,in the amended scale, in 14 out of 17 cases. The poor preservation of the distal femur and proximal tibia was so irregular that no parallels could be drawn between the observations and the predictable burn patterns. The lack of bone-on-bone contact in the knee joint (as opposed to the elbow joint) may also play a role in the poor preservation. The preservation of the patella did show agreement with expected burn patterns. During flexion once the patellar ligament is compromised, the patella is released from the tibial tuberosity and knee joint and the patella retracts toward the hip exposing the femoral condyles and the tibial plateau (Pope 2007).

Burned bone fractures and biomechanical signatures

Bone burns from the outside to the inside as the overlying soft tissues, including the periosteum are compromised. When the bone is no longer shielded by tissue, the direct heat on the bone causes the elastic collagen to burn away and leaves behind the brittle mineral component transforming ductile bone tissue into a weakened state in which bone will fracture and fragment (Mayne 1990; Holden et al. 1995; Stiner et al. 1995; Warren and Maples 1997; Herrmann and Bennett 1999; De Haan 2007). The expected burned bone biomechanical signatures were consistently observed throughout the sample. These typical burn fractures included longitudinal, transverse, and step fractures of the long bones, carpals and tarsals; superficial patina fractures of the long bone epiphyses, ilia and cranial vault bones; delamination of the cranial vault bones and long bone epiphyses; and curved transverse fractures on the diaphyseal and metpahyseal fragments and epiphyses of the humerus, tibia, and femur (Symes et al. 2008).

The locations of fragmentation and separation, and the preservation of certain metaphyses and epiphyses corresponded with known heat-related fracture sites and support the normal burn patterns in the published literature (Mayne 1990; Pope 2007; Symes et al. 2008). For instance, although not included in the inventory for the current study, well preserved radial heads, distal ulnae with intact styloid processes, and proximal ulnae with nearly complete olecranon processes were observed. The preservation of these elements is consistent with the normal heat related fractures associated with the elbow joint and wrist joint when they undergo pugilistic flexion (Symes et al. 2008).

The expected heat related separation of thin cortical bone from underlying trabecular bone was observed throughout the sample (Pope 2007). In particular, delamination exposed the underlying diploe of cranial vault fragments. In some cases only the trabecular structure of the femoral necks and humeral and femoral heads survived while the overlying cortical bone was completely absent. This type of preservation was marked in one particular case (perhaps osteoporotic remains) 77-05D, a 74 year-old female.

Areas of bone with shallow or minimal tissue shielding, such as the cranial vault and anterior aspect of the tibia have unique thermal exposure fracture patterns compared to the rest of the postcranial skeleton (Heglar 1984; Bohnert et al. 1997; Klepinger 2006; Pope 2007). Typical patina fractures that resemble a cracked painted canvas and marked delamination ranging from superficial flaking of the iliae to total separation of the cortex of long bone shafts were noted in the current study.

The fragmentation of the skull was consistent with descriptions of the normal destruction associated with commercial cremations found in prior publications. According to Warren and Maples (1997) and Bass and Jantz (2004), the cranium survives cremation relatively intact but fragments upon contact as its tensile strength is compromised. Of the 24 skeletal elements that were included in the inventory in the current study, only the frontal, occipital, parietals, and zygomatic bones were scored in all 19 cases. According to the amended scale, the zygomatic bone had the best preservation of the cranial bones, and was observed and scored over 50% complete 46% of the time, while the occipital and parietals had the second best preservation among cranial bones and were scored over 50% complete 26% of the time.

The high frequency of scored cranial vault and mandibular fragments may be due to their distinctive nature and the ease with which they were identified compared to the vague diaphyseal long bone fragments as suggested in earlier studies (McKinley 2000; Brickley 2007). The author performed a rough count of fragments prior to initiating data collection and found that for the cranial vault in particular, the number of identifiable cranial fragments could grossly overestimate the MNI of cremains, because delamination nearly doubles the amount of fragments that are typical in unburned fragmentary crania. This observation is supported by the literature (McKinley 2000; Brickley 2007).

Body position

The differential preservation of certain skeletal elements can also suggest the position of the body during the burning event. Standard cremation procedures dictate that a body is placed supine (face up) in the retort with its back against the floor of the retort, with no exception (Jonathan Snell, pers. comm.). A body is typically loaded feet first into the retort in order to localize the torso directly beneath the main cremation burner that is located in the anterior part of the chamber closest to the door. However, obese individuals are often loaded in headfirst so that the main jet ignites the lower limbs until the rendered fat ignites. Then the cremation burner is shut off and the body is allowed to consume itself. Once one-half to two-thirds of the body weight is burned off, the cremation burner is switched back on in order to complete the reduction of the body until only bones remain.

Normal patterns for a body exposed to heat in a supine position include the destruction of the bones closest to the surface of the body: anterior and lateral aspects of ribs, the sternum, the clavicles, the ilia and the pubis of the os coxae (Bohnert et al. 1998). The torso burns slower and in most cases later than the rest of the body due to the high moisture content of the underlying thoracic and abdominal organs. However in the commercial crematory context, this may be accelerated due to the intentional placement of the torso directly under the main cremation burner.

The survival of the occipital bone, sacrum, and spinous processes of the vertebrae observed in the current study agrees with Wells (1960), who interpreted such differential preservation as an indication that Early Saxons positioned the deceased on their backs during cremation. Additionally, thoracic organs protect the anterior portion of the vertebral bodies of the thoracic spine. Delamination of the ribs that exposed the underlying trabeculae and differential preservation of the ribs was also observed.

The standard position used in commercial cremations should result in the creation of similar patterns of preservation from one cremation to the next and follow normal burn patterns recorded in experimental research because the body is allowed to assume the pugilistic posture. The supine position creates should create a more predictable burn pattern than unusual positions in which the extremities are restricted under the body such as prone (face down) or on their side.

The position of the heat source in relation to the body must also be taken into consideration in burned bone analysis because the relative position of the heat source influences which region of the body is consumed first (Bohnert et al. 1998; DeHaan 2008). In a typical fire, heat sources can be in different positions around a body and an atmosphere of fluctuations in temperature and intensity ensues as different materials combust resulting in on-and-off exposure (DeHaan 2007; Pope 2007). However, in a commercial crematory retort, the location of the heat source or the primary cremation burner and the after burner are fixed, which greatly minimizes atmospheric dynamics and suggests that the burn pattern should be uniform from one cremation to the next. Therefore, because the cremation burner is typically positioned directly above the torso, in most cases the skeletal elements of the torso should exhibit more complete calcination than the lower limbs. In the current study the clavicles and sternum very rarely survived enough to be given a poor preservation score, which is consistent with the location of the upper body beneath the primary cremation jet. In contrast, the lumbar vertebrae, ischium, acetabulae, proximal femora, and patellae were found to have the best preservation of the postcranial skeleton, which is consistent with the placement of the lower body further from the main cremation burner.

The current research demonstrates that the preservation or survivability of the elements exhibits no distinct patterns based on completeness scores, which suggests that other variables such as weight, fat content, age-at-death, and sex may influence the pattern of burning or affect the completeness of the cremation more than the location of the heat source, temperature and duration of exposure to the fire.

Biological Profile

As is the case with unburned fragmentary remains, the primary difficulty in the analysis of burned fragmentary remains is the preservation of the various elements necessary for biological profile estimation. The application of standard anthropological techniques for the estimation of sex, age-at-death, ancestry, and stature is thought to be problematic because dimensional changes from heat exposure affect both morphological and metric techniques (Eckert et al. 1988; Thompson 2004, 2005). Thompson (2004) suggests that heat-induced changes in strength, porosity, dimension, weight, recrystallization, and the formation of fractures also have indirect and direct effects on anthropological techniques, and that all anthropological analyses of burned human remains will be “wholly and fundamentally inaccurate” (Thompson 2005:6). However, despite extreme fragmentation and heat related changes including dehydration, recrystallization, shrinkage, and warping, the standard morphoscopic and metric techniques used in the estimation of sex and age-at-death in the current study performed well. The success of these techniques agree with Stewart’s (1979) conclusion that other than shrinkage and warping, the sexing and aging of burned bone should offer no extra difficulties than those of unburned commingled or fragmentary remains.

Sex estimation

Preservation allowed for sex estimation based on observations of pelvic morphology in 8 out of 19 individuals in the current sample. Out of these 8 cases, 4 individuals had only 1 observable trait; and the remaining 4 individuals had 2, 3, 4, and 5 traits each. Pelvic based sex estimation was accurate in 7 of the 8 cases in which preservation allowed for the observation of the following features: subpubic concavity, ventral arc, ischiopubic ramus ridge, preauricular sulcus and greater sciatic notch.

Out of the entire sample (N=19) very few observations of the subpubic concavity, ventral arc and ischiopubic ramus ridge were possible. This limited preservation is consistent with the minimal tissue shielding of the pubis as it is located closer to the anterior surface of the body unlike the ischium that is located deep within muscle tissue and experiences fixed tissue shielding. . Fragments of the greater sciatic notch were scored in 7 cases because bone cortex is thickest in this area of the os coxae (White 1991). Therefore, the sciatic notch is more resistant to damage and typically preserves better than the pubis, however the scoring of this feature is highly subjective, particularly when fragmentary as in the current study (Walker 2005).

Sexually dimorphic cranial traits were better preserved than pelvic traits and when all cranial traits were considered. However, there was marked variability in the preservation of disgnostic cranial traits and in the results of sex estimation when using individual traits. The preservation and subsequent application of the diagnostic cranial features used in the current study has been recorded in burned remains analyses for decades (Baby 1954; Merbs 1967; Gejvall 1970; Heglar 1984; Warren and Maples 1997; Mayne Correia and Beatie 2002). However, cranial based sex estimates can be unreliable, particularly when the pelvis and postcranial skeleton are missing entirely or fragmentary as in the current study (Buikstra and Ubelaker 1994; Williams and Rogers 2006; Komar and Buikstra 2008; Walker et al. 2008). Recent studies show that postcranial metric estimators of sex have been found to be more reliable than the skull in American Whites and Blacks (Spradley and Jantz 2003). Therefore, the sex estimates based on cranial and pelvic morphology were considered tentative while the results of metric based sex estimation were given more weight and resulted in more accurate sex estimates.

The most reliable postcranial measurements for sex estimation for both American Blacks and Whites are the humeral head diameter, humeral epiphyseal breadth, and femoral head diameter (France 1998; Spradley and Jantz 2003). In the current study, the differential preservation of the epiphyses resulted in 35 viable postcranial measurements. The following measurements were successfully recorded and contributed to sex estimation: femoral head diameter (n=17), humeral head diameter (n=11), humeral epiphyseal breadth (n=4), distal femoral epicondylar breadth (n=2) and proximal bicondylar tibial breadth (n=1). The survivability of these epiphyses and the viable measurements that emerged support the results of the commercial cremation research of Van Vark (1975) and Warren and Maples (1997).

As a result of the shrinkage known to accompany the burning process, the males in the current sample would likely misclassify as females as recorded in prior archaeological and modern cremation research (Wells 1960; Merbs 1967; Eckert et al. 1988; Mays 1998). Therefore, only measurements with values equal to or greater than the sectioning point presented in Spradley and Jantz (2003) were classified as male and those below the sectioning point were classified as probable female, which yielded the correct classification of 7 of the 8 males that had measurements, leaving only 1 male misclassified as female. Additionally, 6 out of the 6 measured females had measurements below the sectioning point, which may indicate that the heat-related shrinkage is indeed negligible (Wells 1960), and contradicts recent reports that claim all anthropological techniques will be rendered inaccurate by the dimensional changes in heat altered bone (Kleppinger 2006; Thompson 2004, 2005).

While it was outside the scope of the current study, future studies that test recently reported techniques for sex estimation from the patella (Introna et al. 1998; Dayal and Bidmos 2005; Kemkes-Grottenthaler 2005; Mahfouz et al. 2007) and the petrous portion of the temporal bone (Merbs 1967; Kalmey and Rathbun1996; Wahl and Graw 2001), should be undertaken, given that these elements preserved so well. The high incidence of well preserved patellae and petrous portions among the cremains in this study support prior publications on burned human remains (Merbs 1967; Heglar 1984; McKinley 1989).

When estimating the sex of an unknown individual, population and age-related differences in morphology and body size must also be taken into consideration. The William Bass Donated Skeletal collection sample in the current study consisted exclusively of American Whites and D01-2010 from the Texas State Donated Skeletal Collection was an American Black. The high success rate for sex estimation in the current study could be a result of the rather homogeneous population from which the known sample is drawn.

Age-at-death estimation

Age-at-death estimation presented more of a challenge than sex estimation, which is likely a byproduct of the limited choices in sex estimation (male vs. female vs. ambiguous) compared to the broad range of possible ages represented in a sample. Preservation allowed for age-at-death estimation based on macroscopic observations of age-related degeneration in the pelvis in 16 out of 19 individuals in the current sample. Out of these 16 cases, 7 individuals had only 1 observable trait, 7 individuals had 2 observable traits and only 2 individuals had all 3 traits. Age ranges were generated for 11 of the 16 cases from the auricular surface, pubic symphysis or the combined ranges from both features. Out of these 16 cases, the actual age-at-death of 11 individuals fell within the estimated age ranges, the age-at-death was underestimated for 2 individuals, and the remaining 3 individuals had limited age-at-death estimates of 17+ years based solely on the iliac crest, which was the only feature that survived in these cases.

The individuals in the current sample were all over 51 years old at the time of death with the exception of one 42-year-old individual; the majority of the individuals (n=13) had an age-at-death of 65 years or more. Thermal destruction often causes distortion including an increase in porosity and granularity of surface topography in both the pubic symphysis and auricular surface (Holden et al. 1995; Pope 2007). Therefore, porosity should be interpreted as an age-related degenerative change with caution because it might actually be from the breakdown of the bone structure, particularly the dehydration and associated recrystallization that exposes the underlying spongy trabecular structure. Despite these challenges the actual ages-at-death in the current study fell within the age ranges estimated from macroscopic observations of degenerative changes in the auricular surface in 10 out of the 11 cases in which the auricular surface preserved. The results of the current study support the literature on the applicability of auricular surface aging over pubic symphyseal aging in the analysis of burned human remains due to better preservation of the former (McKinley 1989; Ubelaker et al. 1995).

Previous observations of burned bone indicate that the stages of epiphyseal fusion of surviving bones differ significantly from heat related deformation and are very useful in establishing the age-at-death of the individual (Mayne Correia and Beattie 2002; Brickley 2007). Although the anterior iliac crest is the first region of the lower torso to sustain damage when a supine body burns (Pope 2007), the complete union of the anterior iliac crest was observed in 9 cases, which indicated adult individuals (Webb and Suchey 1985). The medial clavicle did not preserve in any of the individuals in the sample. As in prior cremation studies (Baby 1954; Wells 1960), the acetabulum preserved well in many cases and was easily reconstructed to approximate anatomical completeness. While beyond the scope of the current study, the acetabulum could be used for age-at-death estimation based on recently developed techniques (Calce and Rogers In press; Rissech et al. 2006, 2007).

Forensic anthropologists have used cranial suture closure as an age-at-death indicator in the analysis of burned remains for years (Wells 1960; Merbs 1967; Gejvall 1970; Heglar 1984; Brickley 2007). However, cranial suture scoring is considered among the least reliable methods for age-at-death estimation (Singer 1953; Meindl and Lovejoy 1985; Mays 1998; Nawrocki 1998) because suture closure is highly variable within and between individuals and the method is imprecise. Throughout the sample, cranial vault fragments separated along well-preserved suture lines and appeared open and unfused or youthful. For instance, a section of the sagittal suture in a 101-year-old female (case 70-07D) measuring over 5 cm on both the left and right parietal fragments appeared to be preserved in an unfused state. Similarly, a large occipital fragment from a 75-year-old male (case D01-2010) was completely bordered by an unfused lambdoidal suture. Based on these observations, the use of cranial suture closure as an age-at-death indicator in burned remains is misleading at best.

The preservation of evidence of age-related degeneration dominates the burned remains literature regarding age-at-death estimation. Pope (2007) suggests that the presence of degenerative changes of the vertebral column could aid in distinguishing an older individual from a younger one at a multiple fatality scene. Merbs (1967), Bass (2006) and Warren and Maples (1997) use the presence of osteoarthritic lipping in the vertebral column to generate age-at-death estimates that differentiate elderly from younger individuals in archaeological analyses, casework and experimental research, respectively. Ubelaker et al. (1995) uses radiographs to assess vertebral osteophyte formation in the analysis of extensively charred remains from the Branch Davidian Compound. Christensen (2002) suggests that osteoporotic bones undergo more thorough destruction when exposed to fire; in her experimental research, osteoporotic bone consistently exhibited a higher degree of fragmentation and friability than healthier dense bone. Thurman and Willmore (1980) suggest that age-related cortical thinning might influence the results of replicative cremation experiments.

In the current study, moderate to severe osteophytic lipping of the vertebrae was recorded in 14 of the 19 cases. In the remaining 5 cases, the lack of evidence of degenerative changes in the vertebral column or elsewhere may have been the result of the poor preservation observed during data collection. Three of the 5 cases in which no degenerative changes were noted were among the 6 youngest individuals in the sample with ages-at-death of 51, 53, and 59, respectively; however, the other 2 cases had ages-at-death of 101 and 84 years. Therefore, the absence of degenerative changes in these 2 older individuals was highly suggestive of poor preservation due to the decreased bone density and osteoporosis associated with advanced age rather than a true absence of the trait. The cremains of Case 77-05D, a 74-year-old female, were particularly lightweight and markedly friable with increased porosity compared to the rest of the sample, which suggested that the individual suffered from osteoporosis during life. These observations contributed to age-at-death estimates in the current sample

Ancestry estimation

The use of ancestry in forensic anthropology is erroneously viewed as an extension of racial typology that perpetuates racism and inequality and denies both the effects of admixture and the complexities of human variation (Sauer 1992; Kennedy 1995; Loring Brace 1996; Armelagos and Van Gerven 2003;

Hefner 2007; Ousley et al. 2009) Regardless of the controversy, recent developments in ancestry estimation based on cranial and postcranial metric data have revolutionized the development of biological profile and facilitated positive identification.

In particular, the discriminant function program FORDISC compares metric data from unknown individuals to metric data from 12 reference populations of known age, sex, and ancestry (FORDISC Help Files). FORDISC places the unknown into the population group it is most similar to and from which it is most likely derived. FORDISC also provides probability and error rates for each classification, which strengthens the evidentiary value of ancestry estimation within expert testimony in the post *Daubert* judicial climate (Christensen 2004; Hefner 2007; Dirkmaat et al. 2008; Kimmerle et al. 2008; Christensen and Crowder 2009).

The success of metric and nonmetric techniques used by forensic anthropologists in the estimation of ancestry relies on the conjunction of both techniques and the preservation of the cranium and facial skeleton for measurements and morphological observations (Hefner 2007). The overall cranial characteristics and ancestral traits are often unobservable in burned remains due to the extensive fragmentation of the skull and destruction of the facial skeleton. In most intense fire events, heat related damage to the facial skeleton renders ancestry assessment inconclusive (Kalmey and Rathbun 1996; Mayne Correia and Beattie 2002).

Despite such challenges, Eckert et al. (1988) reports that anthropological analysis of the remains of a victim of cranial gunshot trauma whose head was placed directly under the cremation burner in a commercial crematory retort yielded a caucasian ancestry assessment. Furthermore, Dirkmaat (2002) used mid-facial characteristics to determine “suggested ancestry” from the remains of a homicide victim that the perpetrator had intentionally fragmented and scattered in a tended fire in a garbage pit. However, in both of these publications, the observations and mid-facial characteristics utilized therein as the basis for the estimation of ancestry were not specified.

The cranial fragmentation and destruction of the facial skeleton associated with commercial cremation in the current study rendered the cremains unfit for both metric and nonmetric trait based ancestry assessment. No cranial measurements were taken and nonmetric trait observations were so limited they were disregarded as inconclusive. Therefore, definitive statements regarding ancestry estimation could not be made.

In conclusion, the warping and shrinkage associated with burned bone did not present significant limitations in the estimation of sex and age-at-death in this study. Rather, the extensive fragmentation and poor preservation of elements that contribute vital information to the estimation of biological profile presented the greatest challenge because the estimation of biological profile depends on the presence of diagnostic features and sufficient preservation of elements to facilitate metric assessments. Despite extreme fragmentation sex and age-at-death estimation of the calcined remains was possible in the current study when specific diagnostic features preserved. Interestingly, some of these features were found on fragments that received the lowest scores of the amended completeness scale. In particular the greater sciatic notch, preauricular sulcus and ischiopubic ramus ridge of the pelvis and the mastoid process and nuchal area of the cranial vault contributed to sex estimation; while the auricular surface and evidence of osteophytic lipping of the vertebral margins and joint surfaces contributed the most to age-at-death estimates.

CHAPTER V

CONCLUSION

The current research demonstrates the reliable preservation of specific human skeletal elements that indicate sex and age, are recognizable, and can still exhibit valuable information upon which to base a sex and age-at-death estimate. In particular, the preservation of the nuchal crest and mastoid processes of the crania and the greater sciatic notch and presence or absence of the preauricular sulcus facilitated the estimation of sex. Age-at-death estimation depended upon the preservation of the auricular surface, which preserved in nearly twice as many cases than the pubic symphysis and was supplemented by the retention of evidence of degenerative osteophytic growth on the vertebrae and select joint surfaces. Conversely, the thorough destruction of the crania and facial skeleton did not allow for metric or nonmetric assessment of ancestry.

The extent of thermal destruction and associated fragmentation in the current study represents the worst-case scenario, for few fatal fire victims are reduced to a cremated skeleton. Therefore the success in sex and age-at-death estimation from the calcined remains in the current sample is encouraging and suggests that the estimation of biological profile should be possible in other fire contexts in which shorter exposure to fire at lower temperatures yields better preservation than that encountered herein. Although a typical house fire does not reach the temperatures found in commercial crematoria, temperatures in a post-flashover fire in which full room involvement results in a sustained fire can range from 800˚C-1000˚C (1470˚-1830˚F) (DeHaan 2008); the legal minimum temperature for commercial crematory retorts in Texas (912˚C/1675˚F) falls well within this range.

The findings of the current study can be applied to mass fatality incidents in which extensive fragmentation accompanied by burning dominate the condition of the remains (e.g. transportation accidents, terrorist attacks, and other contexts involving explosions). This research provides information and tools that fire investigators and mass fatality responders (especially forensic anthropologists) could utilize in the recognition and subsequent analyses of burned and fragmentary human remains that might otherwise be overlooked, including what to expect when calcined remains are suspected. Ultimately, this study raises awareness about the potential for the recovery of valuable information from extensively fragmentary remains from fire scenes.

The friable nature of the calcined remains in the current study emphasizes the importance of proper recovery and handling of human remains from forensic contexts because recovery itself is destructive. Therefore, thorough photo documentation at the scene and in the lab before and after handling using a scale and angled light in order to better capture the topography of features such as the auricular surface that are crucial for the estimation of age-at-death because the actual “body of evidence” may crumble at the next time they are handled or transported.

The current research also provides a glimpse at the potential for positive identification of an unknown individual based on observations of the following individualizing characteristics that survived the cremation process: evidence of surgical intervention (perforations in bone and actual surgical hardware), dental restorations, tooth roots and alveolar bone, pathological anomalies (fused vertebrae), and evidence of antemortem healing (callus formation).

Despite the seemingly controlled environment of a commercial crematory retort including consistent temperatures, duration of exposure and oxygen availability or atmosphere (DeHaan 2007), preservation was not consistent from one cremation to the next. These unexpected results reflect the dynamic nature of fire and thermal alteration of bone and suggest that other variables affect which elements survive. Further experimental cremation research could build on samples these disparate findings by focusing on samples using people of the same sex of similar age, height, body weights, distribution of fat and degree of musculature and tissue thicknesses burned in the same retort; comparative studies could then be conducted in order to isolate which variables most affect preservation.

Although beyond the scope of the current study, the fracture patterns that were observed may hold vital information in determining whether a fracture to the skeleton is a result of thermal destruction/postmortem or from trauma prior to burning. Both macroscopically and microscopically, the shapes of the fracture margins and fragments may lend themselves to creating a baseline in order to better understand heat related fractures and associated fragmentation. Further research is also needed to develop parameters for the rate of shrinkage of bone in order to develop more robust quantitative techniques involving metrics for sex and stature estimation. More work needs to be done in the classification of burned human remains in order to develop a consistent terminology that reflects the degree of thermal destruction and preservation of remains.

Best practice in forensic anthropology dictates that multiple methods based on metric and morphological data be applied to estimations of biological profile. However, the level of fragmentation and extent of heat-related destruction limits the number of observable traits, which forces the investigator to base estimates on as little as 1 or 2 traits. In conclusion, it is important to stress that diagnostic features for the estimation of sex and age-at-death of the biological profile do preserve after commercial cremation. However, the facial skeleton and cranium do not preserve well enough as to allow observations or measurements for the estimation of ancestry. In order to understand the preferential preservation of features that experience fixed shielding (e.g. auricular surface, femoral head) and flexion shielding (e.g. anterior distal humerus, humeral head) it is important to consider the type and density of the bone and the depth of the overlying tissue (Pope 2007; Symes et al. 2008). The use of the amended 5-point scale developed in the current research allowed for more comprehensive documentation of the differential preservation across the sample and revealed that fragments of skeletal elements that are less than 10%

complete can still hold important diagnostic data. The results of the current study will allow forensic investigators to pinpoint the skeletal elements that preserve and provide information regarding the estimation of biological profile. The positive findings of this research give weight to the claim that sex and age-at-death can be estimated from fragmentary remains, which will augment the existing literature on burned remains and techniques used in mass fatality and disaster response.

APPENDIX A

DATA COLLECTION SHEETS I-IV FOR UNPROCESSED CREMAINS:

I CRANIAL BONE INVENTORY

II POSTCRANIAL BONES-JOINT SURFACE INVENTORY-MEASUREMENTS

III SEX PELVIS/AGE PELVIS

IV SEX SKULL/ANCESTRY SKULL

DATA COLLECTION SHEET I FOR UNPROCESSED CREMAINS

Specimen Number ________________ Observer ________________________

Date ________________ Location of Collection __________________________

CRANIAL BONE INVENTORY

	L %	R%	NOTES
Frontal	___	___	____________________
Parietal	___	___	____________________
Occipital	___	___	____________________
Occip. Condyle	___	___	____________________
Temporal	___	___	____________________
Zygomatic	___	___	____________________
Palatine	___	___	____________________
Maxilla	___	___	____________________
Mandible	___	___	____________________
Mand. Condyle	___	___	____________________
Mental Emmin.	___	___	____________________
Gonial Angle	___	___	____________________

DATA COLLECTION SHEET II FOR UNPROCESSED CREMAINS
POSTCRANIAL BONES - JOINT SURFACE INVENTORY/MEASUREMENTS

No. __________ Observer ____________________ Date _________

BONE (MEAS.)	**L %**	**R %**			**NOTES**:(degenerative changes/epiphyseal lines)
Os Coxae					
Ilium	___	___			____________________________
Ischium	___	___			____________________________
Pubis	___	___			____________________________
Acetabulum	___	___			____________________________
Auric. Surf.	___	___			____________________________
Clavicle	___	___			____________________________
Prox. Humerus	____	____		**(SEX)**	____________________________
(hum. head diam.)	____	____	(mm)	____	____________________________
Distal Humerus	____	____			____________________________
(epicond. breadth)	____	____	(mm)	____	____________________________
Prox. Femur	____	____			____________________________
(fem. head diam.)	____	____	(mm)	____	____________________________
Distal Femur	____	____			____________________________
(epicond. Breadth)	____	____	(mm)	____	____________________________
Patella	___	___			____________________________
Prox. Tibia	____	____			____________________________
(bicond. Breadth)	____	____	(mm)	____	____________________________
Distal Tibia	___	___			____________________________
(max. epiphyseal breadth)	___	___	(mm)		____________________________

Degenerative changes - Vertebrae (grouped)

Cervical ____

Thoracic ____

Lumbar ____

DATA COLLECTION SHEET III FOR UNPROCESSED CREMAINS

Specimen Number _____________ Observer __________________________

Date _____________ Location of Collection _____________________________

SEX PELVIS

Pelvis	L	R
Ventral Arc (1-3)	___	___
Subpubic Concavity (1-3)	___	___
Ischiopubic Ramus Ridge (1-3)	___	___
Greater Sciatic Notch (1-5)	___	___
Preauricular Sulcus (0-4)	___	___
Parturition Scars (P/A)	___	___

AGE PELVIS

Auricular Surface (1-8)	___	___
Pubic Symphysis (I-VI)	___	___

OVERALL SEX, PELVIS ________ **OVERALL AGE, PELVIS** __________

NOTES:

DATA COLLECTION SHEET IV FOR UNPROCESSED CREMAINS

Specimen Number ____________ Observer ______________________
Date _______________ Location of Collection _________________________

SEX SKULL

Skull	L	R	NOTES:
Nuchal Crest (1-5)	________		____________________________
Mastoid Process (1-5)	___	___	____________________________
Supraorbital Margin (1-5)	___	___	____________________________
Glabella (1-5)	________		____________________________
Mental Eminence (1-5)	________		____________________________
Edentulous Mandible	___	___	____________________________
Edentulous Maxilla	___	___	____________________________

OVERALL SEX, SKULL __________

ANCESTRY SKULL

ANS (1-3)	______	NO (0 OR 1)	______
PBD (0 OR 1)	______	ZT (0-3)	______
SPS (0-2)	______	TPS (1-4)	______
ZS (0-2)	______	NBS (1-4)	______
INA (1-5)	______	IOB (1-3)	______
MT (0-3)	______	NAS (1-3)	______
NAW (1-3)	______	NBC (0-4)	______

NOTES:

APPENDIX B

KEYS FOR DATA COLLECTION SHEETS I-IV

1. KEY FOR DATA COLLECTION SHEET I AND II-CRANIAL AND POSTCRANIAL INVENTORIES:
    % = COMPLETENESS
    MEASUREMENTS
    DEFINITIONS AND REASON FOR INCLUSION:

2. KEY FOR DATA COLLECTION SHEET III
    SEX PELVIS
    AGE PELVIS

3. KEY FOR DATA COLLECTION SHEET IV-CRANIAL SEX AND ANCESTRY:
    SEX CRANIAL
    ANCESTRY SKULL

KEY FOR DATA COLLECTION SHEET I AND II
CRANIAL AND POSTCRANIAL INVENTORIES:

% = COMPLETENESS*:

1 = >75% present

2 = 25%-75% present

3 = <25% present

* Above reproduced from Standards For Data Collection From Human Skeletal Remains by Buikstra and Ubelaker, 1994.

MEASUREMENTS:**

HUMERUS:

(hum. head diam) = Vertical Diameter of Head: direct distance between the most superior and inferior points on the border of the articular surface

(epicond. Breadth) = Epicondylar Breadth: distance of the most laterally protruding point on the lateral epicondyle from the corresponding projection of the medial epicondyle.

FEMUR:

(fem. head diam) = Maximum Head Diameter: the maximum diameter of the femur head, wherever it occurs.

(epicond. breadth) = Epicondylar Breadth: Distance between the two most laterally projecting points on the epicondyles.

TIBIA:

(bicondylar breadth) = Maximum Proximal Epiphyseal Breadth: maximum distance between the two most laterally projecting points on the medial and lateral condyles of the proximal articular region (epiphysis)

(max epiphyseal breadth) = Maximum Distal Epiphyseal Breadth maximum distance between the two most laterally projecting points on the medial malleolus and the lateral surface of the distal articular region (epiphysis)

**Above reproduced from Standards For Data Collection From Human Skeletal Remains by Buikstra and Ubelaker, 1994.

KEY FOR DATA COLLECTION SHEET I AND II
CRANIAL AND POSTCRANIAL INVENTORIES CONTINUED:

DEFINITIONS AND REASON FOR INCLUSION:

CLAVICLE: Included because of its value as an age indicator. Most likely irrelevant with current sample, however recording the preservation may contribute to other remains.

PROXIMAL AND DISTAL ENDS OF LONG BONES: Refers to both epiphyses of the humerus, femur, and tibia. Regarding completeness, the presence or absence of features such as various processes, tuberosities, and articular facets will be recorded. Included because of the sex estimation information such measurements can provide in addition to potential preservation of healed pathology or medical intervention.

PATELLA: Included due to its high survivability and expression of pathology.

VERTEBRAE (GROUPED): Grouped indicates that due to the limited time with the collection reconstruction and numbering of the individual vertebrae is unrealistic (except for C1 and C2). Therefore vertebral fragments will be separated into cervical, thoracic, and lumbar based on morphology to the extent preservation allows and degenerative changes such as lipping, collapse, bony spicules, etc. will be noted as well as their location on the fragment. For instance lipping of vertebral body or bony nodule on spinous process.

KEY FOR DATA COLLECTION SHEET III

SEX PELVIS

Ventral Arc, Subpubic Concavity, and Ischiopubic Ramus Ridge)

1 = Female
2 = Ambiguous
3 = Male
-- = Unobservable

Greater Sciatic Notch

1 = most broad (extreme female)
2 = typical female
3 = ambiguous
4 = typical male
5 = most narrow (extreme male)

Preauricular Sulcus (more common in females)

0 = Absent
1 = P.S. is wide typically >0.5 cm, and deep
2 = P.S. is wide but shallow
3 = P.S. is narrow but well defined and deep
4 = P.S. is narrow, shallow, and smooth walled depression

Parturition Scars

P = Present while A = Absent, if present will count them.

* Above reproduced from Standards For Data Collection From Human Skeletal Remains by Buikstra and Ubelaker, 1994.

AGE PELVIS

Auricular Surface (1-8) = Based on Meindl and Lovejoy, 1988

Pubic Symphysis (I-VI) = Based on Suchey and Katz, 1998

NOTE: OVERALL AGE AND SEX TO BE DETERMINED AFTER DATA COLLECTION AND ANALYSIS

KEY FOR DATA COLLECTION SHEET IV

CRANIAL SEX AND ANCESTRY:

SEX CRANIAL:

DEFINITIONS AND SCORING FROM STANDARDS (1994) BY BUIKSTRA AND UBELAKER PG. 19-20.

A dash (--) will indicate the trait was unobservable due to bad preservation.

Edentulous Mandible: refers to any mandibular fragments with obvious healed antemortem tooth loss. Specific teeth will be noted when possible. Included as a potential age indicator.

Edentulous Maxilla: refers to any maxillary fragments with obvious healed antemortem tooth loss. Specific teeth will be noted when possible. Included as a potential age indicator.

NOTE: OVERALL SEX, SKULL WILL BE DETERMINED AFTER ALL DATA COLLECTION AND ANALYSIS

ANCESTRY SKULL

DEFINITIONS AND SCORING FROM THE STATISTICAL DETERMINATION OF ANCESTRY USING CRANIAL NONMETRIC TRAITS BY HEFNER (2007) APPENDIX A PG 99-104.

APPENDIX C
BIOLOGICAL PROFILE SCORES

Table CA - *All sex estimation methods results and comparison (N=19).*

Case No.	Cranial Based Sex	Pelvic Based Sex	Combined Cranio-pelvic Sex	Metric Based Sex	Estimated Sex All Methods	Actual Sex
70-04D	-	M	M	M	M	M
74-04D	F	-	F	F?	F?	F
28-06D	F?	F	F	F?	F	F
15-03D	F?	-	F?	M	M	M
67-07D	M	M	M		M	M
09-05D	M?	M	M	M	M	M
70-07D	F?	-	F?	F?	F?	F
21-05D	F?	-	F?	-	F?	M
16-03D	-	-	-	M	M	M
62-03D	M?	-	M?	M	M	M
33-05D	F?	-	F?	F?	F?	F
33-04D	F	F	F	M	M	M
53-09D	F	F	F	-	F	F
10-04D	-	-	-	F?	F?	F
55-05D	-	-	-	-	-	M
77-05D	F?	F	F	F?	F	F
55-09D	F	-	F	-	F	F
43-05D	?	-	?	F?	?	M
D01-2010	M?	M	M	M	M	M

Table CB—*Cranial morphology observations for sex estimation (N=19).*

Case No.	Nuchal Crest	Mastoid Process	Left Supraorbital Margin	Right Supraorbital Margin	Glabella	Cranial Based Sex	Actual Sex
70-04D	-	-	-	-	-	-	M
74-04D	-	F (L)	-	-	-	F	F
28-06D	-	F (R)	?	-	-	F?	F
15-03D	-	-	-	F?	-	F?	M
67-07D	-	M (L)	-	M	-	M	M
09-05D	M	M (R)	?	M?	?	M?	M
70-07D	-	F? (R)	-	F?	-	F?	F
21-05D	F	-	?	?	-	F?	M
16-03D	-	-	-	-	-	-	M
62-03D	M	-	?	-	-	M?	M
33-05D	-	-	F?	F	-	F?	F
33-04D	F	-	-	-	-	F	M
53-09D	F	-	F	F?	F	F	F
10-04D	-	-	-	-	-	-	F
55-05D	-	-	-	-	-	-	M
77-05D	F	F? (R)	-	-	-	F?	F
55-09D	F	F (L)	-	-	-	F	F
43-05D	-	? (L)	-	-	-	?	M
D01-2010	M?	M? (R)	F?	-	-	M?	M
Total observed	8	9	7	7	2	15	

Table CC—*Pelvic morphology observations for sex estimation (N=19).*

Case No.	Ventral Arc	Subpubic Concavity	Ischiopubic Ramus Ridge	Greater Sciatic Notch	Pre-auricular Sulcus	Pelvic Based Sex	Actual Sex
70-04D	? (R)	M (R)	M (R)	M (R)	M (L,R)	M	M
74-04D	-	-	-	-	-	-	F
28-06D	-	-	-	F (L)	-	F	F
15-03D	-	-	-	-	-	-	M
67-07D	-	-	M (L,R)	-	-	M	M
09-05D	M (L)	-	-	M (U)	-	M	M
70-07D	-	-	-	-	-	-	F
21-05D	-	-	-	-	-	-	M
16-03D	-	-	-	-	-	-	M
62-03D	-	-	-	-	-	-	M
33-05D	-	-	-	-	-	-	F
33-04D	-	-	-	F (L,R)	-	F	M
53-09D	-	F (U)	F (U)	F (L)	F (L)	F	F
10-04D	-	-	-	-	-	-	F
55-05D	-	-	-	-	-	-	M
77-05D	-	-	-	F (L)	-	F	F
55-09D	-	-	-	-	-	-	F
43-05D	-	-	-	-	-	-	M
D01-2010	M (L)	-	-	M? (L)	M (L)	M	M
Total observed	3	2	4	8	4	8	

Note: L-R-U indicate side (left, right, unknown)

Table CD —*Metric analyses with sectioning points (mm) and classification rates for sex estimation (N=19).*

Case No.	Left Hum. Head Diam.	Right Hum. Head Diam.	Hum. Epicon.Br.	Left Fem. Head Diam.	Right Fem. Head Diam.	Fem. Distal Epicon. Br.	Tib. Prox. Bicon. Br.	Final Metric Sex	Actual Sex
70-04D	46 ?	41 F	-	-	43F	-	-	M	M
74-04D	39 F	43 F	50 F(L)	38 F	39F	-	-	F?	F
28-06D	-	39 F	-	40 F	37F	-	-	F?	F
15-03D	-	49 M	-	43 F	-	-	-	M	M
67-07D	-	-	-	-	-	-	-	-	M
09-05D	-	-	50 F(R)	50 M	49M	-	-	M	M
70-07D	-	-	-	39 F	-	64 F(R)	-	F?	F
21-05D	-	-	-	-	-	-	-	-	M
16-03D	-	-	54 F(R)	-	45?	75 F(R)	-	M	M
62-03D	-	46 ?	-	-	45?(U)	-	-	M	M
33-05D	-	-	-	41F	39F	-	-	F?	F
33-04D	42 F	42 F	-	45?	46M	-	-	M	M
53-09D	-	-	-	-	-	-	-	-	F
10-04D	-	-	-	-	39F	-	-	F?	F
55-05D	-	-	-	-	-	-	-	-	M
77-05D	35 F	-	-	-	-	-	55 F(R)	F?	F
55-09D	-	-	-	-	-	-	-	-	F
43-05D	-	-	56 F(L)	-	-	-	-	F?	M
D01-2010	-	44F	-	-	45?	-	-	M	M
Sect. point*/ class.rate:	46mm/83%		60mm/87%	45mm/88%		80mm/88%	74mm/90%		

Table CE—*All age-at-death estimation methods results and comparison (N=19).*

Case No.	Auricular Surface		Pubic Symphysis		Iliac Crest	Estimated Age All Methods	Actual Age
	Score	Age	Phase	Age			
70-04D	6-8	45-60+	-		17+	45-60+	71
74-04D	-	-	-		17+	17+	74
28-06D	6-7	45-59	-		17+	45-59	59
15-03D	6-8	45-60+	VI	34-86	-	45-86	68
67-07D	-	-	V	27-66	-	27-66	42
09-05D	7	50-59	IV	23-57	-	50-59	75
70-07D	-	-	-	-	-	-	101
21-05D	-	-	-		-	-	51
16-03D	6-8	45-60+	-		17+	45+	70
62-03D	6-8	45-60+	VI	27-66	-	45-66	82
33-05D	-	-	-	-	17+	17+	91
33-04D	6-8	45-60+	-		-	45-60+	65
53-09D	7-8	50-60+	VI	34-86	17+	50-86	58
10-04D	6-7	45-59	-		-	45-59	52
55-05D	6-8	45-60+	-		-	45-60+	53
77-05D	-	-	-		17+	17+	74
55-09D	-	-	-		-	-	70
43-05D	-	-	VI	34-86	17+	34-86	84
D01-2010	7-8	50-60+	VI	34-86	17+	60-86	75

APPENDIX D

RAW DATA

DA. Combined *Standards* Cranial Inventory

DB. Frequency of *Standards* Scores – Cranial

DC. Combined Amended Cranial Inventory

DD. Frequency of Amended Scores – Cranial

DE. Combined *Standards* Postcranial Inventory

DF. Frequency of *Standards* Scores – Postcranial

DG. Combined Amended Postcranial Inventory

DH. Frequency of Amended Scores – Postcranial

Table DA Combined *Standards* Cranial Inventory

Case No.	Frontal	Parietal	Occipital	Occipital Condyle	Temporal	Zygomatic	Maxilla	Mandible	Manidbular Condyle	Gonial Angle
70-04D	2	3	3	2	3	2	2	3	1	3
74-04D	3	1	2		2	3	3	3	1	
28-06D	2	2	2		3			3	1	
15-03D	2	2	2		2				1	
67-07D	2	1	2		2	2	2	1	1	2
09-05D	2	2	1	2	2	2	3	2	1	
70-07D	1	2	2		3	3				
21-05D	2	2	2		2	2	2	3		
16-03D	2	2	2		2	2		2		
62-03D	2	2	2	1	2			2	1	
33-05D	2	2	2		2	2		2	2	
33-04D	2	2	2		3		3	3	1	
53-09D	2	2	2	2	2	2	3	3	2	
10-04D	2	2	2		3	2				
55-05D	3	3	3		3		3	2	2	
77-05D	3	2	2	2	2	2	3	3	2	1
55-09D	3	3	3		3		3	3	1	1
43-05D	2	2	2		1	1	3	3		
D01-2010	3	3	3	2	2	3	3	3	1	
Total Scored	19	19	19	6	19	13	12	16	14	4

Table DB Frequency of *Standards* scores – Cranial

	One	two	three	total scores for each box
70-04D	1	4	5	10
74-04D	2	2	4	8
28-06D	1	3	2	6
15-03D	1	4	0	5
67-07D	3	6	0	9
09-05D	2	6	1	9
70-07D	1	2	2	5
21-05D	0	6	1	7
16-03D	0	6	0	6
62-03D	2	5	0	7
33-05D	0	7	0	7
33-04D	1	3	3	7
53-09D	0	7	2	9
10-04D	0	4	1	5
55-05D	0	2	5	7
77-05D	1	6	3	10
55-09D	1	0	6	7
43-05D	2	3	2	7
D01-2010	1	2	6	9
Total Scored	19	78	43	140

Table DC Combined Amended Cranial Inventory.

Case No.	Frontal	Parietal	Occipital	Occipital Condyle	Temporal	Zygomatic	Maxilla	Mandible	Manidbular Condyle	Gonial Angle
70-04D	3	5	5	2	5	4	3	5	1	5
74-04D	5	1	5		2	5	5	5	1	
28-06D	4	4	3		5			5	1	
15-03D	4	2	2		3				2	
67-07D	3	1	3		3	2	4	2	1	3
09-05D	3	4	2	2	3	2	5	4	1	
70-07D	1	2	4		5	5				
21-05D	2	2	3		3	3	4	5		
16-03D	4	4	3		4	2		4		
62-03D	4	3	3	1	4			4	1	
33-05D	4	3	2		4	2		3	2	
33-04D	4	3	2		5		5	5	1	
53-09D	2	3	2	2	3	2	5	5	3	
10-04D	4	4	4		4	4				
55-05D	5	5	5		4		5	3	2	
77-05D	5	4	4	3	2	3	5	5	2	1
55-09D	5	5	5		4		5	5	1	
43-05D	3	3	3		1	1	5	5		
D01-2010	5	5	4	4	2	5	5	4	1	
Total scored	19	19	19	6	19	13	12	16	14	3

Table DD Frequency of Amended scores – Cranial

Case No.	one	two	three	four	five	Total
70-04D	1	1	2	1	5	10
74-04D	2	1	0	0	5	8
28-06D	1	0	1	2	2	6
15-03D	0	3	1	1	0	5
67-07D	2	2	4	1	0	9
09-05D	1	3	2	2	1	9
70-07D	1	1	0	1	2	5
21-05D	0	2	3	1	1	7
16-03D	0	1	1	4	0	6
62-03D	2	0	2	3	0	7
33-05D	0	3	2	2	0	7
33-04D	1	1	1	1	3	7
53-09D	0	4	3	0	2	9
10-04D	0	0	0	5	0	5
55-05D	0	1	1	1	4	7
77-05D	1	2	2	2	3	10
55-09D	1	0	0	1	5	7
43-05D	2	0	3	0	2	7
D01-2010	1	1	0	3	4	9
Total Scored	16	26	28	31	39	

Table DE Combined *Standards* Postcranial Inventory

Case No.	Clavicle	Prox. Humerus	Distal Humerus	Ilium	Ischium	Pubis	Auric. Surface	Acetab.	Prox. Femur	Distal Femur	Patella	Prox Tibia	Distal Tibia
70-04D	3	2	2	3	2	2	2	1	3	3	1	2	
74-04D		1	1	2	3			1	2	2	2	3	
28-06D		2	3		2		2	3	2	3	2		
15-03D		2	2		2	3	2	2	2	2	1	3	2
67-07D	2	3	3	1	1	2		1	3		1		
09-05D		2	2		1	2	2	2	2	3	2		2
70-07D		3	3		3				2	3	2		3
21-05D		3							3		2		
16-03D		2	1		2		2	2	2	2	1	2	2
62-03D		1	2		2	3	2	2	2	3	1	2	2
33-05D		3	2		2			1	2	2	2		2
33-04D		2	3		2		2	2	2	2	3	3	
53-09D		3	3	2	2	3	1	2	3	3	2	3	
10-04D		3	3	3	2		2	2	2	3	3	3	2
55-05D	2	2	3	2	3		2	3	2	3	1		3
77-05D		2	2	3	2		2	3	2	2	2	2	3
55-09D		2	3					3	3	3			
43-05D			2	2	2	3		3	2	3	1	3	
D01-2010	3	2	2	3	2	3	2	3	2	3	1	3	3
Total scored	4	18	18	9	17	8	12	17	19	17	18	11	10

Table DF Frequency of *Standards* scores – Postcranial

Case No.	one	two	three
70-04D	2	6	4
74-04D	3	4	2
28-06D	0	5	3
15-03D	1	8	2
67-07D	4	2	3
09-05D	1	8	1
70-07D	0	2	5
21-05D	0	1	2
16-03D	2	8	0
62-03D	2	7	2
33-05D	1	6	1
33-04D	0	6	3
53-09D	1	4	6
10-04D	0	5	6
55-05D	1	5	5
77-05D	0	8	3
55-09D	0	1	4
43-05D	1	4	4
D01-2010	1	5	7
Total Scored	20	95	63

Table DG Combined Amended Postcranial Inventory

	Clavicle	Prox. Hum.	Distal Hum.	Ilium	Ischium	Pubis	Auric. Surf.	Acetab.	Prox. Femur	Distal Femur	Patella	Prox. Tibia	Distal Tibia
70-04D	5	3	4	5	4	4	3	1	5	5	1	4	
74-04D		1	2	4	5			2	3	4	3	5	
28-06D		3	5		3		4	5	3	5	3		
15-03D		3	4		3	5	4	3	3	2	1	5	3
67-07D	2	4	5	1	2	2		1	5		2		
09-05D		3	3		1	2	4	3	3	5	1		3
70-07D		5	4		5				4	5	3		5
21-05D		4							5		4		
16-03D		4	1		3		4	2	4	2	1	2	4
62-03D		2	3		4	5	4	4	2	5	1	4	4
33-05D		5	2		2			1	2	3	3		4
33-04D		4	4		4		4	3	3	4	4	5	
53-09D		5	5	3	3	4	1	3	5	5	3	5	
10-04D		5	5	5	3		4	4	4	5	5	5	3
55-05D	2	4	5	3	5		4	5	4	5	2		5
77-05D		3	4	5	4		4	4	3	4	3	4	4
55-09D		4	5					5	5	5			
43-05D			2	4	3	5		5	4	5	1	5	
D01-2010	5	2	4	4	4	5	3	5	4	5	1	5	5
Total Scored	4	18	18	9	17	8	12	17	19	17	18	11	10

Table DH Frequency of Amended Scores – Postcranial

Case No.	one	two	three	four	Five
70-04D	2	0	2	4	4
74-04D	1	2	2	2	2
28-06D	0	0	4	1	3
15-03D	1	1	5	2	2
67-07D	2	4	0	1	2
09-05D	2	1	5	1	1
70-07D	0	0	1	2	4
21-05D	0	0	0	2	1
16-03D	2	3	1	4	0
62-03D	1	2	1	5	2
33-05D	1	3	2	1	1
33-04D	0	0	2	6	1
53-09D	1	0	4	1	5
10-04D	0	0	2	3	6
55-05D	0	2	1	3	5
77-05D	0	0	3	7	1
55-09D	0	0	0	1	4
43-05D	1	1	1	2	4
D01-2010	1	1	1	4	6
Total scored	15	20	37	52	54

REFERENCES

Angel JL. Bones can fool people. FBI Law Enforcement Bulletin Jan, 1974.

Armelagos GJ, Van Gerven DP. A century of skeletal biology and paleopathology: contrasts, contradictions, and conflicts. American Anthropologist 2003, 105(1):53-64.

Baby RS. Hopewell cremation practices. The Oho historical society papers in archaeology, 1954;1:1-7.

Bass WM. Is it possible to consume a body completely in a fire? In: Rathbun TA, Buikstra JE, editors. Human identification: case studies in forensic anthropology. Springfield, IL: Charles C Thomas, 1984;159-167.

Bass WM. Anthropology. In: Spitz W, editor. Spitz and Fisher's medicolegal investigation of death: guidelines for the application of pathology to crime investigation. 4th ed. Springfield, IL: Charles C. Thomas, 2006;240-255.

Bass WM, Jantz RL. Cremation weights in east Tennessee. J Forensic Sci 2004; 49(5):901-904.

Bennett JL. Thermal alteration of buried bone. J Arch Sci 1999;26:1-8.

Binford LR. An archaeological perspective. New York: Seminar Press, 1972.

Bohnert M, Rost T, Pollak S. The degree of destruction of human bodies in relation to the duration of the fire. Forensic Sci Intl 1998;95:11-21.

Brickley MB. A case of disposal of a body through burning and recent advances in the study of burned human remains. In: Brickley MB, Ferllini R, editors. Forensic anthropology: case studies from Europe. Springfield, IL: Charles C Thomas, 2007;69-85.

Brooks TR, Bodkin TE, Potts GE, Smullen SA. Elemental analysis of human cremains using ICP-OES to classify legitimate and contaminated cremains. J Forensic Sci 2006;51(5):967-973.

Buikstra JE, Swegle M. Bone modification due to burning: experimental evidence. In: Bonnichsen R, editor. Bone modification. College Station, TX: Center for the Study of the First American, 1989;247-258.

Buikstra JE, Ubelaker DH. Standards for data collection from human skeletal remains. Fayetteville, AK: Arkansas Archaeological Survey, 1994.

Calce SE, Rogers TL. Evaluation of age estimation technique: testing traits of the acetabulum to estimate age at death in adult males. J Forensic Sci. In press.

CANA Cremation association of North America final 2006 statistics and projections to the year 2025 2007 preliminary data. Presented at the 90th annual convention Montréal, Quebec, Canada august 6-9 2008. 1-22.

Christensen AM. Experiments in the combustibility of the human body. J Forensic Sci 2002;47(3):466.470.

Christensen AM. The impact of Daubert: implications for testimony and research in forensic anthropology (and the use of frontal sinuses in personal identification). J Forensic Sci 2004;49(3):1-3.

Christensen AM, Crowder CM. Evidentiary standards for forensic anthropology. J Forensic Sci 2009;54(6):1211-1216.

Currey JD. Bones: structure and mechanics. Princeton, NJ: Princeton University Press, 2002.

Currey JD. Bones: Structure and mechanics. Princeton NJ; Preinceton Univ Press, 2002.

Dayal MR, Bidmos MA. Discriminating sex in South African blacks using patella dimensions. J Forensic Sci 2005;50(6):1-4.

DeHaan JD. Kirk's fire investigation 6th ed. Upper Saddle River, NJ: Pearson Education, Inc., 2007.

DeHaan JD. Fire and bodies. In: Schmidt CW, Symes SA, editors. Analysis of burned human remains. London: Elsevier, 2008;1-14.

Dirkmaat DC. Recovery and interpretation of the fatal fire victim: the role of forensic anthropology. In: Haglund WD, Sorg M, editors. Advances in forensic taphonomy: method, theory, and archaeological perspectives. Boca Raton: CRC Press, 2002;451-472.

Dirkmaat DC, Cabo LL, Ousley SD, Symes SA. New perspectives in forensic anthropology. Yearbook Phys Anth 2008;51:33-52.

Dunlop JM. Traffic light discoloration in cremated bones. Med Sci Law 1978;18(3):163-173.

Dwight T. The size of articular surfaces of the long bones as characteristic of sex; an anthropological study. Amer J Anatomy 1905, 4:19-31.

Eckert WG. The medicolegal and forensic aspects of fires. Amer J of Forensic Med and Path, 1981; 2(4):347-357.

Eckert WG, James S, Katchis S. Investigation of cremations and severely burned bodies. The Amer J Forensic Med and Path 1988;9(3):188-200.

Fairgrieve SI. Forensic cremation: recovery and analysis. Boca Raton: CRC Press, 2007.

Forbes G. The effects of heat on the histological structure of bone. Police Journal 1941;14(1):50-60.

France DL. Observation and metric analysis of sex in the skeleton. In: Reichs KJ, editor. Forensic osteology: advances in the identification of human remains. Springfield: Charles C. Thomas, 1998;163–86.

Gejvall NG. Cremations. In: Brothwell D and Higgs E, editors. Science in archaeology: a survey of progress and research. Rev. and enlarged ed. New York: Praeger Publishers, 1970;468-479.

Glassman DM, Crow RM. Standardization model for describing the extent of burn injury to human remains. J Forensic Sci 1996;41(1):152-154.

Gozna ER. Biomechanics of long bone injuries. In: Gozna ER, Harrington IJ, editors. Biomechanics of musculoskeletal injury. Baltimore, MD: Williams and Wilkins, 1982;1-29.

Haglund WD, Sorg MH. Introduction to forensic taphonomy. In: Haglund WD, Sorg MH, editors. Forensic taphonomy: the postmortem fate of human remains. Boca Raton: CRC Press, 1997;1-12.

Hefner JT. The statistical determination of ancestry using cranial nonmetric traits [dissertation]. Gainesville (FL): Univ. of Florida, 2007.

Heglar R. Burned remains. In: Rathbun T, Buikstra J, editors. Human identifcation: case studies in forensic anthropology. Springfield IL: Charles C Thomas, 1984;148-158.

Herrmann B. On histological investigations of cremated human remains. J Human Evol 1977;6:101-103

Herrmann NP, Bennett JL. The differentiation of traumatic and heat-related fractures in burned bone. J Forensic Sci 1999;44(3):461-469.

Holden JL, Phakey PP, Clement JG. Scanning electron microscope observations of heat-treated human bone. Forensic Sci Intl 1995;74:29-45.

Introna F Jr, Di Vella G, Campobasso CP. Sex determination by discriminant analysis of patella measurements. Forensic Sci Intl 1998;95:39-45.

Kalmey JK, Rathbun TA. Sex determination by discriminant function analysis of the Petrous portion of the temporal bone. J Forensic Sci 1996;41(5):865-867.

Kemkes-Grottenthaler A. Sex determination by discriminant analysis: an evaluation of the reliability of patella measurements. Forensic Sci Intl 2005;147:129-133.

Kennedy KAR. But professor, why teach race identification if races don't exist? J of Forensic Sci 1995;40(5):797-800.

Kennedy KAR. The wrong urn: commingling of cremains in mortuary practices. J Forensic Sci 1996;41(4):689-692.

Kimmerle EH, Konigsberg LW, Jantz RL, Baraybar JP. Analysis of age-at-death estimation through use of pubic symphyseal data. J Forensic Sci 2008;53(3): 558-568.

Klepinger LL. Fundamentals of forensic anthropology. Hoboken NJ: John Wiley & Sons, Inc., 2006.

Komar DA, Buikstra JE. Forensic anthropology: contemporary theory and practice. New York: Oxford University Press, 2008.

Loring Brace C. A four letter word called "race". In: Reynolds LT, Lieberman L, editors. Race and other misadventures: essays in honor of Ashley Montagu in his ninetieth year. Dix Hills, NY:General Hall, 1996;106-141.

Lovejoy CO, Meindl RS, Mensforth RP, Barton TJ. Multifactorial determination of skeletal age at death: a method and blind tests of its accuracy. Amer J Phys Anth 1985, 86:1-14.

Mahfouz M, Badawi A, Merkl B, Fatah EEA, Pritchard E, Kesler K et al. Patella sex determination by 3D statistical shape models and nonlinear classifiers. Forensic Sci Intl 2007;173:161-170.

Mayne PM. The identification of precremation trauma in cremated bone. [thesis] Edmonton, Alberta; Univ of Alberta, 1990.

Mayne Correia PM. Fire Modification of bone: a review of the literature. In: Haglund WD, Sorg MH, editors. Forensic taphonomy: the postmortem fate of human remains. Boca Raton: CRC Press, 1997;275-286.

Mayne Correia P, Beattie O. A critical look at methods for recovering, evaluating, and interpreting cremated human remains. In: Haglund WD, Sorg M, editors. Advances in forensic taphonomy: method, theory, and archaeological perspectives. Boca Raton: CRC Press, 2002;435-450.

Mays S. The archaeology of human bones. London; Routledge, 1998.

McKinley J. Cremation: expectations, methodologies and realities. In: Roberts CA, Lee F, Bintliff J, editors. Burial archaeology: current research, methods and developments. Oxford: BAR British Series 211, 1989;65-76.

McKinley J. The analysis of cremated bone. In: Cox M, Mays S, editors. Human osteology in archaeology and forensic science. London: Greenwich Medical Media, 2000;403-421.

Merbs CF. Cremated human remains from Point of Pines, Arizona: a new approach. American Antiquity 1967;32(4):498-506.

Murad TA. The growing popularity of cremation versus inhumation: some forensic implications. In: Reichs KJ, editor. Forensic osteology: advances in the identification of human remains. Springfield, IL: Charles C. Thomas, 1998;86-105.

Murray KA, Rose JC. The analysis of cremains: a case study involving the inappropriate disposal of mortuary remains. J Forensic Sci 1993;38(1):98-103.

Nawrocki SP. Regression formulae for estimating age at death from cranial suture closure. In: Reichs KJ, editor. Forensic osteology: advances in the identification of human remains. Springfield: Charles C. Thomas, 1998;276-292.

Nelson CL, Winston DC. Detection of medical examiner cases from review of cremation requests. Am J Forensic Med Pathol 2006;27(2):103-105.

Nielsen-Marsh C, Gernaey A, Turner-Walker G, Hedges R, Pike A, Collins M. The chemical degradation of bone. In: Cox M, Mays S, editors. Human osteology in archaeology and forensic science. London: Greenwich Medical Media, 2000; 439-454.

Ortner DJ. Identification of pathological conditions in human skeletal remains. 2nd ed. San Diego: Academic Press, 2003.

Ousley S, Jantz R, Freid D. Understanding race and human variation: why forensic anthropologists are good at identifying race. Amer J Phys Anth 2009;139:68-76.

Owsley DW. Identification of the fragmentary, burned remains of two U.S. journalists seven years after their disappearance in Guatemala. J Forensic Sci 1993, 38(6);1372-1382.

Phenice TW. A newly developed visual method of sexing the Os Pubis. Am J Phys Anth 1969;30:297-302.

Pope EJ. The effects of fire on human remains: characteristics of Taphonomy and trauma [dissertation]. Fayetteville(AK): Univ. of Arkansas, 2007.

Pope EJ, Smith OC. Identification of traumatic injury in burned cranial bone: an experimental approach. J Forensic Sci. 2004, 49(3);431–440.

Rissech C, Estabrook GF, Cunha E, Malgosa A. Using the acetabulum to estimate age at death of adult males. J Forensic Sci 2006, 51(2):213-229.

Rissech C, Estabrook GF, Cunha E, Malgosa A. Estimation of age-at-death for adult males using the acetabulum, applied to four western European populations. J Forensic Sci 2007, 52(4):774-778.

Sauer NJ. Forensic anthropology and the concept of race: if races don't exist, why are forensic anthropologists so good at identifying them? Soc Sci Med 992, 34(2):107-111.

Schultz JJ, Warren MW, Krigbaum JS. Analysis of human cremains: gross and chemical methods. In: Schmidt CW, Symes SA, editors. The analysis of burned human remains. London: Elsevier, 2008;75-94.

Shipman P, Foster G, Schoeninger M. Burnt bones and teeth: an experimental study of color, morphology, crystal structure and shrinkage. J Arch Sci 1984;11:307-325.

Singer R. Estimation of age from cranial suture closure: a report on its unreliability. J Forensic Med. 1953, 1;52-59.

Snell, Jonathan. (personal communication) Certified Crematory Operator and Licensed Funeral Director, Heart of Texas Cremation and Burial Service, Austin, TX. April 18, 2010.

Spradley MK. (personal communication) Director Forensic Anthropology Research Facility. Texas State University-San Marcos, January 2010.

Spradley MK, Jantz RL. Skull vs. postcranial elements in sex determination. Proceedings of the 55th Annual Meeting of the American Academy of Forensic Sciences, Chicago, IL, 17–22 February. Colorado Springs, CO: American Academy of Forensic Sciences, 2003.

Stewart TD. Essentials of forensic anthropology. Springfield, IL: Charles C. Thomas, 1979.

Stiner MC, Kuhn SL, Weiner S, Bar-Yosef O. Differential burning, recrystallization, and fragmentation of archaeological bone. J Arch Sci 1995;22:223-237.

Suchey JM, Katz D. Applications of pubic age determination in a forensic setting. In: Reichs KJ, editor. Forensic osteology: advances in the identification of human remains. Springfield: Charles C. Thomas, 1998; 204-236.

Symes SA, Rainwater CW, Chapman EN, Gipson DR, Piper AL. Patterned thermal destruction of human remains in a forensic setting. In: Schmidt CW, Symes SA, editors. The analysis of burned human remains. London: Elsevier, 2008;15-54.

Thompson T. The assessment of sex in cremated individuals: some cautionary notes. Can Soc Forensic Sci J 2002;35(2):49-56.

Thompson TJU. Recent advances in the study of burned bone and their implications for forensic anthropology. Forensic Sci Int 2004;146S:203-205.

Thompson TJU. Heat-induced dimensional changes in bone and their consequences for forensic anthropology. J Forensic Sci 2005;50(5):1-8.

Thurman MB and Willmore LJ. A replicative cremation experiment. North American Archaeologist 1980-81;2(4):275-283.

Ubelaker DH et al. The role of forensic anthropology in the recovery and analysis of Branch Davidian Compound victims: recovery procedures and characteristics of the victims. J Forensic Sci 1995;40(3):335-340.

Ubelaker DH. Methodological considerations in the forensic applications of human skeletal biology. In: Katzenberg MA, Saunders SR, editors. Biological anthropology of the human skeleton. Hoboken, NJ: Wiley-Liss, 2000;41-67.

Ubelaker DH. The forensic evaluation of burned skeletal remains: a synthesis. Forensic Sci Intl 2009;183:1-5.

Van Vark G.N. The investigation of human cremated skeletal material by multivariate statistical methods, II. Measures. Ossa 1975;2:47-68.

Van Vark GN, Amesz-Voorhoeve WHM, Cuijpers AGFM. Sex-diagnosis of human cremated skeletal material by means of mathematical-statistical and data-analytical methods. Homo 1996;47(1-3):305-338.

Wahl J, Graw M. Metric sex differentiation of the pars petrosa ossis temporalis. Intl J Legal Med 2001;114:215-223.

Walker PL. Greater sciatic notch morphology: sex, age, and population differences. Amer J Phys Anth 2005;127:385-391.

Walker PL. Sexing skulls using discriminant function analysis of visually assessed traits. Amer J Phys Anth 2008;136:39-50.

Walker PL, Miller KP. Time, temperature, and oxygen availability: an experimental study of the effects of environmental conditions on the color and organic content of cremated bone. Poster presentation/published abstract Amer J of Phys Anth 2005;Suppl 40:22.

Walker PL, Miller KP, Richman R. Time, temperature, and oxygen availability: an experimental study of the effects of environmental conditions on the color and organic content of cremated bone. In: Schmidt CW, Symes SA, editors. The analysis of burned human remains. London: Elsevier, 2008;129-135.

Warren MW, Maples WR. The anthropometry of contemporary commercial cremation. J Forensic Sci 1997;42(3):417-423.

Warren MW, Schultz JJ. Post-cremation Taphonomy and artifact preservation. J Forensic Sci 2002;47(3):656-659.

Warwick R, Wiliams PL. Gray's anatomy 35th British edition. Philadelphia: W.B. Saunders Company, 1973.

Webb PAO, Suchey JM. Epiphyseal union of the anterior iliac crest and medial clavicle in a modern multiracial sample of American males and females. Amer J Phys Anth, 1985;68:57-66.

Webb WS, Snow CE. The Adena people. Knoxville: The University of Tennessee Press,1981.

Wells C. A study of cremation. Antiquity, 1960;34:29-37.

White TD. Human osteology. San Diego: Academic Press, 1991.

Williams BA, Rogers TL. Evaluating the accuracy and precision of cranial morphological traits for sex determination. J Forensic Sci 2006;51(4):729-735.

Wilson, Rebecca (personal communication) Forensic Anthropology Center: University of Tennessee-Knoxville, June 2009.

VITA

Teresa Gotay was the first of her family to be born in the continental U.S. She grew up in both the island of enchantment (Puerto Rico) and New England. Teresa attended Tulane University in New Orleans and in 2000 received a grant for undergraduate research in Anthropology and travelled with physical anthropologist Dr. Jon Verano to Peru to take part in excavations and lab analyses of prehistoric human remains with extensive perimortem trauma and postmortem dismemberment. She earned her B.A. in Anthropology from Tulane in 2004. In 2006, while working as an autopsy technician and forensic investigator for the Coconino County Medical Examiner's Office in Flagstaff AZ, she went on a skeletal recovery in the Grand Canyon with forensic anthropologist Dr. Laura Fulginiti. Then in the Fall of 2008, Teresa entered the Graduate College of Texas State University-San Marcos to pursue an M.A. in anthropology with a forensic focus. In November of 2009, she acted as interpreter for forensic anthropologist Dr. Steven Symes in Guatemala while he conducted a trauma and biomechanics workshop for the members of the Guatemalan Forensic Anthropology Team (FAFG).

Email address: terenugent@hotmail.com

This thesis was typed by Teresa Gotay Nugent.