Computed Tomography Analysis and Reconstruction of Ancient Egyptians Originating from the Akhmim Region of Egypt: A Biocultural Perspective

By

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A thesis submitted to the Faculty of Graduate Studies of the University of Manitoba
in partial fulfillment of the requirements of the degree of

DOCTOR OF PHILOSOPHY

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Abstract

Despite popular and scientific interest in mummies, very few studies of ancient Egyptian mummy collections, especially from the same area, have been conducted. As such, this research is the first comprehensive analysis of mummies from Akhmim, Egypt and is one of only a few studies that investigate a large mummy collection from both a biological and cultural point of view. A group of 25 mummies from the Akhmim Mummy Studies Consortium database was evaluated using computed tomography. Using computed tomography and the associated imaging software, two dimensional (2D) x-ray scan images were analyzed, then processed and edited to generate three dimensional (3D) models of each mummy. Both the 2D and 3D images of each mummy were used to collect both biological information and cultural data in a nondestructive manner. Results from this study indicated that the population of Akhmim was very diverse. Furthermore, this research both supports and challenges conventional wisdom on how ancient Egyptians were mummifying their dead.

Acknowledgements

My dissertation would not have been possible without the unwavering love and support of my family and close friends and without the constant support and guidance of my co-advisors Dr. Robert Hoppa and Dr. Jonathan Elias. I thank both of my advisors for giving me the opportunity to work on this project and for all of their advice and direction over the course of this research. I would also like to thank my internal committee members, Dr. Stacie Burke and Dr. Andrew Goertzen, and also my external reviewer, Dr. Ericka L'Abbé, for their valuable feedback and suggestions.

This research would not have been possible without the many contributions made to the Akhmim Mummy Studies Consortium database. Thanks go to all of the individual scholars and institutions that provided access to the mummies, that facilitated mummy scanning, and who collaborated on the project (see Appendix 1 for a full list of contributors). Special thanks go to Carter Lupton of the Milwaukee Public Museum and Sabina Malgora of the Castello del Buonconsiglio di Trento, both of whom are associates of AMSC and have ongoing projects with mummies that are included in this dissertation. Thanks also go to Randy Lykins of Pinnacle Health System.

Lastly, funding for this research was generously provided by the Manitoba Graduate Scholarship, the University of Manitoba's Graduate Fellowship, the Canada Research Chairs Program, and the University of Manitoba Faculty of Arts, Faculty of Graduate Studies, and Department of Anthropology.

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Figure 1 on page 27. Map of Akhmim, Egypt (inset) and surrounding areas, including the cemeteries. © 2014 Jonathan Elias

Figure 7 on page 109. Arm arrangement patterns from Elias et al. (2014). Source: Elias JP, Lupton C, Klales A. 2014. Assessment of arm arrangements of Egyptian mummies in light of recent CT studies. Yearbook of Mummy Studies 2:49-62. © 2014 Verlag Dr. Friedrich Pfeil, München

Chapter 1: Introduction

Ancient Egyptians have been studied more than any other culture past or present. Their belief in life after death engendered elaborate funerary practices and the eventual perfection of mummification of their dead. Once the *ba*, a person's essence, left the body, ancient embalmers were tasked with the eternal preservation of the dead. Unfortunately, much of what we know of this process relies on secondary accounts and scientific analyses (etic perspective) rather than on accounts by the Egyptians (emic perspective). Herodotus published one of the earliest, most complete and most often cited accounts of Egyptian mummification practices in Book II (*Euterpe*) of *The Histories*. Since then, Egyptologists and scholars in Egyptian mummification have narrowly viewed body preparation and mortuary practices in ancient Egypt. Herodotus' description of three mummification techniques, delineated by expense level, is rather simplistic and fails to cover the full range of variation already discovered in Egyptian mummies, yet it continues to be propagated as a veritable account of Egyptian mummification. By studying the bodies, we can come to understand ancient Egyptians from their own perspective rather than basing our conclusions of their mortuary treatments on propagated, and perhaps partially incorrect, historical accounts.

The distinctive religious and spiritual belief system of ancient Egyptians affords us a unique opportunity to study their mortuary practices and population history, namely through the remains themselves. Mummies have the unique ability to "reach across time and space" to provide information about their individual lives and about the culture from which they were a part (Gardner et al. 2004:228). Because of this, Egyptian mummies have been studied using virtually every analytical tool available. With the advent of newer, advanced, and most importantly, non-destructive technologies, mummy studies have moved into a new era of research. Specifically, computed tomography (CT) analysis has become the gold standard within mummy research today and gone are the days of destructive, autopsy driven analyses of mummified remains.

For this research, a series of individuals originating predominantly from Akhmim, Egypt were analyzed using CT scans of the mummified remains which were acquired by the Akhmim Mummy Studies Consortium (AMSC). The goal of this research was three-fold.

1) An attempt was made to better understand the individuals within the AMSC sample and then also to better understand the population variation, history, and diversity of Akhmim. Prior research analyzing Akhmimic mummies by Elias and colleagues (2007) suggest that Akhmim was highly cosmopolitan; therefore, if Akhmim was in fact multicultural and ethnically diverse, then a high level of variation would be present in the AMSC sample. The degree of variation and diversity present in this sample was documented through an analysis of individual and population level demographic data, followed by the craniometric analysis of population affinity and worldwide group classification.
2) A number of historical (e.g. Herodotus' *The Histories*) and modern texts (e.g. Ikram and Dodson 1998) present outsider accounts of the Egyptian mummification process. These texts largely represent our current understanding of this ancient practice and are frequently cited as indubitable

descriptions of the process, especially Herodotus' work. However, more recent works (e.g. Wade 2012, Elias et al. 2014) have begun to challenge these deep-rooted perceptions of mummification. Both of these works clearly demonstrate the disparity between the simplistic accounts given by previous authors and the wide range of variation being discovered by using large samples of ancient Egyptian mummies. A cursory review of this sample at the onset of data collection revealed a wide range of variation in mummification patterns and techniques; therefore, it was hypothesized that ancient Egyptian embalming practices were highly variable and did not precisely follow the prescribed sequence documented by Herodotus in antiquity and since perpetuated. In light of the most recent research and the noticeable variation discovered at the onset of the current research, the mortuary patterns of the AMSC sample were evaluated and then were situated within the larger context of our current understanding of ancient Egyptian funerary practices. Temporal patterns were assessed, as were unique variants and deviations from popularly held dogma within Egyptology.

3) These two areas of analysis (biological and cultural) were combined and synthesized. Too often individual mummies are studied as a singular case study, and even more commonly is emphasis placed solely on either biological parameters (e.g. paleopathology, trauma, sex) or cultural parameters (e.g. mummification method, social status, religious status) with no attempt to bridge these two foci of investigation. Therefore, each parameter was referenced in relationship to all others in an attempt to better understand the

attitudes and beliefs of ancient Egyptians in relation to their funerary practices.

Chapter Two begins with a historical review of mummies through time with an emphasis on interest in and exploration of ancient Egypt, as well as on the rise of scientific mummy studies. The shift from mummies as a commercial object to mummies as a commodity to mummies as a scientific research entity is chronicled with major discoveries and principal investigators described for each era. Next, the focus shifts specifically to the city of Akhmim and to the mummy sample utilized for the present research. Chapter Three focuses first on the theory and physics of computed tomography analyses and second on the application of this technology to physical anthropology and mummy studies. Both the benefits and limitations of this analytical tool are presented when used to investigate mummified human remains. Chapter Four discusses the biological parameters of the sample with consideration given to the reconstruction of each individual's biological profile, including age-at-death, sex, and stature. Results from this ancient Egyptian sample were contextualized within the published scientific literature and also within historic Egyptian accounts of these parameters. Chapter Five shifts attention to the cultural considerations of this sample, specifically those governing the mummification process. A historical overview of what we know of the process is presented, as is the stereotypical representation of this process perpetuated in the Egyptological literature. Next, each facet of the embalming process is discussed in detail beginning with embalming and evisceration procedures and the materials used for each, followed next by body positioning, and lastly by the wrapping patterns which signifies the final stage of the process. The results of this chapter were situated within the conventional discussions of ancient Egyptian mummification procedures. Chapter Six begins with a discussion of population biology, how it is measured within physical anthropology, and is followed by the study of population affinity in ancient Egyptian groups. Each individual in the sample was classified into population groups using a worldwide craniometric database. Several highly contentious hypotheses are presented and discussed in light of the craniometric results obtained from this study. The final chapter, Chapter 7, summarizes the contributions of this sample of Akhmimic mummies to our broader understanding of ancient Egypt and details future directions.

Large mummy samples derived predominantly from a single location are rare, yet have much to contribute to our understanding of the population history and the mortuary practices of ancient Egyptians. This research presents an overview of a specific, regionally derived population from the city of Akhmim, while also contextualizing this sample within the entirety of Egypt. The results from this research corroborate many long held beliefs, while also challenging many popularly held notions concerning what we think we know of ancient Egyptian funerary practices and their population history.

Chapter 2: Akhmimic Mummies

2.1 Literature Review

2.1.1 Mummies through Time

Interest in ancient Egypt is a worldwide phenomenon beginning during ancient times and continuing to the present. Surprisingly the birth of Egyptology, more specifically mummy studies, originated in Europe not Egypt. Early interest, curiosity displays, and scientific investigations occurred predominantly in several countries of Europe and was regionally centered. In the late 19th century, American scholars also began scientific investigations. Foreign dominance in the field remains even today; however, the contribution of Egyptian scholars has increased with time.

2.1.1.1 Historical Interest in Ancient Egypt: The study of ancient Egypt and Egyptians has a long history worldwide, primarily because of their "wide academic and popular impact" (Zweifel et al. 2009:406). Today, a number of museums are dedicated to ancient Egypt and a considerable amount of scientific research focuses on this population. Furthermore, Egypt continues to be a popular tourist destination and also numerous pop culture references are noted in the Western World. Through time, Egyptians themselves were historically aware and interested in their own history. For example, the temple of Seti I at Abydos depicts a partial list of rulers from the 1st Dynasty through the 19th Dynasty. Later during the 3rd and 4th centuries BC, both Greek and Roman historians also became extremely interested in ancient Egypt and wrote popular histories, the two most famous of which are Herodotus'' account of Egypt in Book II *Euterpe* of *The Histories* and Manetho's three volume series, *Aegyptiaca*.

2.1.1.2 Early Exploration: Travel to Egypt by Europeans began as early as the

13th century; however, many of these travelers were restricted to the region north of and including the vicinity of Cairo. Vercoutter (1992:30) notes that "Egypt was merely a staging post on the pilgrim route to or from holy places." Two priests, Father Vansleb and Father Claude Sicard, took a more scholarly interest by documenting Egyptian ruins and producing a map of Egypt, respectively (Vercoutter 1992). Interest among intellectuals in ancient Egypt did not begin until later during the Enlightenment, from the mid-17th century to late 18th century, when fascination with ancient Egyptian culture prompted a number of Europeans to visit Egypt. Napoleon Bonaparte's 1798 Egyptian military campaign is arguably the most famous of the Enlightenment explorations of the Nile Valley, yet a number of European scholars visited Egypt and published accounts pre-dating Napoleon's. Bishop Richard Pococke published *A Description of the East and Some other Countries,* of which Volume I included his observations of Egypt in 1743 and Federic Louis Norden's *Voyage d'Egypte et de Nubie* is an account of his 1737-1738 expedition along the Nile that was published in 1755. Vercoutter (1992:49) attributes much of the birth of Egyptology as a discipline and *Egyptomania* to Vivant Denon who published the "immensely popular" *Voyage dans la Basse et la Haute Égypte* in 1802. Denon traveled as part of Napoleon's cultural campaign as a savant of the *Institut d'Egypte* in literature and arts (Peters 2009). He quickly published his account of Egypt upon his return to France. Other scholars accompanying the Napoleonic expedition collected a wide range of data that was later described in the official publication of the expedition, the *Description de l'Égypte,* a twenty volume series released from 1809 to 1829. Similar to Denon's work, the official description of Napoleon's culture campaign "was very influential as it affected many levels of political, social and cultural thought in

Europe from the time" they were published, specifically in regard to *Egyptomania* (Peters 2009:34).

During the early 19th century, large scale looting and exporting of material from Egypt began. There was at that time no Egyptian antiquities department, and therefore, mass quantities of material culture especially and also mummified remains were shipped from Egypt to museums and private collections all over the world. Several factors contributed to European "consular collecting" including increased access to Egypt, extended permission to excavate, and greater support from Muhammad Ali, then head of the Egyptian state (Peters 2009:50). Bernadino Drovetti, a former colonel of Napoleon's, and his agent Jean-Jacques Rifaud amassed large statuary collections that were sold to the Turin Museum and the Louvre (Vercoutter 1992). Following Drovetti's lead, Henry Salt sold his collections (much of which was procured by Giovanni Battista Belzoni) to the British Museum and the Louvre (Lilyquist 1988). Independently, Giovanni d'Anastasy sold portions of his collection to Leiden and the Louvre as well. Both Drovetti and Belzoni succeeding in bringing mummies into Europe in addition to artifacts; however, Belzoni's primary goal was to gather papyri, not mummies. With complete disregard for the mummies encountered during his quest for papyri, Belzoni (1820, as quoted in Vercoutter 1992:182) describes:

> sinking altogether among the broken mummies, with a crash of bones, rags, and wooden cases, which raised such a dust as kept me motionless for a quarter of an hour, waiting till it subsided again. I could not move from the place, however, without increasing it, and every step I took I crushed a mummy in some part or other…It was choked with mummies…I could not avoid being covered with bones, legs, arms, and heads rolling from above. Thus I proceeded from one cave to another, all full of mummies piled up in various ways, some standing, some lying, and some on their heads. The purpose of my researches was to rob the Egyptians of their papyri; of which I found a few hidden in their breasts, under their arms, in the space above the knees, or on the legs, and covered by the

numerous folds of cloth that envelop the mummy

Belzoni's own account is testament to the artifact-driven interest and destruction of human remains in Egypt at the time. Only later did interest in the mummies occur, first as curiosities and later as serious scientific artifacts.

While the wholesale export of important artifacts and remains from Egypt was a deplorable outgrowth of *Egyptomania*, the era spurred the development of a modern period of Egyptology, one that included more rigorous scientific investigations, although not yet to today's standards. Conscientious scholars, John Gardner Wilkinson from Britain and Jean-François Champollion, from France, both documented ancient Egypt during the 1820s with greater scientific rigor than previous periods of investigation (Champollion 1822, Wilkinson 1837). Wilkinson spent 12 years visiting and documenting important Egyptian archaeological sites. In 1837 Wilkinson published his account of the Egyptian culture and history in *Manners and Customs of the Ancient Egyptians*. Champollion's greatest contribution to Egyptology was the decipherment of hieroglyphics from the Rosetta Stone in 1822.

2.1.1.3 Mummy Acquisition: Interest in ancient Egyptian art motifs by Europeans spurred the acquisition, often illegally, of artifacts and mummified remains. In 1858, Auguste Mariette became head of the first organized Egyptian Antiquities Service, created by Saïd Pasha, to protect Egyptian antiquities and conserve archaeological sites (Vercoutter 1992). Despite his intentions, Mariette's methods of excavation were lacking as he regularly used dynamite and failed to record the more than 300 tombs he cleared (Brown 1992). Most of the material discovered during the 1850s and 1860s went to the museum in Cairo and the focus was primarily on artifacts and papyri rather than on mummies (Elias 2013, pers comm).

After artifacts associated with royal persons began to appear on the antiquities market (c. 1871), Gaston Maspero deduced that the Abd el-Rassul brothers "had been dealing in stolen burial goods" from surreptitious excavations in the Theban necropolis (Dunand and Lichtenberg 1994:21). In July 1881, Maspero's assistant Émile Brugsch assumed responsibility for the excavation of the great mummy cachette at *Deir el-Bahari* (DB 320). Forty-six mummies were discovered at one time, in a single location, many of them royal, prompting worldwide interest. This was the biggest archaeological find of that time in Egypt, yet archaeological documentation of the site was nonexistent (Graefe 2003). The royal mummies were emptied from a tomb at *Deir el-Bahari* (DB 320) in a matter of days. Unfortunately, the site was excavated so hastily that the original condition and organization of the cachette remains unknown. Over 100 years later an attempt was made in 1998 by Galina Belova to reanalyze the tomb in order to better understand what Brugsch originally encountered, yet much of the original provenience information was permanently lost (Graefe 2003). News quickly spread after the publication of the discovery in 1882 and illegal looting of the site began (Edwards 1882).

The well-known royal mummies were displayed in the Boulaq museum while the lesser known members of the original 46 were placed in storage (Brown 1992). After 1885, as the Boulaq facility closed, newly-discovered non-royal mummies "deemed of lesser importance" were sold in great quantities by Brugsch (Dreyfus and Elias *in press*:3). Egypt was now in financial distress, and storage space remained an issue. Many of these "lesser mummies" had been excavated at Akhmim.

Thirteen years later (1898) French archaeologist, Victor Loret rediscovered the tomb of Amenhotep II in the Valley of the Kings (Reeves and Wilkinson 1996). Contained within this tomb was a second cachette of royal mummies containing eight kings, an unidentified women, and the bodies of six other royals (El-Mahdy 1989). Once again public interest in Egyptian mummies peaked. Throughout the 1890s and into the first years of the twentieth century, excavations continued in the Valley of the Kings and at the great temple site of Karnak. Mummies continued to stream in from cemeteries of Akhmim and other provincial sites in Upper Egypt (discussed further in detail below).

With time, the excavation of mummies became more organized and systematic. Loret, along with William Flinders Petrie and George Reisner, represented "a new breed of archaeologists," ones who carefully planned and documented and ones who "found archaeology in Egypt a treasure hunt; [and] left it a science" (Brown 1992:30/33). Excavations in Egypt began to be driven by archaeological method and technique, rather than by sheer curiosity.

Mummy acquisition was virtually a free-for-all prior to the Antiquities Department being established. Afterwards, sale of mummies in the hundreds continued; however, those that were permitted to be exported from Egypt were those considered less important. The fate of many of the mummies exported from Egypt in the 19th and early 20th centuries is unknown. Some were destroyed intentionally, some were preserved in various collections, and some never survived their initial journeys. As mummies of both royal and non-royal status flooded the European market, a field of study specifically dedicated to their study emerged.

2.1.1.4 History of Mummy Studies (Table 1): European interest specifically in Egyptian mummies began as early as the 10th century and peaked during the Renaissance

Table 1. Phases of mummy research with principal investigators (PIs) and major developments and features of each phase.

Phase	Years	Phase Name	PIs	Period Features
1	10th C - 1582	Mummy as a Drug	A. Stanwood	Commercial use of mummies (drug, fuel, paper, paint), mummy parts
2	1583 - 1646	Mummy Collections & Proto-museums	B. Paludanus, O. Worm, O. van Heurn	Whole mummies, display, museum origins
3	1647 - 1794	Early Scientific Research on Mummification	G. Nardi, A. Gryphius, T. Greenhill, members of First Egyptian Society, J. Hadley	First mummy autopsies, focus on cultural practices, publications begin
4	1794 - 1880	Rise of Broader Scientific Research	J. Blumenbach, A. Granville, W. Osburn, T. Pettigrew, J. Warren, L. Mitchill, G. Gliddon, S. Morton	Holistic studies, mummy autopsies, public unwrappings, population biology and craniometrics
5	1881 - 1925	Royal Mummy Phase	G. Maspero, D. Focay, M. Ruffer, G. Smith, M. Murray, W. F. Petrie, W. Röntgen	Discovery of Royal Mummies and King Tutankhamen, mummy autopsies, introduction of multidisciplinary teams, photography, invention of x-ray
6	1926 - 1972	Radiology & the Rise of CT	J. Cohen, H. Shay, R. Moodie, J. Harris, E. Wente, H. Winlock, G. Hounsfield	Decrease in mummy autopsies, increase in x-ray, invention of computed tomography, use of large samples, cultural and biological driven research
7	1973 - 1985	CT Era Onset & Rise of Paleopathology	P. Gray, A. Cockburn, Paleopathology Association, R. Davide, P. Lewin & D. Harwood-Nash	Last mummy autopsy, creation of Paleopathology Association, focus on disease, scientific method, precise documentation, development of 3DCT
8	1986 -	3DCT & Other Modern Technologies	AMSC, IMPACT, M. Raven, W. Taconis, M. Marx & S. D'Auria	Dominated by CT and minimally invasive techniques, 3DCT, World Congress on Mummy Studies

period, from the 14th to early 17th century. American interest in mummies occurred centuries later in the 19th century. During the initial periods of interest, mummies were primarily valued for their medicinal properties and commercial value. Gradually, scholars began realizing the scientific value of preserving entire mummies, which resulted in the rise of collections containing mummies and the creation of proto-museums. Once mummified remains were preserved and stored within collections, scientific inquiry began: first with an interest in the mummification process and amulets and then later expanded to include broader research questions, such as on population affinity and the study of disease. The methods used to study mummies expanded with the diversification of research analyses. In the initial phases, unrollings and an autopsy based approach were common until the introduction and widespread use of radiological methods. The current era of mummy studies (Phase 8, discussed in more detail below) is defined by 3DCT of mummies to document both biological and cultural aspects of Egyptian mummies. Below are eight phases of mummy research that have been identified in conjunction with the Akhmim Mummy Studies Consortium.

2.1.1.4.1 Phase 1: Mummy as a Drug (10th C – 1582): European interest was characterized by a non-scientific attitude towards mummies and other artifactual materials coming from Egypt. Mummies were considered objects to be used for commercial purposes. Primarily, mummies were being processed to create a mineral substance believed to have medicinal properties. The term *mumia* refers to a naturally occurring bitumen mineral found in areas near to Egypt, yet the term later came to also refer to ground up mummified remains. Apothecary shops in Europe sold *mumia* for a variety of ailments, but it was especially valued for its healing properties. Other uses included termination of internal bleeding and preservation of the flesh (Hill 1960). *Mumia* originated as early as the 12th century; however, the popularity of the "mummy drug" peaked during the Renaissance period, from the early 14th to early 17th centuries (Pettigrew 1834, Budge 1894:174). Raven (1993) attributes the 1517 Turkish conquest of Egypt for both the rise in popularity and availability of the drug. Pulverized material and mummy parts were imported into Europe in bulk to supply the market, often to Italy or the Netherlands and then redistributed elsewhere. Demand was so high for *mumia* in the 16th century, that traders manufactured remains by simulating the mummification process with contemporary bodies (Budge 1894, Hill 1960). Ambroise Parė, an anatomist and leading French doctor specializing in surgery, fervently attacked the use of *mumia* and called the drug 'wicked' in 1582 (Hill 1960). Despite heavy criticism by Parė and other prominent doctors, *mumia* remained available for sale as late as the early 20th century, although widespread use of the concoction declined rapidly in the late 18th century due to a trade tax placed on the sale of mummified remains and to the questionable efficacy of the drug (Pettigrew 1834, Budge 1894).

Further uses of mummified remains included papermaking, fuel, and paint. The sale of mummy linen to mills for paper, as well as for clothing in Egypt, was mentioned as early as 1140 by an Iraqi physician (Hunter 1947). Entire mummies and their associated linen were being imported into the United States as early as 1855 as a paper source, which at the time was in short supply due to increased demand for books and therefore increased printing and binding. Augustus Stanwood reportedly "brought several shiploads of mummies to his mill" in Maine to manufacture a heavy, brown wrapping paper that was sold to grocers and butchers at this time (Hunter 1947:287). Mark Twain mentions the use of mummies as fuel in *The Innocents Abroad* (1869), as does an earlier 1859 newspaper article (Baker 2001). Some evidence exists for the use of mummies as locomotive fuel for the railway connecting Alexandria and Cairo; however, a more plausible explanation is the use of mummy coffins for fuel, as well as building materials, rather than the mummies themselves (Carne 1826, Lushington 1833). Finally, mummies were also ground up to create an oil paint known as 'mummy brown' during the 19th century (Ikram and Dodson 1998). Unfortunately, the destruction of many mummies occurred during this initial phase and onward, as human remains were highly sought out for their commercial trade value.

2.1.1.4.2 Phase 2: Collection of Mummies and Proto-Museums (1583- 1646): In the second phase of mummy studies, we see a change in the focus and manner in which mummies were purposed. Interest shifted from mummy as a commodity, either pulverized or in parts, to mummy as an object of interest to be preserved in entirety. Hafstein (2003:9/14) notes that "comprehension and collection in the Renaissance are coextensive [as] gathering knowledge, gaining virtue, and amassing objects [were all] tightly intermeshed;" therefore, "knowledge came to revolve around material objects." Cabinets of curiosities owned by royalty, doctors, and wealthy citizens with a wide range of education and interests often contained Egyptian artifacts and mummies. Much of the earliest collecting began in the Netherlands. During the late 16th century, the private collection of Paludanus contained an entire mummy included in his medicinal display, which at this time was a rarity (Raven 1993). Scholars also began building early collections with the display of mummies during the origins of what later became the museum industry. A notable figure of this time was Ole Worm, considered to be a founding father of museology. During the late 16^{th} and into the early 17^{th} century, Worm amassed one of the early European collections that contained entire mummies for display in an educative manner. Furthermore, Otho van Heurn was one of the first scholars "to get interested in their [mummies] significance as anatomical specimens, or even in their archaeological background" during the first quarter of the 17^{th} century (Raven 2005:20). Van Heurn's Leiden Cabinet of Anatomy, which would later be incorporated into the Leiden Museum of Antiquities, contained two Egyptian mummies (Raven 2005). Mummies were incorporated into the national heritage of European countries in what we now call museums. Once a mummy was incorporated into a museum collection it became a "prominent object in the collection, and became the subject of elaborate description" (Murray 2000:50-51). Mummies first needed to be collected and made available as valuable specimens of ancient cultures prior to their scientific study. By the late 17^{th} century, nearly a dozen mummies were documented in museums, private collections, and libraries around Europe (Murray 2000).

2.1.1.4.3 Phase 3: Early Scientific Research on Mummification (1647-1794): Scientific inquiry quickly followed once early collections of mummies were formed during the European Renaissance. Initial investigations often focused on very specific questions. A quest for knowledge on Egyptian mummification and embalming drove early dissections. Interests were predominantly limited to cultural practices rather than the biological aspects of the remains. Giovanni Nardi (1647) published an account of unwrapping two mummies from an Italian collection, although the precise date of the unwrapping itself is unknown. This marks the first documented account of taking entire mummies for scientific study and autopsy. Shortly thereafter, three mummies in the possession of Jakobus Krause, a local apothecary in Breslau, Germany (now Wroclaw Poland), were unwrapped by Andreas Gryphius (1662). Thomas Greenhill also published an account of embalming practices with information gathered from autopsy in *Νεκροκηδεία* (1705). In 1742 London, the First Egyptian Society, of which Charles Perry, Norden and Pococke were members, unrolled a mummy acquired by the Earl of Sandwich (Dawson 1937). Early anatomical dissections of mummies were also conducted by John Hadley in 1763 (Hadley 1764). For 120 years the main focus of unwrapping was for the sake of discovering Egyptian secrets of body preservation. Aufderheide (2003:11) notes that many of these initial investigations were "scattered, uncoordinated and largely unfocused efforts reflect[ing] the beginnings of studies on mummified human remains." By the 18th century, European interest in human anatomy increased the demand for human cadavers for dissection purposes (Paolello and Klales 2013). Inevitably this interest coincided with the availability and interest in Egyptian mummies.

2.1.1.4.4 Phase 4: Rise of Broader Scientific Research (1794-1880): Phase 4 is marked by broader research questions, greater use of the scientific method, and more biologically driven research. Holistic studies, those drawing conclusions based on examination of the body, the container, accoutrements and all inclusions, were done by three notable scholars. There are three studies in Britain between 1825 and 1834 that deserve mention: A.B. Granville's discussion of Irtyersenu in 1825, William Osburn's study of the Leeds mummy, Natsef-Amun, in 1828, and perhaps the most famous, Thomas J. Pettigrew's *A History of Egyptian Mummies*, from 1834. Irtyersenu, also known as Granville's Mummy, was presented to the Fellows of the Royal Society in

1825. Granville decided to autopsy the mummy in 1821 after purchasing the mummy for four dollars from Sir Archibald Edmonstone (Granville 1825). He then completed one of the first biological anthropological investigations of a mummy and provided a diagnosis as to the potential cause of death (Donoghue et al. 2010). The Leeds Mummy, known as Natsef-Amun, was acquired from Thebes in 1823 by M.J. Passalacqua (Brears 1993). The following year, John Blayds purchased and donated the mummy to the Leeds Philosophical and Literary Society (Brears 1993). In late 1824, the society's leader, William Osburn, and a multidisciplinary team headed by physician Teal, autopsied and documented the mummy, which was then subsequently published as a cursory review in the Leeds Intelligencer in 1825 (Brears 1993). A complete description of the scientific endeavor and results were later published by Osburn (1828). Thomas J. Pettigrew became interested in Egyptology after meeting Belzoni and examining several of his mummies (Dawson 1934). Specifically, Pettigrew was fascinated by the mummification process which most likely led to his desire to unwrap mummies. The first mummy Pettigrew unwrapped was one brought to England by Charles Perry in 1741 which he examined privately in his home during the 1820s (Dawson 1934). Pettigrew's first public unrolling occurred in April of 1833 and he continued to hold public unwrappings and educational courses until 1851 (Dawson 1934). Pettigrew investigated more than a dozen mummies in this way and was one of the first to "emphasize bioanthropological information" and to employ a synthesized approach to mummy studies (Aufderheide 2003:10). Pettigrew's (1834) famous *A History of Egyptian Mummies* describes his courses and the mummies he investigated. Each of these three scholars strived toward holism at a time when narrowly focused modes of inquiry dominated Egyptology and mummy studies.

Mummy unwrappings were occurring around the same time in the United States, as well. In 1823 John Warren unwrapped the head of the mummy Padihershef for public display at the Massachusetts General Hospital in Boston (Warren 1823, Barker 1993). The first public unrolling in the United States was of Captain Larkin Thorndike Lee's mummy at the College of Physicians in New York in 1824 by Samuel L. Mitchill and colleagues (V. Mott, J.D. Jacques, N.H. Dering, W. J. Macneven)(Lee 1824, Mitchill 1824). Two additional mummies owned by the museum of Ruben Peale were unwrapped in New York in 1826 (Yale University 2013). During 1850s, George Gliddon unwrapped several mummies in Boston, Philadelphia, and New Orleans as part of his lecture series *Panorama*; however, he may have unwrapped mummies prior to this period as referenced by Poe (1845) (Yale University 2013). Each of the aforementioned inquiries are poorly documented and were likely object or curiosity oriented, rather than serious scientific investigations.

Other pre-modern scientific inquiry is represented by an abiding interest in skeletal form with regard to ancient Egyptian populations and racial theory. Prominent in this regard was Johann Blumenbach who unwrapped a mummy in Germany and then several more during a 1791/2 visit to London (1794). Blumenbach introduced an anthropological component to mummy research by studying them in an attempt to describe the varieties of mankind. Phrenology, craniometrics, and comparative anatomy became even more popular inquiries among 19th century scholars. Therefore, historic studies primarily focused on the skull, to answer questions of race or ancestry. In America, the work of Samuel Morton comes to mind with the 1844 publication of *Crania Aegyptiaca,* whereby from the analysis of three Egyptian mummies Morton suggested evidence for the notion of polygenism, the idea that human races descended from different origins or ancestral types (Stanford et al. 2013). Gliddon and his father later acquired many of the mummy skulls used in Morton's analyses (Yale University 2013).

2.1.1.4.5 Phase 5: Royal Mummy Phase (1881-1925): The early pioneering work of Granville, Osburn, and Pettigrew and the autopsy-based approach developed during Phase 4 continued into the 20th century (up until the mid-1980s). The next phase of mummy research is marked by the discovery of the royal mummies and their influence on the field at the time. The end of this phase is signaled by a shift in methodology, primarily with the introduction of radiology.

For over a decade, Maspero facilitated the unwrappings of the royal mummies from *Deir el-Bahari*. Dr. Daniel Focay completed the autopsies beginning with Thutmose III, followed by Ramses II, Queen Ahmose Nefertari, Ramses III, Amenhotep I, and Seti I in the late 19th century (Brown 1992). Maspero's remaining career primarily centered on the royal mummies. At the turn of the century, a number of mummies were obtained for study when salvage excavations were conducted in the vicinity of the Aswan Low Dam in Nubia (Aufderheide 2003). Early dissectors of these Egyptian mummies included Marc Ruffer, George Andrew Reisner, Grafton Elliot Smith, F. Wood Jones, and Douglas Derry. Dawson (1938) and Aufderheide (2003:13) suggest that Smith examined over 33,000 mummies and likely "dissected more Egyptian mummies than any other worker had done before (and perhaps ever since)." Unfortunately, records and detailed descriptions are lacking for the majority of these mummies. In 1908, Margaret Murray of the University of Manchester dissected a mummy excavated by Sir William Flinders Petrie (Dunand and Lichtenberg 1994). Contrary to Ruffer's work, the Manchester

Museum dissection employed a multidisciplinary team and generated a rather detailed description of the research findings (Murray 1910). Decades later, Howard Carter discovered the tomb of King Tutankhamen in 1922, marking the most sensational archaeological discovery of the 20th century. The mummy of Tutankhamen was autopsied on November 11, 1925 by D.E. Derry (Woods and Woods 2008). The study of mummies subsided during the second quarter of the 20th century as excavations and field work in Egypt decreased and work by many of the leading scholars in the preceding quarter century terminated, two exceptions being the work of Dawson (1927) and Moodie (1931) (Aufderheide 2003).

By the late 19th century knowledge of medicine drastically improved to the extent that mummy analyses become more complete and thorough, eventually with the importance of photography and radiography being realized. Radiographic analysis of mummies using conventional x-rays has been well documented and began less than a year after Röntgen's discovery of x-rays in 1895 (Röntgen 1896, Hughes 2011). The first investigation of mummies using this technique was conducted by Walter König in March of 1896, followed shortly thereafter by Petrie in 1897 (Marx and D'Auria 1986, Notman et al. 1986, Ikram and Dodson 1998) (discussed further in Chapter 3).

2.1.1.4.6 Phase 6: Radiology and the Rise of Computed Tomography (1926-1972): Phase 6 is marked by a decline in the prevalence of unwrappings and an increase in the quantity of radiological projects. This is not to say that mummy autopsies ceased, rather they became less frequent and those that were conducted were much more carefully documented and scientifically driven. Dunand and Lichtenberg (1994) note that x-ray technology in conjunction with Egyptian mummies failed to produce significant results until the 1930s, after the advent of portable machines, and often only royal mummies were studied in great detail.

Roy Moodie (1931) published his findings from the radiological analysis of 17 Egyptian mummies from the Chicago Field Museum for evidence of diseases and injury. Later Jacob Gershon-Cohen and Henry Shay x-rayed several mummies owned by the University of Pennsylvania in 1933 (United Press 1933). With the aid of x-ray technology, Winlock discovered a series of amulets and jewelry within the wrappings of the mummy Wah that he wished to put on exhibit (Winlock 1940). In order to acquire the jewelry and preserve the mummy, Winlock (1940) and his team took careful notes and a series of photographs during the unwrapping process during the 1930s. Many of these initial x-ray studies focused on finding amulets within the mummy bundle. In the 1950s the prior amulet-driven focus shifted to the identification of diseases within the body (Ikram and Dodson 1998). During the 1950s the mummies contained within the collections of the Liverpool and Manchester Museums were radiologically examined (Ikram and Dodson 1998). Maspero prevented the x-ray of the royal mummies that he had not unwrapped during the early 20th century with the exception of Thutmose IV (Smith 1912, Moodie 1931). It was not until 1980 (during Phase 7) that James Harris and Edward Wente successfully x-rayed many of the royal mummies and published their account (Harris and Wente 1980).

The 1970s saw a marked increase in mummy studies, interest in mummies, and the application of newer technologies to mummies, specifically x-ray and computed tomography (Aufderheide 2003). With the advent of x-ray technology, we see a decline in the frequency of autopsies. Godfrey Hounsfield developed x-ray computed tomography in 1967 (Richmond 2004). The first scanner was installed in 1971 and the technology was publically announced by Hounsfield in 1972 at a professional conference (Ambrose and Hounsfield 1973, Beckman 2006). With the introduction of computed tomography, we see a complete shift in the field, as much of the information attainable by autopsy was now available with CT imaging, while also preserving the mummy.

2.1.1.4.7 Phase 7: Computed Tomography Era Onset and Rise of Paleopathology (1973-1985): During this phase, the Paleopathology Association was founded in 1973 and held its first annual meeting in 1974. The impetus to form an association dedicated to ancient disease arose with the x-ray and autopsy of two mummies in February of 1973 by the association led by Aidan Cockburn: Pennsylvania University Museum (PUM) I in 1972 and then PUM II, owned by the Philadelphia Art Museum and on display at the Pennsylvania University Museum (Cockburn et al. 1998). The mummy PUM II was autopsied as part of a workshop entitled *Death and Disease in Ancient Egypt* held at Wayne State University (Roberts et al. 2012). The five symposia organizers informally formed the first Paleopathology Club that quickly morphed into the Paleopathology Association (Roberts et al. 2012). Interestingly, PUM II is a Ptolemaic mummy believed to have originated from Akhmim. Much of the early work, presentation, and repatriation of the association during the 1970s revolved around Egyptian mummies, specifically the PUM series of mummies.

Around the same time, Rosalie Davide spearheaded the formation of the Manchester Egyptian Mummy Project, a multidisciplinary team that used autopsy, radiology, and minimally destructive techniques to analyze the museum’s mummies. Along with a team, Davide autopsied Mummy 1770 in June of 1975 (Davide and

Archbold 2000). Autopsies, which first began during Phase 3, continued into this phase and the last published mummy autopsy marks its end. Until the mid-1980s autopsies of mummies were rather common, despite being highly destructive in nature. The mummy referred to as the "Lyons Sailor" was the last reputable scientific unwrapping and autopsy of a mummy in 1985. Jean-Claude Goyon led the team that unwrapped this anonymous mummy from the Guimet Museum of Natural History after documentation of the mummy with x-ray and CT (Mahdy 1989). The autopsy was filmed for inclusion in two French documentary series (Brancaglion 2008).

During the 1970s and the first half of the 1980s x-ray remained the predominant method of mummy inquiry, despite the introduction of CT technology, which signaled the end of Phase 6. The largest radiological (x-ray) mummy survey during this phase was P.H.K. Gray's (1973) analysis of hundreds of mummies from the British Museum and other museums (Aufderheide 2003). The first analysis of mummified remains with CT was conducted by Lewin and Harwood-Nash (1977) early in Phase 7. The authors examined the brain of an Egyptian boy to illustrate the applicability of CT for use in medical anthropology. Shortly thereafter, Harwood-Nash (1979) used CT to examine the entire body of the mummy Djemaetesankh. X-ray analysis was still much more pervasive than CT analysis of mummies during this phase. At the very end of Phase 7 we see the development of 3DCT imaging (discussed in more detail in Phase 8).

2.1.1.4.8 Phase 8: Three Dimensional Computed Tomography and Other Modern Technologies (1986-present): Later, with the application of CT to mummy analysis and the cessation of clinical-like autopsies, the field moved into the modern era of mummy studies. The current phase of mummy research is dominated by CT studies and to a lesser extent some use of endoscopy and magnetic resonance imaging. As the primary mode of analysis for mummy studies, CT peaked during the late 1980s and into the 1990s. Marx and D'Auria (1986) were the first researchers to conduct a systematic investigation of a sample (11 individuals) of mummies using CT. Since then, CT has been specifically applied to mummy studies in many of the same ways it has been used in the other sub-fields of anthropology and also for additional analyses unique to mummified remains. Improvements in CT technology has led to greater access to the technology, better scanning, and an increase in the quantity of CT mummy research. Specifically the ability to acquire more images with decreased slice thickness in less time and the use of multidector scanners have aided mummy studies using CT. The most recent trend in CT mummy studies has been the use of volumetric rendering of 2D images into 3D models known as 3DCT. Three large mummy CT projects are underway or have documented large collections of Egyptian mummies: the Akhmim Mummy Studies Consortium (2001), Raven and Taconis' (2005) scanning and compilation of the mummies at the National Museum of Antiquities in Leiden, and the IMPACT Radiological Database (Nelson and Wade 2011).

Also during this phase we see the formation of the World Congress on Mummy Studies to unite the field and foster international collaboration. The first annual World Mummy Congress was held in 1992 with 151 presentations (Aufderheide 2003). The original meeting was so successful, that the congress began meeting every three years since its inception. This current phase of mummy studies is only in the beginnings or infancy period.

2.1.2 Akhmim

Akhmim is located in the heartland of Egypt just 292 miles south of modern day Cairo in Upper Egypt, near to the boundary with Middle Egypt (Figure 1). At Akhmim the Nile River makes a sharp bend from northeast to southwest; therefore, the city lies north of the river on the eastern bank. Akhmim's extensive history includes continuous occupation of the area from Predynastic to modern times. The city served as a significant religious, artistic, and political center in ancient Egypt; however, the relative importance has changed throughout the periods and is not well understood for certain phases of Egyptian history. Today, Akhmim is the largest city in Upper Egypt on the eastern bank of the Nile and has a population just over 90,000 people. The modern-day city of Akhmim and its surrounding areas are situated overtop previous occupations thereby making it difficult to study earlier phases, but also attesting to continued use (McNally and Schrunk 1993, Bard 1999).

Akhmim was a dominant provincial center; however, archaeological evidence from the city varies considerably between the major periods of history. McNally and Schrunk (1993) suggest early occupation of the area during the Neolithic period based on ceramic evidence found near Akhmim. Although scholars generally agree that Akhmim was occupied during this period, extensive evidence is lacking for the city itself. According to Kanawati (1981) the first nomarchical (Egyptian provincial governors) tombs in Akhmim date to the later 5th Dynasty, yet one can suppose that a similar political and economic structure already existed in this region. At this time, Akhmim may have been a central storage location for the grain of Upper Egypt during the reign of Pepi II, as granaries are depicted in Old Kingdom tombs of el-Hawawish (Kanawati 1981).

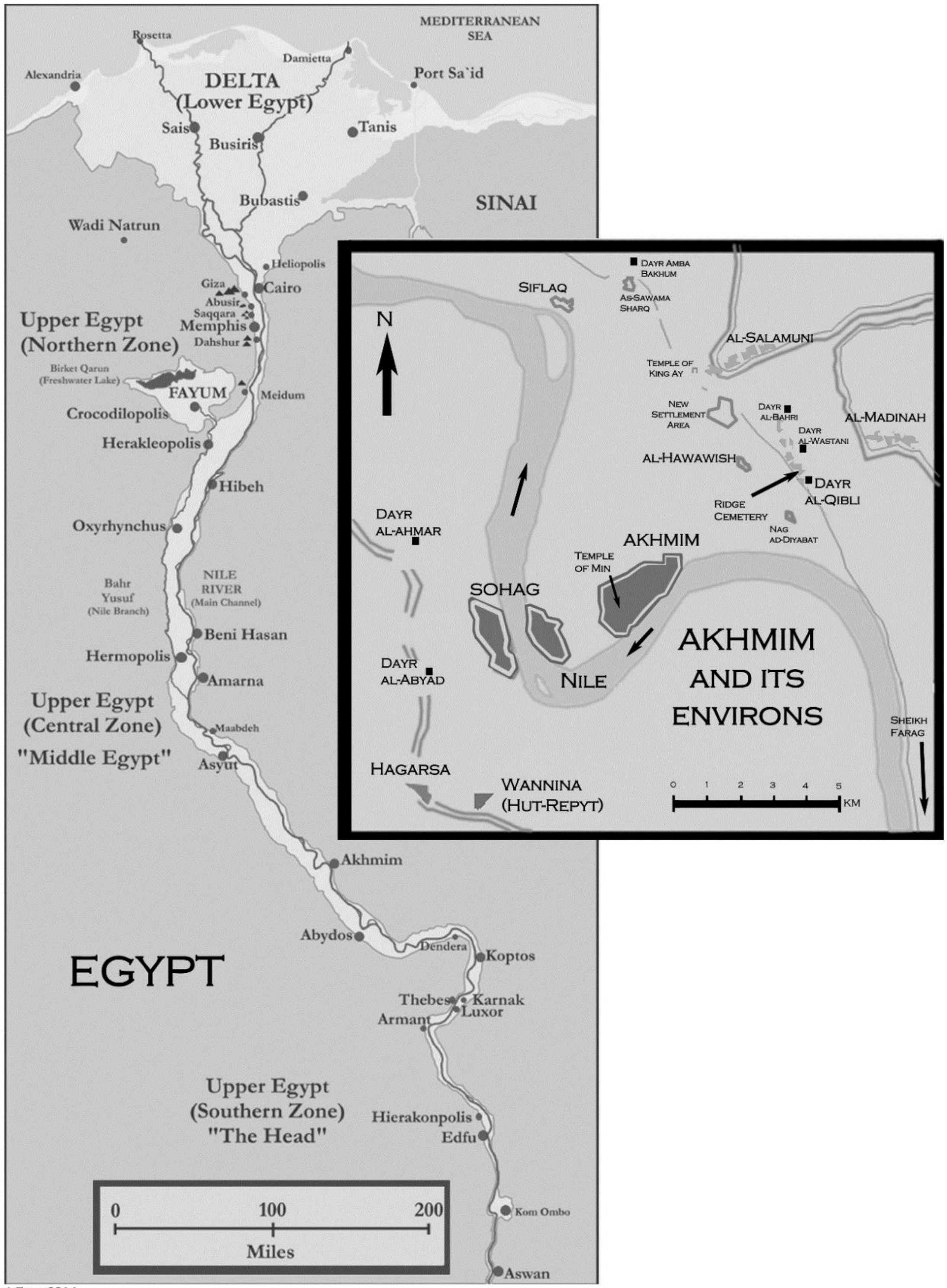


Figure 1. Map of Akhmim, Egypt (inset) and surrounding areas, including the cemeteries © Jonathan Elias (2014)

Akhmim, as a dominant provincial center, “was established during the 5th and 6th dynasties by powerful nomarchs of local origin,” including Tjeti-iqer and Horwey I (Franke 1993, Elias 2013:3). Titles found on the tomb of Kheni (short for Khen-ankhu) from the late 6th Dynasty include: “chieftain of the nome of Min,” “father of Min,” “overseer of the prophets of Min,” and “overseer of Upper Egyptian grain in the northern provinces” (Kanawati 1981:32 II Fig. 15). Akhmim’s integral location also served as a center for trade and commerce originating from the Red Sea region and this may have contributed to the city’s rise as a capital (Elias 2013, pers comm). During the Pharaonic period, Akhmim served as the capital of the ninth nome of Upper Egypt. First mention of this designation does not occur until the 12th Dynasty of the Middle Kingdom, yet it is believed that Akhmim likely served as the capital prior to this period (Fischer 1964, Smith 2002). At the fall of the Old Kingdom and leading into the First Intermediate Period, artwork and inscriptions from Akhmimic tombs depict overall unfavorable conditions, as was the case with much of Egypt at this time (Bard 1999). Many texts suggest poor conditions during the later Old Kingdom caused strife between Upper and Lower Egypt and may attest to why less is known of Akhmim’s role and governmental status during this transitional period. Greater evidence exists for the status of Akhmim during the New Kingdom. Royal estates and statuary in and around Akhmim attest to the importance of the city at this time (Elias 2013). Furthermore, several of Egypt’s rulers during this period either originated in Akhmim or had familial ties to the town (Bard 1999, Elias et al. 2007). Both parents of Queen Tiye (middle 18th Dynasty wife of Amenhotep III) were wealthy individuals from Akhmim: her father, Yuya served as “priest” and her mother, Thuya was “chief of the entertainers of Min” (Tyldesley 2006).

King Ay (late 18th Dynasty pharaoh) is also believed to have originated from Akhmim and may be the brother of Tiye. Into the Third Intermediate Period women of the royal family had clerical posts in Akhmim (Elias 2013, pers comm). Akhmim regained prominence during the 29th and 30th Dynasties owing in part to the renowned status of the city for magic, magicians, and medicinal powers (Elias 2013, pers comm). Akhmim continued to be an important center during the Late Ptolemaic and Roman periods and was known as Panopolis at this time. During the Graeco-Roman period, the population of Akhmim actively resisted foreign rule and likely became more diversified as displaced populations from other parts of Egypt migrated to the area (Gill-Robinson et al. 2006). Akhmim remained strongly native or patriotic and the population generally disliked their Macedonian rulers and their newly introduced Greek gods. In Late Antiquity, Akhmim "reached a peak of productivity" and was a textile manufacturing center (Griffith 1911, McNally and Schrunk 1993:5). It must be remembered that ancient Egypt was a riverine civilization, centered on the Nile, and the patterns of river traffic may also explain Akhmim's early and continued importance as a political and economic center.

In addition to being a significant administrative center, Akhmim was also a dominant religious center. The name Akhmim "derives from *Khent-Min* 'foremost (place) of (the god) Min'" and attests to the religious importance of the city (Elias 2013:3). Akhmim was dedicated to the god Min, the god of reproduction and the protector of caravans, travelers, and miners (O'Connell 2008). Elias (2013:3) suggests that Akhmim may have had a "reputation for fertility" based on the density of cultivable land in comparison to the areas in the vicinity. The god Min originated in Upper Egypt sometime during the Predynastic period. A fertility cult associated with a god named Min appears before the 1st Dynasty on statuary and according to Herodotus, Egypt's first king was Min (Menes) (Book II.99). The temple of Min was immense and remained standing up to the 14th century and possibly later (Elias 2013). Akhmim also served as the worship center of the gods Isis and Horus, two gods associated with Min. In religious centers like Akhmim, conflict arose between the old pagan traditions and with the introduction of Christianity and organized religion (Bard 1999). Akhmim was known as Shmin during the Christian Coptic era. Later when the empire abandoned paganism under the rule of Constantine in 325, Christianity became the official religion and Akhmim "became the center of monastic life" (Merrill 1894:259). Mertens (2002) suggests alchemy, hermetism, and Gnosticism had a significant role in Akhmim, then known as Panopolis, during the Graeco-Roman era. In late antiquity, Akhmim was known as a town of scholars and a center of learning.

Cemeteries outside of the city of Akhmim, tell us most of what we know about the city during ancient times. Three have been the most extensively studied to date: the *al-* or *el-Hawawish* "ridge cemetery*"* referred to as *Friedhof A*, el-Hawawish *Friedhof B* aka *al-Madina* (var. *el-Medineh*), and the third designated as *al-Salamunī* or *Friedhof C* (Kuhlmann 1983, Elias 2007) (Figure 1 inset). The "ridge cemetery," located near *Dayr-al-Qibli* var. *Dayr-al-Adhara*, a monastery, is potentially the largest and primarily contains tombs from the Late Period through the Roman era. Reis Khalil identified tombs ranging from the 6th Dynasty to the Graeco- Roman period here as well (Maspero 1893). Tombs of earlier dates may have been re-utilized in later periods because coffins exist from this location dating to earlier times. *Friedhof B* is the earliest of the three cemeteries dating to the Old Kingdom and located in the cliffs east of *Friedhof A*. Kanawati (1981) indicates that tombs of this cemetery came into reuse during the Middle Kingdom. The *al-Salamunī* cemetery sits at the tip of a major mountain top site north of Akhmim. To date, researchers have identified Old Kingdom tombs. Debate exists as to whether early New Kingdom (18th Dynasty) tombs are also present (Schiaparelli 1885, Whittemore 1914, Kuhlmann 1983). Surface remains date to the Graeco-Roman period and may be indicative of later populations' re-use of the site. Most of the skeletal and mummified human remains from Akhmim originated from these cemeteries, primarily from *Friedhof A.* The cemetery areas of Akhmim were discovered prior to 1884, yet their excavation and salvage did not take place until this time. A member of Napoleon Bonaparte's expedition noted disturbances at Akhmim and of mummies being desecrated as early as 1799. Nearly a century later, French Egyptologist Gaston Maspero (1893) noted extensive looting of the Akhmimic cemeteries. Upon inspection of the site in December of 1881, Maspero described "the first time that [he] thought about researching the cemetery, villagers were carrying to their homes sarcophagi of white stone, some in human form. The villagers, questioned on their provenance, responded vaguely. They attached no value to these antiquities and gave no assistance to search for them" (Maspero 1893:241-215). Petrie (1886, 1932) also specifically mentions illegal looting at Akhmim by French Consul M. Frenay, during the early 1880s. The first excavations at Akhmim were undertaken by Maspero from 1884 until the early 1890s in the *el-Hawawish* "ridge cemetery" area (Elias 2013). Akhmimic cemeteries were placed under the supervision of an organized Egyptian antiquities department, yet they were excavated in a haphazard manner and not to today's standards. Maspero (1893:215) describes the excavation: "15 days and we uncovered 20 tombs, drawing from them 800 mummies.

Never has an ancient city merited the name 'necropolis' more. There are dead in the thousands." The "ridge cemetery" mummies primarily date to the late 20th Dynasty, as well as, from the Third Intermediate, Late, Graeco-Roman and later periods (Maspero 1893, Elias and Lupton 2005, Elias 2013). *Friedhof B* was excavated from January to February of 1912 by Percy Newberry. Prior to Newberry's arrival, Pierre Lacau published on Old and Middle Kingdom coffins excavated from the area from 1904 to 1906; although, no records exist of the actual excavation. More recently, a number of archaeological projects have been undertaken in Akhmim and the surrounding territory by the Egyptian Archaeological Institute, the Egyptian Antiquities Service, the Australian Centre for Egyptology, the German Archaeological Institute, and the University of Minnesota.

Mummified remains began to be exported out of Egypt to all over the world after the initial discovery and excavations of several of these sites was publicized. While some of the human remains were stolen from the site by looters, especially prior to an organized recovery, many were later excavated quickly and then legally sold to travelers, as Akhmim became a center for the trading of antiquities (McNally and Schrunk 1993, Elias et al. 2007). During the 19th century, a number of these mummies ended up in North American museums, collections, and universities (Elias and Lupton 2005). Today Akhmimic mummies can be found on every inhabited continent including countries such as Chile, South Africa, The United States, Canada, New Zealand, and several countries within Europe. Much of the material originating from Akhmim that is now globally dispersed lacks provenance information; however, texts, artifacts, and mummified remains can be associated with Akhmim in several ways based on external information.

In the best cases, merchant paperwork details the sale and possession of specific mummies and artifacts. More frequently other factors must be used to link the item in question to Akhmim. Unique stylistic patterns of text and funerary assemblages, including the cartonnage, are specific to certain locales throughout Egypt. Stylistic funerary assemblages are specific to Akhmim, sometimes even to individual artists, and can typically be attributed to certain time periods as well. Inscriptions also link artifacts to Akhmim. Specifically, local gods indicate origin and many individual's titles and/or names reference Min, Horus and Isis (DePauw 2002). Once an object can be attributed to Akhmim, a period can generally be determined and can be based on absolute dates, such as inscriptions and radiocarbon dating, or other methods including, stylistic and iconographic criteria, or the evolution of titles and language (DePauw 2002). To date, the Akhmim Mummy Studies Consortium has tracked and identified over 150 Akhmimic mummies, many in locales outside of Egypt (Elias and Lupton 2008). Absolute dating methods, such as radiocarbon, as well as external contextual information have been used to identify the origin and dates of the mummies used in this research by AMSC.

2.2 Materials

Computed tomography scanning of Akhmimic mummies has been underway since 2001 by AMSC and is being conducted "in an effort to more fully understand Akhmim's ancient population" (Elias et al. 2007:30). The majority of the mummies included in this research sample originate from Akhmim and nearby areas including Thebes and Sheikh Farag. As of September of 2013, 33 mummies are included in the AMSC database including 25 active CT scanned adult mummies, two child mummies, and five mummies with inactive data (i.e. inactive Digital Imaging and Communications of Medicine files, aka DICOM files, or plain-film radiography). For the current research, the 25 adult individuals with active CT images (in DICOM format) were included in the sample for analysis, 17 of which are from Akhmim. Four mummies are from the nearby region of Thebes or Sheikh Farag, two are from Upper Egyptian locales (Fayum), and two are unprovenienced. Most mummies in the collection are from the early Graeco-Roman (Ptolemaic) Period with others also from the First Intermediate, Third Intermediate, Late, and Roman Periods (Table 2). The mummies in the sample span over a 2,000 year period. To date, research and publications using this sample have focused on

*Table 2. Chronology of Ancient Egypt.**

Period	Time Range	Dynasties
Predynastic	Prior to 3100 BC	
Early Dynastic	3100 BC - 2686 BC	1 - 2
Old Kingdom	2686 BC - 2181 BC	3 - 6
First Intermediate	2181 BC - 2040 BC	7 - 11
Middle Kingdom	2040 BC - 1650 BC	11 - 13
Second Intermediate	1750 BC - 1550 BC	14 – 17
New Kingdom	1550 BC - 1069 BC	18 – 20
Third Intermediate	1069 BC - 656 BC	21 – 25
Late	664 BC - 343 BC	26 – 30
Second Persian Occupation	343 BC - 332 BC	
Graeco-Roman	332 BC - 642 AD	

* from Russmann (2001)

the life history of specific individuals, mummification rituals, paleopathology, and public education through museum exhibits. Skull models and facial reconstructions have been conducted to explore morphological features related to population affinity, specifically with individuals from the Second Persian and Ptolemaic periods. Additionally, investigations of familial relationships and also cultural practices, primarily related to the mummification process, have been explored by AMSC in this sample of Akhmimic mummies.

The CT images in DICOM format of each mummy were obtained by AMSC for analysis. A description of the 25 mummies analyzed for this research is presented below and includes the common name, the owning institution name and catalog number (if known), the origin, the discovery and sale of the mummy, the period from which the mummy dates and the information used to determine that date, the social status and current display status, and lastly, the date(s) of radiographic analyses (both traditional x-ray and CT). Information concerning each mummy was based on data gathered by Dr. Jonathan Elias, director of the AMSC, and relayed via personal communication (2013) or through preliminary reports on individual mummies authored by Dr. Elias. Multiple lines of evidence were analyzed by Dr. Elias to gather the information presented below for each mummy, including: primary historical documents, personal letters, coffin inscriptions, published Egyptological accounts (museum catalogs), and journal publications. Additional contextual information was obtained from the owning institution's websites and is noted below when utilized. Status was determined by Dr. Elias based on an examination of 1) the quality of funerary preparation, 2) the level of soft tissue preservation which is indicative of the quality of body preparation, and 3) on the individual's titles and/or honorifics (detailed information is presented in Appendix 2, Table A2.1 and A2.2). Determining status and social class from ancient Egyptian remains alone is incredibly complex. Herodotus listed seven classes in ancient Egypt based on occupations (Book II.164). According to Herodotus, at the highest level of society were the pharaohs, who were placed just below the level of the gods, while the lowest level of society consisted of the slaves and servants. Mummification of the body was reserved for the upper levels of society and was not something that the lowest class could afford (El-Mahdy 1989). The quality of funerary preparation therefore mirrors societal stratification. In this research, status is separated into three categories: lower, middle, and higher. These categories essentially reflect levels of middle class citizenship (i.e. those below the pharaohs and above the slaves and servants). Appendix 2 presents the status classification for each individual and details the features used to arrive at a particular status assessment by Dr. Elias.

2.2.1 Mummy Sample

AMSC 1

Common Name: Pesed

Institution: WCAC No. 48- Westminster College (WC) in New Wilmington, PA

Origin: Akhmim

Discovery & Sale: Discovered late in 1884 or in the spring of 1885 and was one of four mummies purchased by two missionaries, John Romich Alexander and John Giffen in Egypt.

Date: Graeco-Roman (Ptolemaic) Period, between 400 to 220 BC, based on radiocarbon dating of linen and on the stylistic patterns of the funerary treatment.

Social Status: Middle

Current Display Status: Mummy is displayed at WC in the base of the coffin and the lid is presented above.

Radiographic Analyses: X-rayed in 1982. CT scanned in 2001 and 2005.

AMSC 2

Common Name: Nefer-ii-ne

Institution: RPM 30.318.1- Reading Public Museum (RPM) in Reading, PA

Origin: Akhmim

Discovery & Sale: Believed to have been excavated in 1885. RPM purchased the mummy in 1949 from the University of Pennsylvania (Penn) after being on loan since 1930 from the University. Penn acquired the mummy from Émile Brugsch in 1893.

Date: Graeco-Roman (Ptolemaic) Period dated to the mid-3rd century BC based on radiocarbon dating of linen dating to 2220 +/- 40 BC with a calibrated result of 390 to 180 BC (95% probability). The stylistic patterns of the funerary assemblage date to 250 BC.

Social Status: Middle

Current Display Status: Mummy is displayed at RPM in the base of the coffin and the lid is present.

Radiographic Analyses: X-rayed in 1972. CT scanned in 2003.

AMSC 3

Common Name: Ta-irty-bai

Institution: 01.1A- College of Wooster Art Museum in Wooster, OH

Origin: Akhmim

Discovery & Sale: Discovered late in 1884 or in the spring of 1885 and was one of four mummies purchased by two missionaries, John Romich Alexander and

Reverend John Giffen in Egypt.

Date: Graeco-Roman (Ptolemaic) Period dated to the mid-3rd century BC based on radiocarbon dating of linen indicating a date of 2230 +/- 40 BC and with a calibrated result of 390 to 190 BC (95% probability).

Social Status: Middle

Current Display Status: The mummy is not currently on display.

Radiographic Analyses: X-rayed in 1964. CT scanned in 2004.

AMSC 4

Common Name: “Annie” / Anonymous

Institution: ANSP 1903.1A- Academy of Natural Sciences (ANSP) in Philadelphia, PA

Origin: Akhmim (possibly originated from surrounding area and was given a burial in Akhmim)

Discovery & Sale: Acquisition by Charles Huffnagle, consul to Calcutta, was most likely in the 1884 or possibly the 1885 excavation season. By June of 1885, the mummy was in the United States. In 1885 a family member of Huffnagle donated the mummy to ANSP. It was officially added into the collection at ANSP in 1903, but may have been acquired the decade prior.

Date: Graeco-Roman (Ptolemaic) Period, dated to the 3rd century BC based on the stylistic patterns of the funerary assemblage, including the artistic work of the coffin and attached cartonnage plaques.

Social Status: Lower

Current Display Status: Not on display at ANSP. The coffin and mummy are part of a traveling science museum exhibit entitled “Lost Egypt,” owned and operated by the Center of Science and Industry, Columbus, Ohio.

Radiographic Analyses: Mummy was scheduled for x-ray in 1977, but it is unknown whether this actually occurred. CT scanned in 2006.

AMSC 5

Common Name: Possibly Ankh-hapi

Institution: 978.14958 A-C- Musee St. Rémy in Reims, France

Origin: Akhmim

Discovery & Sale: Believed to have been excavated at either the end of 19^{th} C or during excavations ordered by Gaston Maspero beginning in the spring of 1884. Little is actually known about the discovery and sale.

Date: Graeco-Roman (Ptolemaic) Period, 3^{rd} century BC, based on the stylistic patterns of the funerary assemblage, including the artistic work of the coffin.

Social Status: Middle

Current Display Status: Unknown

Radiographic Analyses: CT scanned in 2004.

AMSC 6

Common Name: “BECHS” / Anonymous Female

Institution: Coffin #654.139 / Skull possibly BECHS-63.219- Buffalo Museum of Science (BMS) in Buffalo, NY

Origin: Akhmim

Discovery & Sale: On loan to the BMS from the Buffalo and Erie County Historical Society. The mummy was in its collection before 1892 and was originally part of the Joseph C. Greene Collection.

Date: The coffin is dated to the Third Intermediate Period, during the mid-8th century BC (740 to 730 BC) during the 25th Dynasty based on the shape and funerary stylistic patterns. The cartonnage is Graeco-Roman (Ptolemaic) Period (3rd century BC); however, the mummification pattern of the mummy's head is more consistent with the Third Intermediate Period than the Ptolemaic period.

Social Status: Indeterminable

Display Status: Coffin is currently on display at BMS.

Radiographic Analyses: CT scanned in 2006.

AMSC 7

Common Name: Padiherupakhered

Institution: 10265- Milwaukee Public Museum in Milwaukee, WI

Origin: Akhmim

Discovery & Sale: Adolf Meinecke, a trustee of MPM, acquired and sold the mummy and coffin in December 1887 for $74.68 to the MPM. The donation was made to help establish the museum. This sale occurred three months after the donation of Djedhor (AMSC 8) to MPM by Adolf's son Ferdinand. The mummies are believed to have been purchased in Europe, possibly from

Germany. Stangen, a German who conducted tours in Egypt, likely was the original importer of the mummies.

Date: Graeco-Roman (Ptolemaic) Period, approximately 250 BC or 3rd century, based on the stylistic patterns of the funerary assemblage, including the artistic work of the collar.

Social Status: Middle

Current Display Status: Neither the coffin or body are currently on display.

Radiographic Analyses: CT scanned in 1986, 1999, 2006, and 2011.

AMSC 8

Common Name: Djedhor

Institution: 10264- Milwaukee Public Museum in Milwaukee, WI

Origin: Akhmim

Discovery & Sale: Ferdinand Meinecke donated the mummy to the MPM in 1887, just three months prior to the sale of AMSC 7 to the museum. The mummies are believed to have been purchased in Europe, possibly from Germany. Stangan, a German who conducted tours in Egypt, likely was the original importer of the mummies.

Date: Late Period (Saite) between the 7th and 6th centuries BC. Radiocarbon was conducted on a piece of linen in 1987 and provided a mean date of 600 BC after calibration. Radiocarbon of the associated coffin produced an earlier date of 1440 BC; however the reuse of wood was common and may explain the discrepancy in dates.

Social Status: Middle

Current Display Status: Coffin and mummy are currently on display at MPM.

Radiographic Analyses: CT scanned in 1986 and 2006. The cranium was also CT scanned in 2011.

AMSC 9

Common Name: Anonymous Female

Institution: 5199- Buffalo Museum of Science in Buffalo, NY

Origin: Unprovenienced

Discovery & Sale: Unknown

Date: Third Intermediate Period, likely between 680 to 665 BC, based on funerary preparation and specifically on the lack of resin in the cranial vault and linen within the orbits.

Social Status: Indeterminable

Current Display Status: Not on display, contained in storage.

Radiographic Analyses: CT scanned 2006.

AMSC 10

Common Name: Djedhor, also known as Wesirwer

Institution: Cairo TR 6.9.16.1- Egyptian Museum in Cairo, Egypt

Origin: Akhmim

Discovery & Sale: Likely excavated after 1884 and was never sold to anyone outside of Egypt. It was placed in the Cairo museum by the year 1916.

Date: Graeco-Roman (Ptolemaic) Period, from the early 3rd century to approximately 290 BC, based on the stylistic pattern of the coffin, specifically the collar, and its resemblance to the coffin of AMSC 1 (Pesed) which has been dated using radiocarbon.

Social Status: Higher

Current Display Status: Unknown but as of 2007, the coffin and mummy were on display with the coffin closed.

Radiographic Analyses: CT scanned in 2006.

AMSC 11

Common Name: Nesmin

Institution: Cairo TR 6.9.16.2- Egyptian Museum in Cairo, Egypt

Origin: Akhmim

Discovery & Sale: Likely excavated after 1884 and was never sold. It was placed in the Egyptian Museum in Cairo by the year 1916.

Date: Graeco-Roman (Ptolemaic) Period, from the early 3rd century to approximately 250 BC based on the stylistic pattern of the coffin and its resemblance to the coffin of AMSC 2 (Nefer-ii-ne), which has been dated using radiocarbon.

Social Status: Higher

Current Display Status: Unknown but as of 2007, the coffin and mummy were on display with the coffin closed.

Radiographic Analyses: CT scanned in 2006.

AMSC 12

Common Name: Muthotep, var. Muthetepti

Institution: Cairo TR 21.11.16.11- Egyptian Museum in Cairo, Egypt

Origin: Akhmim

Discovery & Sale: Probably excavated after 1884 and was never sold. It was placed in the Egyptian Museum in Cairo by the year 1916.

Date: Graeco-Roman (Ptolemaic) Period, from the 3rd century BC around 250 BC, but possibly a bit earlier, based on the plausible genealogy (relation to AMSC 10) and the stylistic patterns of the coffin and funerary preparation.

Social Status: Higher

Current Display Status: Coffin and mummy are on display. Coffin is opened so that the mummy is partially visible.

Radiographic Analyses: CT scanned in 2006.

AMSC 13

Common Name: Ta-Repyt

Institution: Cairo TR 21.11.16.13- Cairo Museum in Cairo, Egypt

Origin: Thebes

Discovery & Sale: Probably excavated after 1884 and was never sold. It was placed in the Egyptian Museum in Cairo by the year 1916.

Date: Graeco-Roman (Ptolemaic) Period, from the late 3rd century BC to possibly early 2nd century BC, based on the stylistic patterns of the funerary treatment.

Social Status: Higher

Current Display Status: The base of the coffin and the mummy are currently both on display. The lid is currently in storage at the museum.

Radiographic Analyses: CT scanned in 2006.

AMSC 14

Common Name: Pahat

Institution: 1903.7.44- Berkshire Museum (BM) in Pittsfield, MA

Origin: Akhmim

Discovery & Sale: Likely excavated during the 1885-1886 season at Akhmim and most certainly before 1888. Zenas Crane provided Roy Hopping with the finances to acquire a mummy for the BM. Hopping purchased the mummy from Professor Ward's Natural Science Establishment in Rochester, NY in the year 1902. The mummy was originally purchased by Ward from the Egyptian Antiquities Service through dealings with Émile Brugsch.

Date: Graeco-Roman (Ptolemaic) Period, from 250 to 225 BC, based on the stylistic patterns of the funerary assemblage.

Social Status: Middle

Current Display Status: Mummy is on display at BM in the open coffin.

Radiographic Analyses: CT scanned in 1984, 2007 and 2010.

AMSC 15

Common Name: Shepmin, var. Shep-(en)-min

Institution: VC CC79.001- Vassar College in Poughkeepsie, NY

Origin: Akhmim

Discovery & Sale: Likely excavated during the 1885-1886 season at Akhmim and most certainly before 1888. Shepmin was purchased by a classics professor at the college through dealings with Émile Brugsch.

Date: Graeco-Roman (Ptolemaic) Period, dated to the second half of the 3rd century BC, based on stylistic patterns of the funerary assemblage, specifically the lapid of the wig.

Social Status: Middle

Current Display Status: The mummy is not currently on display and is being stored at the college's art center.

Radiographic Analyses: CT scanned in 2008.

AMSC 16

Common Name: Anonymous Adult Male

Institution: LASM MG64.1.1A- Louisiana Art and Science Museum (LASM) in Baton Rouge, LA

Origin: Thebes

Discovery & Sale: LASM (previously known as the Louisiana Arts and Science Center) obtained the mummy from the now defunct Commercial Museum of Philadelphia, PA. At that time, the Commercial Museum of Philadelphia was owned by the Trade and Convention Center of Philadelphia who were subscribers to the Egyptian Exploration Fund. They may have received the mummy in 1921 in recognition of their support and donations to the fund.

Date: Graeco-Roman (Ptolemaic) Period, from the 2nd century BC possibly as late as 150 BC, based on the stylistic patterns of the funerary assemblage.

Social Status: Lower

Current Display Status: The mummy and intact plaques are currently on display at LASM.

Radiographic Analyses: X-rayed in 1984. CT scanned in 1986 and 2007.

AMSC 17

Common Name: “Putnam 1” or “Isis-Neferet”

Institution: AR 21190- Putnam Museum (PM) in Davenport, IO

Origin: Akhmim

Discovery & Sale: The mummy Putnam 1 was owned by multiple private citizens subsequently after arrival to the United States and was eventually bequeathed to the PM by B.J. Palmer in 1966. Shortly after arrival in the United States, the mummy was unwrapped in entirety.

Date: Dated to the Graeco-Roman (Alexandrian) Period, during the 4th century from approximately 330 to 320 BC, based on stylistic mortuary patterns and the accompanying mask.

Social Status: Middle

Current Display Status: On display at PM.

Radiographic Analyses: CT scanned in 2007.

AMSC 18

Common Name: “Putnam 2”

Institution: AR 6-4-129d- Putnam Museum in Davenport, IO

Origin: Fayum

Discovery & Sale: Specifically purchased for the museum’s collections by Charles E. Ficke in 1896 from an antiquities dealer in Egypt.

Date: Likely from the Graeco-Roman Period based on the funerary preparation, specifically the style of the cartonnage mask.

Social Status: Middle

Current Display Status: On display at PM.

Radiographic Analyses: CT scanned in 2007.

AMSC 19

Common Name: Ankhwennefer

Institution: 1898.6.1- Washington State Historical Society (WSHS) in Tacoma, WA

Origin: Akhmim

Discovery & Sale: The mummy and two coffins were accessioned to the WSHS in 1898 by the donor Allen C. Mason who originally acquired the assemblage during an 1891 tourist trip to Luxor, Egypt. The mummy was on loan from 1959-1983 to the University of Puget Sound for use in biology courses.

Date: Late (Saite) Period, 26th Dynasty, based on style of the coffins.

Social Status: Higher

Current Display Status: The mummy is not on display, while the status of the coffin is unknown.

Radiographic Analyses: X-rayed and CT scanned in 1995 and then re-scanned in 2008.

AMSC 20

Common Name: Irethorrou

Institution: #2081 (original accession number from 1895) / #42895- Fine Arts Museums of San Francisco (FAMSF) in San Francisco, CA

Origin: Akhmim

Discovery & Sale: Haggin Museum in Stockton, CA displayed the mummy and coffin on loan from FAMSF from 1944-2009. The mummy was given to the M.H. deYoung Memorial Museum in 1917 from the estate of Jeremiah Lynch, a politician and member of the Bohemian Club. Lynch took his first trip to Egypt in 1889-1890 and subsequently published *Egyptian Sketches* detailing his account and his 1890 purchase of three mummies.

Date: From the early Late (Persian) Period, 6th century around approximately 500 BC, based on the funerary assemblage including the style of the coffin, especially the collar.

Social Status: Higher

Current Display Status: Mummy and coffin were on display in their own exhibit from 2009-2010, but are currently off display and in storage.

Radiographic Analyses: CT scanned in 2009.

AMSC 23

Common Name: Ta-an (name on the coffin, although mummy is from another period)

Institution: # unknown- Earlham College in Richmond, IN

Origin: Coffin from Akhmim/ Mummy from Fayum

Discovery & Sale: Purchased from the government museum in Boulaq by Earlham College President, J.J. Mills in 1889. The mummy was shipped, picked up and displayed in Indianapolis by Dr. Joseph R. Evans and then moved to Earlham College to be displayed during commencement. By 1896 the mummy belonged to Department of Anthropology at the college and was subsequently rescued from a fire in 1924 by students at the college.

Date: Graeco-Roman (Ptolemaic) Period for the coffin based on stylistic patterns of funerary treatment. The mummy dates to the Late Period, approximately 600 BC, based on the preparation of the body and its resemblance to AMSC 8 (Djedhor) which has been dated using radiocarbon.

Social Status: Lower

Current Display Status: Unknown, but likely on display with the coffin.

Radiographic Analyses: X-rayed in 1979. CT scanned in 2011.

AMSC 25

Common Name: “Anon-Rod”

Institution: MPM EG-01- Milwaukee Public Museum in Milwaukee, WI

Origin: Unprovenienced

Discovery & Sale: Unknown

Date: The cartonnage is post New Kingdom based on its stylistic patterns. The mummy is likely Graeco-Roman (Ptolemaic) Period based on stylistic patterns of the funerary preparations.

Social Status: Indeterminable

Current Display Status: Not currently on display and is being held in storage.

Radiographic Analyses: CT scanned 2011.

AMSC 27

Common Name: Ankhpakhered (name on the coffin, although mummy is from another period)

Institution: # unknown- City Museum of Archaeology and Paleontology (CMAP) in Asti, Italy

Origin: Akhmim

Discovery & Sale: Ernesto Vergano acquired and owned the mummy before 1920. In 1920 his sons donated the mummy to the museum.

Date: The coffin dates to the early phase of the 25th Dynasty, late 8th century around 735 BC, based on the stylistic patterns of the funerary assemblage. The mummy is likely post-25th Dynasty and perhaps the coffin was reused for this mummy. Radiocarbon dating of linen provided a range of 360 to 20 BC with a 95.4% confidence level. A bone sample provided a date of 390 to 170 BC with a 95.4% confidence level. The palm-rib canes contained within the body cavity provide a range or 370 to 110 BC with 95.4% confidence level. Given these dates the body is dated to the Late Period, between the 4th and 2nd centuries BC.

Social Status: Lower

Current Display Status: Currently on display at CMAP with the coffin.

Radiographic Analyses: CT scanned in 2009.

AMSC 29

Common Name: Tjeby

Institution: VMFA 53.30.1- Virginia Museum of Fine Arts (VMFA) in Richmond, VA

Origin: Sheikh Farag

Discovery & Sale: Discovered and excavated in November of 1923 by Harvard University and the Boston Museum of Fine Arts Archaeological Expedition. The mummy was acquired by VMFA in 1953.

Date: First Intermediate Period based on stylistic patterns of the funerary assemblage.

Social Status: Higher

Current Display Status: On display with the coffin at VMFA.

Radiographic Analyses: CT scanned in 1986 and 2013.

AMSC 30

Common Name: Padihershef

Institution: # unknown- The Paul S. Russell, MD Museum of Medical History and

Innovation at the Massachusetts General Hospital (MGH) in Boston, MA

Origin: Thebes

Discovery & Sale: Brought to the United States in 1823 by Jacob Van Lennep, a Dutch merchant, who gave the mummy to the city of Boston to be located in MGH. Padihershef was one of the first mummies to arrive in the U.S and the very first to be exhibited.

Date: The late Third Intermediate Period, 25th Dynasty around 680 to 664 BC based on the stylistic patterns of the funerary assemblage.

Social Status: Middle

Current Display Status: Outer coffin is displayed at the George Walter Vincent Art Museum, Springfield Massachusetts (no. 85.32.1). Inner coffin and mummy on display at MGH.

Radiographic Analyses: X-rayed in 1931, 1976, and 2013. CT scanned in 2013.

2.3 Discussion

Nearly all of the mummies with documented historical information were discovered during the late 19th century or during Phase 5 of mummy research. Interestingly, the mummy of Padihershef (AMSC 30) was one of the very first mummies brought to the United States (during Phase 4) and is the earliest mummy arrival still accounted for and surviving today in America. Many of the mummies contained within this sample originated from the work of Gaston Maspero and his associates at Akhmim. Due to the nature of cemeteries in Akhmim and their use through time, the majority of the Akhmimic mummies in the United States, and in this sample, date to the Ptolemaic period of Egyptian history. Therefore, this sample allows an unparalleled opportunity to study a large sample of mummies from a specific region in Egypt, while also considering temporal trends and changes.

Chapter 3: Computed Tomography in Egyptian Mummy Research

3.1 Literature Review

3.1.1 Theory and Application of Computed Tomography

X-ray computed tomography imaging is performed using an x-ray source and a detector that rotate around the subject being imaged, allowing the acquisition of projection x-ray data from multiple angles. These projection data are reconstructed into a series of 2D image slices in which the intensity of each pixel is proportional to the x-ray attenuation property of the material represented by that pixel. The x-ray attenuation is stated in terms of a Hounsfield Unit (HU) or CT number (Carlton and Adler 2001). The HU is "defined as the difference of the linear attenuation coefficient of a given voxel [or pixel] from that of water, divided by the linear coefficient of water" (Lang 2010:590). These numbers vary linearly from -1000 to +3000 depending on the material; "-1000 corresponds to air, soft tissue ranges from -300 to -100, water is 0, and dense bone and areas filled with contrast agent range up to +3000" (Bushberg et al. 2002:356). The HU value and image contrast is directly impacted by the peak kilovoltage or kVP, whereby higher kVP values decrease beam attenuation because the higher energy of the beam makes it more penetrating. The higher the kVP, the lower the contrast of the image produced and vice versa. Cropp et al. (2013) found HU values to be impacted by kVP, but also by the specific scanner with numbers varying by manufacturer as well. Tissues in the body attenuate x-rays at different values based on their different material composition. Contrast in pixel shading is dependent upon the material's physical density (g/cm^3) first and then also by the electron density of the material (Bushberg et al. 2002). If the material is denser than water or has a higher atomic number, the CT number increases (Kalender 2011). Milliampere second (mAs), settings “relates to the number of photons emitted in an X-ray beam” (Cinnamon 1999:12). Image noise increases with a decrease in mAs. The digital images created are square arrays of 1024 x 1024 pixels in modern CT machines, commonly 512 x 512 in clinical CT, with each pixel equivalent to one of 4,096 possible shades of gray (12bit) (Cinnamon 1999, Bushberg et al. 2002). Darker shades represent the lower density objects and the white and lighter shades depict the higher density material. Each pixel in the CT image also corresponds to a 3D voxel. The voxel is analogous to the pixel in two dimensions, but also retains the slice thickness that is perpendicular to the scanning plane as the third dimension (Mantini and Ripani 2009, Lang 2010). The volume of the voxel is defined by the beam collimation and slice thickness (Cinnamon 1999).

DICOM is a “global information-technology standard” that was developed in 1993 for the display, storage, and printing of medical imaging data (NEMA 2013:1). Computed tomography images in DICOM format are data sets that contain the CT slice data and attributes associated with the scan, such as identification information, machine settings, and the image pixel data. Before the CT scans can be visualized a number of preprocessing and reconstruction steps occur. Preprocessing involves: 1) producing a digital data set that can be recognized and processed by a computer, 2) calibration of the data, and 3) reconstruction of the pixel and voxel values (Bushberg et al. 2002). After preprocessing, reconstruction of the tomographic images is undertaken. Reconstruction is typically accomplished with filtered backprojection, whereby trigonometry is used to “emulate the acquisition process in reverse” (Bushberg et al. 2002:352). Finally, the image can be displayed digitally. In imaging software the 4,096 gray-scale image is ‘remapped' to approximately 30-90 different shades, so that the human eye can discern the differences between the shades (Lynnerup 2007). The individual slices are 'stacked' unto one another with multiplanar reconstruction. Mismatches in slices are corrected using data interpolation along the z-axis which results in a decrease in resolution (Bushberg et al. 2002). The data can then be viewed in the sagittal, axial, and coronal planes. For 3D models, a two-step process known as volumetric rendering is required. Thresholding differentiates between the materials of the body, for example bone, tissue, and fat, based on the HU value of the voxel. Voxels consisting of multiple materials are volume averaged. Once the area of interest is thresholded from other tissues, a 3D rendering can be generated for visualization using interpolation (Mantini and Ripani 2009). The 3D model can be bisected to expose areas of interest and is particularly useful for investigating internal structures. In addition, "virtual fly throughs" of bodily cavities can be generated with the 3D models and provide an animation sequence through the remains.

Since the invention of CT, several generations of scanners have been introduced that represent the major technological advances. Currently, CT technology is in its seventh generation, referred to as multiple detector array CT machines. Improvements in the later generations include better image quality, faster image acquisition times, more detectors, and an increased fan angle that facilitates an entire body scan (Hsieh 2009). Continual improvements in CT technology and the rapid rate at which improvements are occurring promote greater information for medical, as well as, for "analytic and educational purposes" (Chan et al. 2008:2024). It is in these latter two areas that we see the use of CT technology in physical anthropology and specifically in mummy studies.

3.1.2 Computed Tomography in Physical Anthropology

Historically, "advances in imaging technology…rapidly move from the clinical realm to the analysis of ancient human remains" (Gardner et al. 2004:234). The role of CT within physical anthropology is changing from a novel approach to old problems to an advanced diagnostic tool that can be used explore new hypotheses within the field. Beginning in the early 1980s, numerous applications of CT technology were undertaken to answer anthropologically driven research questions in the subfields of paleoanthropology and forensic anthropology.

Preservation of fossil hominids is of primary concern in paleoanthropology and CT is the only method that can be used to investigate fossils, specifically the internal structures, and to create virtual models without excessive handling or destruction of the specimen (e.g. Conroy and Vannier 1984, Wind 1984, Chhem 2006). Additionally using mirror imaging and interpolation functions, virtual reconstructions can fill in the missing portions of the fossil remains (Zollikofer et al. 2005). Volumetric functions within CT imaging software have been used to create "virtual endocasts" to study brain size and structure in ancient humans (e.g. Tobias 2001). Furthermore, CT imaging techniques permit the stony matrix that often surrounds fossils to be virtually separated from the remains without damage or permanent alteration (Hughes 2011). Specific areas of inquiry within paleoanthropology include: 1) endocranial morphology and brain size (e.g. Zonneveld 1989, Ross and Hennenberg 1995, Conroy et al. 2000), 2) dental development, tooth eruption, and tooth form (e.g. Conroy and Vannier 1984, Schwartz et al. 1998), and 3) locomotion and functional morphology of skeletal regions (e.g. Sumner et al. 1985, Demes et al. 1990, Ohman et al. 1997). Ruff and Leo (1986) note that the initial applications of CT in physical anthropology focused on geometric reconstructions.

Computed tomography was initially used to investigate bone biology in forensic anthropology (e.g. Goldstein et al. 1983, Bridges 1986, Ruff and Leo 1986); however, within the last decade, an entirely new sub-field of "virtual anthropology" has emerged (Weber 2001). Computed tomography has been the primary catalyst for this transition from traditional osteological approaches to virtual methods and geometric reconstructions (e.g. Ramsthaler et al. 2010, Decker et al. 2011). Bones are easily visualized with CT imaging because of their high density, which then lends itself to both morphological and metric assessments (Lynnerup 2009). Computed tomography has primarily been used in this capacity for evaluation of biological profile parameters including age-at-death, sex, and stature. Further use of CT technology includes limb pairings and positive identification in mass disaster scenarios. Computed tomography applications related to positive identification, facial reconstruction, pathologies, and trauma analysis have also been explored, but to a lesser extent than biological profile parameters. Estimations of biological profile parameters from CT data using techniques designed for dry bone specimens performed correctly with low associated error rates. Furthermore, tests of congruency between actual bone versus virtual or printed models for morphological and metric assessments indicate overall agreement between the two methodologies (e.g. Robinson et al. 2008, Verhoff et al. 2008, Gamble and Hoppa 2010). Seemingly, CT imaging and virtual models can replace the use of dry bone when this form of analysis is available. One caveat however of CT, as Grabherr et al. (2009) note, is the association of some learning curve for using virtual skeletons and evaluating the subsequent digital images.

3.1.3 Computed Tomography Studies of Egyptian Mummies

Several recent works by Lynnerup (2007, 2009, 2010), provide comprehensive descriptions of how mummies from Egypt and other parts of the world have been studied, with the most recent paper focusing specifically on medical imaging techniques. To date the following methods have been applied to mummy studies: endoscopy, colonoscopy, tissue histology, infrared reflectography, ultraviolet fluorescence, Raman spectroscopy, forms of radiography, including conventional x-ray and computed tomography, stable isotope analysis, amino acid analyses, ancient DNA, gas chromatography mass spectroscopy, ultrasonography, magnetic resonance imaging, and electron and paleo-electron microscopy. The aforementioned methods represent a "technology transfer of routine diagnostic techniques used in medicine to Egyptology" and to this one could add, anthropology as a whole (Mininberg 2001:192). Newer technology and greater accessibility to it are increasing the rate at which these approaches that are typically used in clinical medicine are being applied to mummy studies (Gardner et al. 2004).

In the earliest studies of Egyptian mummies, autopsies were commonplace despite being destructive in nature, because advanced imaging technologies did not yet exist. These initial investigations and evaluation of mummies took a clinical approach, whereby the individual was viewed solely as a body or source of information that should be autopsied and documented in a medical fashion mirroring today's forensic pathological investigations (Lynnerup 2007). Mummy preservation often "conflict[ed] with interests of experts and the curiosity of the public" (Cesarani et al. 2003:601). Advocates of the autopsy-based approach declined by the 1980s as scientists began fully realizing the value of mummified remains and as the availability of imaging technology increased.

Today, scientists recognize that mummified remains need to be preserved and maintained as an "archaeological artifact" or invaluable resource, not simply as a body (Hjalgrim et al. 1995, Cesarani et al. 2003, Lynnerup 2009:358). Because of this, measures to study mummies that are minimally invasive or non-destructive in nature are being utilized more frequently for research and are becoming the norm for mummy studies (Zweifel et al. 2009).

The purpose of using imaging technologies for mummy studies is to "strike a balance" between preservation and information gathering (Mininberg 2001:196). The most popular non-invasive methods applied to mummy research include conventional radiography and CT. Magnetic resonance imaging (MRI) has been used for mummy studies as well, albeit to a significantly lesser extent and with varying degrees of success. Shortly after Wilhem Röntgen's discovery of x-rays, mummies began to be analyzed with conventional x-rays (Röntgen 1896). Walter König published images of the knees of a mummified child and a profile of a mummified cat, along with other images that included modern teeth (König 1896, Glasser 1934). Just after, Petrie published an x-ray view showing the lower legs of two Ancient Egyptians in 1898. This image, produced sometime in 1897, is arguably the earliest x-ray of mummified adult body parts (Petrie 1898). The value of CT technology for mummy studies was quickly realized after the development of this newer form of radiography by Hounsfield (1973), when Lewin and Harwood-Nash (1977) scanned the brain of an unidentified Egyptian juvenile and the mummy Djemaetesankh. The first systematic analysis of a larger sample of 11 mummies using CT was conducted by Marx and D'Auria (1986). This technique was most commonly used to investigate the two primary foci of overall mummy studies:

mummification techniques and paleopathology. In a review of literature from 1979 to 2005 on CT based mummy studies, O'Brien et al. (2009) found that 74% of the studies utilized CT technology to investigate the mummification process, while 58% utilized CT to evaluate diseases. Within the last fifteen years the use of CT for mummy studies has increased dramatically and research investigations have expanded beyond just the study of mummification and paleopathology (O'Brien et al. 2009). In another meta-analytical review of mummy studies from 1977 to 2005, Zweifel and colleagues (2009) noted that CT has been used equally as much as conventional radiography in the studies assessed; however, the number of studies using CT applications have been steadily increasing since 1977 and has likely already surpassed conventional radiography in frequency of use for mummy studies. Today, it has been argued that CT is the preferred method for examination of mummies because it is non-destructive and is superior to conventional x-ray technology (Hoffman et al. 2002), yet many studies combine both methods in the same research (Zweifel et al. 2009). Further technological advances have also added additional dimensions to CT-based mummy studies with 3D virtual reconstruction models and stereolithography.

3.1.3.1 Benefits of Computed Tomography for Mummy Studies: Increased applications of CT within physical anthropology and in the study of mummified remains lie in the benefits associated with this particular technology. Of the non-invasive methods for studying mummies, CT imaging is most successful and eliminates some of the issues associated with conventional radiography. Greater accessibility to CT machines and computer imaging packages are increasing the rate of CT use, as well as the use of 3D visualization and stereolithography. Three dimensional models are especially pertinent to mummy studies, because they allow easy visualization of internal structures and allows the layers of preparation and the body to be separated for individual analysis. Volume rendering of mummified remains also facilitates forensic facial reconstruction because real tissues can be observed and 3D printing provides a model of the skull from which to work. Computed tomography has likewise aided minimally invasive methods like endoscopy, bioscopy, and colonoscopy through observation of areas of interest and by providing guides for equipment insertion. Finally, CT data can be stored long term in digital format and can be used to generate virtual collections which could potentially increase resource access, information sharing, and research collaborations for the study of mummies.

Computed tomography scanning avoids many of the drawbacks of other methods used in mummy studies. The primary benefit of CT is that the method is non-invasive, and thereby, does not destroy or alter the mummy. With CT mummies can be studied in entirety, including skeletal material, tissue, and the associated funerary preparations, without removal or alteration. The earliest investigations by Lewin and Harwood-Nash (1977) and Harwood-Nash (1979), demonstrated the capabilities of CT for mummy studies. Notman and colleagues (1986) studied several mummies curated in a museum collection and were early proponents of the use of CT to prevent destruction of the mummy by autopsy. In many instances, invasive methods like autopsies are not feasible options for studying the remains, especially in museum settings (e.g. Hjalgrim et al. 1995, Chan et al. 2008). Cesarani and colleagues (2003:598) note that mummified remains can be investigated and the “quality and quantity of available information” gained increases without having to unwrap the actual specimen. Concern for the preservation of mummified remains is likely one of the primary reasons why the use of CT has increased drastically within the last two decades.

In comparison to other non-invasive methods, CT imaging retains more information than conventional radiology and works significantly better than MRI. Traditional radiology reduces a 3D object into a 2D image. All information parallel to the x-ray beam is lost; therefore, traditional x-ray requires multiple images to acquire multiple views of the object being scanned (Bushberg et al. 2002). Information that would otherwise be lost with plain film x-ray is more easily visible with CT imaging (Hounsfield 1973). Traditional radiography also creates differential levels of distortion, whereby the objects closest to the x-ray beam are less distorted than those on the periphery of the beam (Mantini and Rapini 2009). While CT images are also collected in two dimensions, the thickness of each slice is very thin and uniform unlike traditional x-ray (Bushberg et al. 2002). The objects being scanned can be displayed without “disturbing superimposition of juxtapositional structures,” which occurs with conventional x-ray machines (Hjalgrim et al. 1995:329). Computed tomography imaging also has high resolution, both contrast (ability to differentiate objects of similar density) and spatial (ability to differentiate objects in close proximity), is multiplanar, and has virtually no geometric magnification error (Hildebolt et al. 1990, Gardner et al. 2004). Computed tomography analysis displays better resolution than traditional x-ray, which makes this modality more effective for resinated and embalmed mummies (Hoffman et al. 2002). Re-analysis with CT of mummies originally examined with conventional radiography revealed new and significant details, further testifying to the superiority of CT analyses over x-ray. For example, new CT analyses of mummies have helped clarify skeletally derived biological parameters. Re-analysis of a mummy using CT by Gardner et al. (2004) provided a better view of the innominates than those generated with conventional x-ray and the sex estimation was changed from “male” to “female” based on the new data. Furthermore, findings from the CT data are used to make direct comparisons to previous radiological scanning and have demonstrated that CT analyses “adds a whole new dimension… and extends the information obtained” (Baldock et al. 1994:808). Likewise, cultural inclusions, such as jewelry wrapped with the body, are more easily visible with CT and may be overlooked with conventional x-ray depending on the composition of the materials. Using CT, Marx and D’Auria (1986) were able to identify faience, stone, and wax jewelry that were missed in previous studies of the mummy using conventional x-ray. As Elias and Lupton (2005) note, objects with low opacity are more easily visualized with CT than with traditional x-ray technology. Linen wrappings, the cartonnage, jewelry made of natural materials, and visceral packets can be considerably less dense than some bodily tissues, like the skeleton and teeth, and can be more easily visualized for analyses with CT than with conventional radiography. Finally, CT imaging also works better for mummified remains than MRI. In MRI, hydrogen nuclei are used to produce detailed images of the body because of the high levels of fat and water in them, which are required for this technique to work properly (Berger 2002). Magnetic resonance imaging has been attempted for mummy studies in the past, but most studies were inconclusive due to the lack of liquids in mummified remains. One notable exception was a study by Karlik et al. (2007), who successfully obtained MRI images of a mummy brain; however, MRI has yet to gain widespread acceptance and remains considerably more difficult than CT for mummy studies.

Computed tomography is routinely used in most medical facilities and therefore the technology is "relatively inexpensive and readily available" in most places (Gill-Robinson et al. 2006:49). Mininberg (2001) undertook the scanning of 14 mummified individuals housed at the Metropolitan Museum of Art in New York City. Museum staff, CT manufacturers, and radiology technicians from a local hospital volunteered time and equipment for the project. Similar cooperation has been noted by the Akhmim Mummy Studies Consortium (e.g. Gill-Robinson et al. 2006, Elias et al. 2007). The interest in mummies by the general public and members of the medical field likely contributes to easy access to CT equipment for mummy studies. Some clinics and CT machine manufactures (e.g. General Electric) use mummy scans to advertise and test their new equipment, prior to use in clinical settings. Scanning a mummy rather than a live patient also has advantages, because there are no movement artifacts and the images are clearer and have better spatial contrast since x-rays pass more easily through dehydrated tissue (Hughes 2011). In addition, methods used in clinical settings can be borrowed and adapted to mummy studies with CT technology. Hoffman and colleagues (2002) used algorithms designed for clinical purposes, specifically for colonoscopies and bronchoscopies, to create virtual fly through tours of the internal body cavity of mummies. As CT becomes more widespread, scanning is becoming faster, more common, and less costly and can therefore be more readily applied to mummy studies (Wade et al. 2011).

Three dimensional reconstructions are another utility of CT technology. The CT scan data of individual 2D slices are re-stacked and reconstructed with a computer to generate a virtual 3D model. Once a 3D model is generated, morphological assessments, measurements, and volume rendering of cavities are possible. Internal structures, which cannot be visualized with gross inspection or conventional x-ray, can be easily explored using cut-away views of the virtual model. Likewise, specific areas of interest within each individual can be selected and virtually separated for closer inspection. For example, Melcher et al. (1997) isolated individual teeth from the alveolar bone of a mummy in order to view the inter-proximal surfaces and to look for dental pathologies. Without a 3DCT model, these particular surfaces of the teeth could not have been studied. Excerebration and evisceration studies have also been aided by virtual models. Cranial damage can generally be viewed with 2D CT images; however, research on the removal of the brain is improved by using cut-away views because the level of detail is much higher in 3D models. Also, resin can be virtually separated from the cranial vault to better visualize the bone. In the same way, the thoracic cavity can be cut-away to view the route of evisceration and to explore the composition and shape of any visceral packets that may be present.

Models built using stereolithographic printing are another area of CT innovation in mummy analyses. After the creation of the virtual 3D models with CT imaging software, the model can be exported as a specific file type, known as an STL, and can then be printed into a physical model. Zweifel et al. (2009), note that $2/3^{rds}$ of studies conducted for facial reconstruction of mummies used stereolithography. In these cases, the reconstruction artist utilized stereolithographic models of the skull as the skeletal foundation upon which to add soft tissue. Full body reconstructions have also been created, albeit less frequently because of high costs, for use in museum programs and public education (Chhem 2006). Facial reconstruction of mummies is unique because dehydrated skin tissue is usually preserved. For forensic facial reconstruction, the shape of soft tissue structures like the nose, eyes, and ears typically have to be estimated in forensic contexts. With mummified remains these structures are frequently still preserved, albeit in a dehydrated state, and can be used as a reference point for reconstruction (Prag and Neave 1997). Preservation of hair also reveals more specific appearances of what mummified individuals looked like during their life and can be added to reconstructions without estimation (e.g. Marx and D'Auria 1986). For example, Hoffman and colleagues (2002) examined a mummy referred to as "the Braided Lady," because of the vast amount of braided hair preserved and visualized with volumetric rendering. The capacity to generate 3D physical models of the skull and to visualize soft tissues likely result in very accurate reconstructions of these individuals.

Finally, CT can also be used to aid additional information gathering by guiding biopsies and endoscopies. CT imaging successfully guided endoscopic investigation of the heart and thoracic region of an individual mummy by Notman et al. (1986). Other endoscopic investigations of mummified remains have been conducted by using pre-existing openings in the remains as entry ports (e.g. Hamilton-Patterson and Andrews 1978). In a study of two mummified heads, Gaafar et al. (1999) found that CT and endoscopic methods verified each other, suggesting that similar results can be obtained without the use of intrusive methods. Hoffman and colleagues (2002) note that using virtual fly through with the remains may potentially eliminate the need for endoscopy in the future. Rühli and colleagues (2002) tested the applicability of CT for biopsy of tissue in mummified remains. Computed tomography was used to determine the optimal entry location point to sample tissue of interest, in this case related to a pathological condition.

Rühli et al. (2002) found the method to work well for procuring tissue samples with target areas less than $1cm^2$, therefore, only requiring minimal destruction or alteration to the remains

3.1.3.2 Limitations of Computed Tomography for Mummy Studies: Despite the aforementioned benefits of using CT for mummy studies, this particular method of inquiry is not without limitations. There are many challenges directly related to the imaging modality itself. Computed tomography was not designed for scanning mummified and therefore dehydrated remains. Often, funerary preparations of the body and degradation due to the age of the remains and handling of the specimen require modification to CT techniques used in clinical settings. Three dimensional reconstructions may then be limited by the required modifications and then also by the slice thickness of the scan. Another complicating factor for CT based mummy studies pertains to assessing the validity of conclusions drawn in mummy research and to comparative studies. Many authors to date fail to mention technological or methodological specifics of their particular studies. This confounding factor likely arises because of how and why mummies are studied. Many mummy studies have been based purely on curiosity rather than through research driven by the scientific method. Lastly, some researchers have concluded that CT cannot replace or produce the amount of information that can be gained with gross autopsy of a mummified individual. Notwithstanding these challenges, recent mummy research (within the last fifteen years) has shown that many of these challenges can be overcome.

Scanners and the accompanying medical imaging software associated with CT are designed for medical professionals and clinical applications with a focus on living, hydrated soft tissues. As mentioned previously, acquiring scans from deceased individuals is easier because the remains can be scanned without movement. However, a general lack of fluid in mummified remains and thick layers of textile bandaging requires altered scanning protocols to obtain optimal imaging quality. Unfortunately, scanning guidelines and recommendations for mummies have yet to be established. Often, clinical technicians used predetermined settings for living patients. Generating 3D models of mummified remains is also significantly more difficult in mummies than in living patients and often requires more time and effort to render and segment the CT image data files. Embalming practices and the use of resin to prepare remains will alter the radiopacity of tissues in the body and make differentiation between bones, soft tissue, and linen wrappings more difficult in mummies, especially during volumetric rendering. For example, Baldock et al. (1994) indicated that the use of natron, a natural agent used for dehydration made of sodium carbonate, caused the tissue of the mummy Tjentmutengebtiu to appear denser and therefore more opaque. David and Archbold (2000) and Cesarani et al. (2003) had similar problems differentiating between tissue and linen wrappings because of embalming and resin. The latter suggests the use of manual, virtual “unwrapping” of mummies, rather than using predetermined threshold settings within the software. Manual editing of individual slices may be the only option to separate out the cartonnage, the skeleton, and the wrappings properly during the generation of 3D models (e.g. Gill-Robinson et al. 2006). The manual editing process is considerably more time consuming than using predefined settings, but can result in a more accurate rendering. Accuracy of manual editing can be periodically checked by generating 3D models, as done by Gill-Robinson et al. (2006). Differentiation between materials and tissues is best accomplished by visual assessment and evaluation of the CT numbers if uncertainty exists. Additionally, degradation of skeletal and other tissues may worsen visualization with CT or may require altered thresholding from the standard, clinical setting used for bones in medical imaging software (Lynnerup 2009). With a sample of mummies it will likely not be possible to standardize and use the same setting for each individual to render out areas of interest. Post-processing and segmentation of the image means, as Lynnerup (2009:368) suggests, that CT scanned images and "3D renderings should not be viewed as a totally objective and 'true' representation of internal structures and tissues." Because of this, more work is being done to establish or suggest standardized guidelines and methodologies for CT scanning of mummies because of the inherent variation in post processing (Cesarani et al. 2003). Despite the perceived subjectivity suggested by Lynnerup (2009), many skeletal biology studies have demonstrated a strong congruency between results using virtual CT models and actual bone. Corroboration of techniques from studies within forensic anthropology remain encouraging for mummy studies and suggest that virtual models may not be as subjective as previously considered.

Limitations based on slice thickness are also suggested by Lynnerup (2009) as one cause of subjectivity in 3D renderings. Computed tomography slice thickness can range from 0.05mm to 10mm depending on the scanner used, the machine settings, and the preference of the researcher (Lang 2010). Essentially the slice thickness is a trade-off with the time required to acquire the scan and the imaging capabilities of the computer. Greater slice thickness makes more efficient use of the x-ray beam, achieves better contrast resolution, and takes less time to generate the CT images, but larger slice thickness also results in a reduction of spatial resolution (Bushberg et al. 2002). For skeletal based research, Ruff and Leo (1986) recommend using the smallest slice thickness possible, but this may not always be a viable option with mummy studies. In some early investigations of mummified remains, different slice thicknesses were used for different parts of the body to save time and money or because of dosage concerns. Investigators feared that greater exposure time may degrade DNA; therefore, slice thickness was increased to limit dosage (e.g. Gotherstrom et al. 1995, Grieshaber et al. 2008, Chan et al. 2008). Baldock and colleagues (1994) choose 1mm slice thickness for the teeth, 2mm for the head, and 4mm for the remainder of the body because the authors were primarily interested in the dentition and excerebration procedures. More recent studies have also employed smaller slice thickness for the head and larger ones for the remainder of the body (e.g. Jansen et al. 2002). Other researchers specifically choose to decrease slice thickness in areas of the body considered of interest prior to scanning (e.g. Mininberg 2001). Improvements in CT technology since then have resulted in faster scanning times and thinner slice thicknesses being used for entire bodies (e.g. Cesarani et al. 2003). Overall, inconsistencies in slice thickness and using a greater thickness will impact the visualization of the individual, especially when generating 3D models. The impact of discrepancies in slice thickness ultimately depends on the specific research questions and modes of investigation.

A further challenge with mummy studies using CT technology is the general lack of consistency for 1) acquiring the scans, 2) reporting the methodology used, and 3) clarifying the purpose of the research at the onset of the project. Frequently, mummies are explored simply for pure curiosity's sake, without specific scientific intent, rather than for hypothesis driven research (see O'Brien et al. 2009 for a review of 26 years of mummy research). Failure of many researchers to outline the specific settings and methodology used for CT scanning further confounds the study of ancient mummies and the conclusions derived from such studies (O'Brien et al. 2009). This approach to studying mummies is problematic for a number of reasons. Beginning research investigations without clearly defined protocols and defined hypotheses can impact the resulting information gained and the validity of conclusions drawn. This approach also hampers repeatability and comparative research. While it may eventually prove impossible to completely standardize how mummies are studied, detailed descriptions of the methods and settings used by researchers will solve some of the aforementioned issues. Also the rapid evolution of CT technology creates an added layer of difficulty for standardization. Furthermore, if mummies are likely investigated for purely descriptive purposes, researchers can take the data they gather to generate hypotheses to be further explored in their sample or in other samples of mummies.

Finally, some researchers have still argued that this method does not provide all of the detail and information that could be obtained during an autopsy even with the numerous advantages of CT technology. Despite this criticism, Dedouit et al. (2010), having recently compared autopsy and CT studies in a mummy, found that the results agreed between the two for areas investigated: biological profile, trauma, and pathology. These findings suggest that autopsies of mummified remains do not need to be conducted to gain the same level of information. Additionally, the benefit of preserving the human remains outweighs the information attainable with gross autopsy. Melcher et al. (1997:336) conducted both gross inspection and CT investigations of a mummified individual and consequently recommend that “CT should be used in preference to all other methods presently available for examining mummies.” Today, CT is the gold standard for mummy research.

3.2 Materials and Methods

3.2.1 Computed Tomography Data

For each mummy, the CT images were accessed via discs currently owned by AMSC. These data discs were provided by the institutions originally responsible for scanning the mummies, sometimes in conjunction with AMSC and sometimes independent of AMSC. For this research, the CT images of each individual mummy were analyzed in Vital Images: Vitrea 2 Version 4.1.0.0 and Materialise MIMICS medical imaging software for visualization and analyses. Both programs are designed for use in clinical settings with hydrated bodies by physicians and healthcare professionals, yet both also work well with mummified remains. Each mummy was visualized using all 2D planes of reference to aid in the initial interpretations, as well as, in 3D. In Vitrea, volumetric rendering was accomplished using the predefined settings in the program. In MIMICS, the ‘bone’ thresholding setting in the software was used to render areas of interest. In some cases, the thresholding setting had to be modified in order to differentiate bone from resinated linen or adhering cartonnage. All of the biological and cultural assessments (discussed further in Chapters Four and Five) were assessed in Vitrea. Additional analyses, specifically landmark measurement data, were collected in MIMICS (discussed further in Chapter Six).

3.2.2 Scanning Protocol

The mummies in the AMSC sample were scanned by radiologists and CT technicians in diverse medical facilities over more than a decade; AMSC was not always able to specify protocols. Therefore, the scan settings used for each mummy varied by institution and by specialists collaborating in the research. For each mummy, the scanning procedure was documented by collecting the kVP and mAs. Slice thickness (Thk) was also collected for each individual. When individuals were not scanned in entirety, the following data was collected: the kVP and mAs values for the different scans, the portions of the body included in each scan, and the portions (if any) of the individual that were missing from the scan.

3.3 Results

The scan settings for each mummy were rather varied. The kVP values ranged from 100 to 140 (Table 3). The mummies with higher kVP values, for example kVP 140 in AMSC 4, had lower contrast than mummies with lower kVP values, for example kVP 100 in AMSC 23 (Figure 2). The mean kVP value for the entire sample was 121 kVP and the mode was 120 kVP. The mAs settings were highly variable and had a mean of 1740 (Table 3). Slice thickness ranged from 0.6mm to 7.5mm (Table 3). In cases where the cranium and postcrania were scanned separately, the cranium was scanned at a lower slice thickness than the postcrania. Spatial resolution was somewhat comprised in AMSC 17 and 18 because of the 3mm slice thickness used when scanning these individuals and in the thoracic region of AMSC 16 because of a 7.5mm slice thickness (Figure 3). All other individuals were scanned under 3mm, with a mean slice thickness of 1.45mm and a mode of 1.25mm for the entire sample.

Table 3. Computed tomography scan settings for each individual in the sample.

AMSC #	Year Scanned*	kVP	mAs	Thk (mm)	Portion	Full Scan	Missing
1	2005	120	100	1.000	All	Yes	N/A
2	2003	120	12523	1.250	Upper Half	Yes	N/A
		120	32670	2.500	Lower Half		
3	2004	120	318	1.250	All	Yes	N/A
4	2006	140	12773	0.625	All	Yes	N/A
5	2004	140	250	0.625	Cranium	No	Lower Legs
		120	657	1.250	Postcrania		
6	2006	120	98	0.750	Cranium†	No	Postcrania
7	2011	120	3	0.625	All	No	Feet
8	2011	120	11	0.625	Cranium	No	Feet
		120	12	1.250	All		
9	2006	120	95	0.750	Cranium†	No	Postcrania
10	2006	110	229	1.250	Cranium	No	Lower Legs
		130	80	1.250	Postcrania		
11	2006	110	231	0.630	Cranium	Yes	N/A
		110	83	1.250	Postcrania		
12	2006	130	80	1.250	Cranium	Yes	N/A
		130	81	1.250	Postcrania		
13	2006	130	78	1.250	Cranium	Yes	N/A
		130	70	1.250	Postcrania		
14	2010	120	0	0.625	All	Yes	N/A
15	2008	120	100	1.250	All	Yes	N/A
16	2007	120	17	1.250	Cranium	Yes	N/A
		120	35	7.500	Thorax		
		120	5	2.500	Lower Half		
17	2007	120	500	3.000	All	No	Feet
18	2007	120	500	3.000	All	No	Feet
19	2008	120	300	1.000	All	No	Lower Legs
20	2009	120	40	1.000	All	Yes	N/A
23	2011	100	125	0.600	All	Yes	N/A
25	2011	125	5	0.625	Cranium†	No	Postcrania
27	2009	120	140	1.500	Cranium	No	Lower Legs
		120	36	3.000	Upper Half		
		120	28	2.000	Lower Half		
29	2013	100	0	0.625	All	No	Lower Legs
30	2013	120	375	1.000	All	No	N/A

* Year of most recent scan in the case of mummies that have been scanned more than once.
† Only the cranium was available for scanning and analysis.

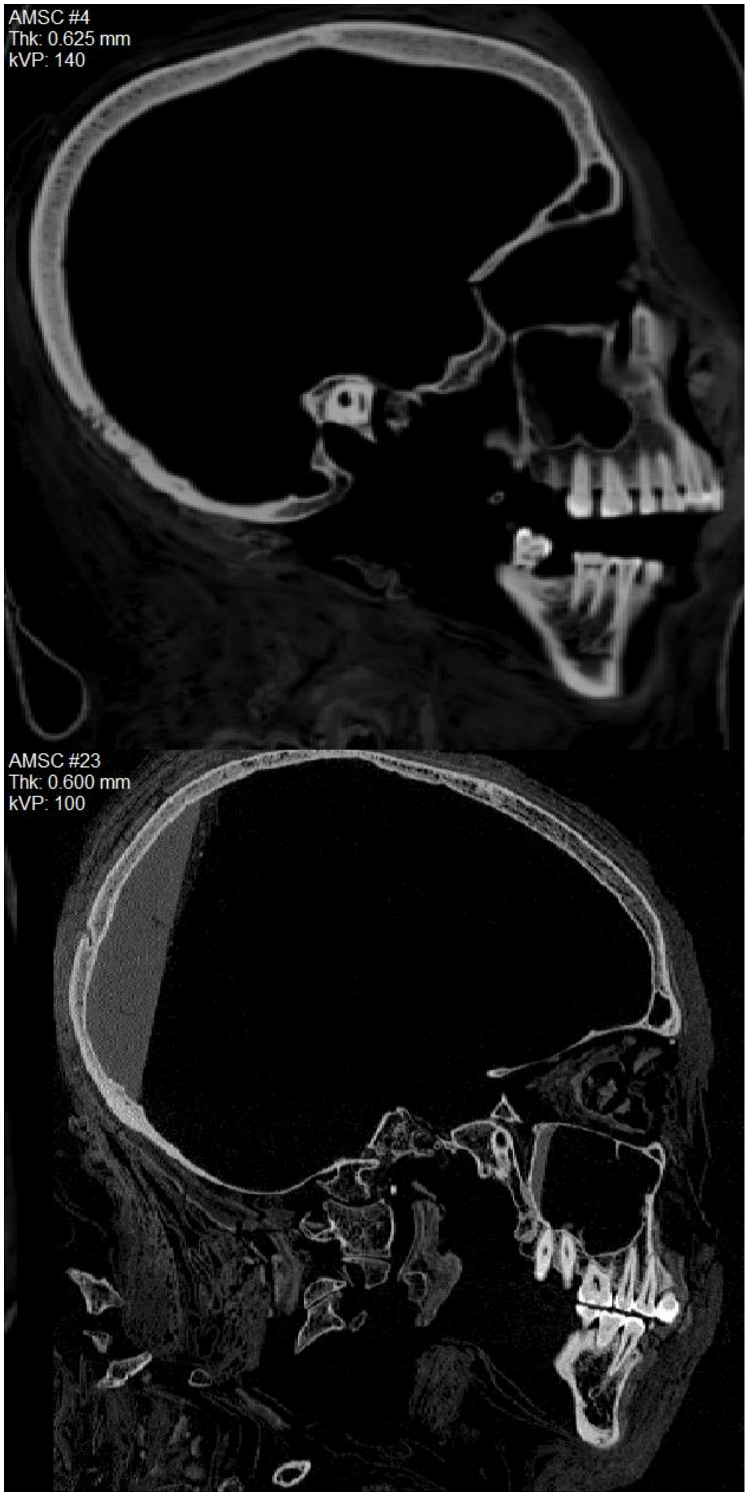


Figure 2. Impact of kVP value on image contrast quality. The higher kVP value in AMSC 4 produced lower contrast than the lower kVP values in AMSC 23.

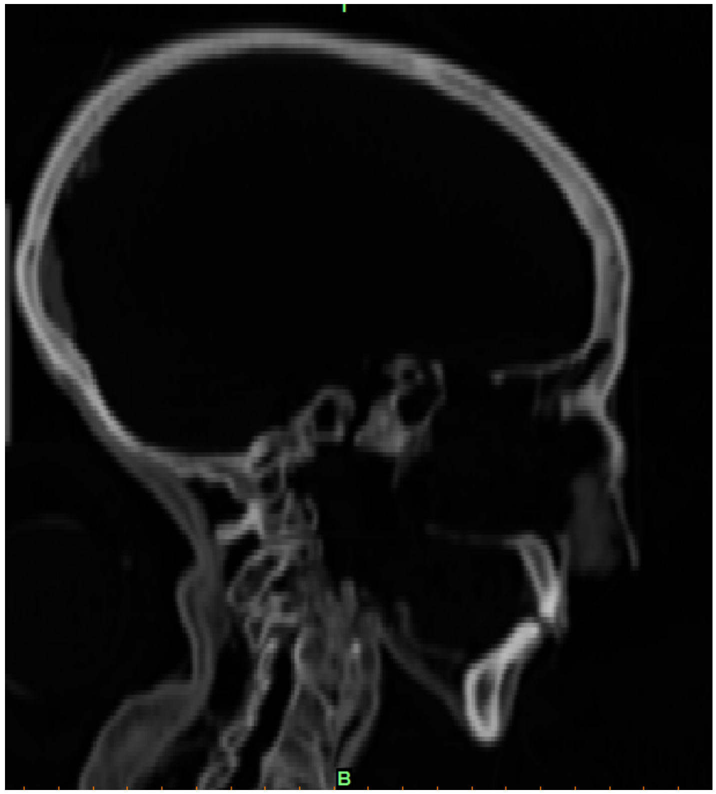


Figure 3. Poor image quality and increased pixelation in AMSC 17 because of a higher slice thickness (3 mm).

Thirteen of the 25 mummies were scanned in entirety. Portions of the remaining 12 mummies were not scanned (Table 3). In AMSC 6, 9, and 25, only the head was available for scanning and subsequent analyses. In four individuals the feet were excluded from the scan. In another five individuals the lower legs (from approximately mid-femur onward) were not scanned. In several mummies (n=7), the cranium was scanned separately or the individual was divided into upper and lower halves (n=3).

3.4 Discussion

The high degree of variation in scan settings reflects the predominant use of CT for medical diagnoses rather than for archaeological analyses. Analysis revealed that settings, and resulting image quality, used for some mummies were clearly superior than the settings used for others. In the future, optimal scanning protocols will be developed based on the present research to guide future analysis of mummified remains encountered in archaeological contexts. The directors of AMSC found that analyses and 3D reconstructions become compromised with higher scan thicknesses (5mm +) and in some cases, this warranted the rescanning of certain mummies at lower slice thicknesses (e.g. AMSC 7, 8, and 14). Going forward, the present study suggests that mummies should be scanned at a slice thicknesses under 3mm and preferably at 1.25mm or less. As technology is improving, faster scan times and lower energy dosages may enable researchers to consistently collect more slices.

Although the scan settings varied between individuals, it was still possible to accurately collect both the biological and cultural parameters discussed in Chapters Four through Six, suggesting that the information attainable with computed tomography analysis is comparable to that obtained with destructive methods. In some cases, the feet or lower legs were not scanned so as to mediate concerns of ancient DNA (aDNA) degradation and to preserve a portion of the remains for any possible future DNA analysis (e.g. AMSC 7 and AMSC 8). Energy dosage levels (beam energy based on kVP) has been a concern in mummy studies because some believe that higher energy levels will degrade the specimen enough to prevent the collection of ancient DNA. No studies to date have actually tested if aDNA fragmentation does occur in mummified remains that have been scanned using computed tomography. Tests in fresh non-human tissue have shown DNA to fragment with higher energy exposure, while another study demonstrated a need for higher energy levels to penetrate mummified remains

(Gotherstrom et al. 1995, Grieshaber et al. 2008). The methodology used in both of these studies, however, have been criticized by Paredes and colleagues (2012). Furthermore, DNA degradation from radiation exposure is higher in fresh, rather than mummified, remains because of the indirect effects of free radicals generated from hydrolysis of water (Wallace 1998). Based on the variation in image quality documented in this sample, a kVP value of at least 100 is recommended to obtain sufficient contrast resolution. Choosing to not scan non-critical portions of the mummy, such as the lower legs or feet, is an appropriate alternative to the use of lower kVP levels.

3.5 Conclusions

Due to the nature of how this sample was acquired, it was not possible to dictate or recommend scan protocols prior to the CT scanning of each mummy. The variation in scan settings instead could only be documented and interpreted to produce future recommendations for the CT scanning of mummified remains. As expected, the variation in kVP values and slice thickness did impact the image quality for each individual; however, this variation did not significantly impact data collection or analyses of the biological and cultural parameters evaluated in the present research. Furthermore, it was possible to collect a wide range of data, thereby attesting to the value of CT for the analysis of Egyptian mummies.

Chapter 4: Biological Profile Estimation

4.1 Literature Review

Biological profile estimation is fundamental for physical anthropologists attempting to describe unknown individuals and also to recreate past population demographics. There are four main components or parameters to establishing a biological profile for an unknown person: sex, ancestry, age-at-death, and stature. Skeletal biologists are tasked with estimating these parameters based on an individual's skeleton. Methods used to assess these components consist of either 1) morphological traits, also known as nonmetric, qualitative, or anthroscopic traits or 2) metric traits, also known as quantitative measures. Historically, morphological assessments dominated physical anthropology, especially for sex and ancestry estimation; however, there has been a shift in the past several decades towards the development of quantitative approaches (Dirkmaat et al. 2008). Metric methods are generally perceived to be more reliable and valid methods for biological profile estimation and are referred to as "objective" measures, while morphological methods are considered "subjective" (Rogers and Saunders 1994). More recent tests of the reliability and experience required to assess biological profile parameters in the crania and pelvis have shown that accuracy rates using nonmetric methods are much more comparable to metric methods than previously believed (Rogers and Saunders 1994, Williams and Rogers 2006, Hefner 2009, Vollner et al. 2009). One should note that in addition to comparable classification accuracies, strong correlations also exist between morphological traits and osteometric measures for both sex and ancestry, suggesting that both are acceptable for biological profile estimation

(Chevrund et al. 1979, Kenyhercz et al. 2012). While the classification accuracy of most metric and morphological methods for the skull and pelvis are comparable, metric techniques still outperform morphological methods for the postcrania. In many cases, both types of methods are employed for each component to make the final estimation of the biological parameter in question.

4.1.1 Sex

For sex estimation, skeletal biologists are essentially interpreting the sexually dimorphic features of the skeleton for discrimination. Males and females are differentiated primarily based on two biological features: morphology and size. Morphologically, males generally have more rugose muscle attachment sites and more robust cranial features than females. Postcranially, females differ from males in the pelvic region mainly because of the functional requirements of childbirth. For size, males on average tend to be taller and heavier than females in most populations. Male body size varies from eight to ten percent larger than female body size within the same group (Rogers and Mukherjee 1992); consequently, males in most populations will tend to have larger skeletal measurements in comparison to females. Overlap between males and females in skeletal size and form does occur and can vary from slight differences to very significant differences depending on the population. Considerable variation exists within and between populations and must be considered when estimating sex.

Virtually every bone of the human skeleton has been assessed for its potential for sex estimation due to the incomplete nature of skeletal remains that are often encountered in forensic and bioarchaeological contexts. Historically however, the bones most often *used* for sex estimation have been the bones of the pelvis and the skull (Klales et al. 2012, Klales 2013). Researches have generally agreed that the innominate is the best indicator of sex because of the functional differences between males and females that are associated with childbirth in the latter (Letterman 1941, Phenice 1969, Stewart 1979, Krogman and Isçan 1986, Walker 2005). To date, morphological traits of the pubic bone are the most reliable indicator of sex in the pelvis (Phenice 1969, Rogers and Saunders 1994, Klales et al. 2012). As with the pelvis, there are a number of morphological traits that have been widely utilized for sex estimation using the skull (c.f. Krogman 1962, Williams and Rogers 2006 for a list of traits).

Sex and gender were intertwined in ancient Egypt and some researchers have argued that gender roles in relationship to an individual's biological sex was influenced by other factors including social status, ethnicity, and age (Meskell 1999, Sweeney 2011). We know that individuals of both sexes were mummified in ancient Egypt and an abundance of both male and female mummies have survived. Historically sex estimation in mummies has relied on both biological and cultural clues. Preserved soft tissue, specifically in the genital region, is indicative of an individual's sex in the case of mummies that have been unwrapped. Traditional skeletal morphology and metric methods have been applied and adapted in the case of x-ray or CT analysis for those mummies still wrapped and for which the soft tissue did not adequately preserve or was not clearly visible. Finally, cultural factors often corroborate sex identification. These include coffin inscriptions and coffin adornments or sex specific preparatory treatments such as a genital coverings. In rare cases the funerary preparations may reflect gender roles that disagree with the biological sex of an individual (Sweeney 2011). For this reason, it remains wise to consider both the biological indicators and cultural contextual clues to estimate the sex of an ancient Egyptian individual.

4.1.2 Age-at-Death

Skeletal changes occur throughout an individual's life for the most part on a fixed schedule beginning with bone formation or ossification, followed by bone fusion, and then bone degeneration. Using this rough timetable of bony events, anthropologists can observe the known changes to estimate the age-at-death of an unknown individual (Nafte 2009, Byers 2011). It is important to note when assessing age-at-death, physical anthropologists are attempting to determine chronological age of an individual based on physiological, developmental or skeletal age. Environmental and genetic factors influencing skeletal development may produce inconsistencies between the two types of ages and must be taken into consideration (Lampl and Johnston 1996).

In adults, aging is based on degenerative changes that occur in a progressive sequence; however, there is considerable variation in timing of these events and also a great number of factors that can alter or influence this schedule. Because of this, age ranges for adults are considerably broader than those provided for sub-adults and typically are reported in five, ten, or fifteen year age ranges. Adult age-at-death estimation is primarily based on methods analyzing the changes of the pubic symphyses, the auricular surface, the sternal ends of the ribs, and cranial suture closures (e.g. Lovejoy et al. 1985, Meindl and Lovejoy 1985, Isçan and Loth 1986, Brooks and Suchey 1990, Buckberry and Chamberlain 2002, Osborne et al. 2004). In all three of the aging methods using the postcrania, the bone morphology in these regions progresses from a smooth, youthful appearance to a coarse, porous and general roughened appearance with time (Byers 2011). In the crania, the sutures progress from open to closed and sometimes obliterated throughout life. Dental attrition and wear patterns have also been assessed for age-at-death estimation; however, these methods are considerably less reliable for age estimation than the aforementioned methods. Another area utilized for age-at-death estimation looks at the density and structure of trabecular bone and also bone histology. It is important to note that although methods of age estimation have been developed for single skeletal regions, adult age-at-death is best estimated using multiple areas if available.

The Egyptians viewed attainment of old age as divine reward for a life well-lived (Strouhal 1992). Their proclivity for intentional mummification reflects their desire to prolong their bodies for the afterlife. The *Papyrus Insinger*, named after Maspero's associate Jan Herman Insinger who purchased the scroll while in Akhmim, describes an expected lifetime of 100 years (RMO 2013). According to Manetho's *Aegyptiaca*, Pepi II took the throne at the age of six and reigned for 94 years, making him 100 at death. The statue inscription of Nebneteru, from the time of Osorkon II (9th century BC), tells us that he reached an age of 96 years (Lichtheim 1980). While the *Papyrus Insinger* suggests a long life for the ancient Egyptians, scholars agree that life expectancy in antiquity was considerably lower than what it is today and that ancient Egyptians were no exception. Studies from the past two decades have asserted that the average mean age-at-death for non-high status individuals was only about 20 to 25 years of age, while an average life expectancy for higher status individuals ranged from about 40 to 50 years (Strouhal 1992, David et al. 2010). Meskell (2001) suggests that life expectancy at birth was likely much less than 20 years, while Leca (1981) suggests a higher average mean age-at-death of 36 years when infant mortality is excluded. High infant mortality, poor sanitation, epidemics and disease were all compounding factors contributing to a low life expectancy in ancient times. In any society, higher status individuals as a whole tend to have better access to resources and prolonged life expectancy when compared to lower status individuals in the same population.

Interestingly, the dead are always portrayed as young individuals in Egyptian funerary art despite the individual's true age (Dunand and Lichtenberg 1994). While adult Egyptian mummies are prevalent, preserved child mummies are rarer. The occurrence of child mummies, albeit low, does reveal that individuals of all ages were mummified. Age-at-death estimation of Egyptian mummies has relied on standard morphological techniques and often the exact method of determining an individual's age is not presented in the literature.

4.1.3 Stature

Skeletal elements have been found to have high correlations to living stature; hence, a number of methods have been developed for stature estimation based on single bone lengths or combinations of multiple bone measurements. Bones of the lower limb are more accurate and produce estimates with smaller error than bones of the upper limb, because the legs directly contribute to height while the arms do not (Ruff 2007). Stature estimation is the last step in biological profile estimation, partially because many of the formulae to calculate it are sex, age and population specific.

Fully (1956) developed a full skeleton method that combined maximum length measurements of the skull, vertebral column, the femur, the tibia, and ankle height. Combinations of fewer elements was later presented in Fully and Pineau (1960). Other methods have since been proposed using specific skeletal elements to estimate stature, because remains are frequently fragmentary in forensic and archaeological contexts and all the bones required for the Fully method may not be present. Steele (1970) developed methods for stature estimation using fragmentary long bones by looking at the correlation between portions of the bone to total bone length to address the issue of fragmentary remains (Stewart 1979). To date long bones, and specifically those of the leg, are most often utilized for stature estimation. The most cited method for stature is Trotter and Gleser's (1952, 1958) formulae using single bones or combinations of bones; however, inconsistencies have been noted for measurements of the tibia (Ousley 1995, Jantz et al. 1995).

Historically estimates of ancient Egyptian stature have been based on total mummy bundle length (Smith 1912). More recently Trotter and Gleser's (1958) equation for "Negro" populations replaced the use of bundle length. The "Negro" equations have been used as opposed to the "White" equations, because the limb proportions of dynastic Egyptians are more similar to groups of African rather than Caucasian descent (Robins and Shute 1983, Zakrzewski 2003). Furthermore, the limb proportions in ancient Egyptians has remained relatively stable through time and show no evidence of variation related to class (Zakrzewski 2003, Raxter et al. 2008). A modified version of the Trotter and Gleser equation was presented by Robins and Shute for ancient Egyptians (1986). Using the modified equation, Zakrzewski (2003) found that male stature peaked during the Early Dynastic period, while female height did not peak until later during the Old Kingdom. The author also found that both sexes showed a decline in stature prior to the Middle Kingdom, a time at which sexual dimorphism in stature was also found to be less than in previous periods. Most recently, Raxter and colleagues (2008) have devised regression equations customized to ancient Egyptian populations which were found to be more accurate than using Trotter and Gleser's "Negroid" equation and had lower standard error estimates than most other long bone stature regression equations.

4.2 Materials and Methods

The biological profile of each individual was estimated based on the analysis of the skeleton and preserved soft tissue without prior knowledge of the individual's sex in cases where it is known by the coffin assemblage or inscriptions. Both the 2D CT images and the generated 3D reconstructions were evaluated. The methods used for each parameter are detailed below, with the exception of population biology. Egyptian population biology, ethnicity, and population variation have been heavily studied and are discussed fully in Chapter Six. Morphological and metric methods were used when applicable for parameter estimation.

4.2.1 Sex Estimation

The pelvis, when available, and the cranium were morphologically analyzed for sex estimation. For the pelvis, the axial and coronal views were evaluated in addition to the 3D virtual model. Traits of the pelvis that are traditionally used in forensic and bioarchaeological contexts were assessed for "maleness" or "femaleness" (e.g. Phenice 1969, Buikstra and Ubelaker1994, Rogers and Saunders 1994). A 3D model of the skull was generated using the predefined settings found in Vitrea 2. Cranial traits traditionally used for sex estimation were also analyzed (e.g. Buikstra and Ubelaker 1994, Williams and Rogers 2006). In the case of conflicting sex estimation results based on individual traits, the majority rule was employed and more weight was given to results from the pelvis than from the cranium. Once the skeletal analysis was complete, the soft tissue of the primary and secondary sex organs was assessed and the name and titles associated with the individual were considered. Because some titles were associated with both males and females, for example "scribe," titles were taken in context with the biological sex findings and were not considered wholly indicative of male or femaleness (Sweeney 2011).

4.2.2 Age-at-Death Estimation

The entire available skeleton was assessed in both 2D and 3D. Level of maturation was evaluated based on the union of epiphyses to the diaphyses and also on dental eruption. If the third molar was erupted and all bones were entirely fused, specifically the medial clavicle and basio-occiput, methods of age-at-death assessment based on degeneration were next evaluated. While frequently employed for age-at-death estimation in the skeleton, the pubic symphysis and auricular surface of the innominate could not be evaluated in digital form. Other methods used on dry skeletal material were adapted for use with a digital data set. Often, using the exact method to determine skeletal age-at-death ranges was impossible, yet it was possible to determine broad age categories (e.g. young adult: < 35 years, middle aged adult: 35-59 years, senescence: 60+ years). The ectocranial suture closure method of Meindl and Lovejoy (1985) could not be assessed because of the interpolation and smoothing present on the 3D models. Specifically, it remained impossible to differentiate between a score 1 and a score 2. However, it was possible to determine in 3D, and in 2D, whether the length of the cranial suture was open or had areas of obliteration, which provided a general age-at-death category. The sternal ends of the ribs were evaluated to determine if osteophytic lipping and cartilage calcification were present. Next, the density of the trabecular bone in the proximal femur was assessed using the method outlined by Szilvassy and Kritscher (1990). The degree of dental attrition and the presence of dental pathologies related to dental decay were assessed. Each individual was assessed a narrow age-at-death range in years and then was also categorized based on a broad age range: young (less than 35 years), middle (35-59 years), and old (60+ years).

4.2.3 Stature Estimation

Mummy length does not necessarily correspond to the stature of the living individual as suggested by Elliot Smith (1912) (Robins and Shute 1983). As a result, using single bone elements instead is likely more appropriate for stature estimation. Furthermore, Robins and Shute (1983) found a high correlation between estimates of stature from individual skeletal elements; consequently, the left tibia alone was used in the current research to estimate stature when present. The tibia was chosen because of all the bones used for stature estimation by Raxter et al. (2008), the tibia had the lowest standard errors of estimates. In cases when the left tibia was damaged, the right was used. In several individuals the entire tibia was not scanned so stature was estimated using measurements of the left femur when present or the left humerus instead, when both the femur and tibia were absent. These three bones were chosen because Robins and Shute (1983) found overall good agreement between the stature values obtained for each when compared to one another in a sample of Egyptian mummies. All measurements were taken in centimeters. The following sex equations devised by Raxter and colleagues (2008) for dynastic Egyptians were utilized to calculate stature in this sample:

Tibia:	♂ 2.552(tib) + 70.18	♀ 2.700(tib) + 61.89
Femur:	♂ 2.257(fem) + 63.93	♀ 2.340(fem) + 56.99
Humerus:	♂ 2.594(hum) + 83.85	♀ 2.827(hum) + 70.94

For individuals 30 years of age and older, stature was corrected for age using the following equation provided by Trotter and Gleser (1952), as recommended by Raxter et al. (2008):

subtract 0.06(age in years-30)

Because age was estimated as a range, the lowest age-at-death within this range was used to calculate the age corrected stature estimate.

4.3 Results

4.3.1 Sex

Males were more prevalent than females in the sample by a nearly 2:1 ratio (Table 4)(Appendix 3, Table A3.1). Nine individuals were classified as females, while 16 were classified as males. Three of the individuals (AMSC 6, 9, 25) did not have postcrania associated with the cranium; therefore, only the head was assessed. In these three, sex estimation is considered less reliable than in the remaining sample that included the pelvis for sex estimation. For the soft tissue, it was not possible to identify secondary sex characteristics in females (i.e. breast tissue), but in many cases it was possible to discern the sex of the individual, including females, based on the genitalia. Seven males had clearly visible penile tissue, with one (AMSC 5) also having a penile covering or sheath. Titles and coffin inscriptions (e.g. phrases such as “son of,” “daughter of,” “father of,”

Table 4. Biological profile parameters for individuals in the sample.

AMSC #	Sex	Age-at-Death	Mean Age	Age Cat.	Est. Stature	Status*
1	Female	65+	65	Old	5'	M
2	Female	late 40s	48	Middle	5' 2"	M
3	Female	25-35	30	Young	4' 11"	M
4	Female	30s-40s	39.5	Middle	5'	L
5	Male	30s-40s	39.5	Middle	5' 7"	M
6	Female	20-40	30	Young	N/A	I
7	Male	20-25	22.5	Young	5' 3"	M
8	Male	45-55	50	Middle	5' 2"	M
9	Male	30s	35	Young	N/A	I
10	Male	50s	55	Middle	5' 5"	H
11	Male	45-55	50	Middle	5' 7"	H
12	Female	50s	55	Middle	5' 2"	H
13	Female	30s	35	Young	5' 2"	H
14	Male	40s	45	Middle	5' 3"	M
15	Male	40s	45	Middle	5' 4"	M
16	Male	25-30	27.5	Young	5' 6"	L
17	Female	30s-40s	39.5	Middle	5' 2"	M
18	Male	50s	55	Middle	5' 5"	M
19	Male	30-45	37.5	Middle	5' 5"	H
20	Male	25-30	27.5	Young	5' 4"	H
23	Female	35-45	40	Middle	5'	L
25	Male	40s	45	Middle	N/A	I
27	Male	30s-40s	39.5	Middle	5' 7"	L
29	Male	20-25	22.5	Young	5' 10"	H
30	Male	20-25	22.5	Young	5' 2"	M

* H=higher status; M=middle status; L=lower status; I=indeterminable status

etc.) corroborated the biological sex estimation in ten individuals.

4.3.2 Age-at-Death

Individuals in the sample ranged from early adulthood (early 20s) to senescence (60+ years) (Table 4) (Figure 4) (Appendix 3, Table A3.1). The mean age-at-death for the sample is 40.4 years with most males and females falling into the middle aged category (Figure 5). The majority of the sample (60%) fell into the middle aged category (n=15).

42.3% of the higher status individuals died as a young adult, while only 27.3% of middle and 25.0% of lower status individuals within the sample died as young adults. The only individual within the old age category was AMSC 1 (Pesed), a person known to be of middle status.

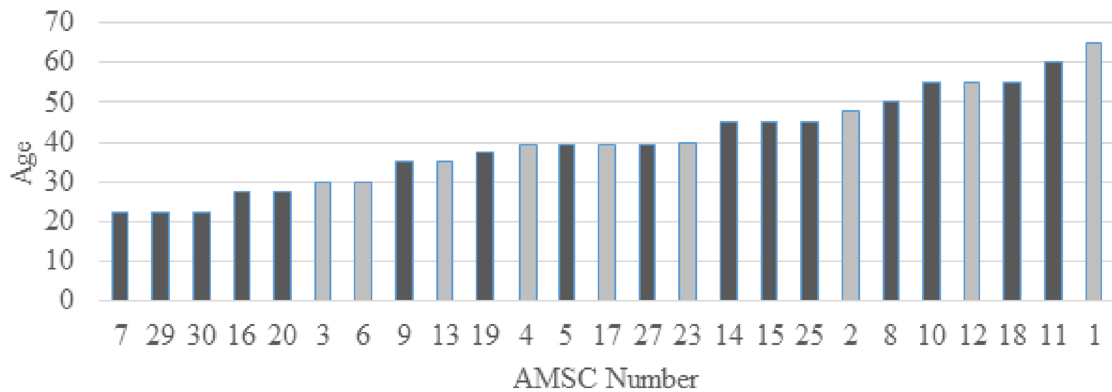


Figure 4. Estimated mean age-at-death distribution for each individual (females: light gray, males: dark gray).

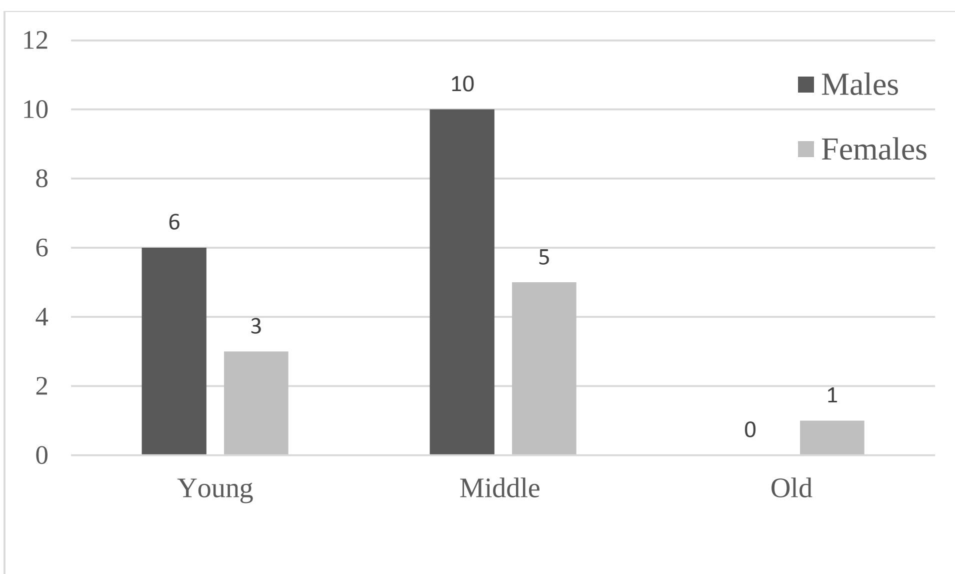


Figure 5. Age-at-death category distribution for males and females.

4.3.3 Stature

On average the males were taller than the females as expected due to sexual dimorphism (Table 4). The females ranged from 4’ 11” to 5’ 2” with a mean height of 5’ 1” (155.0cm) (Figure 6). Males showed greater variation in stature with a range from 5’ 2” to 5’ 10” and a mean of 5’ 4” (165.2cm) (Figure 6). At 5’ 10” AMSC 29 was the tallest of all individuals and may be an outlier to the group, at over three inches greater in stature than the next tallest individuals.

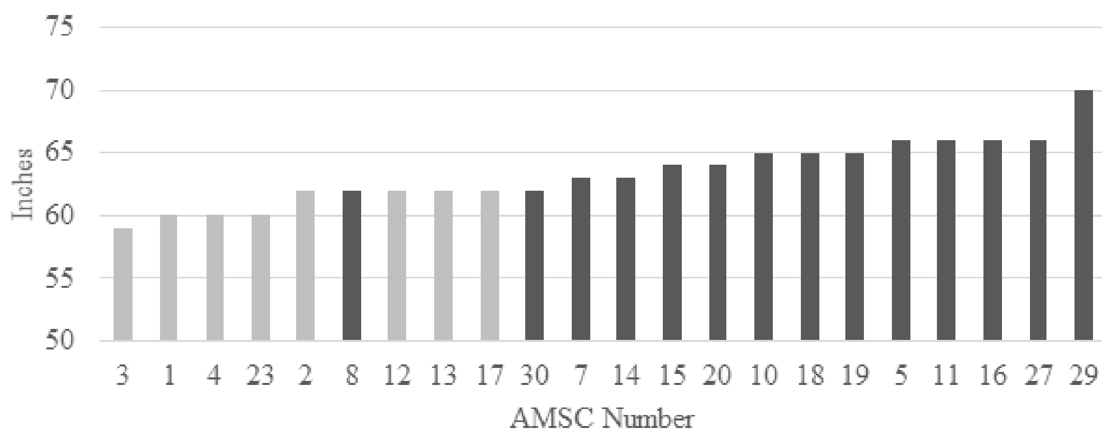


Figure 6. Estimated stature distribution for each individual (females: light gray, males: dark gray).

4.4 Discussion

4.4.1 Sex

Walker (1995) coined the phrase “sexism in sexing” to reflect the general rule that males are represented in greater numbers at archaeological sites, despite a general inconsistency with average sex ratios in past populations (Weiss 1972). He attributes this to likely better preservation in males and perhaps erroneous sex estimation from the crania in elderly females (Weiss 1972, Walker 1995). Interestingly, males (64%) were almost twice as prevalent as females (36%) in this sample as well; however, the caveats of archaeological sites mentioned by Walker (1995) do not apply to this particular sample. Furthermore, in an analysis of 275 mummies, Salter-Pederson (2004) found the same sex ratio (63% male, 37% female) in mummies with definitive sex assignment. Corroboration of soft tissue and cultural information with the biological sex estimation from the skeleton suggest a lower rate of error than with the skeleton alone. Furthermore, the mummification process likely eradicates the issue of differential preservation between males and females. One likely explanation for the sex ratio difference in this sample may be cultural in origin and may relate to the factors that have historically impacted mummy acquisition. A large number of the mummies in this sample were sold to American and European travelers to Egypt during the late 19th and early 20th centuries. Male mummies were more likely to represent a king or ruler and therefore may have been perceived as being more desirable for purchase than a female mummy and could have commanded a higher price. Interestingly, the earliest AMSC data sets were females of middle status. It is unlikely that females were buried separately from males in the same family, but we cannot completely discount the possibility of sequestration by sex among members of the priestly class (Elias 2013, pers comm). At the same time, within the AMSC sample there is a data skewing that favors the preservation of information relating to men rather than women at Akhmim. For example, the names of females are frequently lacking from genealogical records (see Appendix 2, Table A2.2).

4.4.2 Age-at-Death

It should be noted that several factors limit the interpretation of life expectancy in this sample, 1) no children are included in the sample, only adults, 2) most individuals are of middle to higher status within the middle class sector of society, and 3) the sample size is rather small. Despite these limitations, the age data available is worth exploring and some very generalized interpretations can be gleaned. The age-at-death of the mummies in this sample varied considerably with individuals ranging from their early twenties to over 65 years of age, with a mean of 40.4 years. The mean age-at-death range is slightly older than the 36 years presented by Leca (1981). As expected, most individuals died during middle adulthood, between 35-59 years. Just under a third of this sample (31.8%) were individuals of higher middle class status. Interestingly and rather unexpectedly, this status category accounted for the highest percentage (42.3%) of individuals dying in young adulthood. In this sample, higher status individuals were more likely to die in young adulthood than the lower and middle status groups. Findings from this research generally contradict the notion that most low status individuals in ancient Egypt died during early adulthood, while the majority of higher status individuals died later in life during middle or later adulthood. Additionally, one quarter of the sample survived until their fifties, suggesting that life expectancy in ancient Egypt may have been older than previously documented in the literature.

4.4.3 Stature

All individuals analyzed with the exception of AMSC 29 post-date the decline in Egyptian stature documented by Zakrzewski (2003). Interestingly AMSC 29 is the tallest of all individuals within the sample at 5’ 10” (177.6cm). The stature of AMSC 29 is congruent with Zakrzewski’s (2003) finding that male height peaked during the Old Kingdom. AMSC 29 dates to immediately after the Old Kingdom solidly in the First

Intermediate Period. In fact, AMSC 29 is above the mean computed stature presented by Zakrzewski for both the Old Kingdom and the Middle Kingdom. With the exception of this individual, the ranges from this sample for females (150.4-158.4cm) and males (157.5-170.4cm) are generally below the means of pre-Second Intermediate Period Egyptians presented by Zakrzewski (2003) for females (152.3-162.7cm) and males (162.8-173.0cm). These results are within the stature ranges presented by Raxter et al. (2008). Results from this study suggest congruency with similar studies and supports the decline in overall stature after the Old Kingdom as presented by Zakrzewski (2003). Zakrzewski (2003) postulates that the decline in stature found in their sample may be related to changes in social hierarchy. The greater variation in stature in males is likely a result of a larger sample size of individuals as compared to females in this sample.

4.5 Conclusions

Two parameters of the biological profile, sex and stature, within this sample are consistent with previous published literature, while the age-at-death estimates challenge conventional wisdom concerning life expectancy in ancient Egypt and its relationship to status. Results from this research suggest that 1) in this sample, higher status individuals were more likely to die than middle status individuals during early adulthood and 2) individuals of all status levels survived into late-middle adulthood perhaps more frequently than previously believed. Given the small sample size used in this research, all of these findings are not going to be statistically significant; however, they are worth noting when considering the demography of ancient Egyptians because they challenge past literature.

Chapter 5: Cultural Preparation

5.1 Literature Review

Perhaps more than any other culture, ancient Egyptians are renowned for the development of elaborate funerary practices associated with their belief in life after death. They are widely believed to have pioneered and perfected the intentional mummification of their dead. Unfortunately, the Egyptians themselves have left no direct explanation of the logic underlying the technical aspects of the embalming process they used. Their description of body positioning and body wrappings are few in number, despite the plethora of Egyptian texts surviving today. From their own accounts we know of the materials used during the embalming process, but much of what we know of their funerary practices stems from ancient secondary accounts and later scientific inquiry.

In general, burials of the Predynastic period have been characterized by natural mummification. Recent archaeological evidence from Hierakonpolis showed that mummification existed as a process at least for some of the elite before the Old Kingdom. Certainly by the 4^{th} Dynasty we see a rise in intentional mummification, first with the elite classes, with eventual extension to lower status sectors of society (Taylor 2001). Mummification techniques continuously became more elaborate and diverse until reaching a perceived zenith during the New Kingdom. New research by Jones and colleagues (2014) from Mostagedda in Upper Egypt has shown that components of intentional embalming existed much earlier than previously believed and now challenges the aforementioned and generally accepted timeline of mummification. Linen funerary wrappings from burials dating to the Late Neolithic Badarian Period and the Predynastic Chalcolithic Period were found to be impregnated with resin comprised of multiple natural materials (Jones et al. 2014). A review of the literature reveals considerable temporal and spatial variation in mummification techniques. Unfortunately, description of the mummification process by historical and modern scholars lacks a degree of standardization required for comparability. Methods of reporting on all aspects of the embalming process are left to individual researchers and are inconsistent or even absent from many publications.

5.1.1 Embalming Practice

The two papyri commonly referred to as the “Ritual of Embalming” (*Papyrus of Boulaq, No. 3,* in the Cairo Museum and *No. 5158: Cataloque des Manuscrits égyptiens de Louvre*, in the Louvre, Paris) are actually better understood as documents describing the procedures for wrapping the body following mummification (Smith and Dawson 1924). Both works are religious in nature; they describe the directions, prayers and incantations associated with bandaging, rather than body preservation (Smith and Dawson 1924).

Our primary concept of how Egyptian embalming worked derives from the accounts of the classical authors Herodotus (late 5th century BC) and Diodorus Siculus (1st century BC). These non-Egyptians describe the process of mummification more fully than the Egyptians themselves, yet the reliability and inclusiveness of these descriptions is worth evaluating. Smith and Dawson (1924) note that these works are from a time of heavy foreign influence in Egypt and that the information contained within these works likely resulted from second-hand knowledge, as the process of mummification is highly ritualistic and sacred. Furthermore, both descriptions focus on accounts from a specific group of embalmers in a specific region, during a specific time period. Despite these limitations, both sources are often cited in mummy science literature as if they are holistic accounts of the mummification process. We now know that Herodotus may have oversimplified the variability of Egyptian mummification, reducing it to three techniques, differentiated by expense level. His account fails to cover the full range of variation already discovered in Egyptian mummies.

A great deal of variability exists in the manner of preparation often with regional, temporal, and individual variation present. Very generally speaking, the embalming process begins with excerebration to remove the brain and evisceration to remove the internal organs with the exception of the heart. The body cavity is then washed and sometimes filled with spices and other natural vegetation. Next the individual is dehydrated using natron salts before being washed a second time. Finally the deceased is positioned, resinated, and wrapped before being placed within a coffin or sarcophagus. The entire process is said to last for a period of seventy days (Herodotus II.86).

5.1.1.1 Excerebration: The removal of the brain, or excerebration, began during the Middle Kingdom and becomes a more refined process during the New Kingdom (D'Auria 1988). Wade and colleagues' (2010) work supports Strouhal's earlier (1992) assertion that variation in brain treatments was first seen in the elite class, followed by appearance in commoner groups. Often the brain was partially liquefied prior to excerebration. Aufderheide (2003) postulates that the brain may have been allowed to partially decompose prior to excerebration to facilitate easier removal. Embalmers removed the brain through the nasal passage causing damage to the nasal conchae, ethmoid, and sometimes also to the sphenoid, nasals, and orbital plates. Herodotus describes the nasal excerebration process as follows, "they take first a crooked piece of iron, and with it draw out the brain through the nostrils, thus getting rid of a portion, while the skull is cleared of the rest by rinsing with drugs" (Book II.86). Interestingly, of the three methods described by Herodotus, only the first method mentions excerebration. The exact route of nasal excerebration varied, yet preference was given to the left nostril as an entry route; although, the reasoning behind this preference is not well understood (Pirsig and Parsche 1991). A multitude of names exist in the literature for removal of the brain via the nasal passage. In staying consistent with most recent literature, this route of excerebration will herein be referred to as transnasal craniotomy. By the New Kingdom, transnasal craniotomy "became a standard procedure" (Ikram and Dodson 1998:118). In rarer instances, the brain was either removed through the foramen magnum following dislocation of the cervical vertebrae or was left intact to naturally desiccate. Wade and colleagues (2011) suggest that mummies lacking brain tissue and also lacking evidence of transnasal craniotomy underwent a "transforaminal craniotomy" without disruption of the cervical vertebrae; however, natural desiccation could also account for this observed phenomenon. Once removed, the cranial cavity was rinsed and sometimes filled with linen or resin, while the nasal region was sometimes plugged with resin or linen tampons following excerebration.

5.1.1.2 Evisceration: The earliest evidence of evisceration and preservation of the organs comes from Queen Hetepheres' tomb dating to the 4th Dynasty (Iskander 1980). Later, Herodotus describes the evisceration process as follows, "they make a cut along the flank with a sharp Ethiopian stone, and take out the whole contents of the abdomen, which they then cleanse, washing it thoroughly with palm wine and again frequently with an infusion of pounded aromatics" (Book II.86). The incision typically occurred along the left flank just above the iliac crest of the innominate; however, the angle and orientation of the incision varied during different time periods. The embalmers then used their hands to remove the viscera (Ikram and Dodson 1998). Of the major organs, the heart was the only one frequently left intact, as Egyptians believed the heart to be the center of wisdom and feeling (Brown 1992). If the heart was inadvertently removed during the evisceration process, it was replaced within the body cavity or in rarer cases symbolically replaced with a heart scarab (Raven and Taconis 2005). Less common practices involved the removal of the viscera *per ano* or vaginally. In both of these genital evisceration methods, linen wadding, resinated linen, or a concentration of resins, are typically found in the affected area.

Once removed, viscera were sometimes included in canopic chests, canopic jars, or in visceral packets. Canopic chests first appeared during the 4th Dynasty which corresponds to the earliest evidence of evisceration. Canopic jars were introduced later during the First Intermediate Period (Ikram and Dodson 1998). The earliest of these canopic jars took anthropoid forms, while later forms depicted either the head of the king or a non-specific human head. Later during the New Kingdom, the canopic jars represented one of the four sons of Horus: Imseti for the liver, Hapi for the lungs, Duamutef for the stomach (and often the small intestines), and Qebehsenuef for the large intestines. Popular belief suggests that each canopic jar contained a different organ, when in actuality multiple organs have been found in the same jar, as well as only portions of the organ as opposed to the whole. In some cases the canopic jars contained no viscera but were included as a symbolic representation of the four sons. By the 21st Dynasty, viscera were being returned to the body in packets almost exclusively with only several known exceptions during the 26th Dynasty and Ptolemaic Period (Ikram and Dodson 1998). Four visceral packets, representing the four sons of Horus and originally represented by four canopic jars, are the most common quantity included within the body cavity. Elias and colleagues (2014) draw attention to the temporal differences in the organization and placement of these packets throughout Egyptian history. During the Third Intermediate Period (21st to 25th Dynasties), visceral packets were oblong in shape and loosely organized within the abdomen, while increasing in size through to the Late Period (Elias et al. 2014). By the end of the Late Period and into the Graeco-Roman Period, visceral packet form took a more organized cylindrical shape and were placed above the abdomen into the upper thoracic region (Elias et al. 2014). Sometimes single or multiple packets were also placed between the legs during the 25th and 26th Dynasties, yet this practice is far less common. A review of literature makes clear the temporal variation in evisceration practices including if and how the organs were removed and then also how they were returned to the remains during embalming.

5.1.1.3 Materials Used: The aforementioned *Boulaq* and *No. 5158* papyri contain descriptions of the various materials employed during the embalming process. Additionally, texts such as the *Amherst Papyri* contain specific itemized funeral expense lists including explicit materials, many of which also appear in the *Ritual of Embalming* papyri. Later works by Herodotus and Diodorus Siculus include some materials throughout their respective sections on the embalming process as a whole. To date, Maksoud and El-Amin (2011) provide the most comprehensive list of the materials encountered in Egyptian mummies, the most widely used were: natron, coniferous and non-coniferous resin, juniper, mastic, myrrh, cassia, bitumen, and beeswax (Maksoud and

El-Amin 2011). The quality and quantity of materials used during the embalming process varied among individuals and was potentially influenced by social status and wealth during certain periods.

For many years, the consensus has been that Egyptians used botanical resins through much of their history, until switching to bitumen, a mineral tar, in later times (Smith and Dawson 1924). Ancient texts strongly suggest that what we call "resin" for purposes of convenience, was a compound material with complex chemical signatures. An inscription in the Temple of Horus at Edfu indicates that such mixtures were thought of as being recipes belonging to class of divine substance (*`3t nṯr*) in which even "dry" and "fresh" resins were distinguished, as well as, including other in-mixed botanical elements present in quantity (Chassinat 1918, Montet 1950). Early spectrographic work with bitumen showed that it contains metallic elements lacking from materials of botanical origin, and that these metals (Ni, V, and Mo) were present in mummy in-fills as early as the 21st Dynasty (1000 BC) (Spielmann 1932). Bitumen was being used in mixtures that also contained resins of botanical origin and botanical by-products such as wood tar. The notion that particular time periods saw the exclusive use of one material rather than another may be overstated in the literature. The true sequence of resin use through time is currently unknown. What we do know for certain is that resin was applied to various parts of the body in a liquid state and then hardened and that materials of both botanical and non-botanical origin were used during the embalming process.

Only very recently have x-ray attenuation properties been discussed as a method of identifying the materials found within mummies. A number of recent articles have been published on the topic of radiological analysis of ancient Egyptian mummies, specifically on the capabilities of Hounsfield Units (HU) to take measurements on materials found within mummy bundles in order to aid material identification (e.g. Villa and Lynnerup 2012, Atherton et al. 2013, Gostner et al. 2013). Atherton et al. (2013) recognizes the importance of recording HU values in analyses and looked at a large number of animal mummies with this goal in mind. Gostner and colleagues (2013) established the HU values of objects of known identity, and then used these to guide the identification of unknown objects encountered in mummified bodies. Other recent publications present a single value to describe an object (Davey 2013) or include a range of expected values (Wade 2012) for specific materials. To date, there is no consensus on the HU properties of specific materials used during the mummification process in ancient Egypt. Furthermore, within the Egyptological literature, many of the studies using HU values to identify materials fail to take into consideration the impact of kVP and scanner manufacturer on the HU values obtained.

5.1.1.4 Body Positioning: While ancient Egyptian excerebration and evisceration methods have been well studied, Elias and colleagues (2014:49) note that “the consideration of body orientation and limb positioning has lagged behind in the interpretation of Egyptian mummies.” When body position is reported, researchers tend to only describe specific portions of the body deemed significant. No attempt is made to use body position as an analytical tool to understand temporal and spatial trends in ancient Egypt. A lack of consistency in terminology when reporting aspects of body position in mummies makes comparative studies difficult and further complicates our understanding of this component of the embalming process. Furthermore, temporal and spatial trends in body positioning are not well understood.

Sprague (1968, 2005) proposed a set of terminological and classification methods to systemize the descriptions of the disposal of the dead encountered in archaeological contexts. Several of Sprague's classification schemes are applicable to the description of Egyptian mummification including flexure of the body and head positioning. Given the lack of standardization and the wide variety of terminology in Egyptology, a concise classification system would allow for comparability between studies.

5.1.1.4.1 Articulation: A discussion of body position is contingent upon the degree of articulation. When considering the degree of disarticulation one must further consider timing, either during preparation or postmortem due to taphonomic agents. Petrie's work at Deshasheh in 1897, as part of the Egypt Exploration Fund, is most famous for producing some of the earliest x-ray images of ancient Egyptian physical remains. Yet, the mummy shown in Petrie's Figure 37 is not of a classic Old Kingdom mummy, but rather of a body described by Petrie as "dissevered" (Petrie 1897). Petrie devised a classification scheme based on the degree of disarticulation he encountered at Deshasheh, yet his work has largely since been ignored. Instead of a paradigm shift and additional research on the topic, Egyptologists have generally focused on classic mummies to the detriment of other variants, including disseverated bodies.

A review of the literature reveals the tendency to describe mummies that are not fully articulated as belonging to lower status individuals; however, evidence to support such a claim is largely unsubstantiated (Klales and Elias 2013). Furthermore, disarticulated mummies have been considered to be "bad" mummies to possess, less desirable, or even "fake" (e.g. El-Mahdy 1989:93). El-Mahdy offers a taphonomic explanation of disseverated mummies based on one he encountered at the Liverpool City

Museum. The author attributes this “disjointed muddle of bones” to a perceived decline in mummification standards during the Graeco-Roman Period whereby, bodies sometimes entered into an advanced state of decay before the mummification process began (El-Mahdy 1989:93). El-Mahdy (1989:93) goes further to refer to a disarticulated child mummy being “exposed as a fake” mummy because it was discovered to be disarticulated within the bundle. Similarly, Dorman (2003) contrasts well preserved mummies to the poorly preserved body of Ramose, who had bones missing and out of place. Dorman partially attributes the differences seen in Ramose as the result of desiccation prior to wrapping, taphonomic agents after burial, and from a potential secondary burial. Lastly, Salter-Pederson (2004) analyzed published reports on 275 Egyptian mummies for the presence of damage. The author found that 21.7% of the sample had damage attributed to embalming practices, specifically from “being wrapped too tightly” causing the thorax and pelvis to become dislocated, jumbled or fractured (Salter-Pederson 2004:54). An additional 22.9% of the sample showed postmortem plundering damage. Generally, what we see in the literature is the assumption that disseverated mummies are the results of taphonomic processes including a decline in embalming practices and damage during preparation resulting in “fake” or non-classic mummies.

5.1.1.4.2 Flexure: Degree of flexure is addressed more frequently in Egyptian mummy literature than the other components of body orientation. Flexure depends on the orientation of the legs relative to the trunk of the body. In an *extended* position, the legs extend outward from the trunk with no bend of the knees. A *semi-flexed* position consists of the knees and subsequently the legs being bent at an angle of ninety degrees or more.

The *flexed* position, also sometimes referred to as the “fetal” position, consists of the knees being pulled tightly in towards the upper thorax and the knees are at less than a ninety degree angle. The knees are closely joined in both the flexed and semi-flexed positions. Finally, when the body is oriented in a position other than the aforementioned three, it is said to be *contorted*.

Natural Egyptian mummies of the Predynastic period were buried in a flexed or semi-flexed position in either sand pits, pottery or within wooden coffins (Aufderheide 2003). The onset of the mummification process during the Old Kingdom signals a shift to an extended body position from the Predynastic flexed posture. Strouhal (1992) attributes the shift to an extended position so as to allow for evisceration via the abdomen.

5.1.1.4.3 Arm Positioning: Hand and arm positions have been studied much less than body flexure. Early in the investigation of mummies, Pettigrew (1834:67) described several arm and hand positioning patterns: 1) along the thighs with palms touching the thighs, 2) hands placed upon the pelvis with hands either palm down or in contact with one another, 3) crossed upon the chest with predominantly the right arm atop the left, and the rarest 4) one arm across the chest and the other either along the body or atop the pelvis. Pettigrew (1834) concludes that these positions are used indiscriminately between the sexes and between individuals of different ages. In the nearly 200 years since Pettigrew, the study of arm and hand positioning with regard to mummies has remained stagnant. Researchers have tended to include only a basic description of the arms for their particular case study and often use their own unique terminology to describe what they are finding. The first comprehensive description of Egyptian mummy arm and hand placement was an analysis of 72 mummies dating from the New Kingdom to the Graeco-

Roman period conducted by Elias and colleagues (2014). The authors describe ten arm arrangement variations, grouped into three broad categories: extended, flexed and a combination of both (Figure 7). To this, the authors add the disposition of the hands including: flexed, slightly flexed/curled, and tightly flexed/grip. This study has shown that considerable variation exists in the arrangement of the arms and hands in Egyptian mummies and that these patterns cannot be used to directly indicate the sex or social status of the individual.

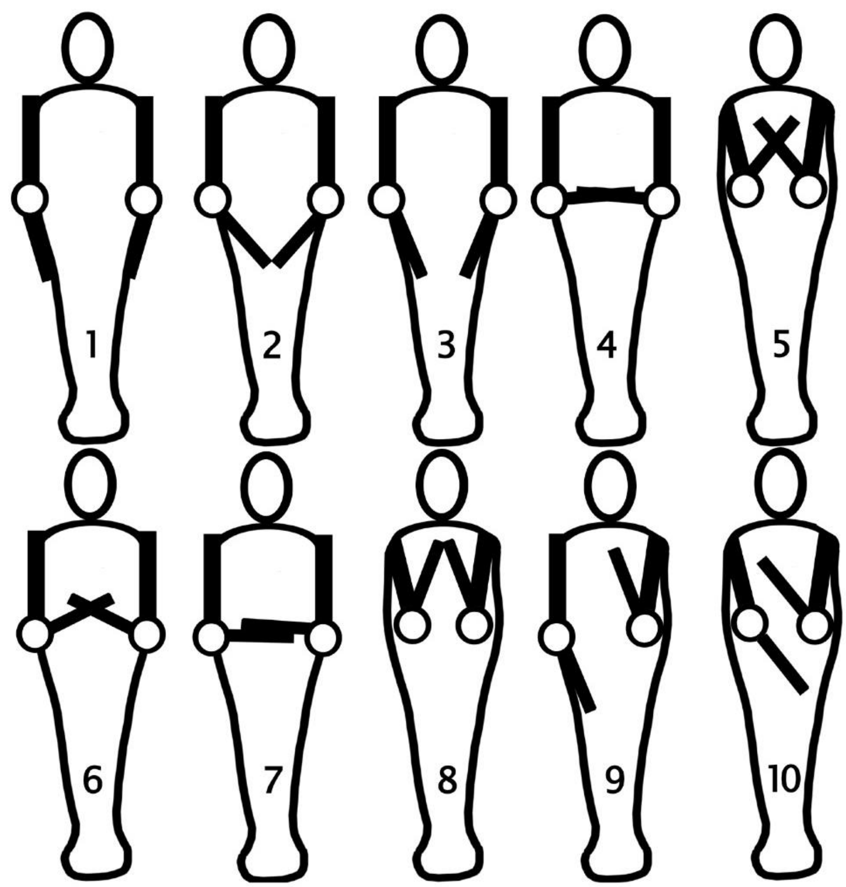


Figure 7. Arm arrangement patterns from Elias et al. (2014).

5.1.1.4.4 Head Position: Finally, for Egyptian mummies head orientation, as an aspect of body position, has been discussed the least. When mentioned by scholars, descriptions of head position suffer from many of the complications of arm position, mainly the use of unique terminology or poor general descriptions, both of which make comparability difficult or nearly impossible. To date, an inclusive study of head positioning among Egyptian mummies through time has not been conducted.

5.1.1.5 Wrapping Pattern: The quantity of linen, linen width, wrapping pattern, bundling style, and inclusion of linen padding vary through time and by individual status. Prior to the 18th Dynasty, the linen acquired for wrappings were reused from garments and linen sheets, while later linen was produced specifically for the mummification ritual (Ikram and Dodson 1998). Pettigrew (1834) suggest that the body was first positioned and then wrapped; this sentiment has been accepted as absolute in the literature since Pettigrew's time. Descriptions of the specific wrapping pattern were largely absent from publication of those mummies that were unwrapped and autopsied prior to the modern CT period of mummy studies. Superimposition of structures in conventional radiography further prevents a detailed analysis of linen wrapping patterns. Ikram and Dodson (1998) provide a review of the different wrapping patterns through the major periods in Egyptian history and also provide the conventional description of how mummies were wrapped. The authors detail the process beginning with wrapping of the head (in a top down fashion), next the torso and appendages, and followed finally by bundling legs and the entire individual before placement of the cartonnage and the body into the coffin.

5.2 Methods

5.2.1 Embalming Practice

Each mummy was individually analyzed for all aspects of the embalming process to discern individual variation and temporal trends in body treatment during the mummification process. During analyses of each area of interest, all three 2D views (coronal, sagittal, and axial) were evaluated in addition to the 3D volumetric rendering. In many cases, postmortem disturbances to the mummy bundle complicated determination of specific embalming features and are noted below.

5.2.1.2 Excerebration: First the presence or absence of brain tissue within the cranial vault was determined. If tissue was absent or only minimal remnants of the meninges remained, the route of excerebration was noted. For transnasal craniotomies, individual bones of the cranium were evaluated for presence or absence and any factures or breakage was considered indicative of excerebration damage. Resin, wadding, and linen tampons found within the nasal cavity were documented, as these were common practices during certain periods in ancient Egypt. For transforaminal excerebration, the articulation between the condyles of the occipital and cervical vertebra one was assessed. When the cervical portion of the vertebral column was disturbed or fully disarticulated from the cranium, the excerebration route was considered indicative of a possible transforaminal excerebration. In the event that the brain was absent from the cranial vault and no clear indicators of transnasal or transforaminal excerebration were present, the excerebration route was considered indeterminable. A chi-square test was run to assess correlations between excerebration variables (e.g. route, resin, linen tampons).

5.2.1.2 Evisceration: The thoracic, abdominal, and pelvic cavities were examined to determine which, if any, organs remained present. Next, the evisceration route was determined in the cases of organ removal. When an incision into the body cavity was discovered, the location of the cut was documented. In addition, the use of a resin plug or linen wadding to close the incision was also noted, as well as the number of visceral packets contained within the body cavity. Evisceration was considered to be either *per ano* or vaginal if no abdominal interruptions occurred and if linen wadding or a concentration of resin were noted in either of these cavities.

5.2.1.3 Materials Used: Computed tomography analysis alone cannot compare to other laboratory methods for material analysis; therefore, it was not possible to document precisely all materials that were used during the mummification process. In being consistent with previous research, large areas of opacity were considered to be resinous materials and could be documented. The level of opacity and location were used to determine if the material was in fact resin. When resin was present, the character of the resin (homogenous or heterogeneous) and HU properties were documented. Lastly, the correlation between body locations with resin were analyzed using a chi-square test of significance.

5.2.1.4 Body Positioning: The coronal view and 3D volumetric renderings proved most useful for determining the various aspects of body positioning. Articulation was first evaluated for each individual. For those that were disarticulated, the degree of disarticulation and regions affected were recorded. Flexure were noted in accordance with Sprague (2005). Arm position was coded from one to ten based on the variants illustrated and described in Elias et al. (2014) (Figure 7). Five head rotation categories as described by Sprague (2005) indicate which way the individual is "looking." By using the term "looking" as an indicator of direction, Sprague (2005) avoids anatomical directions that can become confusing if the individual is not in a supine or extended position. Sprague's categories include looking left, right, ahead, chin to chest, and backward extension. Head position was scored in accordance with the terms defined by Sprague when the remains where articulated and in anatomical order.

5.2.1.5 Wrapping Pattern: The wrapping pattern was assessed using the axial, 2D view and 3D volumetric renderings. The individual layers of linen bandaging were analyzed to discern the direction of wrapping (top to bottom or vice versa) and the pattern of wrapping (i.e. whether the bundle was wrapped in entirety or if individual appendages were wrapped prior to the bundle being wrapped).

5.3 Results

5.3.1 Embalming Practice

5.3.1.2 Excerebration: Two individuals were not excerebrated, AMSC 16 and 30, while another two, AMSC 6 and 27, were only partially excerebrated (Table 5). Each of the remaining mummies displayed evidence of excerebration. A transnasal craniotomy was the most common route of brain removal (86.9%) with a preference for removal via the left nostril. A non-metallic excerebration tool actually remains within the vault of AMSC 7 (Figure 8). In the mummy Djedhor (AMSC 8) all brain tissue is absent, yet the nasal cavity is intact, as is the articulation of the neck and skull (Figure 9). Interestingly, AMSC 8 shows clear signs of trepanation which may have possibly been used as the route of excerebration (Figure 9). Two mummies, AMSC 27 and 29, show evidence of possible transforaminal excerebration; however, it must be noted that both of these individuals are classified as disseverated (see section below Body Positioning: Articulation). Both of these individuals also have very unusual features, as compared to the remaining sample. Vegetation, believed to be reeds or a similar grass-like fibrous

Table 5. Excerebration patterns for individuals in the sample.

AMSC #	Excerebrated	Route	Cranial Resin	Nasal Linen	Facial/Nasal Resin	Comments
1	Yes	Transnasal	Yes	No	Yes	
2	Yes	Transnasal	Yes	Yes	No	
3	Yes	Transnasal	Yes	No	Yes	
4	Yes	Transnasal	No	No	No	
5	Yes	Transnasal	Yes	No	Yes	
6	Yes	Transnasal*	No	Yes	No	
7	Yes	Transnasal	Yes	No	Yes	Tool in R Orbit
8	Yes	Trepanned	Yes	Yes	No	Linen in Crania
9	Yes	Transnasal	No	Yes	No	
10	Yes	Transnasal	Yes	No	Yes	
11	Yes	Transnasal	Yes	No	Yes	
12	Yes	Transnasal	Yes	No	Yes	
13	Yes	Transnasal	Yes	No	No	
14	Yes	Transnasal	Yes	No	Yes	
15	Yes	Transnasal	Yes	No	Yes	
16	No	N/A	No	No	No	
17	Yes	Transnasal	No	No	No	
18	Yes	Transnasal	No	No	No	
19	Yes	Transnasal	No	No	No	Head Unwrapped
20	Yes	Transnasal	No	No	No	
23	Yes	Transnasal	Yes	Yes	No	
25	Yes	Transnasal	No	No	No	
27	Yes	Transforaminal?*	No	No	No	Reeds through FM
29	Yes	Transforaminal?	No	No	No	Sediment in Crania
30	No	N/A	No	No	Yes	

* Partial Excerebration; FM: Foramen Magnum; R: Right; ? = potentially (cannot be confirmed or denied)

plant material, pass from the body cavity through the foramen magnum and into the vault in AMSC 27 (Figure 10). The lack of significant brain tissue, coupled with disturbance of the cranio-vertebral articulation and the intact nasal cells resulted in a classification of transforaminal excerebration in this individual. Likewise, the mummy of Tjeby (AMSC 29) may have possibly undergone a transforaminal craniotomy, as we see clear disruption of the cranial articulation with the vertebral column (Figure 11). Unlike AMSC 27,

Figure 8. Excerebration tool (arrow) left in the right orbit of AMSC 7 (Padiheru).

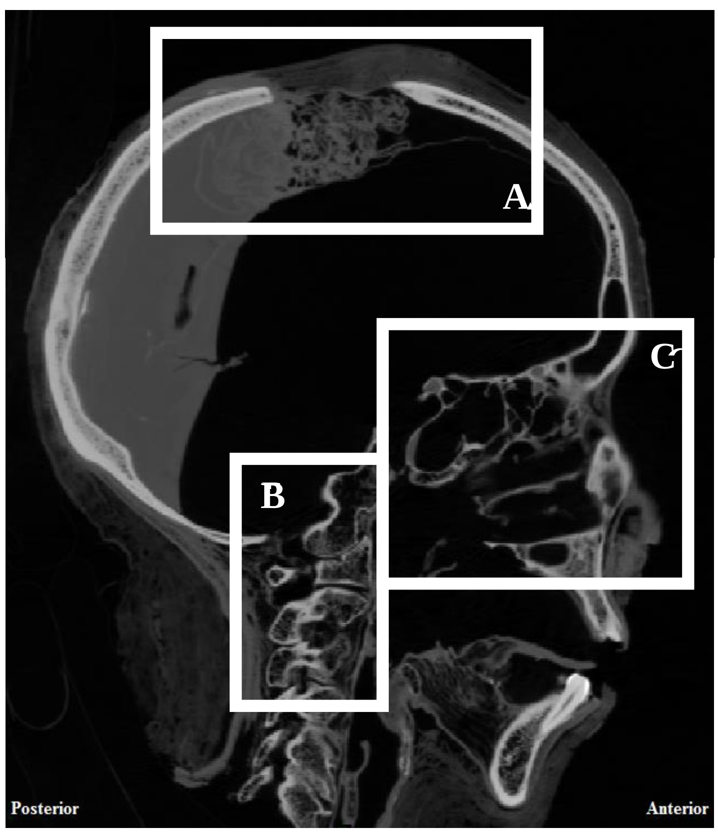


Figure 9. Excerebration AMSC 8 (Djedhor). A: trepanation, B: complete articulation of cervical vertebrae and occipital condyles, C: intact nasal passage.

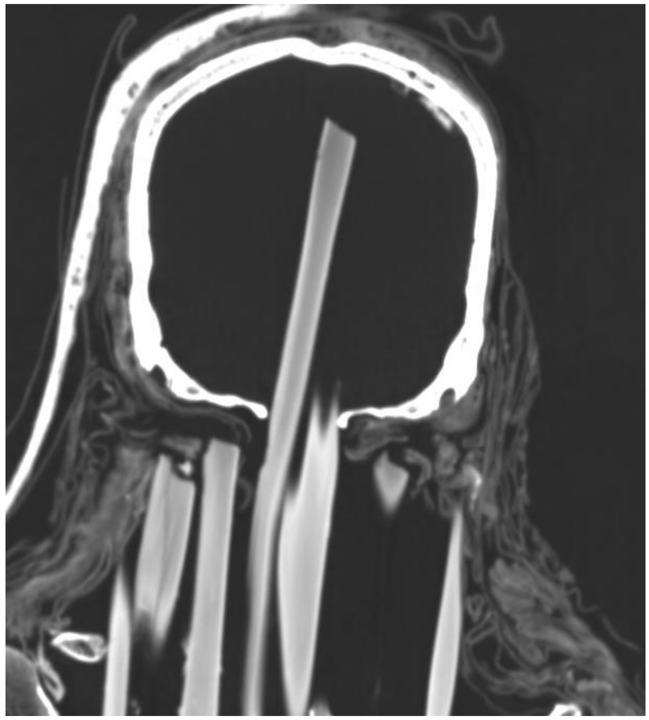


Figure 10. Vegetation, possibly reeds, passing through the foramen magnum of AMSC 27.

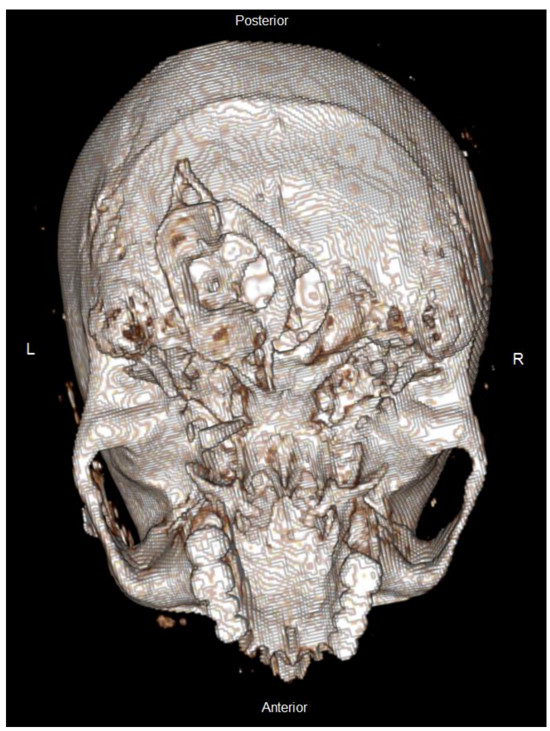


Figure 11. Disruption of cervical vertebra one in AMSC 29.

Tjeby contains a large quantity of sedimentary material in the cranial vault. Within this sample, some degree of variation was found in excerebration method and also in the treatment of the crania following excerebration.

Half of the sample has resin present in the cranial vault; although, the quantity of resin and number of pours varied considerably. Each of the individuals with cranial resin date to the Late and Graeco-Roman Periods, while the earliest mummies in the sample (dating to the First and Third Intermediate Periods) did not have resin in either cranial location (vault or facial/nasal) (Figure 12). The presence of cranial vault resin was

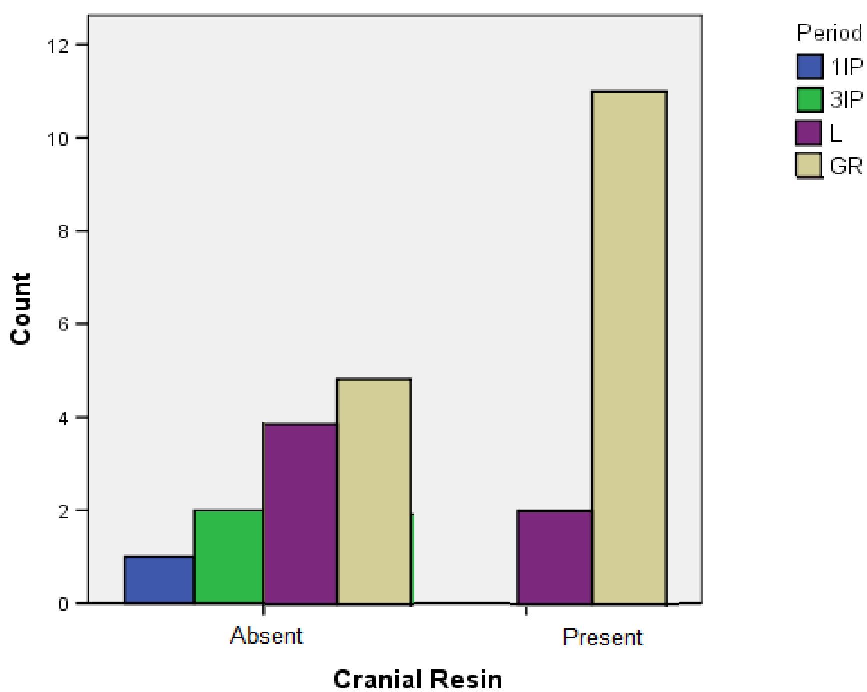


Figure 12. Presence of cranial resin by period (1IP: First Intermediate Period, 3IP: Third Intermediate Period, L: Late Period, GR: Graeco-Roman Period).

significantly correlated ($p = 0.002$) with the presence of facial/nasal resin at the $p < 0.05$ level. Individuals without cranial resin also typically lacked facial resin in the nasal region (Figure 13). Nasal tampons or wadding were found in five individuals (Table 5).

Presence of linen in the nasal cavity was significantly correlated ($p = 0.041$) with the absence of facial resin at the $p < 0.05$ level, indicating when linen was used post-excerebration, facial/nasal resin was not used (Figure 14).

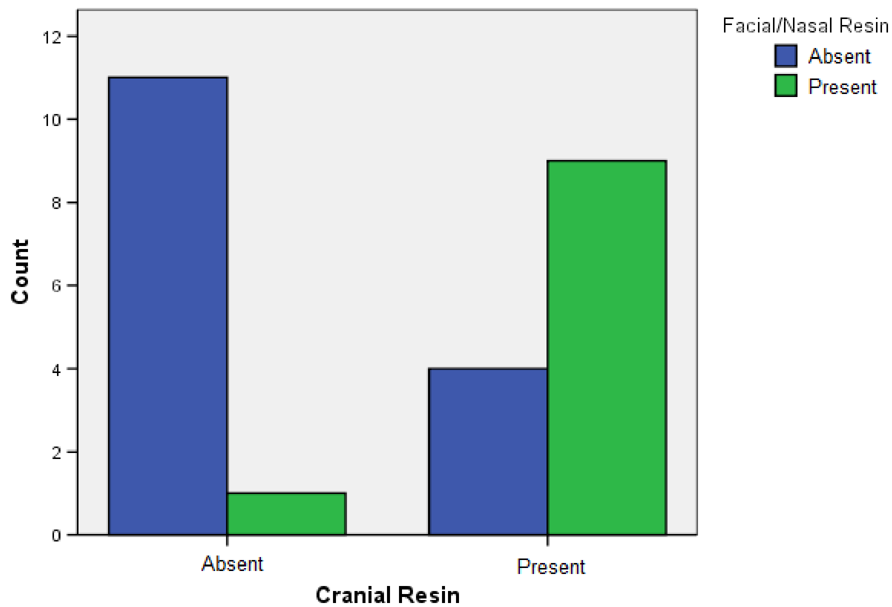


Figure 13. Correlation of cranial vault resin to facial/nasal resin.

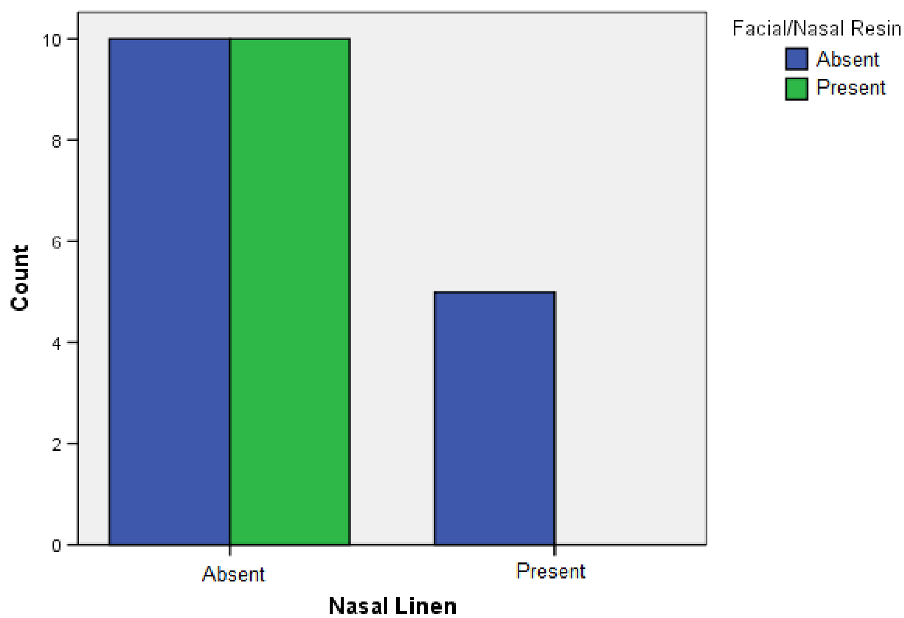


Figure 14. Correlation of nasal linen or wadding to facial/nasal resin.

5.3.1.2 Evisceration: Three mummies within the sample (AMSC 6, 9, 25) have crania only; as a result, evisceration was assessed only in the remaining 22 individuals with associated post-crania. Of these 22, all but one (AMSC 16) lacked the internal organs traditionally removed during the evisceration process (Table 6). In AMSC 8, 23, 27, and 29 the mummy is categorized as disseverated (see discussion below) and therefore, most exhibit a considerable degree of manipulation to the body. In the disseverated mummies, with the exception of AMSC 8, it was not possible to determine

Table 6. Evisceration patterns for individuals in the sample.

AMSC #	Eviscerated	Heart	VP*	Evis. Location	Resin Plug	Linen	Disseverated
1	Yes	Present	4	LA	Yes	Yes	No
2	Yes	Present	4	LA	Yes	Yes	No
3	Yes	Present	4	LA	Yes	Yes	No
4	Yes	Present	4	LA	No	Yes	No
5	Yes	Minimal	4	LA	No	Yes	No
6	Crania Only	N/A	N/A	N/A	N/A	N/A	No
7	Yes	Minimal	1	LA	No†	Yes	No
8	Yes	Present	Absent	A	No	No	Yes
9	Crania Only	N/A	N/A	N/A	N/A	No	No
10	Yes	Present	4	LA	No	Yes	No
11	Yes	Present	Absent	LA	Yes	Yes	No
12	Yes	Present	4	LA	No	Yes	No
13	Yes	Present	4	LA	Yes	Yes	No
14	Yes	Present	4	LA	Yes	Yes	No
15	Yes	Present	4	LA	No	Yes	No
16	No	Present	N/A	N/A	N/A	N/A	No
17	Yes	Present	4	LA	No	Yes	No
18	Yes	Absent	4	LA	No	Yes	No
19	Yes	Present	4	LA	No‡	No	No
20	Yes	Minimal	5	LA	No	No	No
23	Yes	Absent	Absent	Indeterminable	Indeterminable	Indeterminable	Yes
25	Crania Only	N/A	N/A	N/A	N/A	N/A	No
27	Yes	Absent	Absent	Indeterminable	Indeterminable	Indeterminable	Yes
29	Yes	Absent	Absent	Indeterminable	Indeterminable	Indeterminable	Yes
30	Yes	Minimal	Absent	PA	No	No	No

* VP: Visceral packets (#), LA: Left abdomen, A: Axially, PA: *Per ano*, † Anal packing, ‡ Skin flap over incision

the route of evisceration because of disruption to the body cavity. Of the possible evisceration routes, removal of the organs via an incision to the left abdomen was most prevalent (n=16) in non-disseverated mummies. One individual, AMSC 8 was eviscerated through an axial incision (Figure 15), while another, AMSC 30, was eviscerated *per ano* (Table 6). Most (87.5%) of the individuals eviscerated via a lateral incision had either a resin plug over the incision or linen wadding in the vicinity of the incision, or a combination of both. A large flap of skin was discovered in AMSC 19 rather than resin or linen wadding.

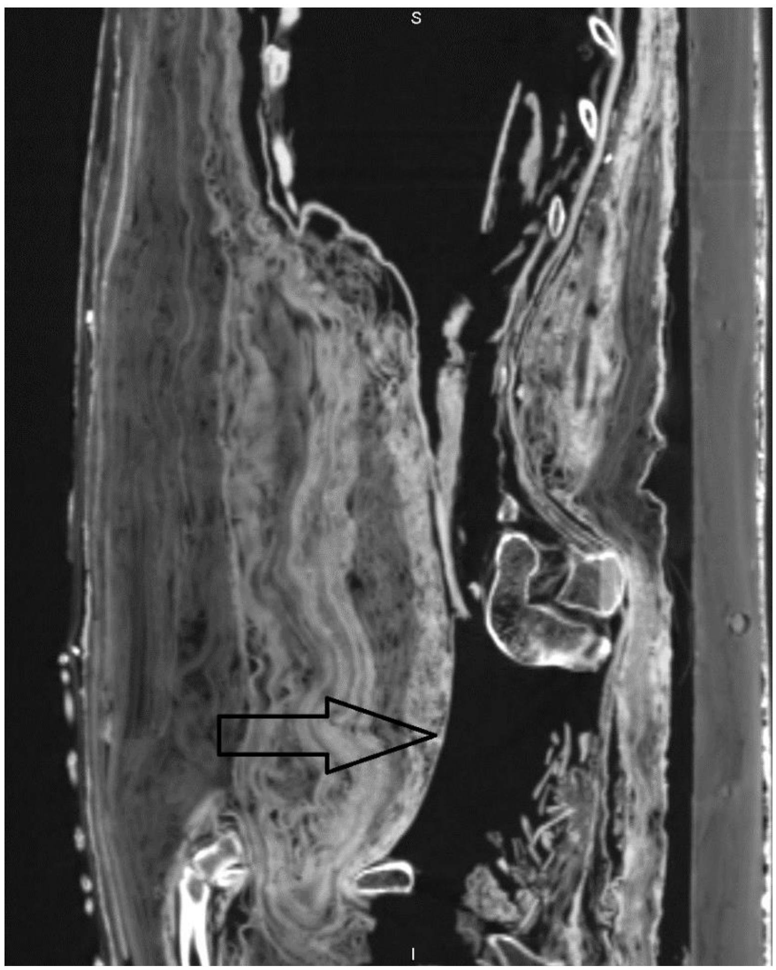


Figure 15. Axial incision (arrow) in the lower abdomen of AMSC 8.

Significant cardiac tissue was present in 14 mummies that were eviscerated and the single individual that was not eviscerated. Minimal remnants of cardiac tissue were present in an additional four mummies. Four mummies, including three of the disseverated individuals, had no remnants of the heart remaining (Table 6). Heart retention was correlated ($p = 0.048$) by temporal period at the $p < 0.05$ level, with full retention increasing through time (Figure 16). Visceral packets were present in all but three of the eviscerated, non-disseverated mummies. When present, the number of packets ranged from one to five, with four being the most common number of packets (Table 6).

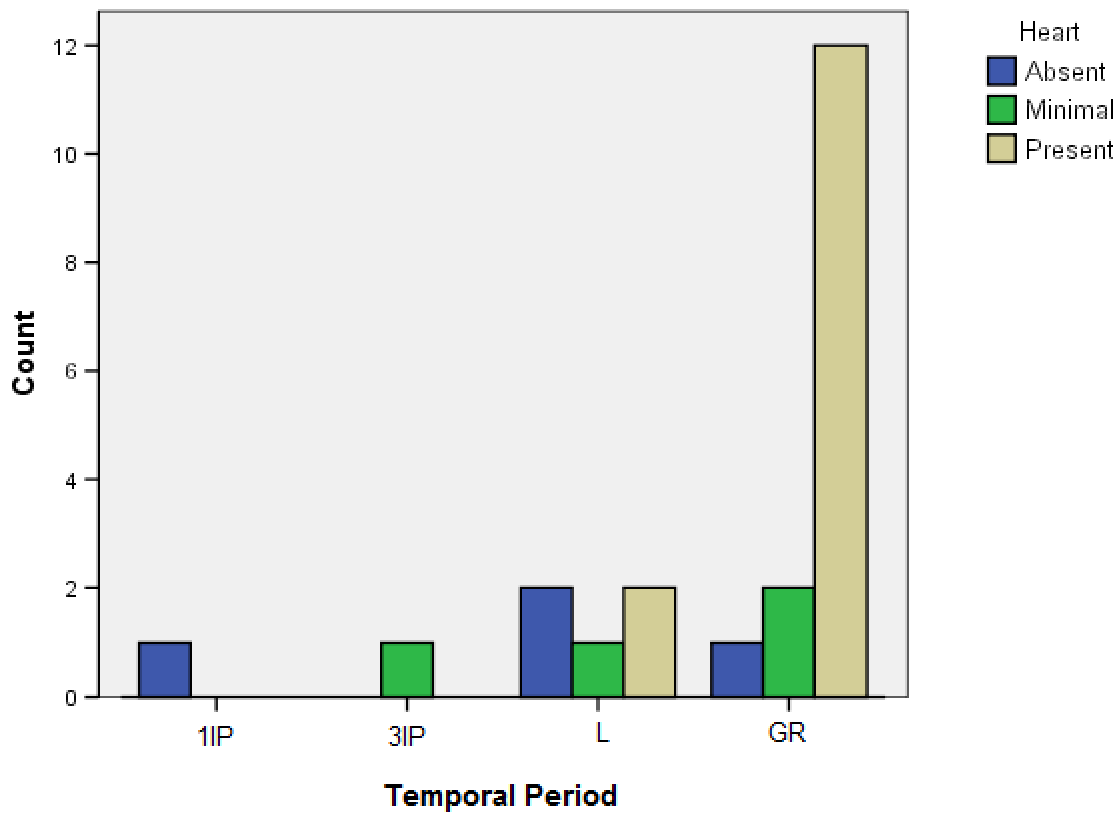


Figure 16. Correlation of heart retention with temporal period (1IP: First Intermediate Period; 3IP: Third Intermediate Period; L: Late Period; GR: Graeco-Roman Period).

5.3.1.3 Materials Used: Resin was documented in the crania (discussed above).

Specifically large quantities of resin were found in the vault and to a lesser extent along the face in the nasal region, in the posterior mouth, and in the throat region. Resin was also associated with the abdominal evisceration incision. Lastly, large quantities of resin were found in the body cavity (thoracic cavity and pelvic canal) (Table 7).

Table 7. Resin presence by location.

AMSC #	Cranial Resin	Facial/Nasal Resin	Resin Plug	Thoracic Resin
1	Yes	Yes	Yes	Yes
2	Yes	No	Yes	Yes
3	Yes	Yes	Yes	Yes
4	No	No	No	No
5	Yes	Yes	No	Yes
6	No	No	N/A	N/A
7	Yes	Yes	No	Yes
8	Yes	No	No	No
9	No	No	N/A	N/A
10	Yes	Yes	No	Yes
11	Yes	Yes	Yes	Yes
12	Yes	Yes	No	Yes
13	Yes	No	Yes	Yes
14	Yes	Yes	Yes	Yes
15	Yes	Yes	No	Yes
16	No	No	N/A	No
17	No	No	No	No
18	No	No	No	No
19	No	No	No	Yes
20	No	No	No	Yes
23	Yes	No	Indeterminable	No
25	No	No	N/A	N/A
27	No	No	Indeterminable	No
29	No	No	Indeterminable	No
30	No	Yes	No	Yes

The presence of thoracic resin was correlated (χ^2=8.867) with status at the $p <$ 0.05 level (p = 0.012) (Figure 17). Visually homogenous resin deposits ranged from -70 to 260 HU, while the more heterogenic deposits showed a greater degree of variation and ranged from -160 to 400 HU (Figure 18). Presence of resin in one portion of the body was correlated at the $p < 0.05$ level with resin in each other location of the body (Table 8). The exception to this was the non-correlation of an abdominal resin plug and the presence of facial/nasal resin.

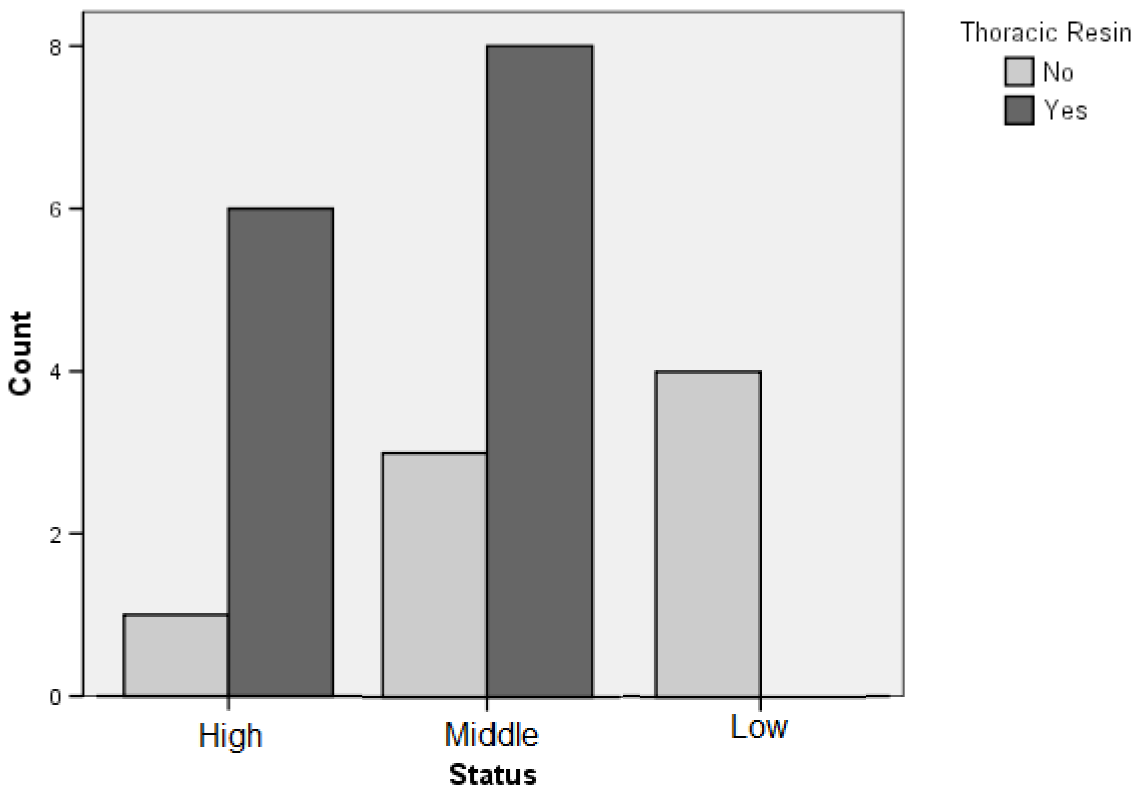


Figure 17. Correlation of thoracic resin to status level.

5.3.1.4 Body Positioning: It was not possible to assess body position in AMSC 6, 9, and 25, as these individuals only had crania available for analysis. In the case of the

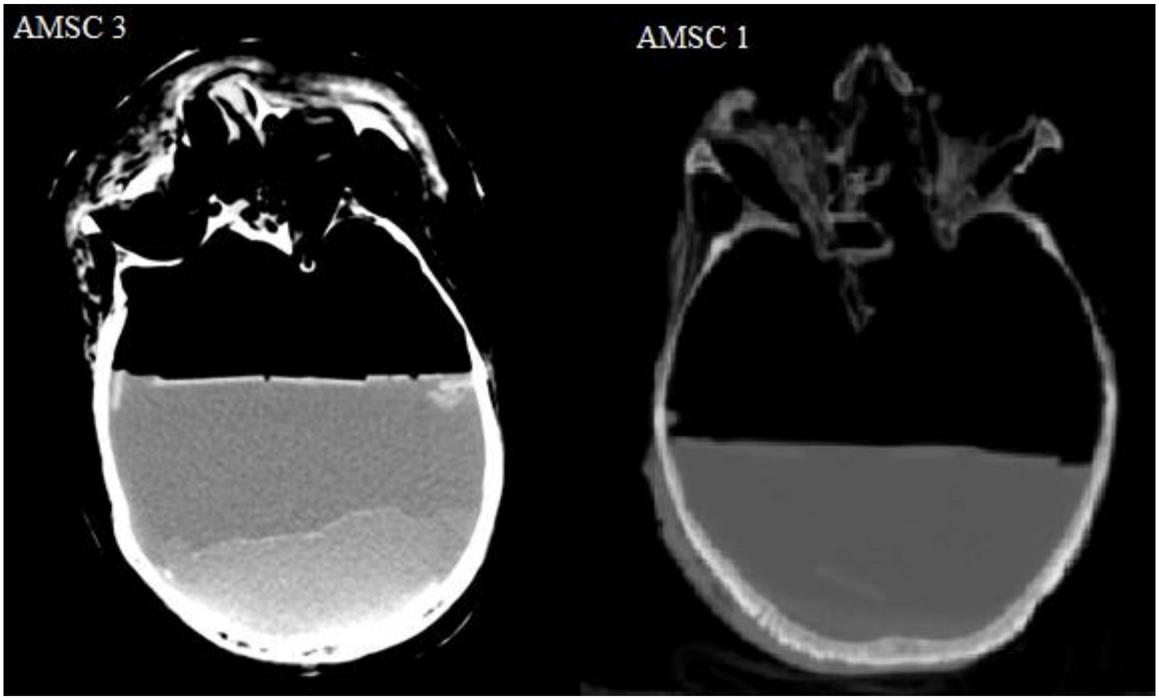


Figure 18. Variation in resin opacity. Heterogeneous (left) and homogenous (right) deposits.

Table 8. Chi-square correlation of resin based on location (significant values bolded).

	Cranial	Facial/Nasal	Plug	Thorax
Cranial	1			
Facial/Nasal	**0.002**	1		
Plug	**0.025**	0.112	1	
Thorax	**0.008**	**0.001**	**0.002**	1

disseverated mummies, the ability to assess body position factors was dependent upon the degree and manner of disarticulation.

5.3.1.4.1 Articulation: An analysis of the mummies in this sample revealed that most (72%) conform to the notion of a classic, articulated mummy as described by

Herodotus and Diodorus Siculus. The mummified bundle of four individuals appears intact; however, the skeletal remains within the bundle are disheveled and not anatomically oriented (Figure 19). In staying consistent with Petrie's originally classification of disarticulated mummies, these individuals are considered disseverated.

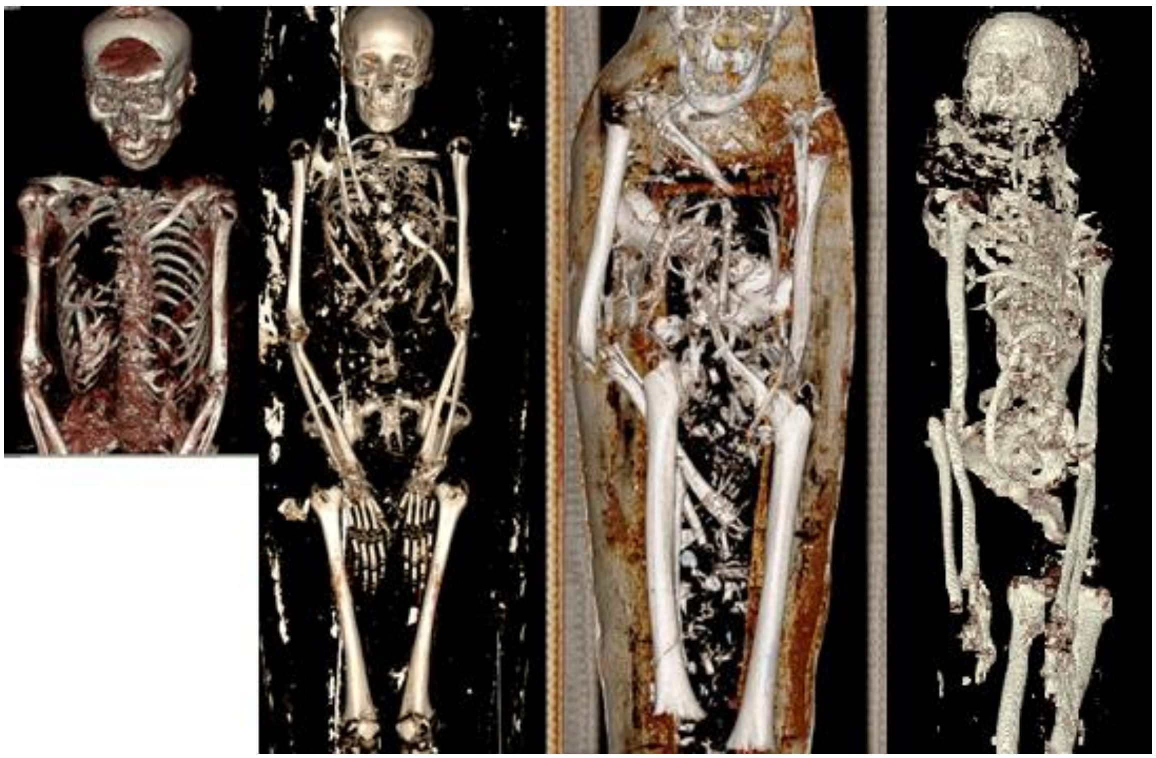


Figure 19. Disseverated mummies. In order from left to right: AMSC 8, AMSC 23, AMSC 27, and AMSC 29.

Degree of disseveration ranges from minor bone elements (AMSC 8 has disarticulation of the clavicles only), to considerate disruption of the thoracic region (AMSC 23), and lastly to extensive disruption of the entire skeleton (AMSC 27 and AMSC 29). The remaining 18 individuals with post-crania are fully articulated. In some of these cases, minor bone elements are missing from the bundle (e.g. missing patella in AMSC 4, Figure 20).

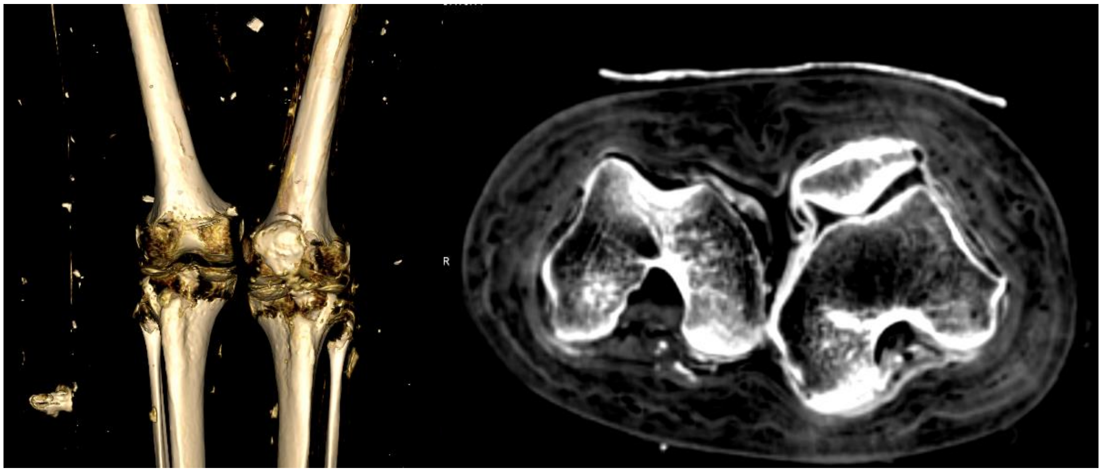


Figure 20. Missing right patella of AMSC 4.

5.3.1.4.2 Flexure: All fully articulated mummies are in the extended position with the legs placed parallel to one another in close proximity and with feet in dorsiflexion (when present) (Table 9). The postcrania of the four disseverated mummies are also roughly aligned in an extended position (Figure 19).

5.3.1.4.3 Arm Position: The placement of the arms was evaluated in 20 individuals (Table 9). The degree of disseveration in AMSC 8 was minimal and the manner of disseveration in AMSC 23 only significantly disrupted the thoracic region, thereby making assessment of arm position possible in these two disseverated mummies. Arm position five, flexed position with the arms crossed upon mid-chest, was most prevalent (65.0%) in the sample. In all of these cases the right arm was placed anterior to the left arm. Arm variant two, extended position with the forearms angled towards the groin and with hands placed between the thighs, was the next most prevalent (30.0%) position. Lastly, one individual (AMSC 5) had arm variant ten. In this mummy, the left arm is bent at the elbow and resting along the opposite shoulder, while the right arm is pronated and resting on the opposite thigh. Arm position was correlated (χ^2=10.629) with

Table 9. Body position parameters and wrapping patterns for each individual in the sample.

AMSC #	Period	Sex	Status*	Flexure	Arms	Head	Wrapping Pattern
1	GR	F	M	Extended	5	Ahead	WP-2S
2	GR	F	M	Extended	5	Ahead	WP-2S
3	GR	F	M	Extended	5	Backward	WP-2S
4	GR	F	L	Extended	2	Ahead	Double Bundle
5	GR	M	M	Extended	10	Dislocated	Left: WP-4S Right: Single Bundle
6	3IP	F	I	N/A	N/A	Dislocated	N/A (crania only)
7	GR	M	M	Extended	2	Ahead	Double Bundle
8	L	M	M	Extended	2	Ahead	Double Bundle
9	3IP	M	I	N/A	N/A	Dislocated	N/A (crania only)
10	GR	M	H	Extended	5	Ahead	WP-2S
11	GR	M	H	Extended	5	Ahead	WP-4S
12	GR	F	H	Extended	5	Ahead	WP-4S
13	GR	F	H	Extended	5	Backward	Corded
14	GR	M	M	Extended	5	Dislocated	WP-2S
15	GR	M	M	Extended	5	Ahead	WP-2S
16	GR	M	L	Extended	2	Ahead	Single Bundle
17	GR	F	M	Extended	5	Chin	N/A (partially unwrapped)
18	GR	M	M	Extended	5	Backward	Single Bundle
19	L	M	H	Extended	5	Backward	N/A (unwrapped)
20	L	M	H	Extended	5	Ahead	WP-2S
23	L	F	L	Extended	2	Ahead	N/A (disseverated)
25	GR	M	I	N/A	N/A	Dislocated	N/A (crania only)
27	L	M	L	Extended	D	Ahead	N/A (disseverated)
29	1IP	M	H	Extended	D	Dislocated	N/A (disseverated)
30	3IP	M	M	Extended	2	Ahead	Double Bundle

H: higher, M: middle, L: lower; I: indeterminable, D: disseverated, WP-2S: two-stage winding pattern, WP-4S: four-stage winding pattern

status at the $p < 0.05$ level ($p = 0.031$) (Figure 21). All lower status individuals had arm variant two, while all the higher status individuals as arm variant five. Individuals of middle status showed more variation in arm positioning and displayed variants two, five, and ten.

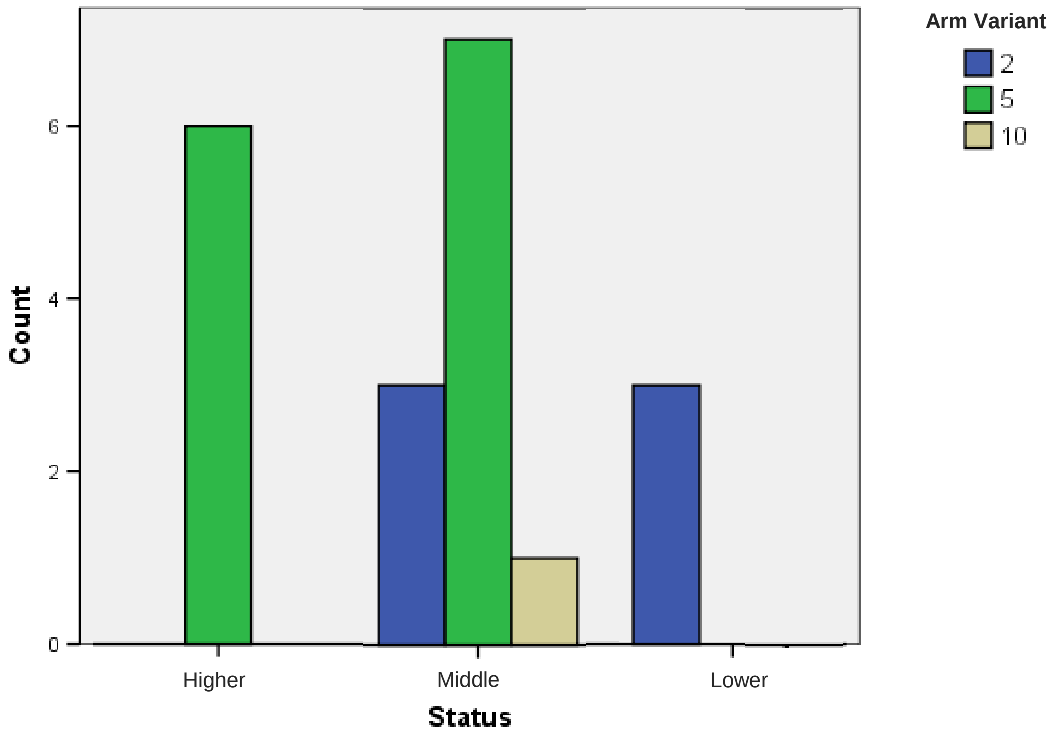


Figure 21. Correlation of arm variants (from Elias et al. 2014) with status.

5.3.1.4.4 Head Position: The crania was either fully or partially dislocated from the post crania in six individuals (Table 9). In the remaining 19 individuals, an ahead position of the crania was most common (73.7%) followed by a backward extension position (21.1%) and then the chin to chest position (5.3%). In the ahead position the crania was upright in proper anatomical position, but was sometimes slightly askew to either the left or the right.

5.3.1.5 Wrapping Pattern: Five wrapping patterns were noted within this sample. Variants are grouped into two broad categories depending on the positioning of the arms. When the arms were crossed, three different patterns were encountered: one with the use of cord and two using linen only to secure the arms. In mummies with extended arms, two additional wrapping variants were discovered.

In individuals with crossed arms (variant five from Elias et al. 2014), three distinct wrapping patterns were identified. Arm positioning was achieved during the wrapping process by either tying the arms with cordage or secured in place with the use of linen only. The cordage pattern involves the use of cord within the linen bandaging to secure the position of the arms across the chest prior to wrapping. Two other non-corded patterns were identified and used linen alone to secure the arms in place. Both non-corded patterns involve wrapping the individual in a continuous, counter-clockwise motion (from the left side of the body to the right side). Often each limb was wrapped prior to positioning and onset of full body bundling. Once the limbs had been bandaged, bundling commenced from the feet upwards with the lower limbs wrapped first, followed by the torso. The upper limbs are wrapped next, followed by the neck and cranium.

The simplest of the non-corded patterns identified is herein referred to as the Two-Stage Winding Pattern (WP-2S). For this form of preparation, each arm in its entirety (upper arm/humerus and forearm/radius and ulna) was treated as a single entity. Once the torso and lower limbs were wrapped, the left arm was positioned and wrapped as a single entity and was then joined with the torso bundle. Next the entire right arm was secured to the body bundle and positioned across the left arm. Finally, the entire body bundle was wrapped as a whole. A more complex pattern was also identified, herein known as the Four-Stage Winding Pattern (WP-4S). For this form of preparation, each portion of the arm (upper arm/humerus and forearm/radius and ulna) was treated as separate entity. Once the lower appendages and torso were bundled, the left, upper arm was wrapped and secured to the thoracic region. Next the left forearm was positioned and wrapped into the bundle containing the thorax and upper, left arm. The pattern then repeats for the right side. The right, upper arm was wrapped and included in the bundle containing the thorax and left arm. Next, the right forearm was positioned and secured to the rest of the bundle. A final layer of wrappings surrounded the entire bundled body.

The corded wrapping preparation was found in a single individual (AMSC 13). Instead of using linen wrappings to secure the arms in a crossed position, a cord-like material of thin diameter (6.4mm) was used. The non-cordage approaches with the use of linen only was the most prevalent in this sample and the Two-Stage pattern was most common. Seven individuals displayed the Two-Stage pattern, while two individuals displayed the Four-Stage pattern (Table 9). All mummies with the Four-Stage pattern were individuals of higher status, as was the single individual with the cordage preparation.

In individuals with extended arms (variant two from Elias et al. 2014), two distinct wrapping patterns were identified. The first involved placement of the arms and then wrapping commenced as a single body bundle, known as the single bundle method. In the second variation, the torso was wrapped prior to placement of the arms and full bundle wrapping and is herein referred to as the double bundle technique. The double bundle pattern was most common (n=4), while the single bundle method only occurred in two individuals. Only individuals of lower and middle status in this sample displayed the two bundling (single and double) variations. One mummy, AMSC 5, displayed a unique arm arrangement (variant ten from Elias et al. 2014) in which one arm is extended and one is flexed. In this individual, the left, flexed arm mirrored the pattern seen in the WP-4S, while the right, extended arm mirrored the single bundle pattern found in individuals with arm variant two (Table 9). In the remaining individuals (n=8), wrapping pattern could not be discerned for one of several reasons: the mummy was partially or fully unwrapped, only the crania was available for analysis, or the mummy was disseverated.

5.4 Discussion

In examining the AMSC collection, it is clear that the embalmers adopted strategies or had a "recipe book" of strategies for dealing with the cadavers in their charge. These strategies are a collection of techniques developed over decades within individual workshops that were constrained by the needs of ritual and efficiency.

5.4.1 Embalming Practice

5.4.1.1 Excerebration: Findings from this sample suggest that a certain degree of variation is present in excerebration methods and temporal trends emerge, specifically in resin usage. The high incidence of transnasal craniotomies, as compared to the low incidences of potential transforaminal excerebration, intact brain tissue, and trepanation, corresponds to Ikram and Dodson's (1998) assertion that nasal excerebration was a standardized procedure beginning by the 18th Dynasty. In this sample, transnasal excerebration was most common. Often the left nostril was the preferred route of removal as also noted by Pirsig and Parsche (1991). With the two individuals (AMSC 27 and AMSC 29) suspected of transforaminal excerebration, it should be noted that the high degree of post-cranial disseveration may be a confounding factor. In both mummies, the articulation of the cervical vertebrae and crania are disrupted; however, brain tissue may have dissipated via natural decomposition rather than deliberate excerebration. Tjeby (AMSC 29) is a First Intermediate Period mummy which may explain why this individual was not excerebrated transnasally, as this method was not believed to have become popular until much later in the New Kingdom. Furthermore, AMSC 29 has a high quantity of sedimentary material in the vault and packed around the skull to support the funerary mask. AMSC 27 is a Late Period mummy and uniquely has reeds placed through the foramen magnum. At this time, it is not possible to say with absolute certainty that both of these individuals underwent transforaminal craniotomy. The interaction between the excerebration method, the disseveration process, and the inclusion of non-typical materials must first be understood.

The association of cranial resin in the vault to excerebration has been well documented among Egyptian mummies. Vault resin was discovered in half of the sample specifically in mummies dating to the Late and Graeco-Roman Periods. While limited in number (n=4), all of the mummies within this sample pre-dating the Late Period lack cranial resin, possibly suggesting an increase in resin usage after the Third Intermediate Period. Ikram and Dodson (1998) suggest that the practice of using resin became common during the New Kingdom; however, the present research suggests resin use may have been less prevalent than previously believed prior to the Late Period. Furthermore, only two (AMSC 8 and AMSC 23) of the five Late Period mummies contained resin in the cranial vault, suggesting some degree of variation even within the Late Period. Both individuals (AMSC 6 and AMSC 27) with partial excerebration also lacked vault resin. AMSC 6 is an anonymous female from the Third Intermediate, while AMSC 27 is an Akhmimic mummy from the Late Period. The temporal period for both of these mummies make them consistent with the lack of resin in the other pre-Late Period mummies and in the case of AMSC 27, with the variation found within the Late Period mummies. Each individual that had linen tampons or wadding, lacked resin over the face and nasal area. This may suggest that the embalmers believed that resin was unnecessary to seal the excerebration route when linen was used. The lack of facial resin in individuals that were potentially excerebrated transforaminally lends further evidence in favor of this conclusion.

According to Herodotus, the removal of the brain was only included in the first and most expensive embalming method (Book II.86). The latter two methods refer only to the evisceration process, which was a less invasive process than described in the first method (Book II.87&88). The brains of both AMSC 16 and AMSC 30 were fully intact. AMSC 16 is an anonymous male from Thebes, dating to the late Ptolemaic Period, while Padihershef (AMSC 30) dates to the Third Intermediate Period. Both individuals are not of higher status (AMSC 16: lower status, AMSC 30: middle status) which, if adhering to the methods and expense levels delineated by Herodotus, explains why the brain was left in place. The organs also remain in place in AMSC 16 and no signs of evisceration or breach of the body cavity were encountered. On the other hand, AMSC 30 was fully eviscerated *per ano* rather than through a flank incision. This individual may have been prepared in accordance with the second, or mid-range expense, method described by Herodotus: whereby "having filled their syringes with oil which is got from cedar-wood, with this they forthwith fill the belly of the corpse, and this they do without having either cut it open or taken out the bowels, but they inject the oil by the breech [buttocks]…on the last of the days they let the cedar oil come out from the belly, which they before put in; and it has such power that it brings out with it the bowels and interior organs of the body dissolved" (Book II.87).

These two non-excerebrated individuals (AMSC 16 and AMSC 30) lend varying degrees of support to Herodotus' account, however, the lack of evisceration in AMSC 16 cannot be explained by Herodotus' description of embalming. Furthermore, the excerebration hook identified in AMSC 7 has a low attenuation value and therefore, cannot be a "crooked piece of iron" as described by Herodotus (Book II.86). Padiheru (AMSC 7) is a Ptolemaic mummy, thereby postdating Herodotus. It may be possible that non-metallic tools were also used to remove the brain, which may further indicate the ease with which the brain could be removed from the cranial vault. The presence of an excerebration tool in AMSC 7 that was non-metallic can also not be accounted for in Herodotus' narrative, nor can the presence of reeds or sediment in the vaults of AMSC 27 and AMSC 29, respectively. Therefore, based on findings in this sample, the methods described by Herodotus are too simplistic to be used as a veritable account of ancient Egyptian embalming. Rather, *The Histories* should be used in conjunction with modern scientific inquiry to fully understand ancient mummification practices.

5.4.1.2 Evisceration: Findings from this research mostly correspond with the literature. Specifically, all but one individual (AMSC 16) with post-crania were eviscerated and the flank incision, described early on by Herodotus, was the most prevalent preparation method in this sample. While the left abdomen route was most common, other variants such as axial and *per ano* evisceration were also documented and indicate variation among embalmers. In this sample, the individuals whose route of evisceration was other than through the left flank, dated to the Late Period and Graeco-Roman Periods. Greater variation in embalming practices may have occurred during these period of Egyptian history; however, trends cannot be definitively identified solely based on two individuals that deviate from the norm.

All mummies in this sample that are not disseverated post-date the 21st Dynasty, the period when visceral packets replaced canopic jars; therefore, it was expected that most, if not all, would contain packets. This was the case for all but AMSC 8, 11, and 30. Interestingly two of these individuals (AMSC 8 and AMSC 11) date to either the Late Period (26th Dynasty) or the Ptolemaic Period, which corresponds to assertions by Ikram and Dodson (1998) that deviation from the use of visceral packets did sometimes occur during these two specific periods. In the disseverated mummies, with the exception of AMSC 8, the lack of visceral packets in each may be a result of postmortem manipulation rather than intentional omission during the embalming process. Also in accordance with the prevailing Egyptian belief system, is the high retention of cardiac tissue, despite the removal of the viscera and the use of packets to represent the four sons of Horus. Overall, the patterns of tissue removal/retention found within this sample follow known Egyptian cultural prescriptions.

5.4.1.3 Materials Used: Although extensive within the context of a mummy, in a strictly spatial sense, resin deposits were often not very large entities. Opacity levels varied within a single deposit and between individuals. The wide range of values found in this sample for the density of resin suggest that no single reading suffices as a signature to describe the true characteristics of the resin. Gostner and colleagues (2013:1007) correctly state that "the HU value alone is therefore not ever sufficient to unequivocally identify the material composition of a foreign object with certainty, but can considerably narrow down the list of possible substances." In this sample, resins of a very homogenous nature were encountered as were ones of a very heterogeneous nature. Homogeneity may be the result of viscosity factors and dilution based on how the material was originally mixed and then subsequently poured. Certain deposits are not homogenous and this lack of homogeneity is part of a resin deposit's visible signature. In the heterogeneous resin deposits, stratification of layers likely indicate multiple pours into the vault. Complexities of a single resin deposit cannot be accounted for with a single HU value and may be misleading as to the true nature of the deposit. Therefore, it is recommended that a range should be presented with an average and deviation from the mean (+/-) as opposed to a single HU number to adequately describe and interpret the material. Furthermore, the kVP and CT scanner manufacturer should also be noted because of the dependency of HU values on these parameters.

Cranial vault resin was not significantly correlated with status, while the presence of thoracic resin was significantly correlated with individuals of middle or higher status. These findings may suggest that the use of resin in the cranial vault may have been more ubiquitous than use resin elsewhere. Furthermore, deposits within the thorax are often larger than those in the vault and therefore likely reflects the greater expense of incorporating resin in the thoracic cavity.

5.4.1.4 Body Positioning: Findings from this research indicate that certain aspects of body positioning were more variable than others.

5.4.1.4.1 Articulation: The current research reveals that disseverated bodies are evident among mummies of the First Intermediate, Third Intermediate, Saite, and Late Periods. Disseveration spans a far greater temporal range than just the Old Kingdom, as indicated by the mummies originally described as disseverated by Petrie (1897). Because of this temporal range, disseveration is likely not a formative phase leading towards classic mummification during that time. It is also clear that treatment was not limited to one geographic area, one particular sex, or one particular age range in this sample. Interestingly, while the disarticulation associated with disseveration is thought to be caused by taphonomic processes resulting from reduced care and concern, what we find instead is that disseveration is an alternative approach to body disposal having its own cultural significance. It is worth assessing the practice in its own right and not as a mode inferior to a perceived ideal.

Suggesting that Egyptians allowed any decomposition to occur seems very "un-Egyptian" and seems to go against their own funerary literature and their wish for eternal preservation, so perhaps disseveration as a process has been misinterpreted. In some cases, decomposition prior to mortuary preparation occurred, sometimes with a bone or two missing or desiccation of soft tissue structures like the ears and nose that resulted in prosthetics. However, what we are seeing in many of these disseverated cases is clearly different in extent and pattern. In the mummy of Ta'an (AMSC 23), for example, the entire thoracic cavity is disarticulated and jumbled, but the limbs are in precise anatomical order. If decomposition was significant enough to disarticulate the thorax, the same level of decomposition might be expected to occur in the appendages, but the joint areas are unaltered and even the small bones of the hands are completely intact. We see a similar pattern in the First Intermediate Period mummy of Tjeby (AMSC 29) as well. This individual was of high status and likely suggests that disseveration was not a haphazard or careless activity. Disseveration should be properly seen as a time-honored approach to handling the body.

Based on what we are seeing with this sample, we offer a new definition of disseveration, as the deliberate treatment in which skeletal elements of the body are separated and sometimes repositioned, necessarily resulting in a certain amount of disarticulation which has historically led to the erroneous conclusion that these bodies have been taphonomically disturbed. Certain visual characteristics can be used to help identify a true disseverated body from a taphonomic disruption that resulted in disarticulation. First, the wrappings will be completely or nearly all intact indicating no external penetration to the bundle. Second, the limbs will generally be articulated, and often so will the accompanying joints. Thirdly, deliberate rearrangement of bone and signs of reassembling by a human agent may be encountered. The hallmark of these types of bodies seems to be the disarticulation of the thoracic and pelvic cavities, with no lateralization or settling of bones to one side or the other. Lastly the mandible may be slightly disarticulated, falling from the mandibular notches, or fully disarticulated and contained in the thoracic region of the bundle.

The Egyptian Book of the Dead, a New Kingdom funerary text, discusses the notions of avoiding decay and rot and the wish to preserve or keep the body intact for the afterlife. Deliberate disseveration of the body by embalmers during mummification seemingly goes contrary to their wishes to be preserved eternally intact. However, words spoken by one of the four sons of Horus, Qebehsenuef, specifically refers to assembling the bones and limbs of the body during mummification in Spell 151 of the Book of the Dead. It may be plausible that embalmers removed the limbs and emptied the thoracic cavities to prevent bloat and decay and then essentially put the body roughly back together, as a form of control over decomposition. While the religious texts certainly favor the classical mummy notion, none of the dissevered bodies encountered in this sample have suffered in the way that the funerary texts imply that the Egyptians were afraid. The main way in which embalmers are going about making sure the body is being kept together is just being defined differently. For the thorax to be taken apart, reassembled and put back in the body is still very Egyptian. With disseveration, the bodies are still preserved which is essentially the crux of what embalming was meant to achieve.

5.4.1.4.2 Flexure: All mummies with post-crania are in an extended position, remaining consistent with the literature that an extended posture was introduced during the Old Kingdom with the advent of the mummification process. Strouhal (1992) suggests that an extended posture aided the process of evisceration. While this holds true for most of the individuals in the sample, AMSC 16 is not eviscerated, yet is positioned in an extended pose. AMSC 16 is a Theban mummy of the Ptolemaic period. The late date of this particular mummy may explain why the tradition of an extended posture was utilized despite not being eviscerated.

5.4.1.4.3 Arm Positioning: Results confirm Pettigrew's (1834) statement that the crossed arm position (variant five, Figure 7) is present in both males and females and is used indiscriminately. Historically, the crossed arm variant has been associated with elite mummies of royal status (Smith and Dawson 1924). Royal mummies of the New Kingdom period almost exclusively exhibit the crossed arm variant, likely contributing to the erroneous perception of variant five being reserved for elite individuals only. Higher status individuals in this sample were more like to exhibit position five, yet this position was found also in individuals of middle status and therefore, cannot be used alone as a determinate of royal and/or high status. Most of the mummies within the sample date to the Late and Graeco-Roman Periods. Perhaps what we are seeing is an extension of body treatment patterns of the elite (from the New Kingdom) into other segments of society during later periods in Egyptian history (Elias et al. 2014).

5.4.1.4.4 Head Position: The ahead position, as described by Sprague (2005) was much more prevalent than other head positions; however, both the backward extension and chin to chest positions were found in this sample. The high degree of variability in head position may suggest a more random process of positioning. Head arrangement may have been a conscious choice made by individual embalmers or may have been dictated by the natural desiccation of the remains. Comparative analysis is hampered because no studies to date have examined head position in Egyptian mummies and in studies which present this component of body positioning, terminology is not standardized and can be difficult to interpret.

5.4.1.5 Wrapping Patterns: The wrapping patterns associated with the crossed arm variant were likely developed to keep the arms properly positioned during the wrapping process. Only one mummy (AMSC 13) had the corded variant found in individuals with crossed arms. This pattern may have been more prevalent in the past despite the low frequency of occurrence in this sample. Furthermore, the tying of the arms is most likely not restricted to individuals of the crossed arm variant only. The Bristol mummy presented by El-Mahdy (1989) clearly shows the forearms of the mummy tied together within the mummy bundle. In this individual, the arms are extended along the thighs and not crossed. It appears that tying was accomplished with linen rather than the cording encountered in AMSC 13. The significance and uniqueness of this feature were not elaborated upon by El-Mahdy (1989). While tying has been discovered in

Egyptian mummies, the reasoning behind its sporadic use are not currently well understood.

Orientation and position of the mummy's body must be noted prior to discussion of the wrapping style because bandaging method is contingent upon the positioning of the body. Ancient Egyptian embalmers appeared to have a strategy or predefined method of body positioning and wrapping pattern prior to the onset of preparing the bundle. This research refutes Pettigrew's (1834) conclusion that the body was first positioned, then wrapped, then placed within the coffin. With the use of CT, it appears that a plan was employed (i.e. embalmers knew at the onset of preparation how the arms would be positioned); however, they were placed in position during the wrapping process itself. We see this with the variations in wrapping styles found within this sample, specifically in reference to how the arms were arranged. Furthermore, the literature on wrapping patterns to date may be too simplistic to cover the full range of variation (e.g. Ikram and Dodson 1998).

5.5 Conclusions

Ancient Egyptian mummification and embalming were not practiced haphazardly. Clear trends have emerged for some components of the process, while others seem much more variable, which may be a result of temporal or spatial deviations. Given that Egyptian texts on this subject matter are scant or altogether lacking, the historic texts of Herodotus and Diodorus Siculus give us a basic understanding of the embalming process; however, the current research has shown these writings to be very basic in their descriptions of the ancient practices of embalming and mummification. Furthermore, the latter two methods described by Herodotus are frequently ignored as variants to what we consider traditional or classic mummies, yet these alternative techniques may explain some of the variation found within this sample.

An analysis of embalming practices in this sample both support and challenge conventional wisdom. Specifically, the results concerning the relationship of arm position to status, the disarticulation of the body as a taphonomic process, and the manner in which the body was positioned and wrapped refute unsubstantiated dogma within the field. Conversely, several aspects of the process discovered in this sample are consistent with historic and current literature, including: predominance of transnasal excerebration, the onset of resin usage, evisceration via the left flank, and the high incidence of four visceral packets within the body cavity. It remains clear from the current research that specific aspects of the embalming process, such as excerebration and evisceration, appear to be better understood than other facets of the process, such as body positioning and wrapping.

Chapter 6: Population Affinity

6.1 Literature Review

Physical anthropologists have long been concerned with human population biology in order to better understand settlement patterns, evolutionary trends, population diversity, and overall human variation. Both geographical and biological distance measures have been employed to assess relatedness in groups and have been specifically applied to studies of ancient Egyptians. Historically, the population biology of Egyptians has been of central importance to anthropological investigations and continues to be so today. Several questions concerning the peopling of Egypt and the changing biological diversity of these people through time have been explored using available skeletal material and mummified remains. To date, genetic markers, cranial and dental nonmetric traits, and craniometrics research have been conducted in an attempt to accurately describe the population biology of ancient Egyptians.

6.1.1 Population Biology

Within the physical anthropology literature, population biology, often also known as population affinity, refers to the phylogenetic relationships between human populations, specifically from skeletal morphology (though this can be augmented with molecular evidence). Population affinity is highly researched because of the theoretical implications for studying human origins or evolution, migration patterns, peopling events, and population interactions. Affinity is assessed to determine within and between group similarities and differences and also to document human biological variation present worldwide. The diversity of any given population is based on the complex interaction of genes, genetic forces, selection, and the environment.

The “similarity or dissimilarity between populations is indicative of degrees of biological affinity” and can be assessed in a number of ways (Keita 1993:131). Geographical and biological distances are two measures used to study population affinities. Geographical distance, or spatial distance, refers to the proximity of populations based on geographic location. This distance is influenced by geographical boundaries that inhibit or promote gene flow and migration. Genetic restrictions and geographic boundaries between groups can be expected to influence phenotypic expressions of traits that will in turn differ between groups. Based on gene interactions and the effect of genes on the phenotype, populations that are in close geographic proximity to each other will be more similar than more distant and geographically dispersed populations. On the other hand biological distance, also referred to as biodistance, measures relatedness of groups based on a suite of traits. Distance between groups is assessed in terms of differences in mean trait frequencies or expressions (Howells 1973). Biological distance is calculated to “assess the effects of temporal and spatial distance on subpopulation divergence” (Konigsberg 1990:49). In skeletal biology, biodistance assesses the relatedness of populations, especially when genetic distance studies cannot be used, for example in past populations with badly degraded skeletal material (Buikstra et al. 1990). Konigsberg (1990) notes that a positive correlation exists between geographic distance and the observed biological distance between groups, whether assessing the phenotype or genotype. A number of methods and statistical applications have been developed to assess these differences among populations, as well as, to appreciate the interplay between the two measures when assessing human variation.

Within physical anthropology several methods have been used to assess population distance and relatedness. Studies of population affinities focus on the human genotype, through modes of inheritance, and also on the visible expression of those genes, or the phenotype. Therefore, these studies can be grouped into two broad classes: phenotypic variation and genotypic variation. The phenotype, or observable characteristics of a person, is influenced by both the genes carried by a person as well as by environmental factors. The study of population affinity by physical anthropologists has primarily focused on traits that are less impacted by environmental factors (Keita 1993); however, climatic variation has been documented as having an impact on skeletal morphology (Betti et al. 2008). As a result, many factors must be considered when assessing population affinity based on the phenotype, as is the case with morphological assessment of the crania and dentition. The assessment of population affinity is also complicated by a variety of factors including: sampling problems with the archaeological data, criteria chosen for analysis (e.g. metric versus non-metric parameters), forces of evolution (e.g. mating patterns, selection, gene flow, genetic drift, and migration), and the interplay between genes and environment (Hiernaux 1972).

6.1.2 Population Affinity of Ancient Egypt

Debate about the affinity of the ancient Egyptian population has focused historically on “questions of ancestry or with estimating the effects of gene flow and migration” (Schillaci et al. 2009:235). Egypt’s central location between Europe, the Middle East, and Africa, likely contributed to its genetic and biological diversity through “colonization or migration from all directions” (Keita 1993:129). Because of this, numerous studies have been conducted to analyze the genetic, morphological, and metric variation of this population in an attempt to answer who the ancient Egyptians were and from where they came. Skeletal and mummified remains have been studied extensively in an attempt to address several central issues regarding this population and its biological affinities. The results of the studies presented below vary considerably based on the material analyzed, method of analysis, and general conceptions about how biological affinity is to be interpreted (Batrawi 1946).

During the Dynastic Period, two disparate regions, Upper and Lower Egypt, became unified into a single, complex, politically stratified society. Two hypotheses have been suggested for the development of the Dynastic Period political structure and culture in ancient Egypt: the first suggests immigration or population replacement from foreign groups. This long held belief, hypothesized early by Petrie (1932) and later supported by Emery (1961) (as found in Smith 2003), suggests that a "dynastic race" migrating from either the north or east was responsible for the rise of a civilized state in Egypt. The second hypothesis suggests that the structure of Dynastic Egypt resulted from a Predynastic indigenous development (Irish 2006). This debate ultimately focuses on whether a foreign culture or an indigenous group is responsible for the rise of civilization in Egypt. When assessing population biology based on human remains, Schillaci et al. (2009) note that diversity and increased variation would be expected during the Dynastic Period to support the first hypothesis. Conversely, homogeneity of populations, both temporally and geographically, would be expected to support the second hypothesis. To date most recent skeletal research using biodistance measures supports population stability in ancient Egypt and suggests little influence of foreign populations during the Dynastic Period (e.g. Irish 2006).

Secondly, there remains discourse as to whether Upper Egyptian groups share a population history with the Lower Egyptian groups or if each area shares a more similar population biology with another non-Egyptian group than with each other. Greene (1981) notes a prevalent North-South phenotypic cline in the modern Egyptian population, specifically in cranial form and skin color. Because of these noticeable differences, Upper and Lower Egyptian groups have been investigated using both geographical and biodistance measures to explore the affinity between the two areas. The hypothesis of distinct variation between the two geographic groups has historically been the perspective held of Egyptian populations. Lower Egyptian groups have tended to pool more with European and Mediterranean groups, while Upper Egyptians are biologically more similar to southern African groups (Morton 1844 as found in Keita 1993, Howells 1973, Hillson 1978, Kieta 1990). The geographic proximity of Lower Egyptians to the Mediterranean Sea and of Upper Egyptians to Nubia likely explains the phenotypic and genotypic differences between the two areas. Using human remains, the degree of variation within each population group has been explored to assess population affinity and the results have varied considerably by the methodology employed.

6.1.2.1 Genetic Studies: A number of genetic factors influence the biological affinity of individuals and population groups. These factors include the rate of mutations, population size, migration rates, and the intensity of selection acting on those groups (Konigsberg 1990). Other factors that influence biological inheritance and affinity include genetic drift and gene flow. Early investigations into the relationship between world populations began with genetic data, most notably the ABO blood group system. Additional developments in population genetics have expanded the study of affinity from simple inherited traits to more complex genetic markers. Most recently polymorphisms have been applied to genetic studies of population affinity and to exploring the relationships between groups. The identification of many polymorphisms within the last few decades led to a rapid increase in genetic studies concerning these variants. One major concern or limitation with genetic studies overall when attempting to assess population affinity or relatedness between groups is that “the extent of the genetic variability in the population as a whole” must be known when assessing individuals within the population (Brown and Brown 1994:722).

Extracting aDNA from preserved mummified tissue is sometimes easier than collecting it from skeletonized remains; therefore, this method of inquiry is especially valuable for mummy studies (Brown and Brown 1994). Studies of variation between and among Egyptian populations have namely focused on autosomal differences in aDNA and mitochondrial DNA (mtDNA). Blood group analyses have been used to study kinship relations where familial relationships were suspected. Broader population diversity studies have also been conducted using the ABO blood system. Analysis of blood groups in living Egyptian populations by Batrawi in 1946, showed that the entire population is relatively homogenous and likely reflects stability of the population through time. More complex molecular studies infer that portions of the modern day Egyptian population from the Nile Valley share a mtDNA lineage with Sub-Saharan Africans (Pääbo and Di Renzo 1993). From these data, two different phylogenetic relationships become apparent. In the first, two Egyptian branches emerged independently from an African ancestor. In the second, two Egyptian branches emerged which were more closely related to each other than to the Sub-Saharan lineage. The later phylogeny suggests one migration into the Nile Valley region prior to splitting. Analysis of the H*pa*I polymorphism and the first hypervariable segment of mtDNA by Krings et al. (1999) support the second hypothesis. In their study, the Upper and Lower Egyptian samples show low levels of divergence from one another suggesting "bidirectional" migrations along the Nile River Valley and a single migration event (Krings et al. 1999:1166). The aforementioned studies support the notion that Egyptian populations are closely related to one another and likely shared a population history resulting in genetic homogeneity.

Genetic forms of classification were cited by some scientists as being superior to skeletal assessments (Boyd 1950). However, this statement has later been argued because more recent studies have demonstrated the comparability of skeletal studies to genetic studies (Mielke et al. 2006). Relethford (1994:55) notes that "the degree of differentiation is essentially the same in both genetic markers and cranio-metric traits… [and] average worldwide craniometric variation may primarily reflect a balance between gene flow and genetic drift." Therefore, skeletal assessment can contribute as much or more evidence concerning population diversity as the genetic evidence.

6.1.2.2 Nonmetric Studies: Qualitative skeletal traits "provide useful data for insight unto processes of assortative mating, levels of interbreeding, gene flow, drift, and population dissimilarity" and to this, one could add population similarity because traits are genetically controlled (Keita 1993, Tyrrell 2000:289). Greene (1981) suggests that the inductive approach to constructing the biological affinity of the Nile Valley should be used rather than the typological deductive approach which assumes differences are present. With the inductive approach, comparisons are made between groups to establish whether population diversity exists and to what degree it is present in the groups being studied (Greene 1981). Both cranial and dental nonmetric traits are frequently assessed for population affinity between and among Egyptian groups using the inductive approached outlined by Greene.

Initial measures of studying biological distance relied on frequency counts of qualitative traits to investigate population affinity (Edgar 2002). Skeletal nonmetric traits occur in all populations just with varying frequencies, thereby making them useful for assessing biological diversity. Trait presence or absence is calculated and frequency rates are compared among and between populations to evaluate degree of relatedness. Frequency maps, known as isoincidence lines, of nonmetric skeletal traits have been plotted similar to those created for blood groups (Berry and Berry 1972). Multivariate analysis of these same skeletal variants offers a more robust statistical method than single trait frequency comparisons in the populations being studied. The use of nonmetric traits for the exploration of population diversity is not without limitations. Issues with using nonmetric variants include the correlation of traits to sex and age, asymmetrical expression of traits, correlation of variants to one another, and initial trait selection all of which should be recognized in qualitative studies (Tyrrell 2000).

Dental morphology and trait variation between groups is presumed to reflect genetic differences and is therefore useful for the study of biological diversity within and between groups (Scott and Turner 1997). Populations "show considerable diversity in these dental features because of the differences in selective forces … that have been operating in each group" (Molnar 2002:194). Because of the high survivability of teeth in archaeologically derived samples, the assessment of dental nonmetric traits remains a heavily studied field for assessing the population affinity of ancient Egyptians. Based on the analysis of dental nonmetric traits in 15 Egyptian sample groups, ranging from the

Neolithic up to Roman Times, Irish (2006) noted relative population continuity throughout Egyptian history. Schillaci et al. (2009) found similar results using a combination of craniodental nonmetric traits, including tooth groove patterns, enamel extensions, variation in root number and formations, cusp differences, and congenital malformations. Despite the relative homogeneity through time, Schillaci et al. (2009) found the Dynastic Lower Egyptian samples to be more physically diverse than the Upper Egyptian samples, which may suggest greater levels of in-migrations in this population. These arguments ultimately focus on variation within Egyptian groups themselves and whether Egyptian populations are more similar to European, Mediterranean, or African populations. Furthermore, homogeneity through time supports the hypothesis that a foreign dynastic race was not responsible for the rise of a civilized state in ancient Egypt.

Skeletal nonmetric studies have been used less frequently to assess ancient Egyptian population affinity and have focused solely on the crania. Berry and Berry (1967) assessed 30 non-dental cranial nonmetrics, including accessory foramina, metopism, and ossicles, in 13 populations: six of these were Egyptian groups dating from 4000 BC to AD 200. The authors compared the Egyptian samples to one another, as well as to the other seven populations and concluded that the stability of nonmetric traits analyzed through time indicate that an "Egyptian stock" was maintained despite population immigrations (Berry and Berry 1967:376, author's quotations). Additionally, the Egyptian samples were found to be more closely related to each other than to the surrounding populations, further attesting to the persistence of an Egyptian affinity unique to ancient Egypt.

In summary, nonmetric variants have shown relative homogeneity between Upper and Lower Egyptian groups, especially when compared to populations outside of Egypt. These findings suggest similar population history between the two areas. The Lower Egyptian samples have tended to show more variation than the Upper Egyptian samples in nonmetric trait frequencies suggesting greater admixture and gene flow in these groups. Despite this, the two populations are still more similar to each other than to other population groups within the studies discussed above.

6.1.2.3 Craniometric Studies: Craniometrics are measures of the crania designed to capture the form (i.e. shape and size) for quantification and subsequent analyses (McKeown and Jantz 2005). Craniometry was one of the first attempts to quantitatively assess population affinity in human skeletal material and has been frequently applied to physical anthropological investigations to examine evolutionary relatedness among populations of people (Hubbe and Neves 2007). Several studies within physical anthropology have demonstrated the applicability of craniometrics to the study of population distances (e.g. Howells 1973, Relethford 1994). The degree of relatedness is assessed through calculation of geographical and biological distance from a common ancestor or from other populations. The skull is a good source of this information because cranial form is highly influenced by genetics (McKeown and Jantz 2005). Non-genetic contributions to cranial form include climate, environment, and diet or nutrition (Mays 2000); however, today, anthropologists generally agree that genetic factors greatly contribute to the observed variation found in craniofacial morphology and play a larger role than environmental influences (Devor 1987, McKeown and Jantz 2005). Craniometrics continue to be employed for studies of human variation because the skull shows a high degree of stability (Jantz and Owsley 2001). In a summary of several studies, Sholts et al. (2011:335) notes that population histories have a significant impact on "cranial morphology of different groups, even though the evolutionary causes of this variation remains under debate."

Statistical analyses of cranial measurements have long been motivated "by questions concerning patterns or variation, association, causation, and inheritance in human populations" (Slice 2007:266). Measures of distance between populations, groups, or individuals were introduced to assess these questions. Once distance was defined, distance coefficients were calculated for analyses. The three most frequently used distance coefficients used to assess population affinity with quantitative measures of the skull are the Czeckanowski DD measure, Pearson's Coefficient of Racial Likeness, and Mahalanobis D^2 (Grower 1972). Today, Mahalanobis D^2 is the most popular measure of population affinity and was suggested by Hiernaux (1972) as the best measure of distance for metric data. The primary benefit of Mahalanobis D^2 is that this measure takes into account the correlation between traits being analyzed in the discriminant function analysis. Other measures of similarity have also been used as opposed to distance measures and include hierarchal analysis and clustering methods. A review of the literature to date, reveals that most recent studies of ancient Egyptian crania have employed Mahalanobis D^2 when assessing population affinity and group relatedness (e.g. Zakrzewski 2007, Sanders et al. 2014).

Strouhal (1969) notes that ancient Egypt and nearby Nubia have been the most intensively researched areas of the world by anthropological investigations. As discussed earlier, the historic view suggests that Lower and Upper Egyptian groups are unique and share different population histories. Nile Delta populations are believed to be morphologically similar to Mediterranean, Asian, Middle Eastern and European groups, while the Upper Egyptian populations are believed to bear greater similarity to Sudanese and South African groups (Ruggeri 1922). This long-held belief has been exemplified by early craniometric studies (Morant 1925, Woo 1930, Risdon 1939, Crichton 1966). Most of these early investigations used univariate measurements or indices to arrive at their conclusions. Cranial measurements used to differentiate whether Egyptian populations appear more “Caucasoid,” influenced by northern groups, or “Negroid,” influenced by southern groups, include the nasal aperture width and measures of prognathism and frontal prominence (Greene 1981). Based on more robust multivariate analyses of craniometrics, Billy (1977) supports the above hypothesis. Conversely, using simple frequency distributions of single measurements, a degree of homogeneity between Upper and Lower Egyptian samples were found by Wiercinski (1973). Berry and Berry (1972) also found Egyptian samples from differing regions and periods to be more similar to each other than to population groups outside of Egypt. More recent research has confirmed the morphological similarity between Egyptian samples using craniometrics when compared to outside populations (e.g. Prowse and Lovell 1996, Zakrzewski 2007).

In a review of craniometric studies of ancient Egyptians, Brace and colleagues (1993) conclude that through time Egyptians had biological ties with groups to the south, north, east and west. Thereby, “Egypt was basically Egyptian from the Neolithic right on up to historic times” (Brace et al. 1993:25). Craniometric research echoes the sentiment that the population biology of Egyptians is unique to them specifically and though they shared genetic input from neighboring groups either by invasions or migrations, they remained distinct as a population through time (van Gerven 1982, Kieta 1990). Most recent craniometric studies using multivariate analysis of cranial measurements confirm this conclusion, as well (e.g. Zakrzewski 2007, Sanders et al. 2014).

In summary, discord exists between these studies in the degree of variation within the Egyptian samples themselves and their relationship to populations outside of Egypt. A number of studies using craniometrics found distinct clinal differences between Upper and Lower Egyptian samples (Hillson 1978, Keita 1992), yet others found no distinct spatial differences between groups (Zakrzewski 2007). These opposing conclusions may be an artifact of the samples utilized and the specific measurements employed. One should note, however, that the more current literature suggests heterogeneity and diversity within Upper and Lower Egyptian samples, but when compared to one another and to groups outside of Egypt, they are rather homogenous as a population through time and space. Future research with more temporal and regional samples and methodology standardization may potentially be useful to answer the questions surrounding Egyptian biological diversity in the future.

6.2 Materials and Methods

For each mummy, the CT images were imported into MIMICS and converted to a new proprietary MIMICS project. The bones of the skull and neck were selected using the 'bone' threshold (226 to 3071 HUs) to create a new mask. Accessory bone was removed slice-by-slice by manually highlighting and removing unwanted osseous areas in 2D. In some cases, preparation materials such as resin and cartonnage had to be removed as the density of these objects sometimes fell within the 'bone' range. Next, the mask was edited in 3D to remove the final areas of unwanted bone. Finally, a 3D mask was generated from the original, edited mask.

For the current research, assessment of population affinity was restricted to craniometric analyses only. Sixteen cranial measurements were selected using 15 landmarks based on those that are traditionally used in craniometric studies, as presented by Moore-Jansen et al. (1994), and that were also collected by Howells (1973) (Figure 22) (Table 10 and Table 11). Measurements were taken on the 3DCT mask for each individual. The Howells' Craniometric Data Bank consists of cranial measurements from both sexes in 28 worldwide populations (Table 12). For each individual a minimum of 57 measurements were recorded (Howells 1996). The database includes an Egyptian

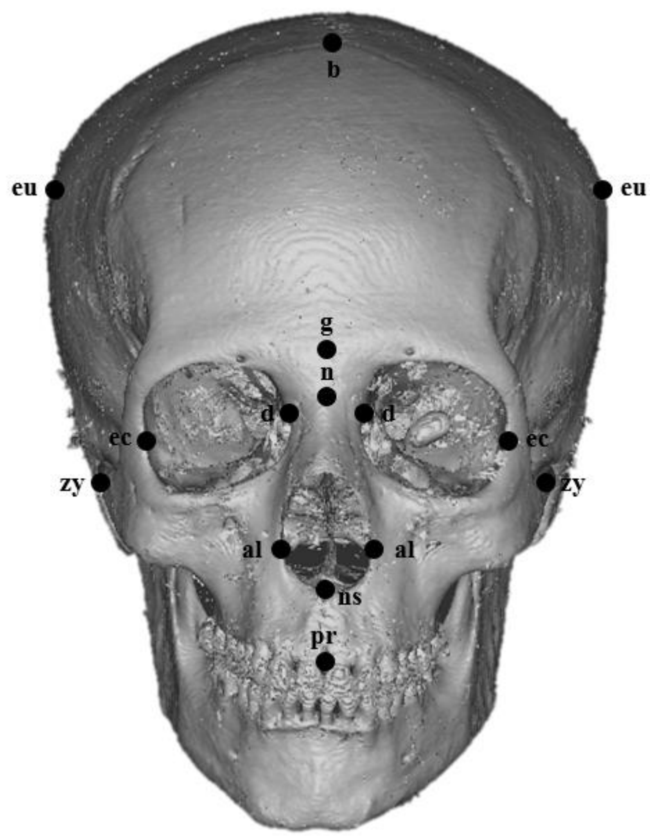


Figure 22. Anterior skull view showing the landmarks used in this study for measurements. Not included: auriculare, basion, lambda, opisthion, and opisthocranion.

Table 10. Selected craniometric landmarks from Moore-Jansen et al. (1994).

Abbreviation	Landmark
al	Alare
au	Auriculare
b	Bregma
ba	Basion
d	Dacyron
ec	Ectoconchion
eu	Euryon
g	Glabella
l	Lambda
n	Nasion
ns	Nasospinale
o	Opisthion
op	Opisthocranion
pr	Prosthion
zy	Zygion

*Table 11. Craniometrics and the landmarks used for each measurement.**

Abbreviation	Measurement	Landmarks
AUB	Biauricular Breadth	au-au
BBH	Basion Bregma Height	ba-b
BNL	Cranial Base Length	ba-n
BPL	Basion Prosthion Length	ba-pr
DKB	Interorbital Breadth	d-d
EKB	Biorbital Breadth	ec-ec
FRC	Frontal Chord	n-b
GOL	Maximum Cranial Length	g-op
NLB	Nasal Breadth	al-al
NLH	Nasal Height	n-ns
OBB	Orbital Breadth	d-ec
OCC	Occipital Chord	l-o
PAC	Parietal Chord	b-l
UPH	Upper Facial Height	n-pr
XCB	Maximum Cranial Breadth	eu-eu
ZYB	Bizygomatic Breadth	zy-zy

* Measurements from Moore-Jansen *et al.* (1994) that are also used in the Howells Data Bank

Table 12. Populations included in the Howells' Craniometric Data Bank.

Name	**Abbreviation**	**Area**
Ainu	AIN	Hokkaido, Japan
Andaman Island	AND	Andaman Islands
Anyan	ANY	China
Arikara	ARI	South Dakota, USA
Atayal	ATA	Taiwan
Australia	AUS	Lower Murray River
Berg	BER	Austria
Buriat	BUR	Siberia, Russia
Bushman	BUS	South Africa
Dogon	DOG	Mali
Easter Island	EAS	Easter Island
Egypt	EGY	Gizah
Eskimo	ESK	Greenland
Guam	GUA	Guam
Hainan	HAI	China
Mokapu	MOL	Hawaii
Moriori	MOR	Chatham Islands
Norse	NOR	Oslo, Norway
North Japan	NJA	Hokkaido, Japan
Peru	PER	Peru
Phillipines	PHI	Philippines
Santa Cruz	SAN	California, USA
South Japan	SJA	Kyushu, Japan
Tasmania	TAS	Tasmania
Teita	TEI	Kenya
Tolai	TOL	New Britain
Zalavar	ZAL	Hungary
Zulu	ZUL	South Africa

population from Gizeh, near the modern day city of Cairo. The Egyptians in this sample date from the Late Period (26^{th} to 13^{th} Dynasty; 660 to 340 BC). Geographically, the Zalavar (Medieval Hungary), Berg (Carinthia, Austria), Dogon (Mali), Teita (Kenya), and Norse (Medieval Oslo) samples are the closest (in order of proximity) to the Egyptian sample. Generally, the Howell's Egyptian sample has been treated as craniometrically representative of ancient Egyptians; however, "historical evidence suggests the series represents people who had strong ties to Ancient Greece" (Sanders et al. 2014:1). A recent study by Sanders and colleagues suggest that the Howells' Egyptian sample was similar to the other late dynastic samples to which they compared the Howells' data set; however, their sample was also found to be similar to Classic Greek samples.

For each individual, these measurements were entered in FORDISC 3.0 to be classified into population group using the Howells' Craniometric Data Bank (Jantz and Ousley 2005). The program FORDISC is frequently used to estimate biological profile parameters in modern forensic cases for unknown individuals and it is also used in bioarchaeology to examine geographical descent. It is a program that uses statistical methods to classify an unknown individual, using skeletal measurements, into one of the known ancestral populations (divided by sex) included in either the modern Forensic Data Bank or in the historic/prehistoric Howells Craniometric Data Bank. The unknown individual is compared to the skeletal measurements for the known populations in the database and then grouped into that population to which it is most similar. For this research, affinity was assessed using discriminant function analysis (DFA) which was performed using leave-one-out cross validation and a forward Wilks' lambda stepwise selection of the cranial measurements in FORDISC 3.0. The program uses Mahalanobis Distance to convert the measurements into linear discriminant function scores which are then used to compare the unknown individual to the mean scores of each reference sample (Jantz and Ousley 2005). In the initial analysis, each individual was compared to all 28 populations contained with the Howells' data set. The classification matrix, posterior probabilities, and typicality probabilities were evaluated to reduce the number of potential population groups into which the unknown individual could be classified prior to a second analysis. The classification matrix represents the degree to which the known reference sample individuals correctly classified using the given measurements and the posterior probability evaluates "the probability that the unknown individual comes from each reference group under the assumption that the unknown actually does belong to one of the groups in the function" (Tatsuoka 1971, Jantz and Ousley 2005:12). Any group with a typicality probability less than 0.05 (i.e. highly dissimilar to the unknown individual) was removed for the second analysis. In the second analysis, the unknown individual was compared and classified into those groups from the original analysis that had typicality probabilities ≤ 0.05. In most cases, the second analysis reduced possible group membership to three to seven (with the exception of AMSC 29). For each classification, the number of variables used in the analysis, group classification, posterior probability, and typicality probabilities were recorded. FORDISC presents multiple typicality probabilities, but only the R-Typicality (Typ R) is presented for the current research because the typicality presented in Typ R includes the rank of the unknown and has fewer statistical assumptions than the other two typicalities (Jantz and Ousley 2005). Next, cluster analysis was conducted in PAST (Hammer et al. 2001) to explore the similarity or dissimilarities between the Howells' Egyptians and the individuals from this sample. The unweighted pair-group average algorithm, which forms clusters "based on the average distance between all members in the two groups," and Mahalanobis Distance were used for computation (Hammer et al. 2009:30).

It should be noted that three individuals (AMSC 12, 17, 20) clearly had signs of biparietal dystrophy which could potentially have skewed some measurements, especially those of the vault. The remaining individuals did not show outward signs of cranial pathologies that would impact the craniometric results. Furthermore, variation in scanning protocols for individuals within the sample prevented the collection of all measurements in some individuals. Common problems included segmentation of the cranium into multiple files and increased slice thickness which skewed specific landmarks. Additional landmarks in the nasal region could not be collected in several mummies because heavy resination of the region made it virtually impossible to differentiate bone from resinated tissue based on the Hounsfield Unit density properties.

6.3 Results

When classified into the Howells' Craniometric Data Bank using discriminant function analysis, seven individuals classified as either an Egyptian male or female (Table 13) (see Appendix 4 for the FORDISC 3.0 classification scatterplots and/or graphs). Each of these individuals date to the Late Period (AMSC 8 and AMSC 23) or the Graeco-Roman Period (AMSC 2, 4, 11, 12, 13). Only AMSC 11 and 23 were highly typical of the representative Egyptian population in the database. The remaining individuals were classified as Egyptian, but had low typicalities, and were closely grouped with the Hungarian, Norwegian and the Asian (Chinese and Japanese populations) groups. Another three individuals classified into one of the remaining African populations, either the Dogon of Mali or the Zulu of South Africa (Table 13); two of these individuals (AMSC 6, 9) were highly atypical, while AMSC 19 was highly

Table 13. Group classification based on linear discriminant function analysis.

AMSC #	# Variables	CV % Correct	Populations*	Posterior Probability	R Typicality	
1	6	59.8	AINF, EASF, GUAF, NJAF, **ZALF**	0.48	0.543	(21/26)
2	3	91.9	**EGYF**, EGYM	0.556	0.111	(48/54)
3	3	51.6	HAIF, **NJAF**, SJAF, ZULF	0.447	0.727	(9/33)
4	6	71.1	**EGYF**, EGYM, HAIF, SJAF	0.476	0	(54/54)
5	6	54.4	ANYM, ATAM, **GUAF**, PHIM	0.365	0.321	(19/28)
6	9	65.7	AINF, **DOGF**, NJAF, SJAF, TASF, ZULF	0.486	0.113	(47/53)
7	6	57.3	ANYF, GUAF, HAIM, **SJAF**	0.463	0.765	(12/15)
8	7	67.3	**EGYM**, MORM, NORM, ZALM	0.647	0.119	(52/59)
9	5	70.9	AINF, BUSM, DOGF, EGYF, **ZULF**	0.516	0.511	(23/47)
10	5	72.3	**AINF**, EGYM, ZALM, ZULF	0.551	0.538	(18/39)
11	5	77.4	**EGYM**, EGYF, ZALM	0.639	0.898	(6/59)
12	5	66.8	**EGYF,** EGYM, NORF, ZALF	0.83	0.296	(38/54)
13	8	73.2	**EGYF**, EGYM**,** AINF, ZALF	0.566	0.037	(52/54)
14	5	71.1	EGYM, AINM, **AINF**, ZALM	0.652	0.385	(24/39)
15	5	63	AINM, EGYM, **NJAM**, ZALM	0.515	0.25	(42/56)
16	8	79.4	**AINF**, AINM, ZALM, ZULM	0.705	0.333	(26/39
17	7	68.9	**AINF**, DOGF, DOGM, ZULF, ZULM	0.698	0.256	(29/39)
18	4	65.6	EGYM, **MORF**, MORM, NORM	0.332	0.192	(42/52)
19	9	70.9	AINF, TEIM, ZULF, **ZULM**	0.454	0.964	(2/56)
20	8	58.1	**AINF**, ANYM, HAIM, NJAF, NJAM, PERM, SJAF	0.726	0.077	(36/39)
23	4	81.5	**EGYF**, NORF	0.796	0.833	(9/54)
25	6	64	**AINF**, EGYF, NJAF, SJAF	0.508	0.051	(37/39)
27	7	70.3	EGYM, **ESKM**, NORM, ZALM	0.718	0.481	(28/54)
29	13	46	**MORM**, all groups	0.948	0	(58/58)
30	10	59.8	AINF, ANDM, EGYM, **MOKF**, NJAM, SJAM, ZALM	0.775	0.26	(37/50)

*Populations retained in the second analysis. The unknown individual was classified into the population group that is bolded, with M representing males and F representing females.

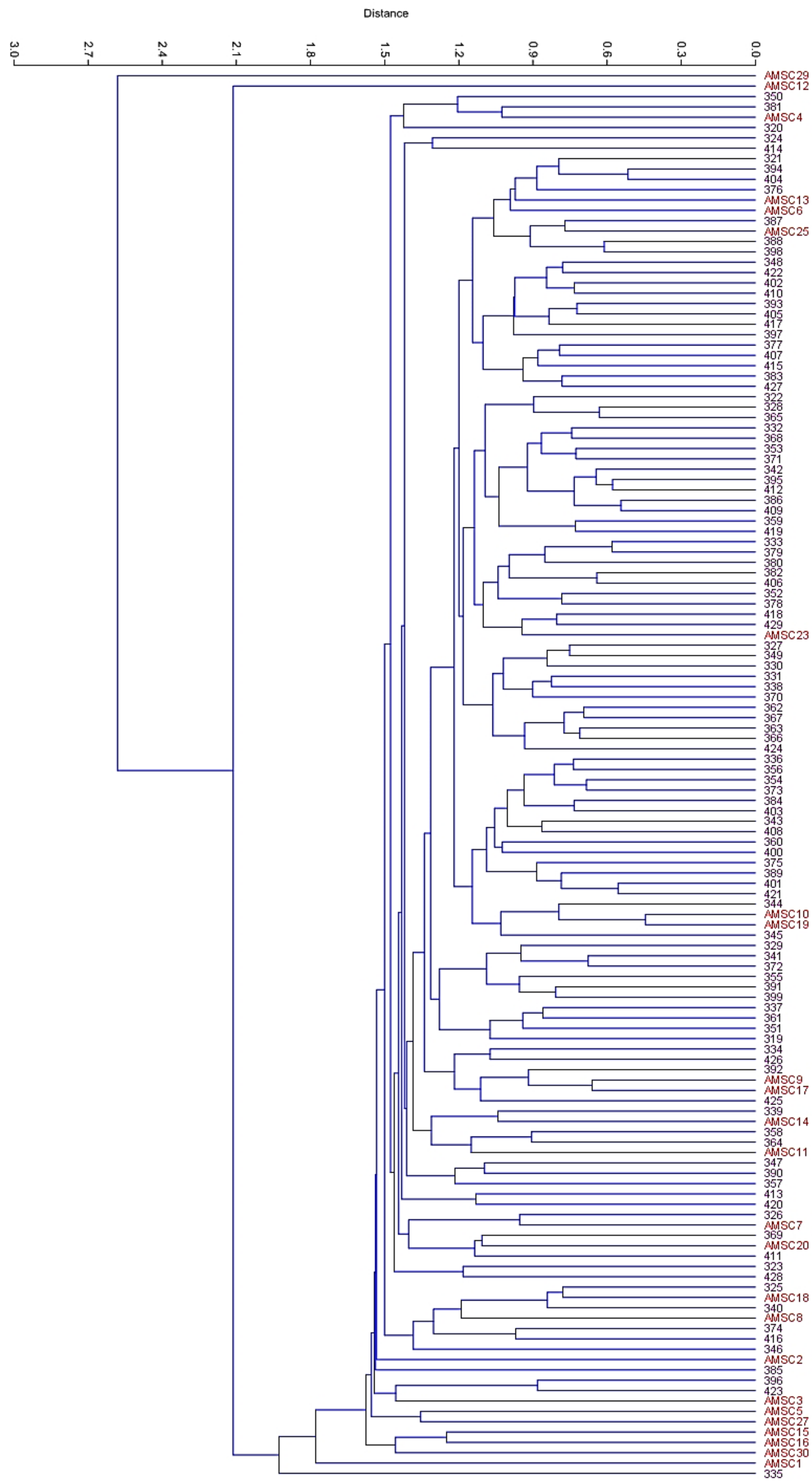
typical (Typ R = 0.964) of the Zulu. Nine individuals classified into one of the three Japanese populations (AIN, NJA, SJA). The remaining individuals classified in the populations from Guam, Hungary, Hawaii, Chatham Islands (n=2), and Greenland. Only 1/5th of the sample individuals were classified as highly typical (Typ R > 0.7) of the populations into which they were grouped (Table 13). Using cluster analysis, most individuals from this sample clustered with the Howells' Egyptians with the exception of AMSC 29 (Figure 23). One individual, AMSC 12, was grouped with the remaining individuals but was in a distinct cluster.

6.4 Discussion

Mummy studies provide tremendous amounts of information to the study of population diversity because of the high level of preservation of soft tissue, skeletal remains, and cultural material. Although this study was restricted to craniometric analyses alone, there are some benefits to this approach. Primarily, interpretations from metric measures and especially craniometrics are less subjective than the interpretation of cultural material. Furthermore, the evaluation of population diversity in ancient Egypt using craniometrics is well documented in the literature and the methodology is generally accepted within the field.

The computed tomography sample used for this research is unique to the study of ancient Egypt for three reasons: the sample is comparatively large by mummy research standards, most of the individuals originated from the same geographic region, and the sample contains individuals from similar temporal periods, some of which are related to one another (Elias and Lupton 2005). The study of this particular sample contributes

Figure 23. Cluster analysis dendogram showing the clustering of the Howells' Egyptians and the individuals within this sample. Generated in PAST version 2.17c (Hammer et al. 2001).



information specific to Akhmim and primarily the Ptolemaic period, but can also be used to increase our understanding of ancient Egyptian culture and population diversity. The continuous occupation of Akhmim throughout Egyptian history, the city's central location near Middle Egypt at an important bend in the Nile River, and the reputation of Akhmim as being highly cosmopolitan make this sample particularly useful for investigating the ancient Egyptian population. While there are some constraints to generalizing about Egypt as a whole based on the material from Akhmim, some of these problems can be overcome by recognizing the limitations of the conclusions drawn from this particular sample.

A high degree of heterogeneity in this sample is suggested by the fact that 25 individuals classified into 11 different populations. Most of the sample (n=17) dates to the Graeco-Roman Period (332 BC to 642 AD), specifically the Ptolemaic, and most of the individuals (n=20) are from Akhmim, or nearby Thebes. While the Howells' Craniometric Data Bank does contain an Egyptian sample, it is derived from the Late Period (664 to 343 BC) in Lower Egypt. Although potentially similar, the Howells' sample is not a truly appropriate classification reference sample, due to both the temporal and geographic disparity. With FORDISC, an individual will be forced into a category for classification regardless of the unknown individual's actual population affinity. The high cross-validated classification accuracies, but low typicalities for most of the individuals classified as Egyptian may speak to the temporal and spatial differences between individuals in this sample and those in the Howells' Craniometric Data Bank. In addition, most of the individuals in the sample (n=18) were classified into a group outside of Egypt. The low typicalities for virtually of all these individuals, suggest that although they were forcibly classified into a particular group, they are highly atypical and non-representative of that particular group into which they were grouped. Overall, these results suggest a high degree of variation in the sample, as well as, a complex population history, likely with influences from many regions.

The present sample dates to very late in the history of ancient Egypt; therefore, it was not possible to assess the “dynastic race” hypothesis with this particular group of mummies. The earliest mummy in the sample, AMSC 29 from the First Intermediate Period, did cluster completely separate from the rest of the sample and Howells’ Egyptian crania. A sample of one makes it difficult to draw conclusions concerning population change through time, yet it should be noted the earliest individual was craniometrically distinct from the later period individuals. The disparity of AMSC 29 from the rest of the sample used in the present research is more likely a result of a temporal distance rather than geographical distance because the individual is from Middle Egypt near to Akhmim. Comparison of this sample to a Predynastic or very early Dynastic groups in the future would facilitate a comparison and determine homogeneity or heterogeneity through time. This research is more informative regarding the second major debate on the similarity or dissimilarity between Upper and Lower Egypt, because Akhmim is situated between Upper and Lower Egypt. The Akhmim sample proved to be incredibly diverse with individuals classifying into many widespread populations. The variability found in this sample more closely resembles the high degree of diversity found in Lower Egyptian samples. As expected, the population with the highest individual membership was the Egyptian sample. Ten individuals grouped within African populations and nine grouped into Asian populations. Lower Egyptian samples have historically grouped with

European populations, while Upper Egyptian samples have grouped with African populations. Historic investigations as early as the late nineteenth century up to and including modern studies have largely ignored the possible similarities of the Egyptian people to Asian groups. The proximity of the Arabian Peninsula to Egypt and the narrowness of the Red Sea likely facilitated the migration of populations from Eastern and Western Asia into Egypt. The high percentage of individuals (36%) that classified into an Asian group rather than the Egyptian, African, or European samples may also suggest a greater influx of groups from the East then previously considered. Overall, the findings from the present research support Brace and colleagues' (1993) notion that Egypt had ties with populations in all geographic directions.

Akhmim was ethnically, linguistically and religiously diverse, especially during the more recent Ptolemaic, Roman and Arab periods (Egberts et al. 2002). The high degree of craniometric variation present in the sample speaks to the cosmopolitan nature of ancient Egyptians from Akhmim. As Kemp (2006) notes, urban centers like Akhmim attracted a wide variety of individuals and tend to exhibit a high degree of population admixture. Individuals from many locales were likely drawn to Akhmim due to its prominence as a religious and provincial center. In larger provincial centers, greater levels of population admixture occurs and can be expected (Strouhal 1969). The continuous occupation of Akhmim from the Predynastic period until present day also likely contributes to the diversity present in this largely Graeco-Roman Period sample. Lastly, the position of Akhmim along a critical bend in the Nile River likely contributed to the diversity of the population of this city. The Nile served as a corridor for the movements of people and goods during all periods of ancient Egyptian history. The biological diversity of Akhmim can be used as a model for other urban provincial, administrative, and religious centers in ancient Egypt, many of which are likely lacking skeletal or mummy samples.

In the future the craniometric data from this Akhmimic sample can further contribute to our interpretations of the biological diversity in ancient Egypt as a comparative sample. Comparisons within the same time period present an opportunity to investigate the perceived lack of autonomy of Egypt during the Ptolemaic period. Elias and Lupton (2007) note that this period in Egyptian history resulted in political and socio-economic changes that would have impacted and been evident in the population itself. Akhmim, and much of Middle Egypt, effectively resisted Ptolemaic rule for a time and remained "native Egyptian" (Chan et al. 2008:2024). Therefore, it can be assumed that the population of Akhmim from the Ptolemaic period would have remained more biologically stable, despite in-migrations, than other areas of Egypt at this time and comparisons can be drawn to investigate population continuity and change in the entirety of Egypt.

Finally, because the material from Akhmim is a sample rather than a single individual, the present research better contributes to our understanding of the population history of ancient Egypt. Frequently investigations have relied on individual case studies. While informative in some regards, Larson (1997) notes that for physical anthropology, the sample rather than the individual is the appropriate mode of analysis for inquires of population diversity. Diversity within this sample may be indicative of population admixture, selection and a number of other forces that shape the population. The diversity present in this sample can be "incorporated as a variable in general models which attempt to account for change and to described periods of transition in the past" in ancient Egypt (Mays 2000:285). Relatedly, any study of past populations lends itself to a greater appreciation of humankind in the past, especially in terms of biological diversity (Lasker 1972, Masali and Chiarelli 1972). Studies of ancient Egyptians are especially insightful in this regard because of the great spans of time available for study and the amount of skeletal and mummified material available.

6.5 Conclusions

Physical anthropologists continue to investigate questions related to population biology in order to better understand specific groups and the history of humankind. Ancient Egypt has attracted more focus and research than any other region of the world. Throughout history multiple methods of inquiry including genetic, morphological, and metric methods, have produced contradictory results regarding the peopling of Egypt and the population biology of Upper versus Lower Egypt. Most recent research using more robust techniques tend to be in agreement that Egyptian populations remained homogenous in comparison to outside groups through both time and space. This is not to say that ancient Egyptians were not biologically diverse or that migrations and other evolutionary forces did not shape the history of this population. Our sample from Akhmim during the early Graeco-Roman Period clearly shows a very diverse population that shares craniometric features with other African groups, as well as, European and Asian populations. In the future, the data and results from this sample can be used in a comparative manner to further expand our comprehension of the complexities of ancient Egyptian population history.

Chapter 7: Conclusions

Human remains provide a less biased perspective unto the past than artistic or literary depictions and can contribute greatly to our understanding of ancient Egyptian society (David 2008). The Akhmim series is one of the largest collections of mummies in the world from the same region and time periods and this research is the first regionally focused investigation of ancient Egyptian mummies from related time periods. As with any sample, the individuals comprising it are only a fraction of the entire population from which they are derived (Richards 2005). Broad generalizations derived from the mummified remains, specifically skeletal evidence, may not be representative of all of ancient Egypt through time and space. For a sample to be considered representative of the population, a randomized group of individuals should be selected for analysis. In the case of Akhmim, the sample available for study is just that.

This sample of mummies from the city of Akhmim, primarily during the Ptolemaic period, facilitates a greater understanding of the broader issue of ancient Egyptian population biology and cultural complexity. We know that archaeological inquiry deals with two levels of analysis: the first is the assessment of an individual site or area, in this case the city of Akhmim, the second level takes what we are able to interpret and understand from an individual site, synthesizes it and then apply this to "higher level hypotheses addressing broader issues" (Brown and Brown 1994:721). This research has effectively demonstrated that large samples of mummies need be studied both biologically and culturally to better understand the ancient Egyptians.

The individual analyses of each mummy within this sample revealed a rather diverse population despite originating predominantly from Akhmim and dating mostly to the Ptolemaic phase of the Graeco-Roman Period. The sample was demographically very varied, with both males and females represented and with individuals that ranged from young adulthood to senescence. Furthermore, all sectors of middle class society were represented in this sample. While some of the biological parameters investigated mirrored previous research on ancient Egyptian population demographics, new findings from this research suggest that life expectancy in ancient Egypt may have been longer than previously believed and status alone does not necessarily dictate a longer, healthier life in this sample. The exploration of population affinity using craniometrics produced both expected and rather astounding results. Akhmim and its surrounding areas have typically been described as very diverse in nature; therefore, the high degree of craniometric variation found in this sample was rather unsurprising. What was more unexpected, was that many individuals within the sample appear metrically most similar to Asian populations rather than African or Caucasian population groups. One major debate concerning the population affinity of ancient Egyptians has centered on the similarity or dissimilarity between them and their neighbors to the north and south. Results from this sample suggest that potential migration and gene flow between Egyptians and their neighbors to the east. The degree of this admixture in the past may have been greater than previously documented in other mummy or skeletal samples to date. Greene (1981) suggests that single populations or skeletal series, in this case the Akhmim material, are the first step to understanding the population affinity of larger group, in this case Egyptians.

Culturally, this group of mummies also proved to be rather diverse. Preparation of most individuals in the sample followed prescribed methods and historical accounts;

however, there were cases that deviated from the norm. Body positioning, specifically of the arms, was the most variable of all body preparation parameters. The greatest contribution of this research to our current knowledge concerning how ancient Egyptians were mummifying their dead pertains to 1) the relationship, or lack thereof, of the crossed arm pattern to royal status, 2) the potentially intentional disarticulation or disseveration of the body during the embalming process, and 3) the various wrapping and positioning patterns discovered and the multipart nature of this process. The latter two components of mummification have largely been ignored in the literature, and I would argue have largely been misinterpreted. The current research dispels some of the ambiguity concerning wrapping patterns and then also elaborates on the disseveration of the body as a unique variant rather than as a "mistake." From the diversity found in this sample it remains clear that the mummification process followed a general sequence that we mostly understand, yet the order and methods used were not set in stone. Regional, temporal, or personal preferences likely contributed to the high level of variation discovered within this sample of mummies.

Lastly, in this research computed tomography analysis of mummification patterns provided as much information as past destructive methods like autopsies, but also allowed the collection of data that would otherwise not be viewable using any other modality. Specifically, by using computed tomography it was possible to discern the exact pattern of body positioning and wrapping of the individual during funerary preparation. Biological parameters including estimation of biological profile parameters and metric assessments, were easily conducted using both two and three dimensional views of the remains. From this research it is clear that the benefits of computed tomography analysis for mummy studies far outweigh the limitations of this modality.

The present research has been rather informative regarding the people of Akhmim and the entirety of Egypt. The complexity of ancient Egypt's population history and the abundant cultural diversity, with change through time, has been further confirmed with this investigation. While ancient Egyptians have been researched and studied from antiquity to present and more than any other population, the present research demonstrates that we have not learned all there is to learn about these people through time and space and there remains value in continuing to study ancient Egyptians using newer technologies and techniques.

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Appendix 1

The following individuals generously contributed time and resources to the AMSC database of mummies used in the current research.

AMSC 1

Westminster College: Dr. Samuel Farmerie, Curator of Cultural Artifacts

Pinncale Health System: Randy Lykins, RT (R); Karen Botts, Director of Radiology

AMSC 2

Reading Public Museum: Scott A. Schweigert, Art Curator

AMSC 3

College of Wooster Art Museum: Kitty Zurko, Director

Wooster Community Hospital: Daniel A. Grabowski, RT (R) MR

AMSC 4

Academy of Natural Sciences, Philadelphia: Dr. Ted Daschler, Curator

Hahnemann University Hospital and Drexel University: Dr. Michael Hallowell, Radiologists; Dr. Steve Chan, Radiologists

AMSC 5

Musée St. Rémi, France: Marc Bouxin, Conservateur en Chef du Patrimonie

AMSC 6

Buffalo Museum of Science: Kathy Leacock, Curator of Collections

AMSC 7

Milwaukee Public Museum: Carter Lupton, Head of Anthropology and History

GE Healthcare in Waukesha, WI: Ron Lundgren

AMSC 8

Milwaukee Public Museum: Carter Lupton, Head of Anthropology and History

GE Healthcare in Waukesha, WI: Ron Lundgren

AMSC 9

Buffalo Museum of Science: Kathy Leacock, Curator of Collections

AMSC 10

Supreme Council of Antiquities / Ministry of State for Antiquities: Mohammed Ibrahim Ali, Secretary General

AMSC 11

Supreme Council of Antiquities / Ministry of State for Antiquities: Mohammed Ibrahim Ali, Secretary General

AMSC 12

Supreme Council of Antiquities / Ministry of State for Antiquities: Mohammed Ibrahim Ali, Secretary General

AMSC 13

Supreme Council of Antiquities / Ministry of State for Antiquities: Mohammed Ibrahim Ali, Secretary General

AMSC 14

Berkshire Museum, Pittsfield, MA: Leanne Hayden, Manager of Collections

Berkshire Medical Center: Dr. Prakash Malkani; John Gable, RT (R)

AMSC 15

Vassar College's Frances Lehman Loeb Art Center: James Mundy, Director; Joann Potter

Vassar Brothers Medical Center: Joseph Langdon, RT (R)

Healthquest: Theresa Mulkins

AMSC 16

Louisiana Art and Science Museum: Elizabeth Weinstein, Curator of Art

St. Elizabeth Hospital, Gonzales, LA: Ron Letourneau, RT (R)

AMSC 17

Putnam Museum: Christina Kastell, Curator

AMSC 18

Putnam Museum: Christina Kastell, Curator

AMSC 19

Washington State Historical Society: Dr. David Nicandri, Director; Stephanie Lile, Director of Education

Tacoma General Hospital: Diane McCoy, RT (R)

AMSC 20

Fine Arts Museums of San Francisco: Dr. Renée Dreyfus, Curator of Ancient Art, Legion of Honor Museum

Stanford Medical Center, Palo Alto, CA: Dr. Rebecca Fahrig, Radiologist.

AMSC 23

Earlham College: Dr. Heather Lerner, Museum Director, Assistant Professor at Joseph Moore Museum

AMSC 25

Milwaukee Public Museum: Carter Lupton, Head of Anthropology and History

GE Healthcare in Waukesha, WI: Ron Lundgren

AMSC 27

Museo Civico Archeologico di Asti

The Mummy Project: Sabina Malgora, Director and Curator Egyptian Section, Castello del Buonconsiglio di Trento; Dr. Albert Zink, Scientific Director of the Institute for Mummies and the Iceman

Fatebenefratelli Hospital, Milan: Dr. Luca Bernardo

AMSC 29

Virginia Museum of Fine Arts: Dr. Peter Schertz

Henrico Doctors' Hospital in Richmond, VA: Dr. James Snyder; Dr. Tom Underhill

AMSC 30

Massachusetts General Hospital: Dr. Rajiv Gupta; Dr. Paul Chapman; Mr. Hubert Murray

Mimi Leveque, Conservator

Appendix 2

The data below were used to determine social status for each individual and was collected and analyzed by Dr. Jonathan Elias © 2014.

Table A2.1. The quality of funerary preparation and level of soft tissue preservation for each individual.

AMSC #	Status	Period	Funerary Quality	Level of Preservation
1	M	GR	PC-g, 4PCS-gh/GM, S, U, F	High
2	M	GR	YB-g, 4PCS-gh/GM, S, U	High
3	M	GR	PC-g, 4PCS/GM*, S, U	High
4	L	GR	PC-p, 4PCS/GM, S	Medium
5	M	GR	PC-g, 4PCS*/GM, S, U	High
6	I	3IP	Unwrapped head	High
7	M	GR	PC-g, 4PCS*/GM, S, U	High
8	M	L	PC-p-di, BC, S, U	Medium
9	I	3IP	Partially unwrapped head	High
10	H	GR	PC-g, 4PCS-ge, S, U, Hy	High
11	H	GR	PC-p, 4PCS-gh/GM, S, U	High
12	H	GR	PC-g, 4PCS-gh/GM, S, U, G	High
13	H	GR	YB-di, 4PCS/GM, BS, S, U, G, F	High
14	M	GR	YB-p, 4PCS/GM*, S, U	High
15	M	GR	YB-p, 4PCS/MM, S, U	High
16	L	GR	PC-p*, 5PCS*/GM*, S, C	High
17	M	GR	Unwrapped	High
18	M	L	No coffin, GM, L, S, ICP	High
19	H	L	Outer coffin: BC Inner coffin: PC-p-di, unwrapped, BC	High
20	H	L	YB-p-gi, BC, S, U, F	High
23	L	GR	No coffin, S*	Medium
25	I	L	Head only	Medium
27	L	L	No coffin, C	Low
29	H	1IP	BC, IM, SLO	Low
30	M	3IP	Outer Coffin: PC-p Inner coffin: PC-p, BC, S	High

Status Level: higher status, L: lower status, M: middle status, I: indeterminable status

Time Period: 1IP: First Intermediate Period, 3IP: Third Intermediate Period, L: Late Period, GR: Graeco-Roman

Coffin: BC: boxed (non-anthropoid) coffin, PC: polychrome coffin, -g: coffin with a gilded face, -p coffin with a painted face, di: dense inscriptions (text), YB: yellow on black coffin

Surface Embellishments: #PCS: #(number) piece cartonnage suit, -gh: gilded highlights, -ge: gilded entirely including the mask, -gi: glass inlays, GM: cartonnage mask has a gilded face, PM: cartonnage mask has a painted face, MM: cartonnage mask has a gilded face (metal other than gold), IM: internal mask (within the shroud), BS: beaded sash present, BC: rectangular beaded coverlet present, L: lattice wrapping, G: garland present, Hy: hypocephalus present

Closing Membrane: S: shroud present, U: external unguent deposit present
Within Bundle Features: C: palm cane support structure, ICP: internalized cartonnage plague under the shroud and within the wrappings, SLO: shaped linen object/emblem, F: features including amulets, wax figures, discs (usually circular)

*missing but inferred based on the general trend of other information present

Table A2.2. The titles and/or honorifics of each individual and their parents.

AMSC #	Sex	Title	Father's Title	Mother's Title
1	F	None	Hm-nTr 8-nTrw Mnw	House Mistress Sistrum-player of Min
2	F	None	smAtj jmj-js Hzj-kA	House mistress Sistrum-player of Min
3	F	Hathor (Funerary Epithet)	Unknown	House Mistress
4	F	None	Anonymous	Anonymous
5	M	None	None	House Mistress
6	F	Unknown	Anonymous	Anonymous
7	M	smAtj	smAtj	Anonymous
8	M	Washer of bodies of the house of Min; Wrapper	None	None
9	M	Unknown	Anonymous	Anonymous
10	M	smAtj Jmj-js Hzj-kA Hm-nTr wHm Mnw-Hr-Ast m Jpw	smAtj jmj-js Hzj-kA Hp.t-wDA.t Hm-nTr wHm Mnw-Hr-Ast m Jpw	House Mistress Sistrum-player of Min
11	M	smAtj Jmj-js Hzj-kA	smAtj Jmj-js Hzj-kA	House Mistress Sistrum-player of Min
12	F	House Mistress Sistrum-player of Min	smAtj Jmj-js Hzj-kA Hm-nTr wHm Mnw-Hr-Ast m Jpw nTrw nTrt m Jpw	House Mistress Sistrum-player of Min
13	F	None	None	None
14	M	smAtj	smAtj	House Mistress Sistrum-player of Min
15	M	smAtj	smAtj	House Mistress Sistrum-player of Min
16	M	Unknown	Anonymous	Anonymous
17	F	Unknown	Anonymous	Anonymous
18	M	Unknown	Anonymous	Anonymous
19	M	smAtj Jpw Hm-nTr 2-nw Mnw-Hr-Ast n Jpw Hm-nTr Hr-nD-it-f hrj-jb Jpw Hm-nTr hnsw p-jwnwt-tr	Hm-nTr 2-nw	House Mistress
20	M	smAtj Jpw Hm-nTr Wsjr-Skr hrj-jb Jpw Fktj n pr-snt Jmj-st-` n zA 2-nw	minw (Same as preceding)	nSmAt n Mnw qmA n psDt (Singer of Min creator of the ennead)
23	F	Unknown	Anonymous	Anonymous
25	M	Unknown	Anonymous	Anonymous
27	M	Unknown	Anonymous	Anonymous
29	M	HAty-` sDAwtj bjtj	HAty-` sDAwtj bjtj	Anonymous
30	M	Hryt-nTr	None	None

smAtj: stolist (priest), Jmj-js: member of the crew (priestly honorific), Hzj-kA: praiser of the spirit (priestly honorific), Hm-nTr: servant of the god (priest/prophet), Fktj: shorn priest, HAty-`: count (aristocratic title), sDAwty bity: seal-bearer of the king of Lower Egypt (artistocratic honorific), Hryt-nTr: necropolis worker, minw: e.g. same as preceding, unknown: no evidence of title recovered, none: individuals did not have a title

Appendix 3

Table A3.1 Traits used for sex and age-at-death estimation.

AMSC#	Sex	Age-at-Death	Sex Estimation	Age Estimation
1	F	65+	Obtuse jaw angle, no zygomatic extensions, pointed chin, pronounced brow ridge, extremely small mastoid process, wide sub-pubic angle, wide pelvic canal	Medial clavicle fused, tooth wear present, vertebral compression and lipping, epiphyseal lines present on some bones, trabecular structure of proximal femur assessed, alveolar resorption present
2	F	late 40s	Reduced brow ridges/glabellar region, external occipital protuberance is small, wide sciatic notch, wide sacrum, wide pelvic canal	Third molar erupted, clavicle fused, epiphyseal lines not very visible, cranial sutures visible but not obliterated, trabecular pattern of femur assessed, vertebral lipping present
3	F	25-35	Long and narrow mastoid, pointed chin, not rugose (lacking brow ridge, muscle markings, gonial eversion, etc.), broad sacrum, wide sciatic notch, large subpubic angle, sub-pubic concavity present	Sutures visible, roots of third molars formed, trabecular pattern of femur assessed (very dense)
4	F	30s-40s	Very gracile, no heavy muscle attachment sites, no zygomatic extension, pointed chin, ascending ramus at ninety degree angle, frontal bossing, ventral arc present, large sub-pubic concavity present, wide sub-pubic angle	Third molars erupted with exception of left maxilla, localized alveolar resorption present, cranial sutures visible and not obliterated, trabecular pattern of femur assessed (fairly dense), manubrium not fused to corpus sterni of the sternum

5	M	30s-40s	Gonial eversion present, pronounced mental trigon, wide mastoid process, pronounced nuchal muscle attachment sites, marked supraorbital ridges, projecting nasal bones, penile sheath, narrow sacrum, narrow sub-pubic angle	Third molar erupted, considerable wear on the teeth, antemortem tooth loss, cranial sutures visible and open with no obliteration, trabecular pattern of femur assessed (fairly dense), proximal clavicle fused
6	F	20-40	Small mastoid, pointed chin, obtuse gonial angle, frontal bossing present, glabellar protrusion, slight external occipital protuberance, mental trigon present	Third molars erupted, sutures all open and clearly visible
7	M	20-25	Slightly obtuse ascending ramus, rounded chin, mental trigon present, zygomatic extension beyond external auditory meatus	Third molars unerupted, medial clavicle not completely fused, cranial sutures all open and visible, trabecular pattern of femur assessed (fairly very dense)
8	M	45-55	Prominent mental trigon, gonial eversion, marked temporal lines, large and wide mastoid process, extension of zygomatic, mandibular angle at ninety degrees, slight external occipital protuberance, moderate brow ridges/glabellar region, narrow sacrum	Third molars erupted, considerable tooth wear present on molars, some compression of the vertebral bodies, cranial sutures visible and not obliterated, trabecular pattern of femur assessed (losing density)
9	M	30s	Pronounced muscle markings (nuchal and temporal regions), zygomatic extension beyond the external auditory meatus, mastoids are small but wide	Third molars erupted, cranial sutures open with none obliterated, some tooth wear present

10	M	50s	Ascending ramus at ninety degree angle, marked external occipital protuberance, marked brow ridge/glabellar region, pronounced muscle markings, mental trigon present, wide mastoid process, narrow sacrum, narrow subpubic angle, marked gonial musculature and eversion	Third molars erupted, tooth wear present, attrition and antemortem tooth loss, partial obliteration of cranial sutures, vertebral compression and lipping, medial clavicle fused, trabecular pattern of femur assessed (not very dense)
11	M	45-55	Gonial angle at ninety degree angle, gonial eversion present, pronounced muscle markings, external occipital protuberance present, marked supraorbital ridges with glabellar protrusion, mental trigon present, long mastoid processes, penile sheath present	Dental wear, cranial sutures visible and not obliterated, trabecular pattern of femur assessed (losing density), vertebral compression with lipping and loss of intervertebral disc space
12	F	50s	Pointed chin, reduced brow ridges but present, not heavily muscled at temporal lines- greater muscle markings on occipital bone, EOP absent, wide sub-pubic angle	Sutures mostly obliterated, compression of vertebral bodies with lipping, alveolar resorption with antemortem tooth loss, trabecular pattern of femur assessed (not very dense)
13	F	30s	Small external occipital protuberance, gonial angle at 90 degrees, small but wide mastoid, mental trigon present, heavy muscle markings (nuchal, temporal, gonial), gonial eversions, non-projecting and wide sacrum, SPC present, wide sub-pubic angle, wide pelvic canal	Third molars erupted, cranial sutures visible and open, minimal tooth wear on molars, clavicles fused, trabecular pattern of femur assessed (fairly dense)

14	M	40s	Gonial eversion present, mental trigon present, gonial angle ninety degrees, wide mastoid process, pronounced supraorbital margin/glabellar protrusion, penile sheath, nuchal muscle markings pronounced , narrow sub-pubic concavity	Third molars erupted, sutures open and visible, considerable tooth wear present, some vertebral compression, lumbar vertebral lipping, ossified costal cartilage
15	M	40s	Prominent mental trigon present, gonial eversion present, pronounced brow ridge/glabellar region, heavy muscle markings (especially along the nuchal plane nuchals), gonial angle at ninety degrees, external occipital protuberance is present, penile wrapping	Third molars erupted, cranial sutures open and visible, trabecular pattern of femur assessed (losing density), some vertebral compression present
16	M	25-30	Gonial angle at ninety degrees, mental trigon present, wide mastoid process, gonial eversion present, narrow sub-pubic concavity, convex ischio-pubic ramus, narrow sacral width	Cranial sutures open and visible, third molar erupted, no wear on teeth, no vertebral compression, medial clavicle not fully fused, trabecular pattern of femur assessed (very dense)
17	F	30s-40s	Heavy muscle markings on nuchal plane, small external occipital protuberance present, some gonial eversion, wide mastoid but short, wide sub-pubic concavity, ventral arc present, some glabellar projection, wide broad pelvis, broad non intruding sacrum	No vertebral lipping present, sutures mostly open and not obliterated, trabecular pattern of femur assessed (fairly dense), third molars erupted, some wear on teeth

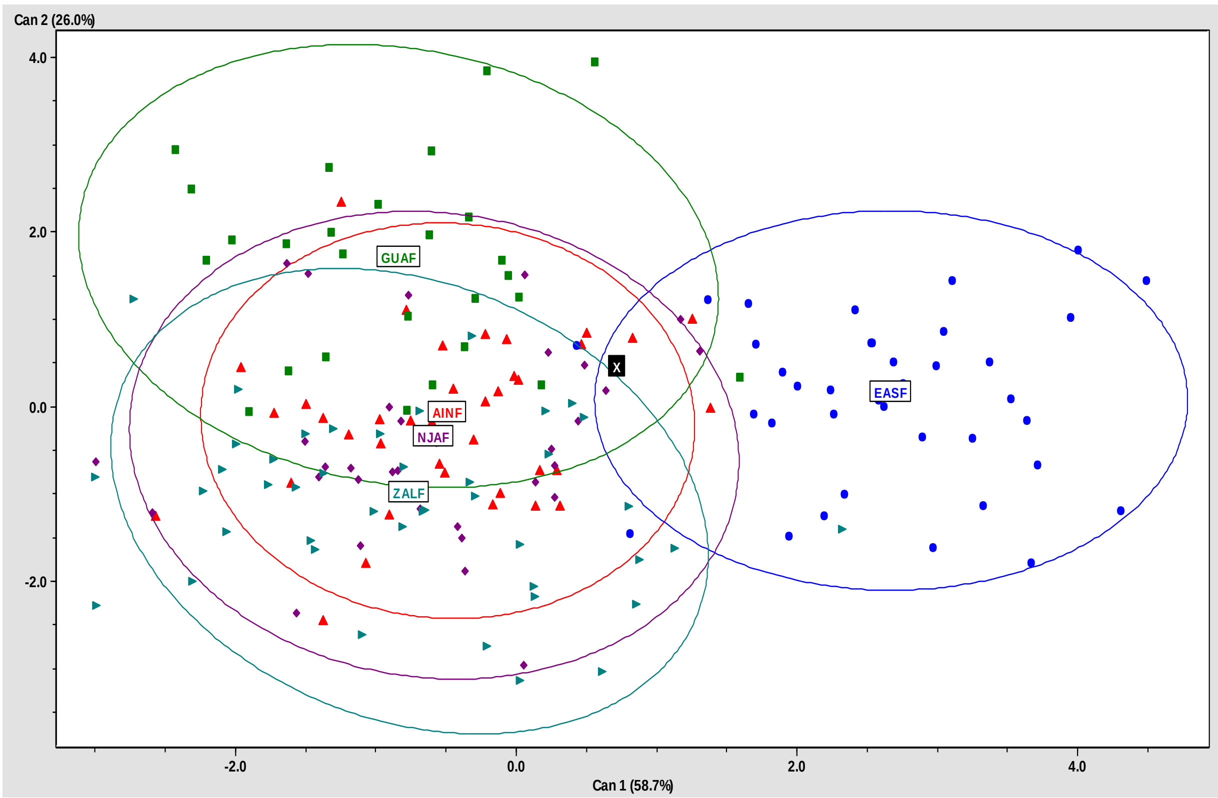
18	M	50s	Anteriorly projecting sacrum, convex sub-pubic concavity, ventral arc is absent, wide medial aspect of the ischio-pubic ramus, very large huge deltoid tuberosity, pronounced brow ridge and glabellar protrusion, gonial eversion, projecting mastoids, penile wrapping	Vertebral lipping with osteophytic growth, trabecular pattern of femur assessed (not very dense), third molar erupted, tooth wear present, epiphyseal lines mostly obliterated
19	M	30-45	Mental trigon present, gonial eversion present, anteriorly projecting sacrum, gonial angle at ninety degrees, wide mastoid process, mental spines present, penile sheath,	Third molar erupted, trabecular pattern of femur assessed (fairly dense), slight vertebral lipping
20	M	25-30	Pronounced supraorbital margin/glabellar region, gonial eversion present, mental trigon present, penile sheath present	Cranial sutures visible and not obliterated, third molars erupted, vertebral body compression, trabecular pattern of femur assessed (fairly dense), proximal clavicle not fully fused
23	F	35-45	Frontal bossing present, obtuse gonial angle, small mastoid, no heavy musculature, pointed chin	Third molars erupted, cranial sutures visible and open, lack of significant tooth wear
25	M	40s	Gonial angle at ninety degree angle, zygomatic extension beyond the external auditory meatus, long and wide mastoid process, pronounced muscle markings	Roots of third molars formed, antemortem tooth loss of molars, cranial sutures all visible and open

27	M	30s-40s	Gonial angle at ninety degree angle, zygomatic extension beyond the external auditory meatus, pronounced supra orbital ridge and extended glabellar region, pronounced muscle markings, wide mastoid process	Considerable alveolar resorption and antemortem tooth loss, cranial sutures visible and not obliterated, lack of lipping on joint surfaces, epiphyseal lines still visible but epiphyses are fused, trabecular pattern of femur assessed (losing density)
29	M	20-25	Marked brow ridge with glabellar protrusion, large and wide mastoid, nuchal muscle markings present, mental trigon present	Third molars unerupted, cranial sutures open, trabecular pattern of femur assessed (very dense), epiphyseal lines very visible
30	M	20-25	Glabellar protrusion, slight supra orbital tori present, ascending ramus at ninety degrees, mental trigon present, gonial eversion, marked muscle markings, penile sheath	Epiphyseal lines clearly visible on all long bones, trabecular pattern of femur assessed (very dense), third mandibular molars unerupted, some alveolar resorption present, sternabrea/sacral fragments not fully fused together

Appendix 4

FORDISC classification scatterplots or histogram for each individual.

AMSC 1



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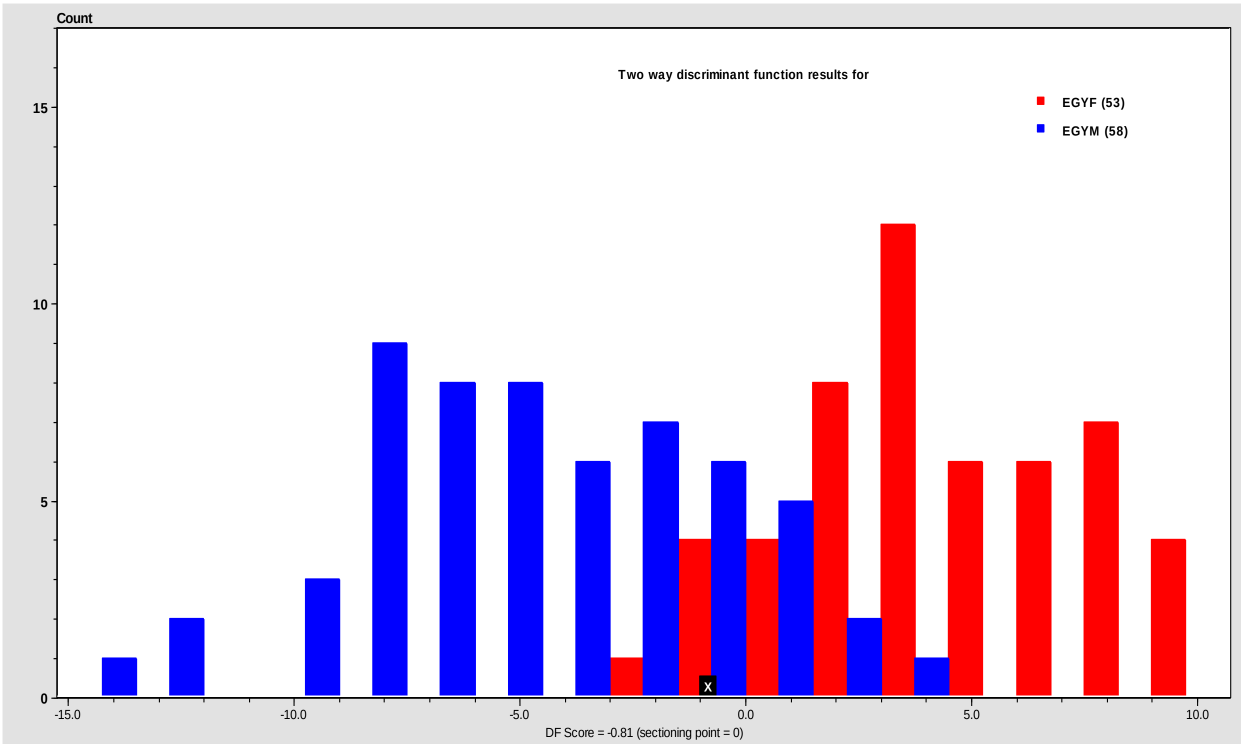
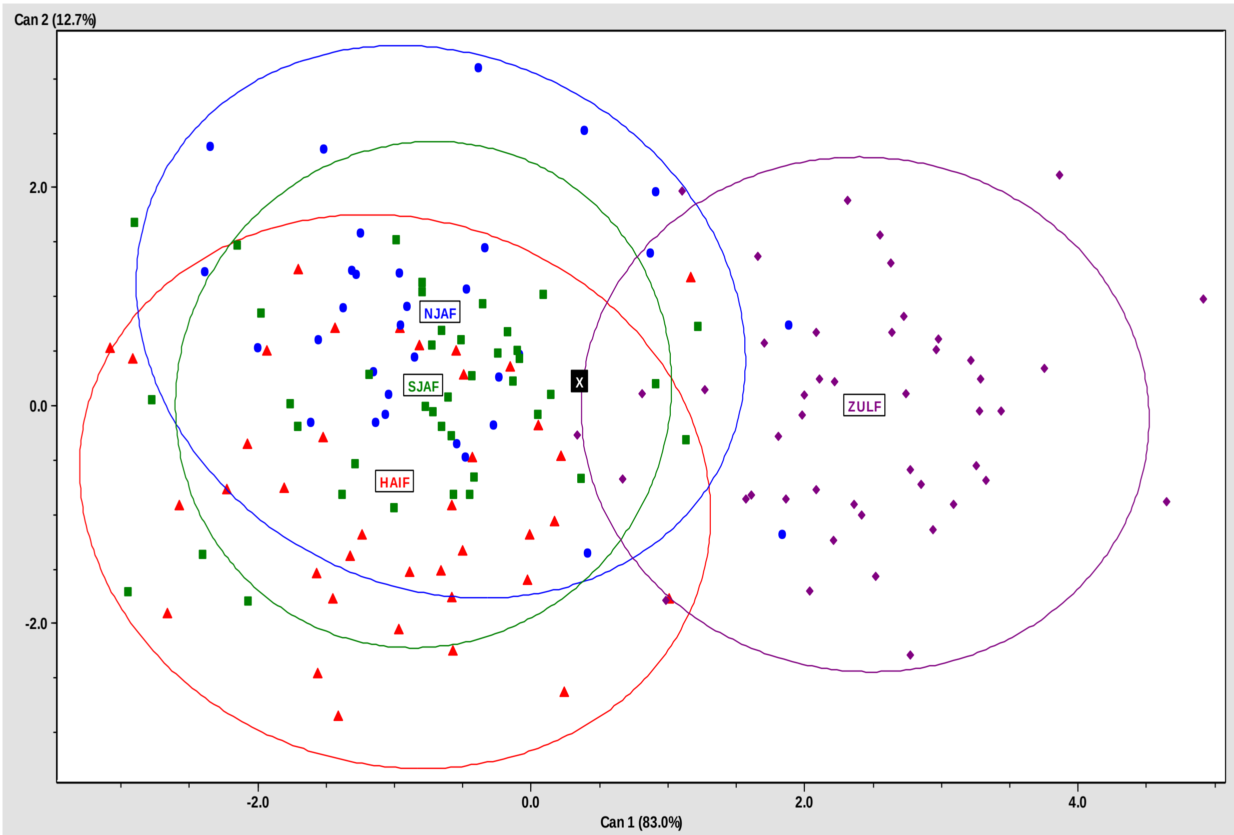


Count
Two way discriminant function results for
EGYF (53)
EGYM (58)
15
10
5
0
-15.0
-10.0
-5.0
0.0
5.0
10.0
DF Score = -0.81 (sectioning point = 0)

AMSC 3



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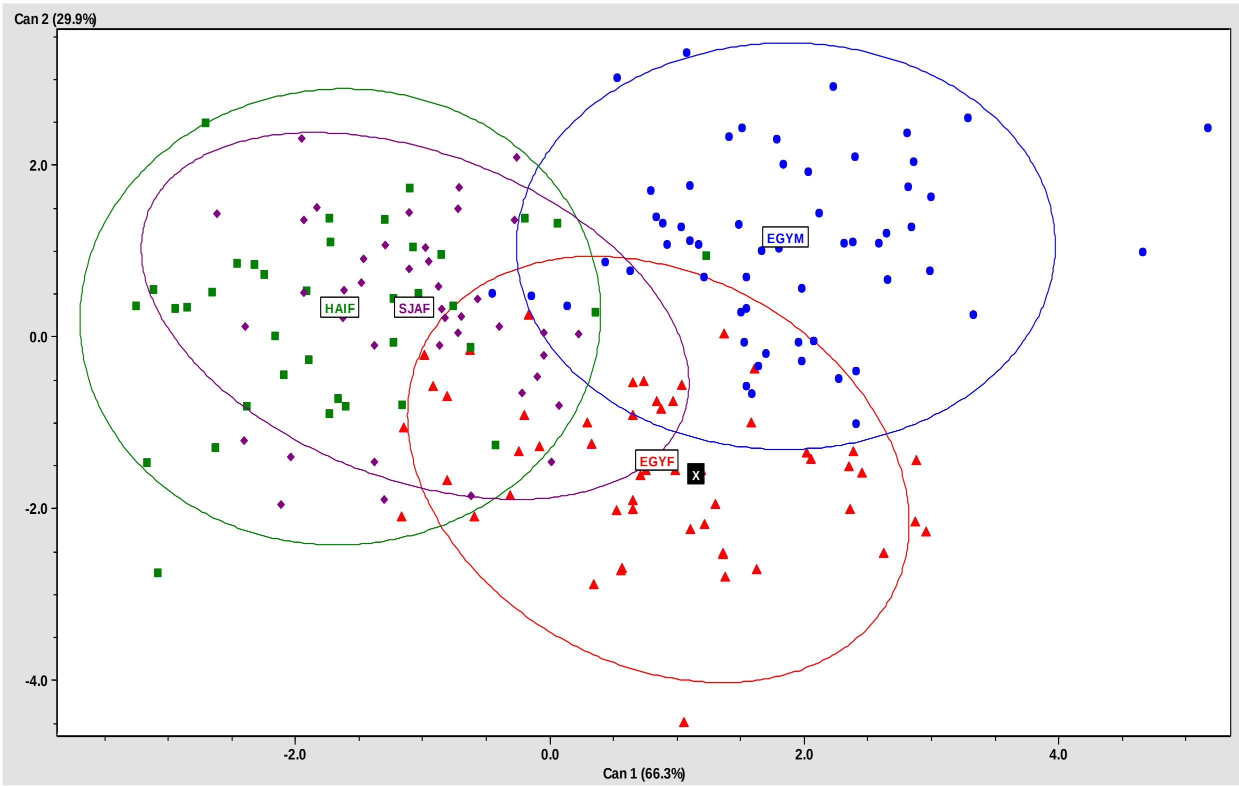

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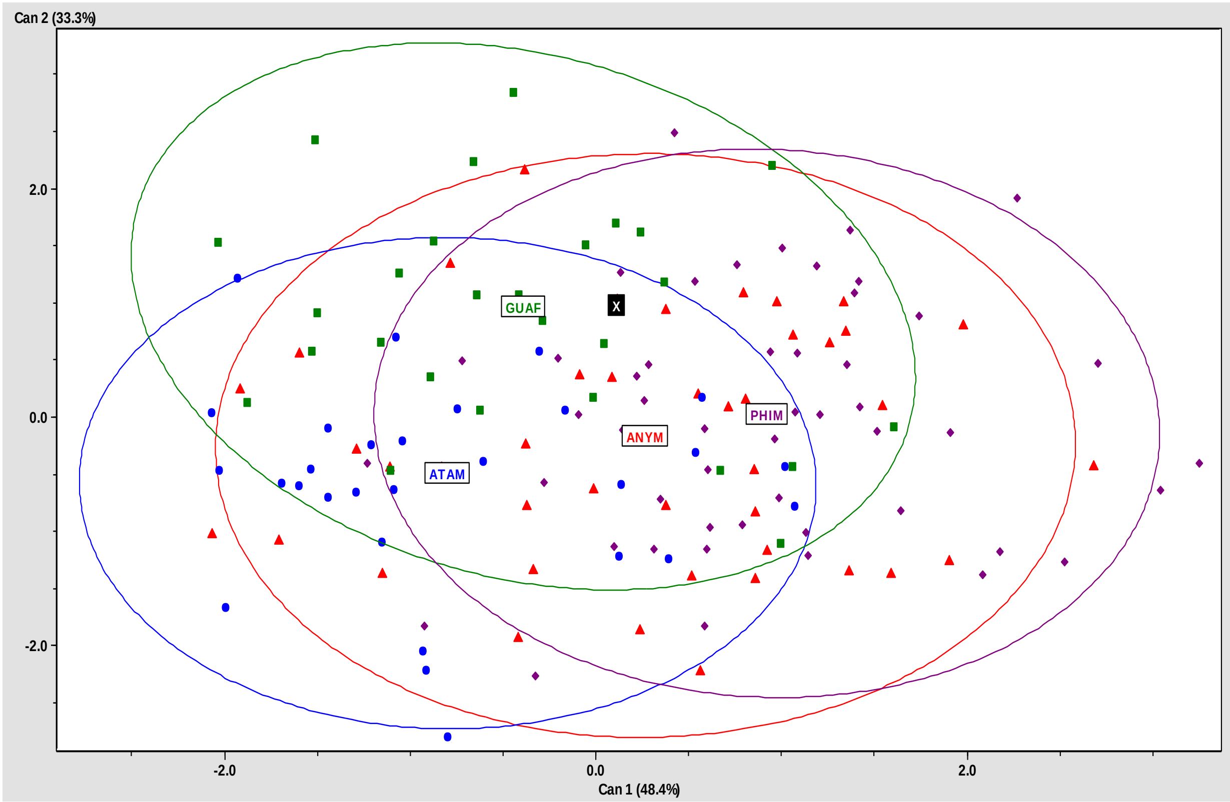

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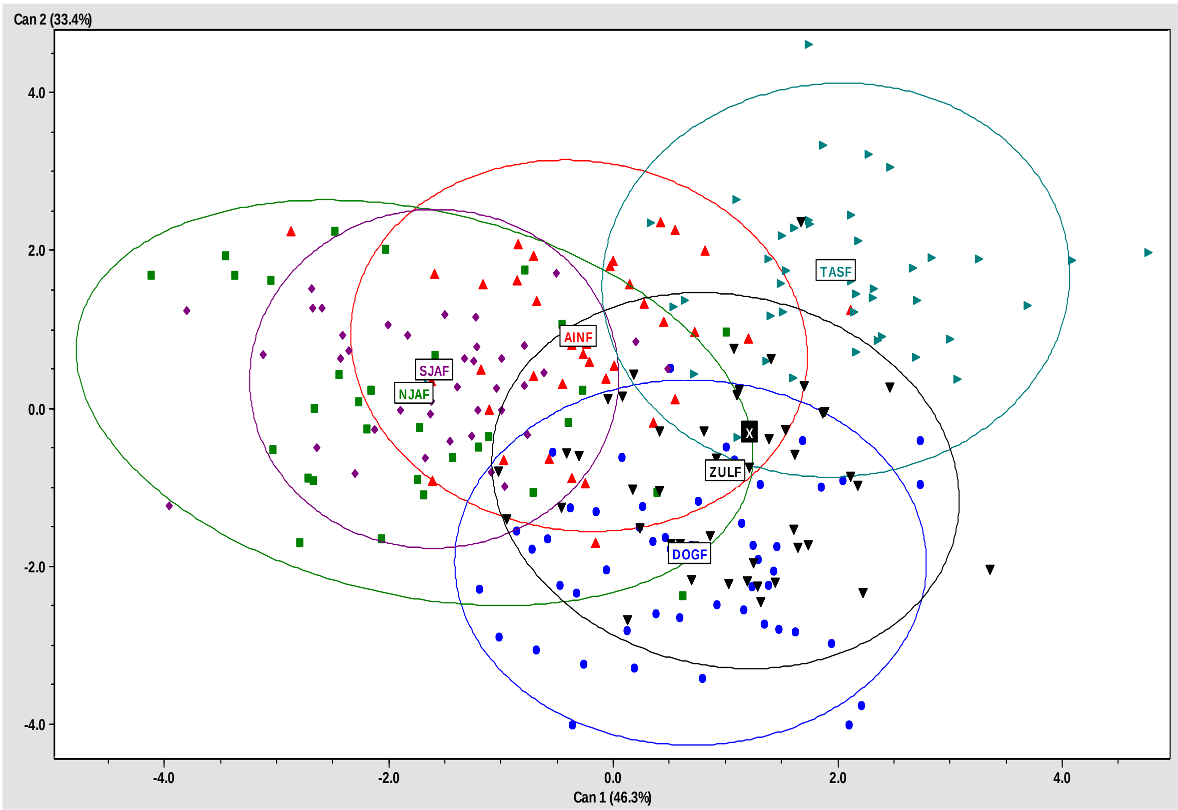
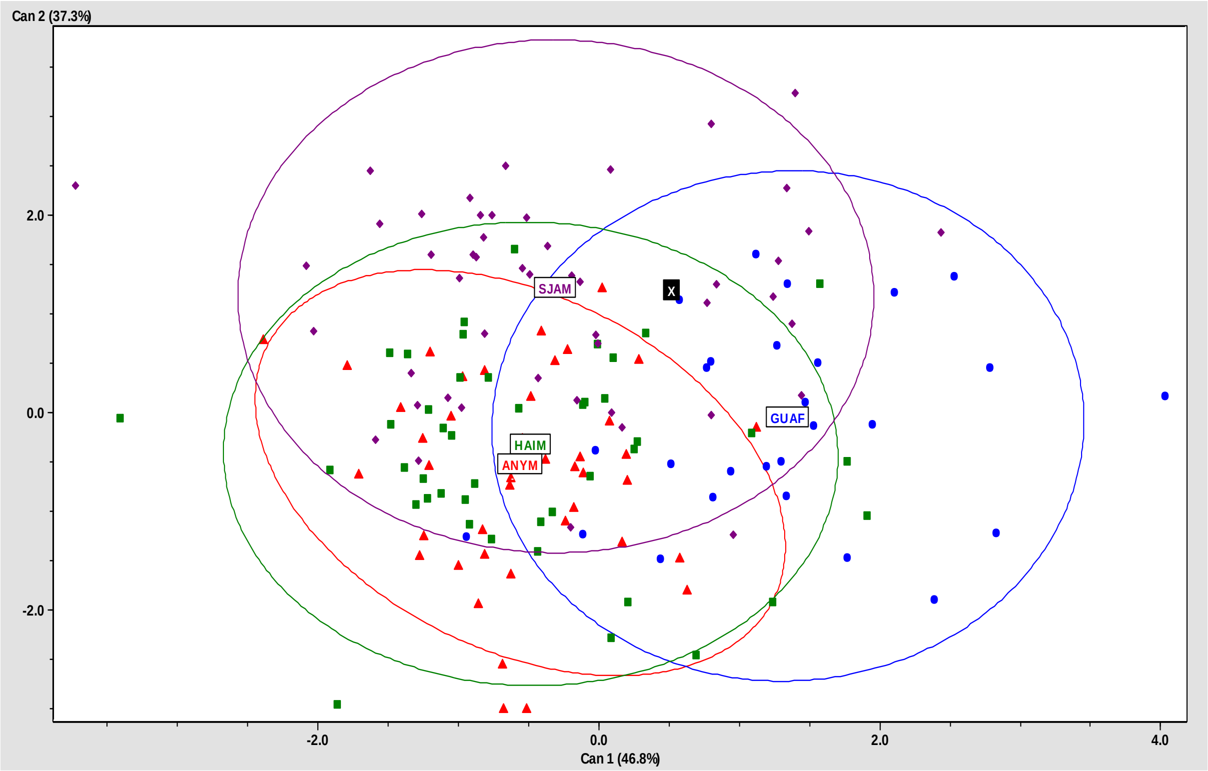


Can 2 (33.4%)
4.0
2.0
0.0
-2.0
-4.0
-4.0
-2.0
0.0
2.0
4.0
Can 1 (46.3%)
TASF
AINF
SJAF
NJAF
ZULF
DOGF
X

AMSC 7



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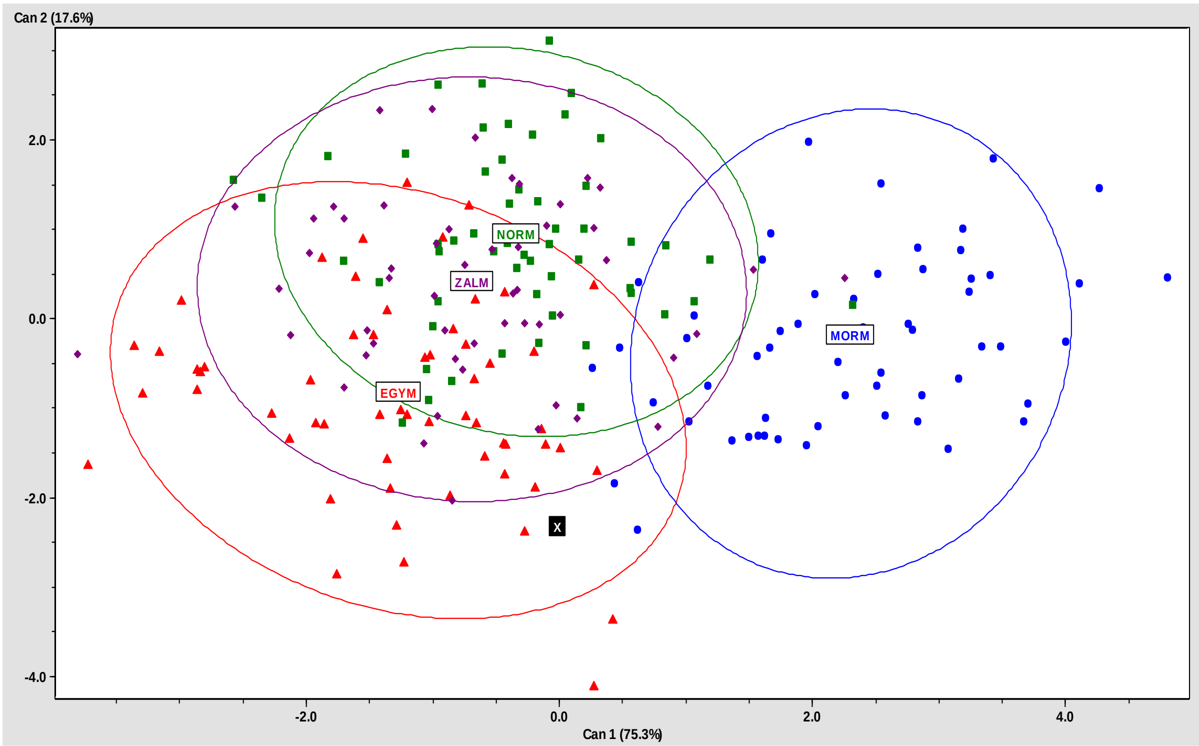

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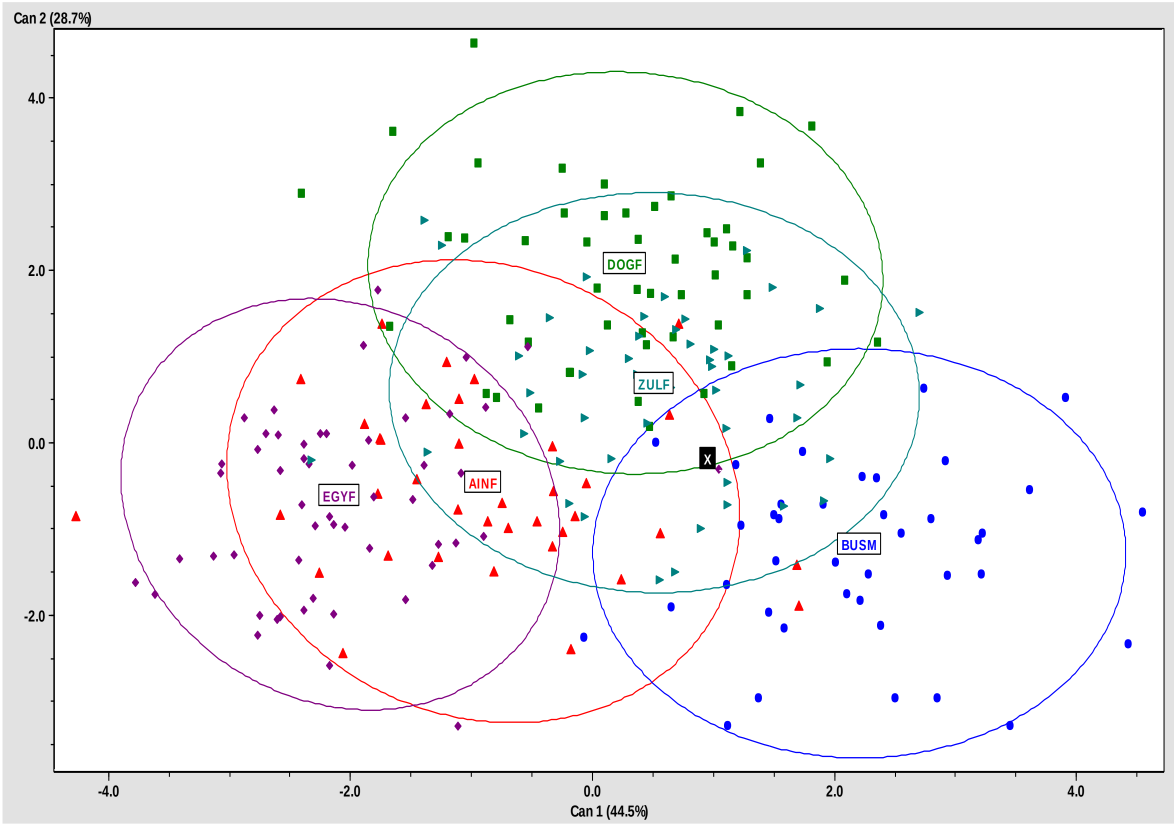

Can 2 (28.7%)
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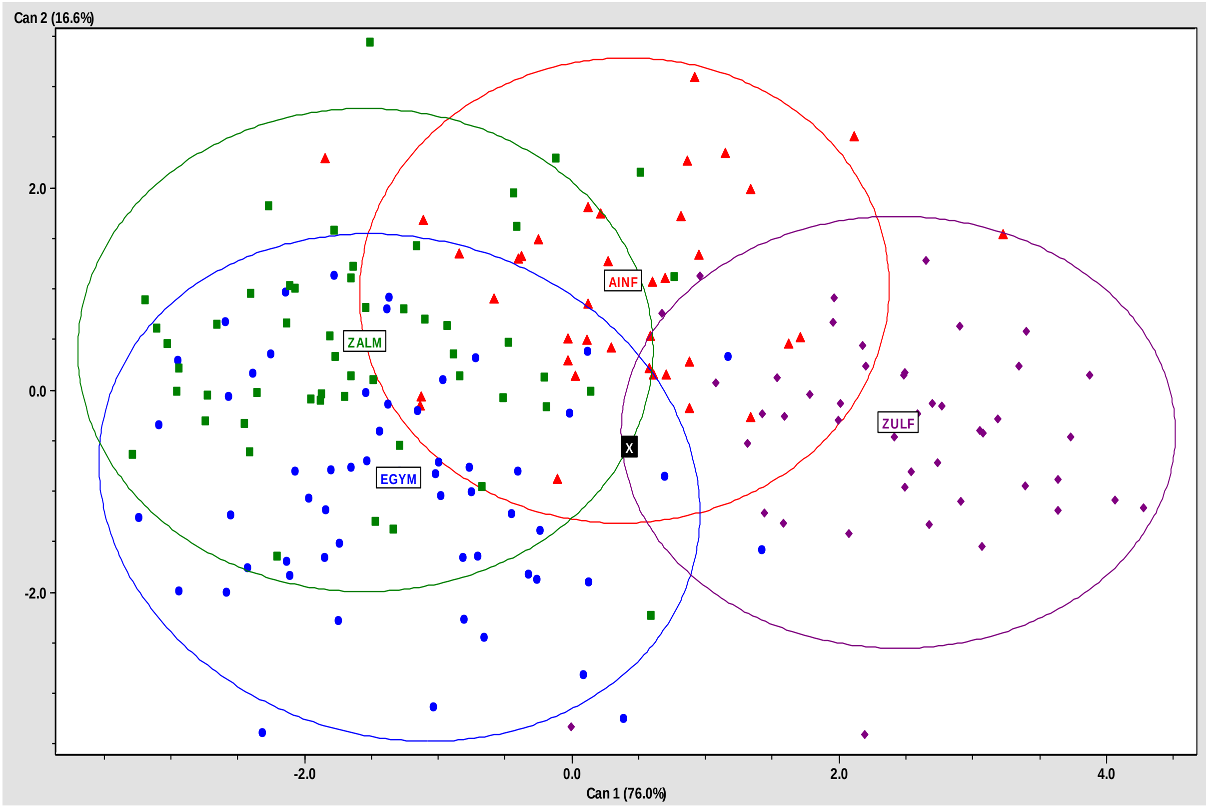
2.0
0.0
-2.0
-4.0
-2.0
0.0
2.0
4.0
Can 1 (44.5%)
DOGF
ZULF
AINF
EGYF
BUSM
X

AMSC 10



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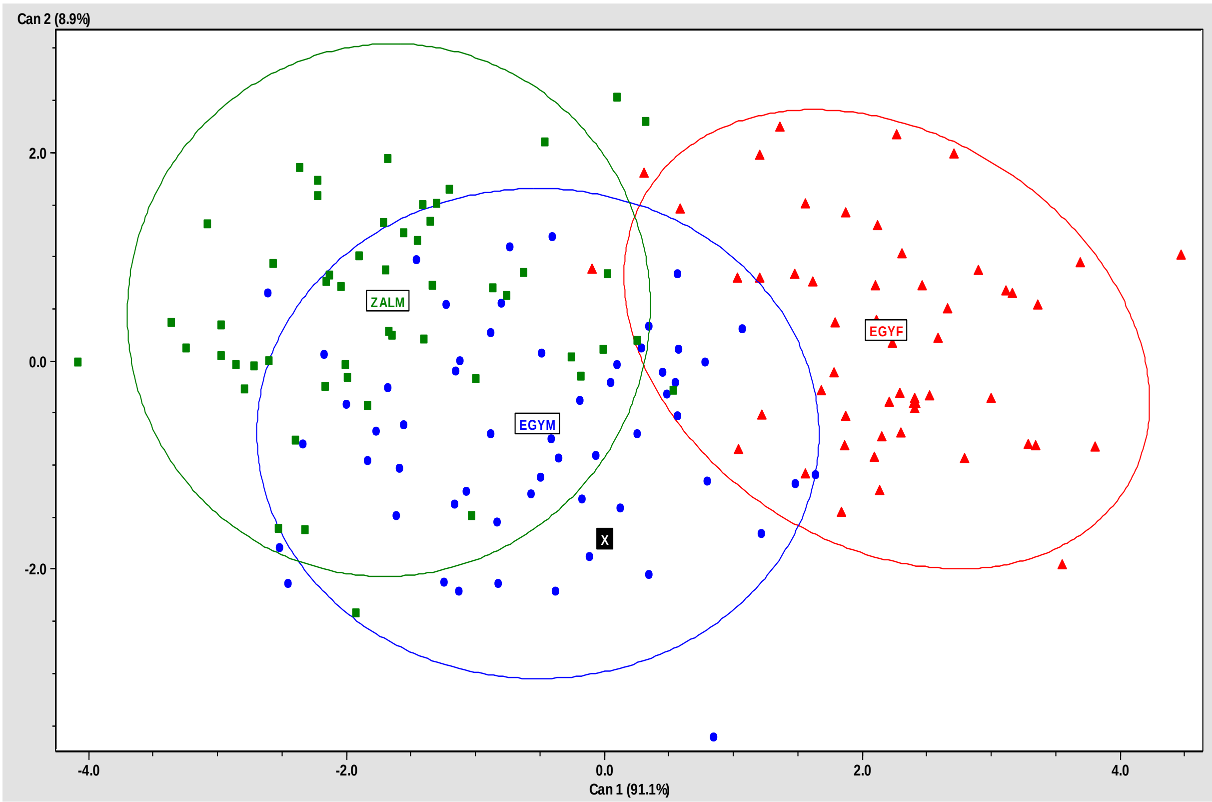

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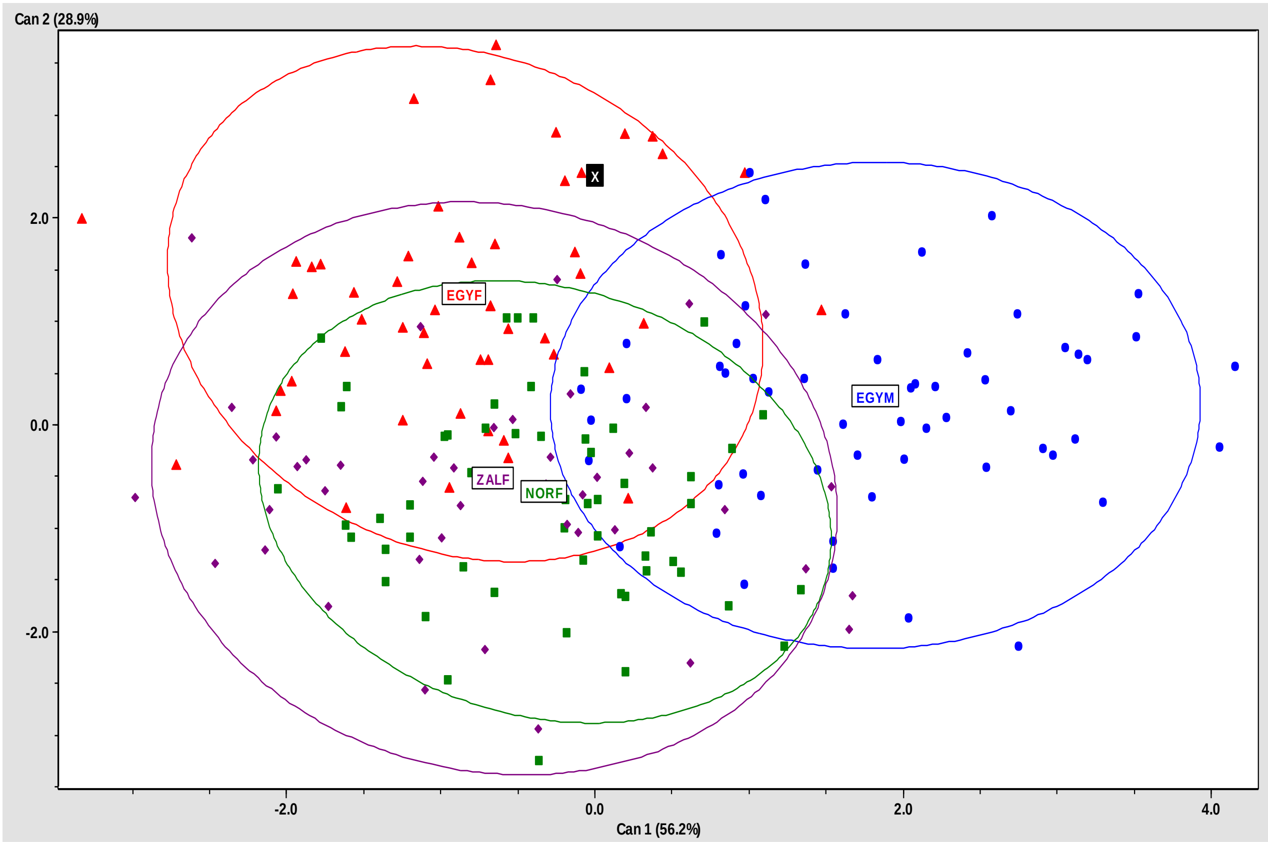

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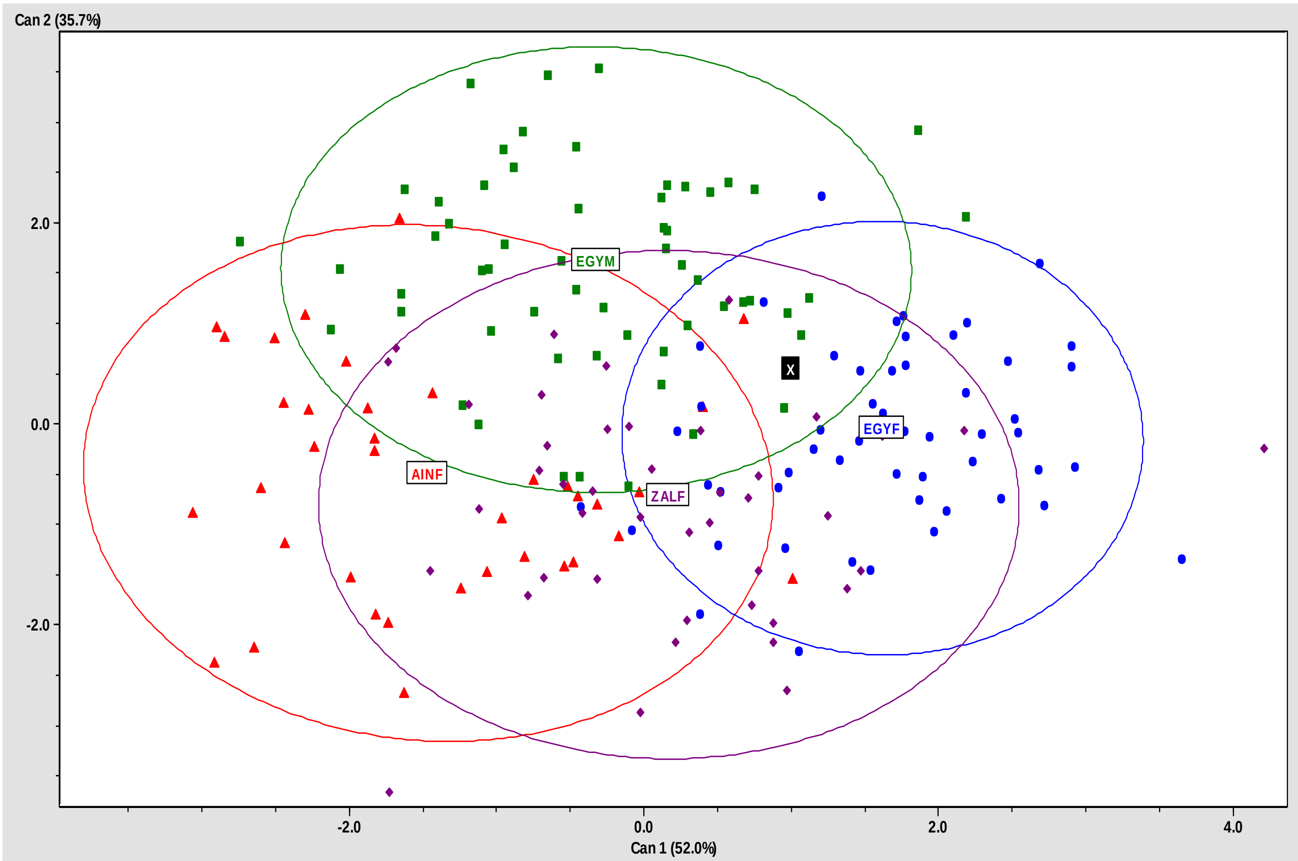

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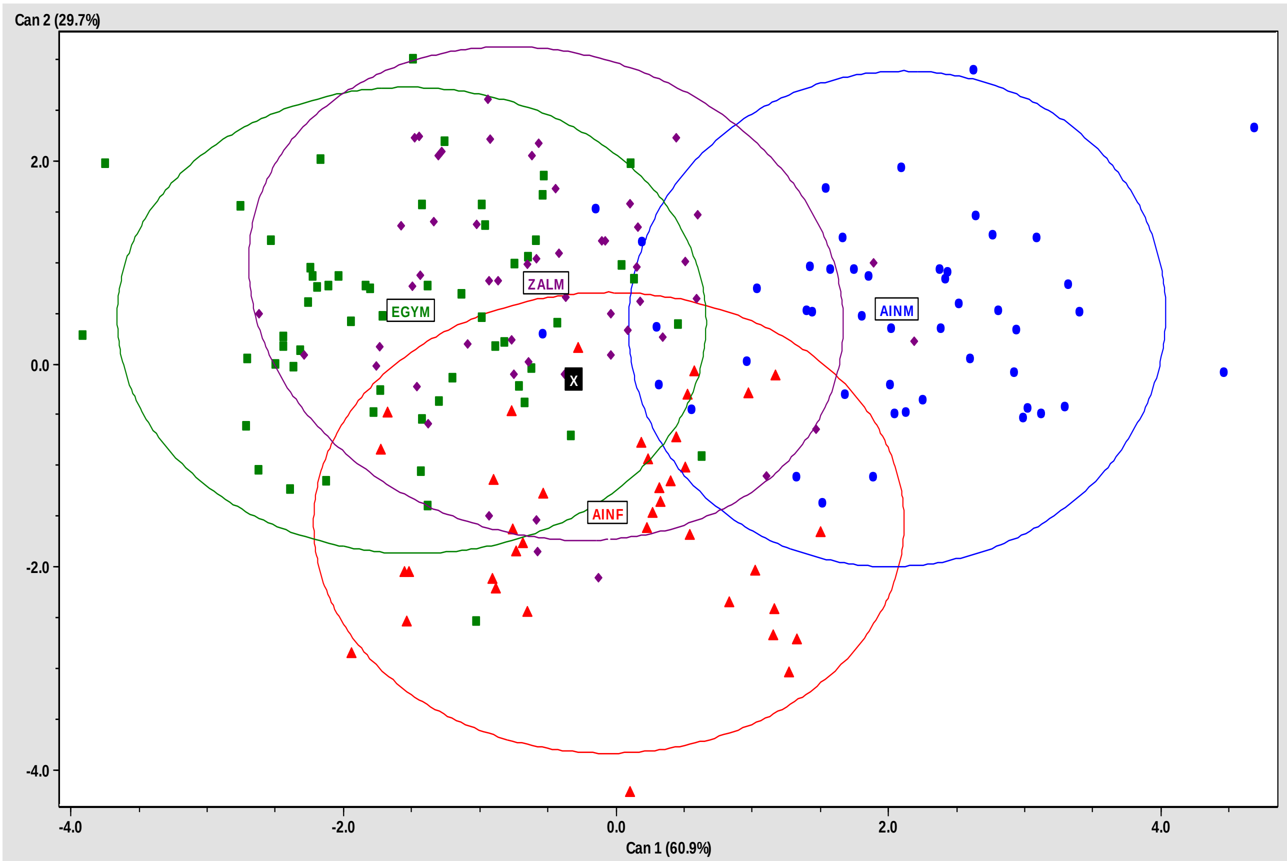

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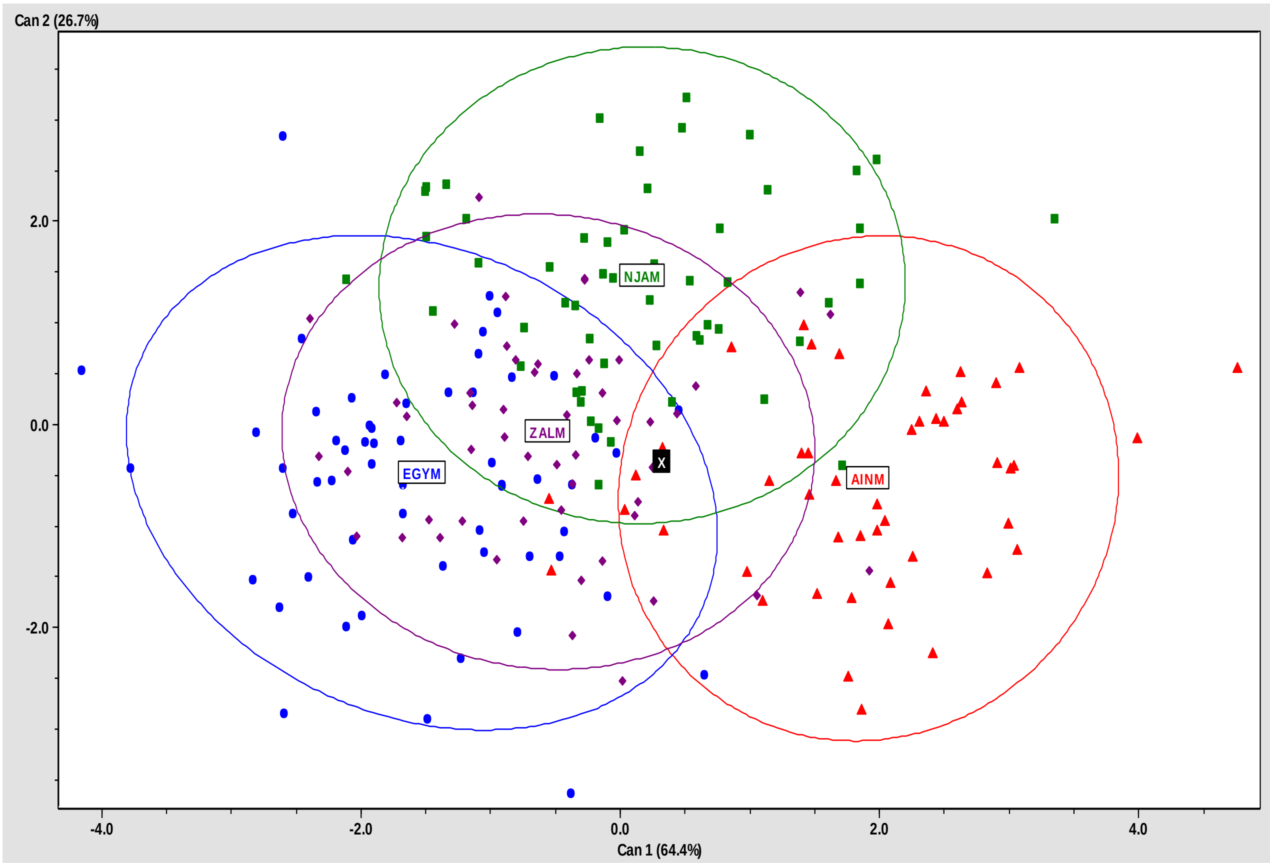

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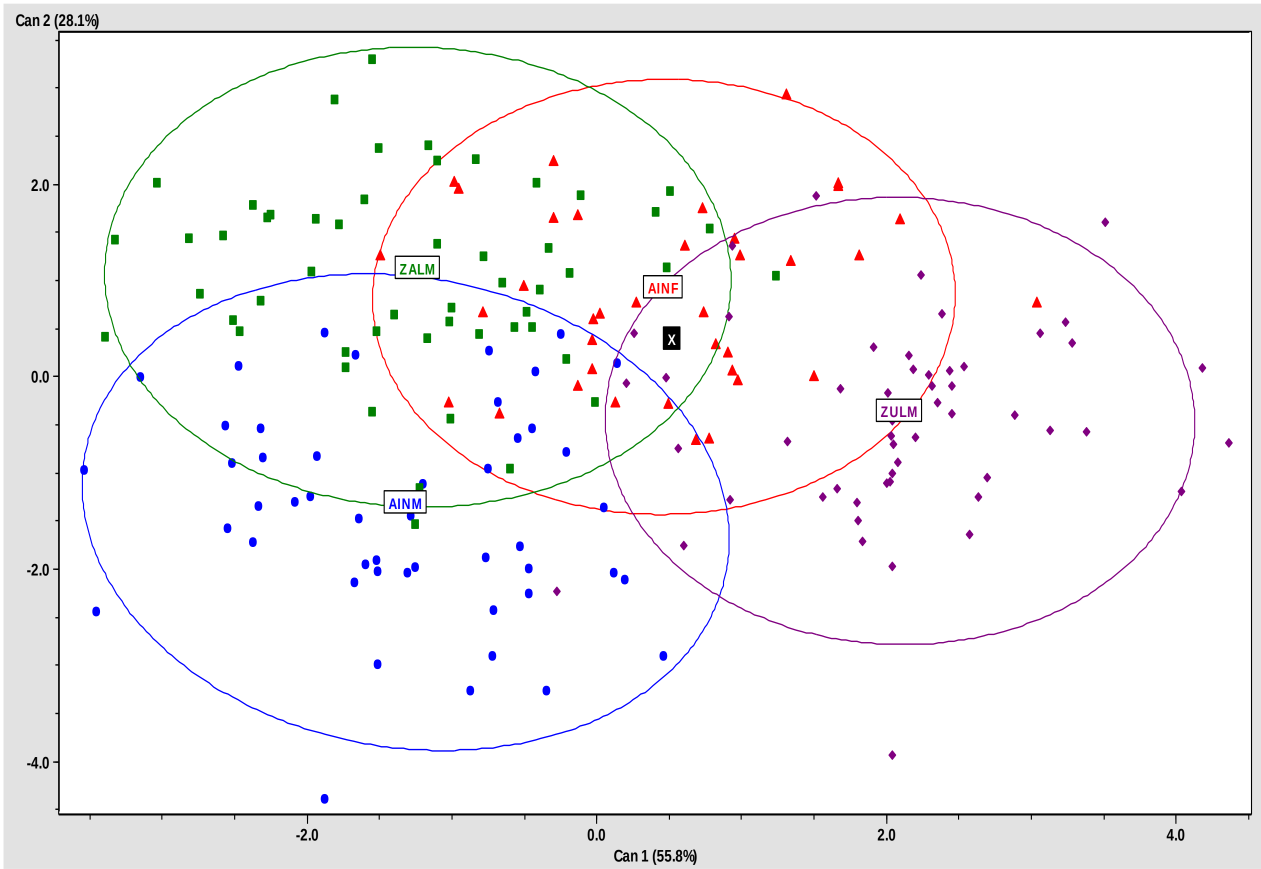

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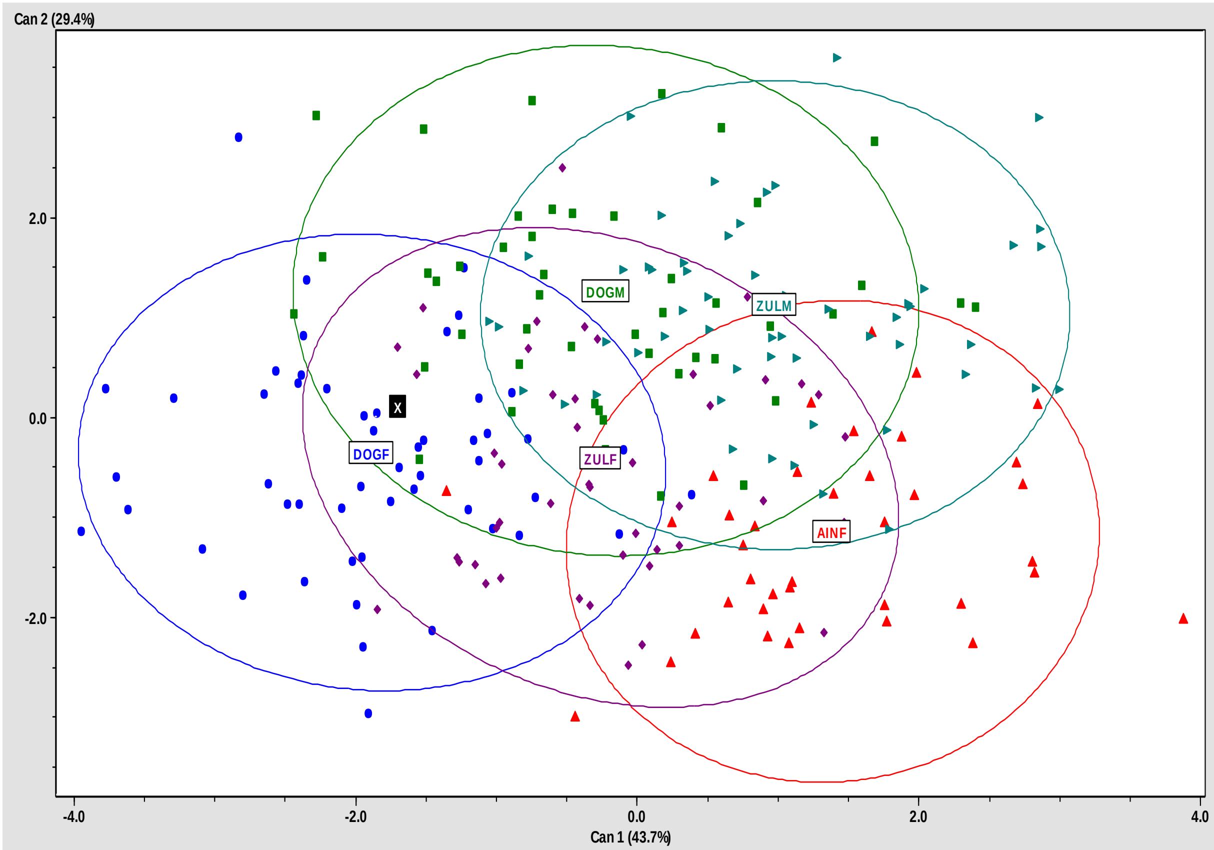
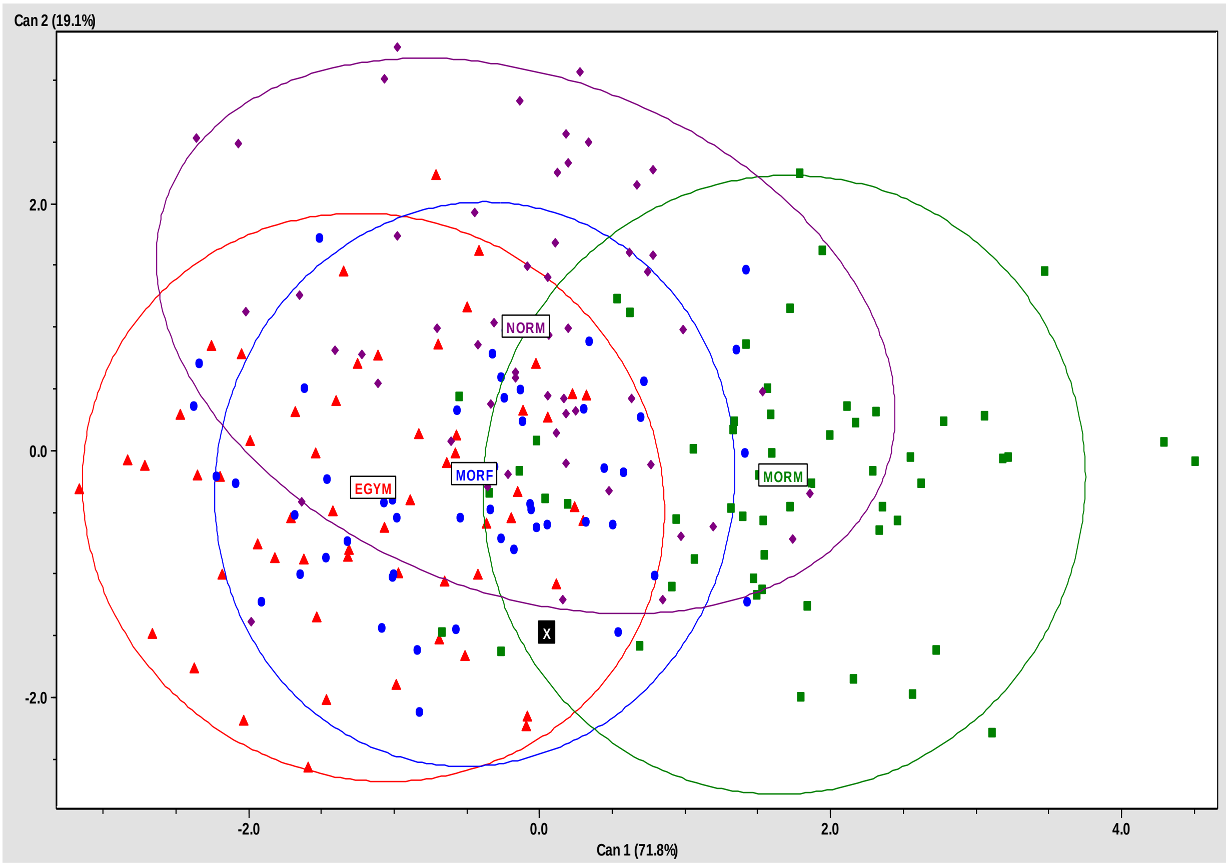


Can 2 (29.4%)
2.0
0.0
-2.0
-4.0
-2.0
0.0
2.0
4.0
Can 1 (43.7%)
DOGM
ZULM
DOGF
ZULF
AINF
X

AMSC 18



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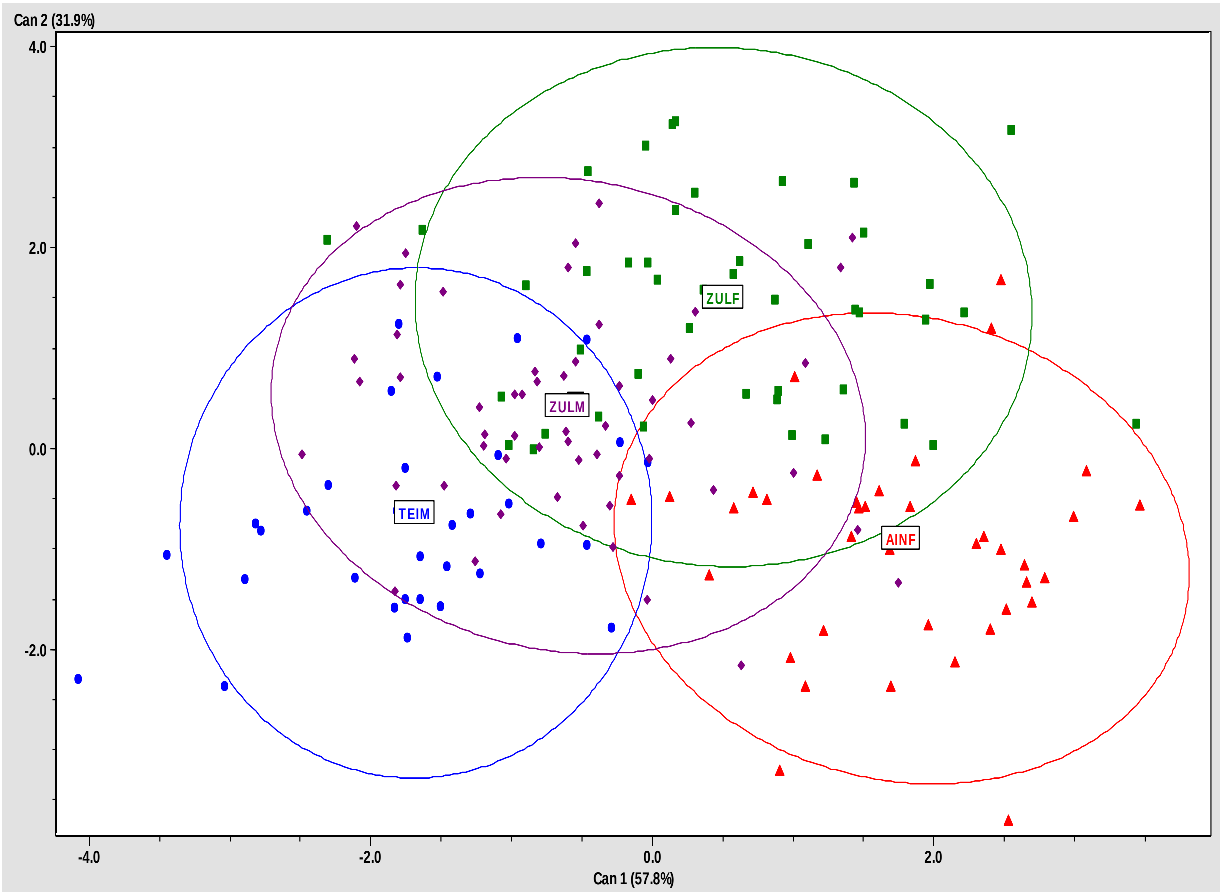
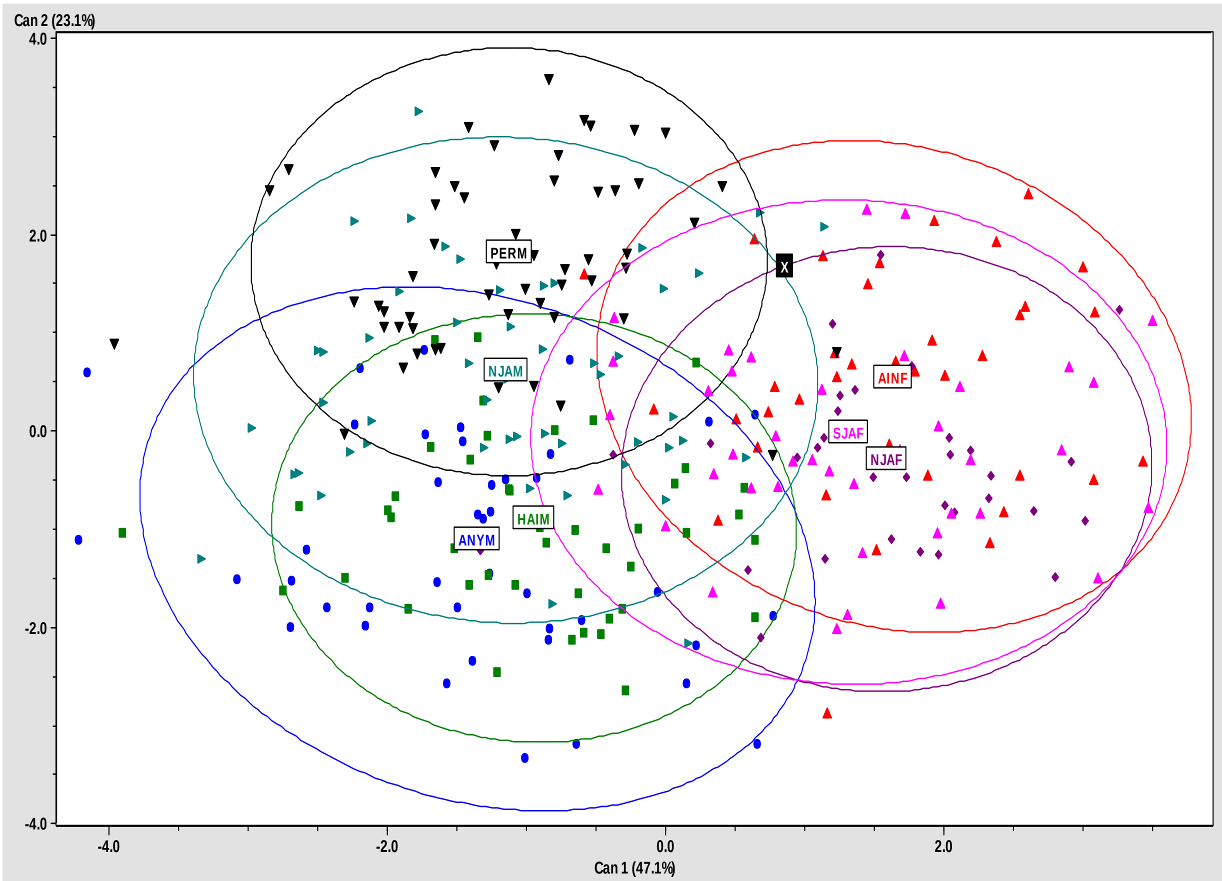
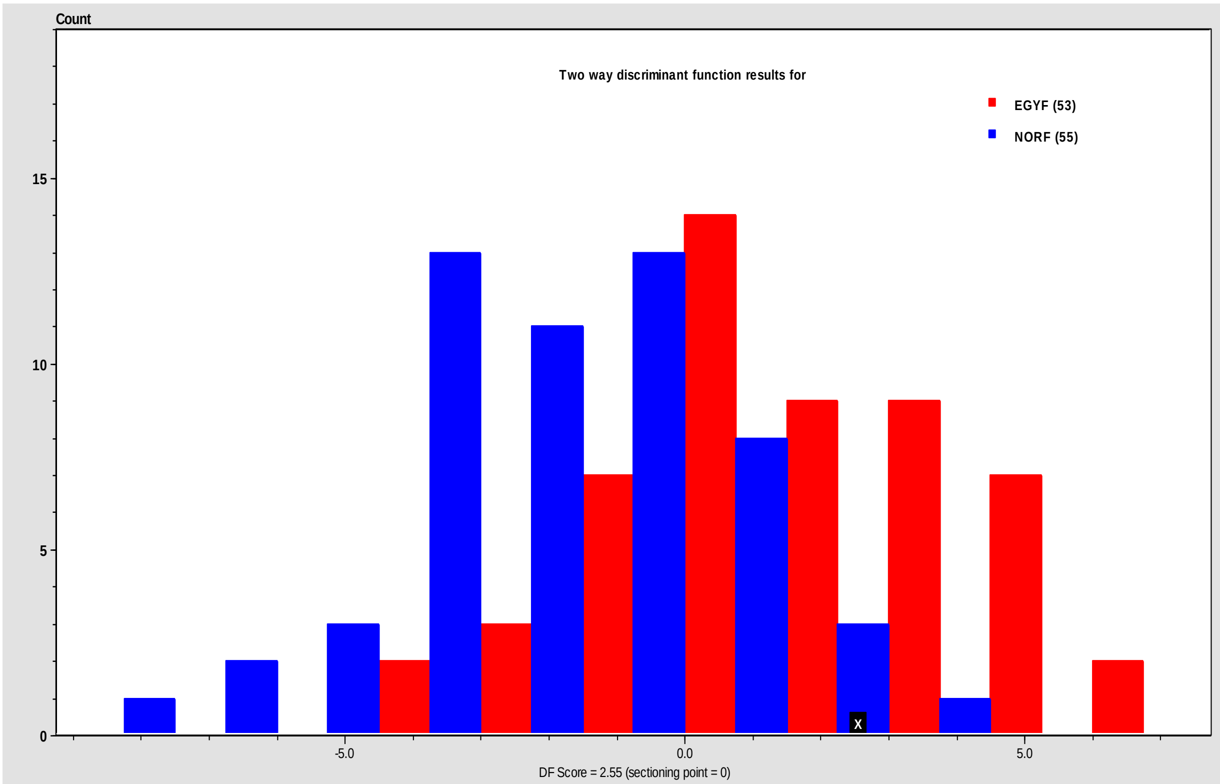


AMSC 20



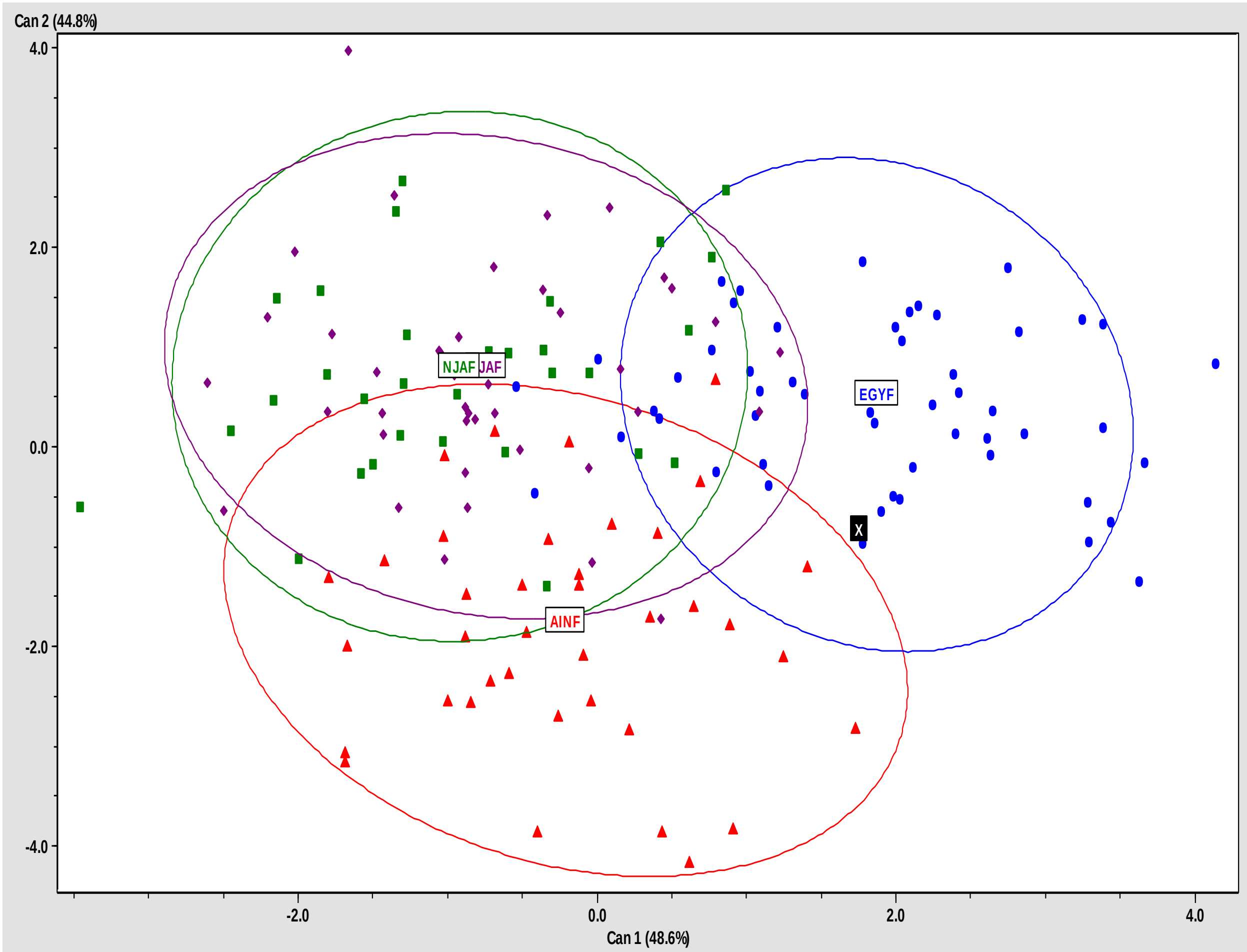
Can 2 (23.1%)
4.0
2.0
0.0
-2.0
-4.0
-4.0
-2.0
0.0
2.0
Can 1 (47.1%)
PERM
NJAM
HAIM
ANYM
AINF
SJAF
NJAF
X

AMSC 23

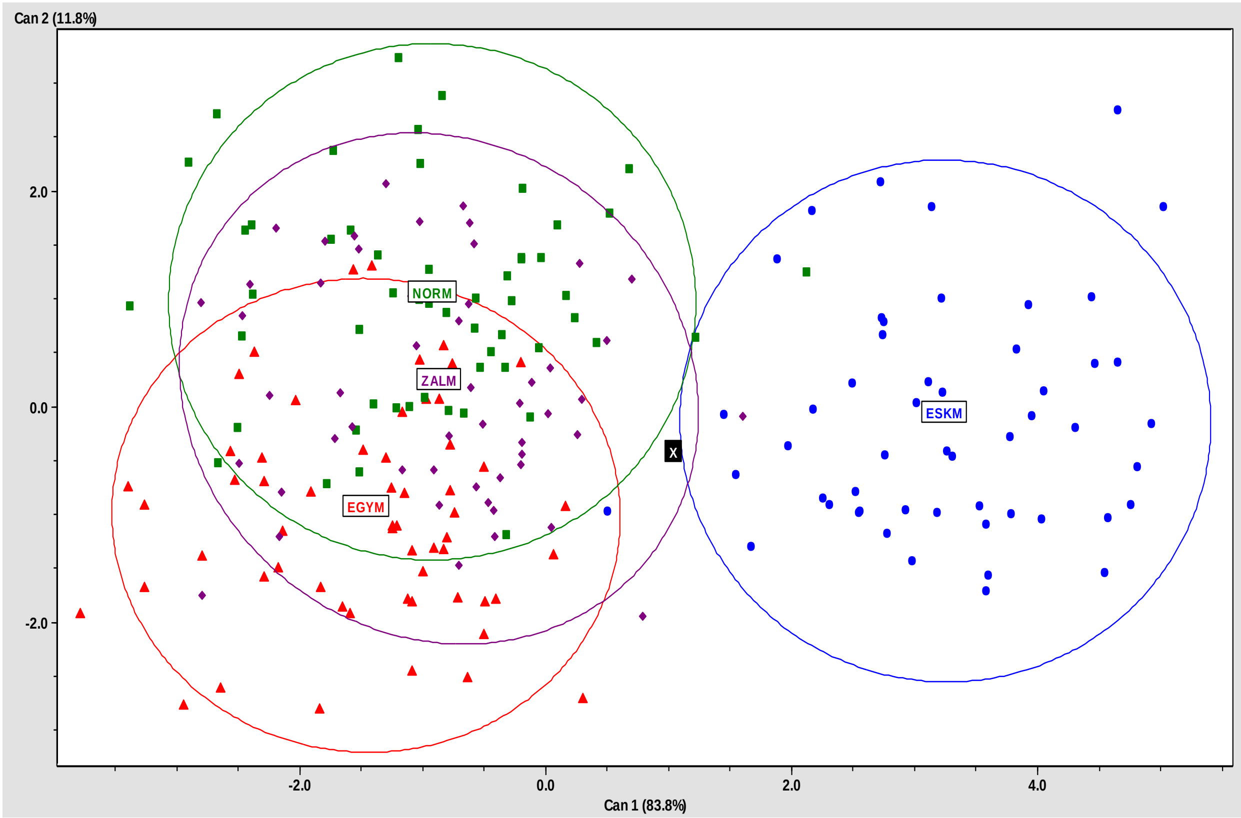


Count
Two way discriminant function results for
EGYF (53)
NORF (55)
15
10
5
0
-5.0
0.0
5.0
X
DF Score = 2.55 (sectioning point = 0)

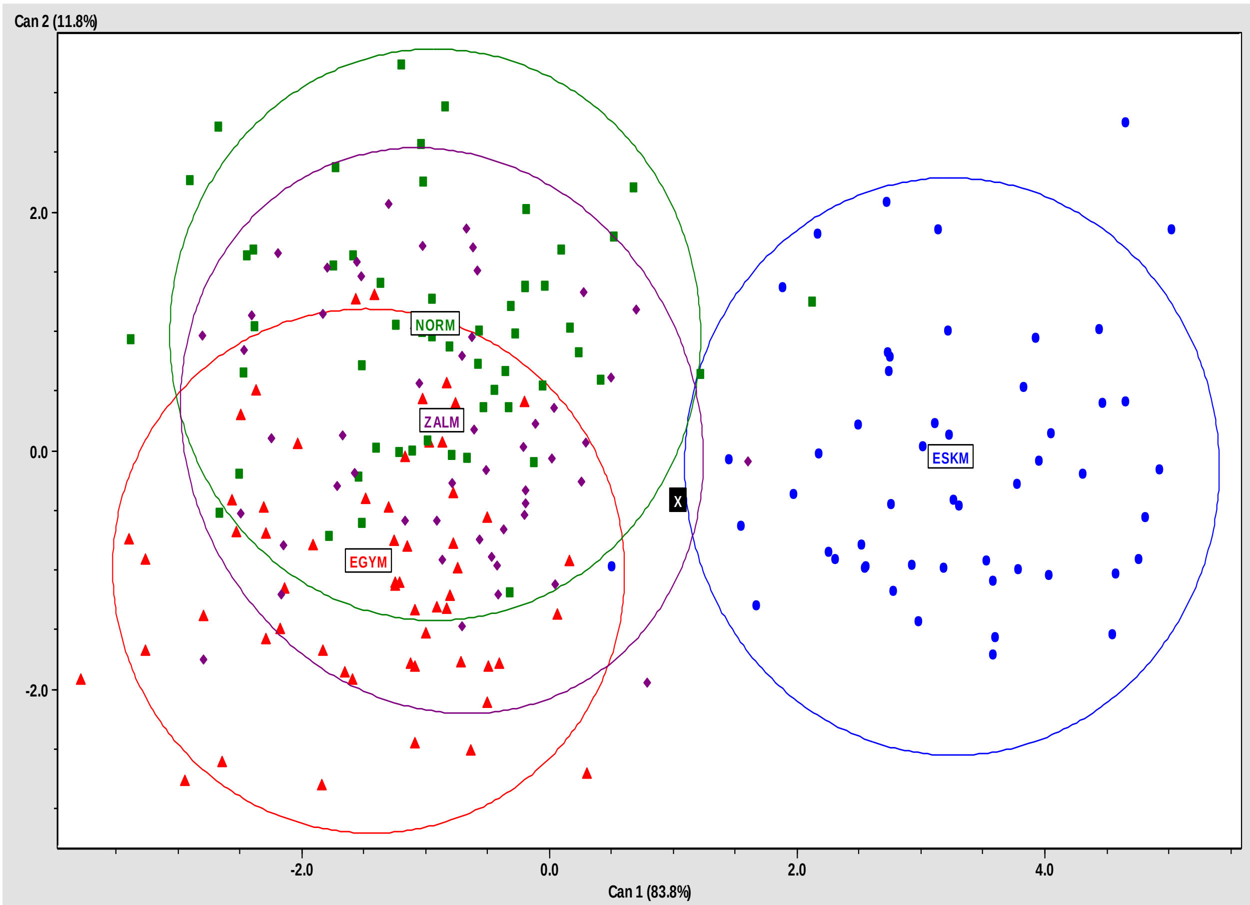
AMSC 25



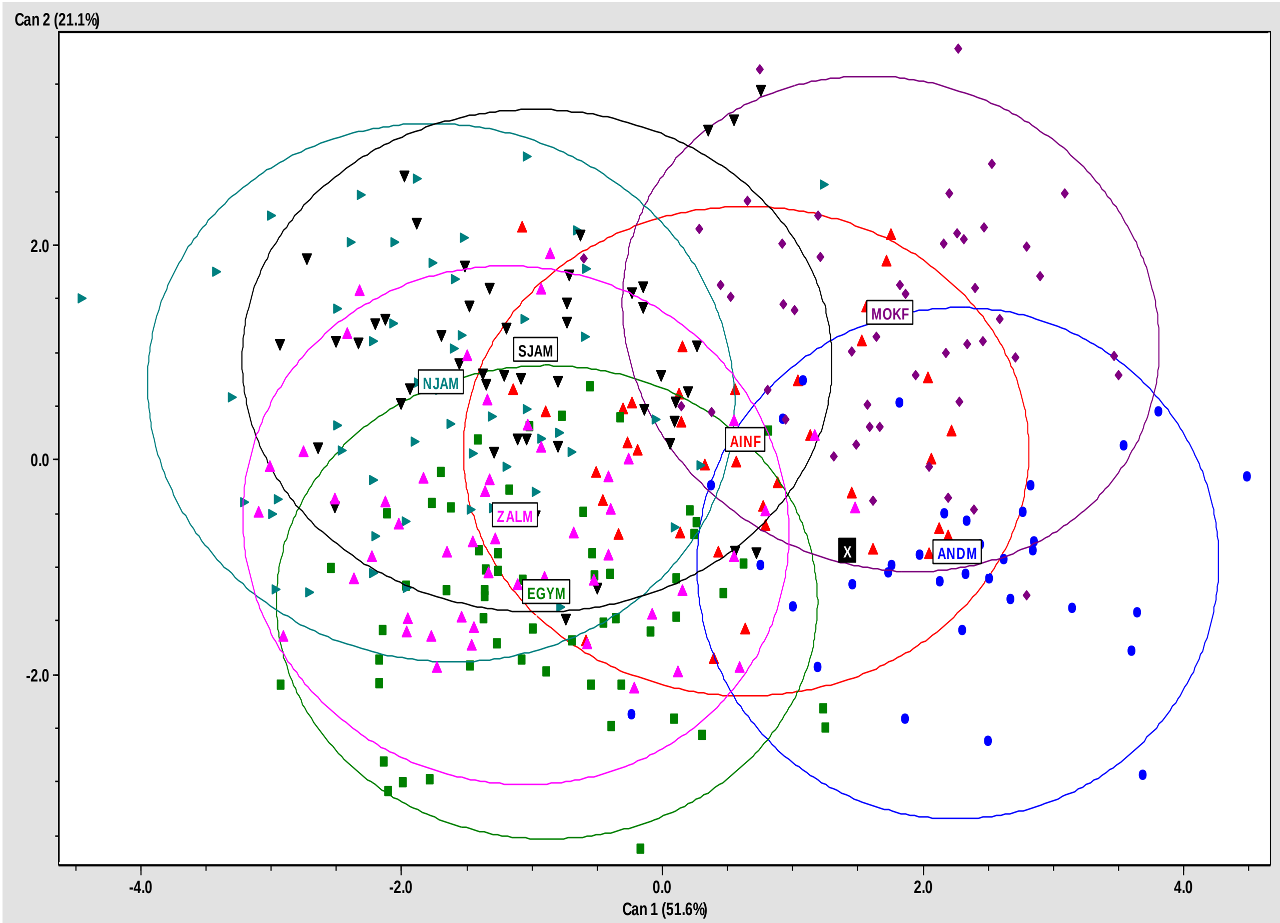
AMSC 27



AMSC 29



AMSC 30



Can 2 (21.1%)
2.0
0.0
-2.0
-4.0
-2.0
0.0
2.0
4.0
Can 1 (51.6%)
MOKF
SJAM
NJAM
AINF
ZALM
X
ANDM
EGYM