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Egyptian Mummy CT Scan Analysis and a Comparison of Midwest Museum Practices for the Grand Rapids Public Museum

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by

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Abstract

To meet the partial requirements for a Master of Arts degree in Anthropology from Western Michigan University, the following internship was completed between June 2015 and September 2016. A Computed Tomography (CT) scan analysis was conducted on the Grand Rapids Public Museum's mummy, Nakhte-Bastet-Iru. This analysis was a collaborative effort by myself and medical and museum professionals. Insight into the mummy's life and culture was uncovered through examination and analysis of paleoradiological views of her remains. Additional research into the practices of other Midwest museums provided valuable knowledge of current trends in the dissemination and exhibition of mummy CT scan data. This internship and research has highlighted the challenges of a mummy CT scan analysis as well as the benefits it can bring to a museum and the field of anthropology. The relationship between these institutions and discipline, which has deep historical roots, continues to provide opportunities to educate the public and further Egyptian mummy research through collaborative CT scanning projects.

Keywords: Egyptian mummy, Computed Tomography, Midwest Museums, CT scan

Egyptian Mummy CT Scan Analysis and a Comparison of Midwest Museum Practices for the Grand Rapids Public Museum

The Grand Rapids Public Museum (GRPM) desired to know more about the health and life of the Egyptian mummy known as Nakhte-Bastet-Iru that has resided in their collection since 1909. To do this, they employed the use of Computed Tomography (CT) with the assistance of Butterworth Hospital of MI, in March of 2015. Soon after it was clear that the interpretation of the CT scan was a far more complicated process than had been expected. To aid in this process I began an internship with the museum. My internship had two main goals: 1) to help in the anthropological interpretation of this scan; and 2) to also provide an outlook on how other Midwestern museums are using their CT scan data which would help the GRPM make decisions about their mummy exhibit and future research. Researching the contemporary practices of Midwest museums happened through in-person visits, website observation, and questionnaire research. This research, combined with the CT analysis case study of the GRPM's Third Intermediate Period (1069-664 BC) Egyptian mummy, provides a thorough examination of the practices in the Midwest along with the challenges and benefits of this very popular technique. Using the experience of my internship, I have determined that although a challenging endeavor, an Egyptian mummy CT scan has the potential to benefit both the museum employing the technique and the field of anthropology as a whole. The research conducted by anthropologists in conjunction with these institutions promotes interdisciplinary research and raises awareness of potential uses of modern research techniques.

In the paper that follows I will summarize the condition and paleopathological findings of the GRPM's mummy. I will also describe the process of the CT analysis, including the strengths, challenges, and limitations of dealing with this type of data. I will explain how the CT scan

analysis process, even the challenging aspects, can benefit the museum itself as well as the discipline of anthropology. The research and exhibit displays produced by these analyses provide opportunities for both the institution and the field of study to educate as well as promote their own interests. I will also present the results of my questionnaire and research of Midwest museum practices that describe how CT scan data and images are being incorporated into physical exhibits and other media. Additionally, this research discusses which methods Midwest museums have selected to use when opting to continue researching their mummies, after the CT scan.

Background

To understand why this project is a relevant topic to museum studies and anthropology it is first important to understand the long historical relationship between Egyptian mummies and the museum industry. This relationship was formed during the 18th century after the "rediscovery" of ancient Egyptian tombs and mummified citizens by the Western world (Raven & Taconis, 2005). The immense number of artifacts removed from Egypt required spaces and professionals to care for them, contributing to the creation of museums of natural history (Brier, 2013). These institutions were not only created to display artifacts to the public, but also were used as research facilities for many archaeologists and other researchers. This new area of research involving Egyptian mummies also contributed to the development of several academic fields of study, including Egyptology, bioarchaeology, and paleopathology.

Although these Egyptian artifacts may appear frozen in time, the 'museum' has evolved in many ways, primarily in the most recent decades. There are now many types of museums that house Egyptian collections. There are still the natural history sort, but also some that cater more directly to Egyptian collections, such as the Oriental Institute in Chicago, IL. There are museums

of archaeology, those that specialize in a particular region of the world, and even museums that deal primarily in death and human remains. Museums now also come in different sizes and are funded by different sources. Some are enormous classic facilities that house millions of artifacts like the Field Museum in Chicago, and others are local museums that although valuable in their own right, have smaller collections, such as the GRPM. Museums have also evolved in the way they research and display these collections, particularly with the most recent use and incorporation of biomedical sciences.

What has not changed is the public's adoration for ancient Egypt and most of all for the Egyptian mummy. The Egyptian mummy remains a staple for museums large and small, all-inclusive or specialized. Within these museums one particular research method has become increasingly popular to utilize on mummies. The biomedical technique known as the CT scan is used to examine the health and burial assemblages of these ancient individuals. This technique allows researchers to non-invasively study the human remains, while also creating new visual material for museum exhibits. Museums that CT scan may choose to expand or improve their mummy or Egyptian exhibit by adding images of their findings. They can display 2D cross sections of the body that show features of the mummification process, such as the empty cranium and route used for brain removal (Loynes, 2015). Any evidence of disease or trauma can be displayed from CT slices of the tissue, bones and teeth (Hawass & Saleem, 2015). Cultural items may also be highlighted. There is also the option of displaying 2D images of 3D models. These 3D models can display the surface of the skin or just the skeletal features depending on what is calibrated (Conlogue, 2015). Three-dimensional models can be saved in "movie" format which does not require a special viewer. They can then be displayed like any other video clip on a mounted TV screen, monitor, or tablet device. Sharing these CT scan images and the knowledge

gained from them helps to educate visitors on mummification practices and ancient Egyptian health. These displays also help to validate the mummy's presence on display and offer insight to visitors on the fascinating mummy research being conducted by multiple disciplines.

These were some of the goals for GRPM with the CT scan of its mummy, Nakhte-Bastet-Iru (Figure 1). She was donated to the museum in 1909 by Edward Lowe, a local Grand Rapids businessman. Mr. Lowe acquired Nakhte's mummified remains from a store in Cairo, Egypt, while on vacation. Her provenance has been supported by an examination of the style and inscriptions on her cartonnage and coffin (Richards, 1996). These indicate she was the daughter of a priest and lived in the city of Thebes (Figure 2). As the daughter of a priest she would be considered middle to high class. The high quality of her linen wrappings and mummification also support this status (Richards, 1996). Through this cultural material it is also estimated that she lived during the 22nd Dynasty (946-712 BC) of the Third Intermediate Period (Figure 3). Previous analysis of cranial and dental x-rays by a biological anthropologist confirmed Nakhte's sex as female and estimated her age at between 18-21 years at the time of her death.

The literature review that follows describes context in which to better understand the mummy Nakhte and her culture. It also expands on the summary above, highlighting the chronological history of the museum and Egyptian mummy relationship as well as the trends in research applied to these mummies. The final section introduces the ethical issues that surround the study of mummies, which museums must be cognizant of, and the recent critiques of museum CT scan usage.

Literature Review

Daily Life of Upper Class Ancient Egyptian Females

Some aspects of Nakhte's daily life may be visible on her skeleton or verified by the cultural material used in her mummification. For example, if she had performed strenuous, or a lifetime of repetitive motions as part of daily work, skeletal markers may be present at her joints (Buikstra & Ubelaker, 1994). Similarly, if Nakhte had periods of poor nutrition there may be evidence on her teeth and long bones (Buikstra & Ubelaker, 1994). To better estimate the qualities of her life, the following is a summary of what is known about upper class activities in ancient Egypt. During the period under question (i.e., Third Intermediate Period), a woman of the upper class in ancient Egypt would have been in charge of the servants in her household and lived a rather easy life. She would have been expected to produce a large family although servants would perform most of the childcare including nursing (Graves-Brown, 2010). An upper class woman could probably read and write and spent most of her time indoors (Graves-Brown, 2010). Domestic violence was common in this time, even between the Mistress of the House and her servants (Graves-Brown, 2010). Hieroglyphics on Nakhte's coffin, indicate she was the "Mistress of the House." Women could divorce, inherit property, disinherit their children, and bring legal actions to court, although to a lesser degree than their male counterparts (Graves-Brown, 2010). Elite women could hold some occupations such as that of a priestess, but it was rare (Brier & Hobbs, 2008). The upper class ate a diet of bread, wine, fowl, milk and a variety of fruits, vegetables, and spices (Brier & Hobbs, 2008). Elite women at this time preferred to dress in white draped dresses, wore abundant jewelry, and used cosmetics often made from fat to color their nails, lips, and eyes (Brier & Hobbs, 2008). Interestingly, the danger of giving birth was equal among all classes of women and their leading cause of death (Graves-Brown, 2010). This

context helps to provide insight into the lifestyle of Nakhte and highlight possible cultural explanations for the physical findings in her CT scan. An understanding of the embalming process performed on Nakhte after her death is equally important and follows below.

Ancient Egyptian Mummification Techniques

The first evidence of artificial mummification in Egypt dates to around 3050 BC (Aufderheide, 2003). Egyptians at this time believed that the pharaoh was a deity and would be judged in the afterlife. They desired to retain their human characteristics in the afterlife, and mummification became a means to preserve their appearance. Methods of mummification are poorly documented by ancient Egyptians. They were secretive about these methods, but some papyri do exist that mainly describe ceremonial practices (Peck, 2015). Through bioarchaeological investigation embalming methods are seen to progress and change through ancient Egyptian history, with real "steps" apparent by the New Kingdom (1550-1077 BC) (Peck, 2015). These steps included extraction of the brain (excerebration) and organs (evisceration), dehydration of the body with a naturally occurring mineral mixture called natron, packing the body with stuffing, anointing the body with oils and perfumes, applying resin to the skin, and finally wrapping the body in linen (Peck, 2015).

Common practices of evisceration and excerebration continued into the Third Intermediate Period, the period in which Nakhte lived. The major shifting trend was an increased desire to better retain the physical appearance and structure of the mummy. One hypothesis is this change was a result of tomb raiding beginning in the 21st dynasty, which revealed subpar preservation of mummies (Dunand & Lichtenberg, 2006). The new practices included subcutaneous packing to better retain the shape of the body and face. Packets were filled with various substances such as sawdust, clay, sand, resin, and linen (Dunand & Lichtenberg, 2006;

Raven & Taconis, 2005). Other new practices were the use of artificial eyes and painting of the skin (yellow for females) (Dunand, & Lichtenberg, 2006). The Leiden Museum in the Netherlands found varying degrees of these signatures in their Third Intermediate Period mummies, and also include the placement of hands on the thighs as the most common position for this time (Raven & Taconis, 2005). Another major change to mummification in this period was that the viscera were no longer placed in canopic jars; instead they were wrapped in linen and returned to the abdominal cavity (Dunand & Lichtenberg, 2006). The 22nd Dynasty also marks the significant use of a cartonnage covering for the mummy, made from compressed cloth and plaster and tied in the back with lacing (Dunand & Lichtenberg, 2006). A cartonnage alone would indicate a cheaper option for middle or lower classes (Dunand & Lichtenberg, 2006). Identifying mummification techniques in mummies is a common way to date the mummy and make statements about social class. The cultural report prepared by Dr. Richards (1996) analyzing Nakhte's coffin and cartonnage allowed for dating and class to be established, but the internal features visible though the CT scans can give even more insight and confirm these analyses.

Early History of Mummies, Museums and Egyptomania

The mummification techniques described above were rather successful. Hundreds of thousands of mummies and their burial goods have been preserved for centuries, often even for several millennia after their deaths. Hundreds of these Egyptian mummies currently reside in museums around the world. Since this internship seeks to examine the current role of museums in mummy CT scanning, an understanding of how and when this relationship evolved is important. First though is a brief explanation of the infatuation with Egyptian culture that began much earlier than the 18th century and later became known as "Egyptomania" (Brier, 2013).

Most scholars associated with mummy research are familiar with the earliest written foreign accounts of mummification through the eyes of Herodotus and are not shy about citing the Greek historian (Brier & Hobbs, 2008; Davey et al. 2014; David, 2008; Fagan, 2004; Myśliwiec, 2000). Herodotus traveled to Egypt in 450 BC, when the pyramids were already 2,000 years old and the practice of mummification even older. These first accounts by Herodotus (1987) began an obsession with ancient Egyptian culture that persists today. The Greeks and Romans continued this fascination with ancient Egypt throughout their eras of occupancy in the region, and for the most part preserved and admired the culture (Brier, 2013; Fagan, 2004).

In the 4th century AD Rome became Christian and subsequently Egyptian religion was forced to decline, leading to an eventual loss of the understanding of hieroglyphics and the outlawing of mummification (Brier, 2013). By the early Middle Ages, all traces of Egyptian religion and knowledge of the ancient culture had vanished, except for vague biblical references (Brier, 2013). Desert sands covered temples and those uncovered were often quarried to build new structures (Fagan, 2004). By the 7th century, Islamic rule came to the region, but tourist travel remained unsafe until the 11th century AD (Fagan, 2004). Egypt was largely forgotten by Westerners. It was not until the 14th and 15th centuries that renewed interest occurred. This rediscovery was primarily due to the trade of a petroleum based substance called bitumen that was used extensively for medicinal purposes by Westerners. Western merchants thought the dark coating on Egyptian mummies was bitumen, although it was actually resin, a plant based substance. Despite their error, mummies began to be sold and used to make medicine, referred to as “mummia” (Raven & Taconis, 2005). This mummia, which was produced by grinding up the mummy, peaked in use by the 16th and 17th centuries, but continued to be found in apothecaries into the current century (Fagan, 2004). The influx of mummia into Western states sparked

renewed curiosity of Egypt. As a result, small collections of antiquities also began to be transported out of the country and were put on display, becoming the basis for future museums (Fagan, 2004). During this period mummies also began to be unwrapped by Westerners in search of valuables (Fagan, 2004). By the Enlightenment period in the late 17th century, a new focus on disease and the body began inspiring the dissection of these mummies as well (Riggs, 2014). By the 18th century, mummies were bought as tourist souvenirs by Westerners and unwrapped out of curiosity and public attraction (Fagan, 2004; Raven & Taconis, 2005). It is also during this time that collecting antiquities became a full-time profession due to the high volume of artifacts and mummies being removed from Egypt. Soon national museums in major European cities began to take form (Fagan, 2004).

Mummia was not the only factor that led to 18th century Egyptomania and the subsequent creation of museums. Colonial rule in Egypt was highly influential to this development as well. Specifically, when Napoleon invaded the region in 1798 and defeated the ruling Muslim Mameluke group, he brought with him a team of scientists and artists to study and record the remnants of ancient Egyptian culture (Brier, 2013). The British later took control of Egypt creating a competition for antiquities, although most went to the British Museum after 1801.

By the 19th century European and American medical practices exploded and the need for cadavers for dissection permeated the medical field, leading to grave robbing and even murder. This need for dead bodies to study led to research using Egyptian mummies. In spite of this new practice, the majority of mummies were still unwrapped and dissected not for research, but out of curiosity and for spectacle. These events often occurred in homes or museums and were highly advertised to the public. By the 1840's so many unwrappings had occurred that even newspapers tired of the hype, since little "payoff" from such events occurred (Riggs, 2014). The media

coverage may have declined, but the practice persisted (Riggs, 2014).

Unwrapping events, which treated mummies in a rather casual way, created a normalizing effect in regards to ancient Egyptian mummies in Western countries. As wealthy mummy owners tired of the responsibility of such commodities in their possession they began to donate them to museums which led to the "artifactation" of the mummy (Riggs, 2014). Tourism and archaeology in Egypt continued to flourish into the mid-19th century and the Museum of Egyptian Antiquities in Cairo was established then as well. Museum collections continued to grow, due in part to a deal brokered between Western sponsors of archaeological digs and the Egyptian government, where Egypt kept half of all discoveries and the other half left the country (Riggs, 2014). As museum collections grew, the need for separate collections areas also grew; specialized curators and preservation techniques became necessary.

It cannot be said that no scientific knowledge was gained through mummy unwrappings and dissection prior to the 20th century, however examples are far and few between. In the 1790's, the German scientist Johan Blumenbach researched mummies to contribute to the growing field of physical anthropology, mostly by looking at race through craniometrics (Riggs, 2014). A British medical doctor, Augustus Granville, unwrapped mummies in his London home in 1821 in front of numerous colleagues, and described the wrapping process, sex of the mummies, took measurements of the pelvis for racial determination, and even pressured museums to disseminate his findings to the public (Riggs, 2014). It is not until post-1900 though when the majority of scientific studies of mummies began, stimulating the development of new sub-disciplines through collaborative work between historians, medical doctors, scientists and museums.

20th Century Museums and Mummy Research

There were many researchers of the 20th century who helped to shape and unite the burgeoning disciplines of paleopathology and Egyptology. Much of this research was performed in collaboration with the museums who housed these collections. The following is a summary of the most influential anthropologists and doctors of this era that contributed to the growth of paleopathological Egyptian mummy studies. By 1900, the study of mummies became more scientific in nature, partly due to the use of x-ray technology; invented in 1896 (Raven & Taconis, 2005). The first to utilize this technology on Egyptian mummies was Elliot Smith in 1900, and he meticulously documented his findings (Riggs, 2014). In the beginning of the 20th century, the interest in the study of ancient "race" preoccupied many anthropologists. Researchers often focused on describing the Egyptian mummy's hair, skin color, and genitalia (Riggs, 2014). Slowly though, the focus increasingly shifted to disease. A colleague of Smith's, Marc Armand Ruffer, coined the term paleopathology during this shift (Riggs, 2014). Ruffer's research involved rehydrating mummy tissue. Through his technique, he was able to diagnose spondylitis, kidney stones, cirrhosis (Riggs, 2014), smallpox, schistosomiasis, arterial lesions, and osteoarthritis in Egyptian mummies (Sandison, 2012). Another early influential paleopathologist was Roy Lee Moodie. Within Egyptian research, Moodie is best known for his 1923 volume *The Antiquity of Disease* which included a collection of Ruffer's papers as well (Cook, 2012).

By the 1930's a move toward more multidisciplinary study was underway (Raven & Taconis, 2005). Eugen Strouhal was another pioneer in paleopathology fascinated with ancient Egyptian human remains (Zink, 2012). A professor and curator at institutions in Russia and Prague beginning in the 1960's, he conducted field schools in Nubia, studied craniometrics, dental pathologies, tuberculosis, tumors, and violence (Zink, 2012). Strouhal is most credited

with having detailed and precise research methods, as well as forwarding the ideas of differential diagnosis and the replication of results (Zink, 2012).

During the latter half of the 20th century the study of Egyptian mummies became rather medicalized. Researchers donned medical attire and used surgical tools during dissection (Riggs, 2014). Additionally at this time, the use of radiocarbon dating, chemical analysis, and eventually CT scanning begins. As research techniques have advanced through the 20th century, access to Egyptian mummies has declined. The steady supply of mummies to museums from archaeologists and tourists initially began to slow in the 1920's, after the first major Egyptian antiquities legislation was passed (Riggs, 2014). This slowing trend continued through the decades and culminated in 1983 with an Egyptian act that banned all illegally traded antiquities (Riggs, 2014). Despite the fewer number of mummies to study, the legitimizing of mummy research as a medical endeavor continues to the present day with the increased use of biomedical technologies.

Current Methods and Research

During the last 15 years mummy research has relied heavily on CT scanning and other contemporary technologies. This trend in utilizing non-invasive methods has grown in popularity since the use of radiographs (x-ray) began in the early 20th century. Radiographic mummy studies are still used today and often as a precursor to CT scanning to identify areas of interest. The portable x-ray machine has its benefits since it is mobile and can be used on site, which is less expensive than other methods (Raven & Taconis, 2005). Some of the newest technologies that have been applied by mummy researchers which may have potential for more widespread use in the future are Terahertz imaging (Öhrström, 2015) and Magnetic Resonance Imaging (Rühli, 2015), although currently CT imaging capabilities surpass them. Endoscopy, which is

minimally destructive if performed carefully, can also be an excellent tool for internal examination and biopsy of mummies (Beckett, 2015). David (2008) gives a thorough examination of current research methods being used on Egyptian mummies, both destructive and not, including DNA analysis, microscopy, and histological. Computed tomography continues to be the most popular paleoradiological technique for several reasons. Scanning by CT allows for 3D digital reconstructions, the density of materials to be determined, the best resolution of images, and no overlap as seen in x-ray imaging (Raven & Taconis, 2005).

It should be noted though that the application of this technology on mummies is not exempt from criticism. A strong critical analysis of the CT scanning trend comes from Cox (2015), who describes many caveats to this type of research. Some of the issues discussed are that uniform research methods are not being used across the field, the understanding of taphonomy and embalming methods of mummies is poorly documented, and the use of single case studies do not allow for meaningful assumptions to be made on the population level (Cox, 2015). Pringle (2001) describes a conversation with paleopathologist and mummy specialist Arthur Aufderheide who stated that CT scans cannot compare to the knowledge gained through dissection. He suggests also that CT scans generate “more information of anthropological interest than biomedical data” (Aufderheide, 2003, p.20). There is also a growing understanding for what Lonfat et al. (2015) describes as “harm to personal identity” through the exposure of personal health information such as revealed from a CT scan (p.1176). These are not new notions, as the principles have been acknowledged in biomedical ethics for centuries, yet only recently have been considered in regards to ancient human remains (Lonfat et al., 2015). Since these criticisms of CT examination exist, it is important to question whether or not this technology is growing in efficiency. Conlogue (2015) does this by pointing out the difficulties

associated with CT scan use in mummy studies including the time consuming nature and experience required to analyze images, the need to use proper settings for best results, and challenges of limiting radiation output. All of these concerns should be reviewed by museums and researchers considering the use of CT technology.

Despite recent scrutiny into CT use, many CT studies have provided exceptional data and highlight the various types of pathological conditions that can be identified. The following examples gave an excellent guide for the possibilities and limitations in interpreting the scans of Nakhte. A study by Wade et al. (2012) examined three mummies from the Redpath Museum in Montreal comparing the CT findings to what provenance was known for each. They examined how previous museum research and documentation of these mummies matched with commonly cited and accepted Egyptian mummification knowledge. The authors found that social class was often inaccurately assumed and the practice of heart retention poorly understood (Wade et al., 2012). This study shows the importance of examining individual mummies to add to the bulk of mummy knowledge, especially in regards to old assumptions on mummification practices.

In *Egyptian Mummies*, a thorough analysis is given of a collection of mummies located at the Leiden Museum in the Netherlands (Raven & Taconis, 2005). The CT study by Raven and Taconis (2005) of 29 complete mummies plus eight additional mumified heads, revealed the material of amulets through density analysis, sex through pelvis examination, age via dental eruption and epiphyseal disc formation, degenerative disease markers, stress assumptions based on Harris lines, embalming methods from wrappings, incisions, and fillings, and stature and cranial findings through measurements. As for preservation of tissue, the researchers found that the longest muscles preserve the best, and in some instances the meninges of the skull and muscle tendons will remain. Other paleopathological findings from the scans include biparietal

osteodystrophy, impacted teeth, and metopic suture retainment.

Many other studies have identified pathology in ancient Egyptian mummies with CT technology. Orthopedic diseases have been researched in a CT study of 50 Egyptian mummies by Fritsch et al. (2015). Davey et al. (2014) used CT scanning to look specifically at teeth exfoliation in children and the potential of antemortem and postmortem trauma as the cause. One of the most praised studies is dubbed the Horus study which examined atherosclerosis, comparing levels in ancient Egyptian mummies with modern populations (Thompson, 2013). Most of these studies involved multiple mummies which differs from this single mummy case study of Nakhte. The examples of pathological findings though, provided an ideal of what was possible to detect in Nakhte's CT scan.

There are two recent full-length publications, the firsts of their kind, which cover exclusively CT scanning of Egyptian mummies. Both of these texts can be considered among the first guides to CT scanning Egyptian mummies which may be used by researchers to aid in interpretations. *Scanning the Pharaohs* (Hawass & Saleem, 2016) is a collection of royal CT case studies that are examined by time period. Each mummy's history is described and the CT findings by anatomical location. *Prepared For Eternity: A Study of Human Embalming Techniques in Ancient Egypt Using Computerised Tomography Scans of Mummies* (Loynes, 2015) covers the scans of 60 Egyptian mummies. This text is organized by anatomical region including head, trunk, skin and soft tissues, identifying variations of mummification techniques by time period for each body location (Loynes, 2015). Special techniques and geographical variation are also covered. Both texts use CT scan slices to illustrate the mummy's findings and explain their methods. Loynes (2015) particularly aims to provide population level information, at times grouping mummies by period and geographical region to speak more directly to trends

among these subsets. These recent contributions to mummy research literature are the product of the need for standardized methods in mummy CT studies and clarification of techniques. They were also the most useful guides employed in the CT scan analysis for this project.

Other, although rarer research techniques being used today include the use of cadavers to recreate mummification practices. The most famous study is that by Bob Brier, whose team produced their own modern mummy by using ancient Egyptian mummification techniques. Recently their modern mummy was studied with CT scanning to compare the effectiveness of the technology in interpreting the mummification process (Wade et al., 2015). Another study by Peacock et al. (2011) recreates the "Opening of the Mouth" ceremony on human heads to identify if the mutilation seen in some mummies was a purposeful attempt to allow the mandible to remain open.

Future of Egyptian Mummy Research

A hindrance to the future of mummy research is an overreliance on some of the early works. For example, Fagan (2004) goes so far as to say that the old accounts of Herodotus haunt the discipline, since they are relied on too heavily and without factual corroboration. Recently there have been challenges to these old stereotypes of mummification knowledge. Wade and Nelson continued the work of their 2012 study mentioned above. They produced a synthetic study comparing the declarations made by Herodotus and other ancient historians on the mummification processes that are highly cited today, by using the IMPACT database (Wade & Nelson, 2013). The IMPACT database is a compilation of mummy data and CT scans from dozens of museums and is available online to researchers (Nelson & Wade, 2015). Studies like these, which compare findings of multiple mummies are a trend in the discipline. The continued push for collaborative databases like IMPACT and The International Ancient Egyptian Mummy

Tissue Bank (David, 2008) are the product of ambitious attempts to produce research on populations of mummies and subsequently have more meaningful conclusions about Egyptian health and life.

Studies of taphonomy are also of great importance to the future of mummy studies. Much of Aufderheide's (2011) work describes the diagenetic and structural changes in mummies to better understand what is preserved over centuries. In particular, he found that the changes brought on by death to the body, including enzyme, bacterial, and insect activity, are deterred by mummification, but still exist. A better understanding of these processes and how they can be identified via the newer non-invasive technologies such as CT scanning are an important area of research (Cox, 2015).

There are good arguments for the use of biomedical technology especially those with volumetric capabilities in mummy research and ensuing museum display. These technologies allow for the ability to easily ship or transfer artifacts in digital form to other museums and researchers (Metallo & Rossi, 2011). They are able to permanently record artifacts that may be at risk of looting or are in poor condition (Metallo & Rossi, 2011). Some of the drawbacks include the difficulty in learning to use such technologies, the inevitability of file formats changing, the cost, and the limits to capabilities (such as imaging shiny objects) (Metallo & Rossi, 2011). A positive though is that museums can offer a more interactive experience for patrons by including 3D reconstructions of biomedical and cultural information into museum websites and exhibits. There are already applications that exist to allow anyone to create 3D images from photographs directly on their cellphones, so it is suggested that museums use this interest and capability to their advantage (Metallo & Rossi, 2011). There is clearly much potential in the future of museum mummy research and display, but the actual use of newer technologies and how subsequent data

is used likely varies. This variation was confirmed by my examination of practices in Midwest museums, and allowed for realistic expectations to be offered to the GRPM.

Ethical Debates in Egyptian Mummy Research and Museum Practices

After discussing the controversial way in which museums evolved, mainly through the mass commandeering of Egyptian antiquities by the West, it is no surprise that ethical standards are important to modern museums. This tangled history coupled with concerns about old and new research techniques as well as exhibition practices, ensures many considerations must be taken by museums who curate Egyptian mummies. Some of the specific concerns are discussed below.

The display of human remains in general continues to be a debated topic, yet ticket sales to such exhibitions continue to perform well (Cassman et al., 2007). Most legislation on the issue acts more as a guideline for the museum industry and is highly subject to interpretation. Views can vary just as much within countries as between them (Cassman et al., 2007). Museums are commonly expected to have a procedure in place to deal with upset patron inquiries, but their decision on how to respond is ultimately their own (Cassman et al., 2007).

There is an ongoing debate between the "sanctity" of ancient Egyptian religious beliefs and the interests of museums and researchers (Riggs, 2014). Museums after all were created to display the curiosities and treasures of the world and how that original goal is balanced with the realities of current times is still controversial. It is pretty well known that the ancient Egyptians were reluctant to share the secrets of their mummification processes, and only a few papyri have been found recording these practices (Raven & Taconis, 2005). Does this mean that we should respect the wishes of a past population, or can alternative inferences be made about what the

Egyptians would have wanted? This issue is described further by Kaufmann and Rühli (2010) who suggest that this emic perspective is unattainable since the ancient Egyptians would not have been able to conceptualize modern day science and research. Yet this statement seems somewhat overreaching since there is some evidence that ancient Egyptian physicians dissected human bodies for science and medical research of their own, at least by the Ptolemaic Period (305-30BC) (Morko, 2016). It is also argued that in some ways the museum has become the new temple, guardians, and caretakers of mummies which may be better treatment than what the ancient Egyptians could have imagined (Riggs, 2014; Kafmann & Rühli, 2010).

Many tactics to address this issue of sanctity are attempted by museums. Some museums encourage patrons to speak the name of the deceased which was an act of tribute desired by ancient Egyptians after death (Riggs, 2014). Conversely, some museums choose to rewrap mummies or take them off display entirely. One Egyptian exhibit allowed patrons to lift a suspended sheet to see the mummy (Cassman et al., 2007). These acts are designed for two reasons: to try to better "respect" the Egyptian mummy and to help the museum visitor be more comfortable with human remains on display. These acts do not really change the debate at heart however, and the ethical dilemma of what the ancient Egyptians would have wanted continues to be debated.

A concern for many researchers and the public is the exploitation of resources from Egypt. The extensive history of looting in Egypt dates back to at least the Third Intermediate Period, when impoverished Egyptians stole from elite tombs and graves. This looting has continued for centuries by natives and outsiders. Eventually, foreign diplomats living in Egypt became essentially antiquities dealers to their homelands. This long history of looting Egypt of its antiquities, legally or not, has had a profound effect on the current stance of the Egyptian

government on antiquities trading. Wherever colonial rule was involved, a concern for indigenous rights and autonomy persists today.

In Egypt, mummies remain on display, but there have been periods especially in the 1980's where they have been removed on the wishes of the ruling party (Riggs, 2014). As of one 2014 survey, only royal mummies and body parts have been repatriated and usually this was initiated by the current owner and not the Egyptian government (Riggs, 2014). There is some pressure placed on returning highly prized antiquities to Egypt, by members of the community there, however legally there is no requirement unless they were stolen. Many wonder if steps will be taken in the future to protect Egyptian mummies further, as has occurred in the United States with federal legislation addressing the repatriation of Native American remains and associated funerary objects. There also exists criticism of the Egyptian people as having "not conveyed and coordinated opinions or concerns" on the repatriation of ancient Egyptian mummies (Riggs, 2014 p.204). Additionally, well known political upheaval in the country leads Egyptologists, museum professionals, and even the public to question the safety and preservation of the Egyptian mummies located there. The argument also remains that ancient Egyptians are the ancestors of many modern people and that associating them solely with the current Egyptian population is not fair or accurate. Furthermore, James (2008) discusses the validity of smaller institutions in general being capable of proper preservation methods, heritage claims, and the accessibility of artifacts to the public, topics that should be considered when deciding where artifacts are housed.

Criticism of the destruction and/or desecration of mummies for scientific research is still debated, even among the professionals of the field. A journalist's account of the Mummy Congress conference in 1998 described this division between those that believe in dissection of

mummies and those that do not (Pringle, 2001). David (2008) is a proponent for tissue analysis, yet strives for organized collection and storage as a means to minimize the amount of samples taken. Kaufmann and Rühli (2010), also prominent researchers in the field, support invasive methods in the interest of progress of medical research, following that ethical issues have been considered. Aufderheide dissected over 800 mummies himself, and championed the process as a necessity to further research on ancient disease that can help current populations (Pringle, 2001). There are reports of over 30,000 mummies having been examined and most dissected by Elliot Smith's team in the early 20th century (Aufderheide, 2003). These staggering numbers, just a fraction of mummies unwrapped, dissected, or simply discarded over history, do cause hesitation for the continuation of destructive methods. Furthermore, wrappings, which were just as important to the ancient Egyptians as the body itself, have tended to be discarded or forgotten in collections departments around the world (Riggs, 2014).

It has also been suggested that completely non-invasive techniques often lack credibility in the field while invasive ones sometimes serve only to confirm a non-invasive discovery (Kaufmann & Rühli, 2010). Moreover, the decision of what is deemed non-destructive or non-invasive is a matter of perspective (Riggs, 2014). Some believe any unnecessary handling to be destructive and CT scanning a mummy to be invasive to the privacy of the person who once lived. This ethical debate continues to be explored more recently in regards to the protection of individual rights such as private medical information. Many projects are also criticized for their true necessity, instead of waiting for future technology or simply preserving the integrity of the artifact for future research. Ultimately the "right" to research is a debatable one and research methods, especially those often deemed destructive and invasive should be considered for necessity and the potential of knowledge to be gained. Understanding the debates surrounding

museums and mummy research was essential to this internship. Analyzing Nakhte's CT scan was a great opportunity, but also a responsibility to be taken very seriously. Below I will share my experience and findings, and the findings of the medical and museum professionals who consulted in this analysis.

CT Case Study

Findings

The analysis of the CT scan data was conducted between May 2015 and July 2016. The CT scan was made available on a Dicom (Digital Imaging and Communications in Medicine) formatted disc, which is standard for medical imaging. The CT slices were studied by myself and several field professionals in an attempt to verify and identify Nakhte's sex, age, time period, and pathological conditions from her skeleton, soft tissue, and mummification materials. The clinical assessments were made by radiologist Dr. John Quick of Butterworth Hospital using a medical workstation. I created three dimensional models and 2D images using Horos v1.1.7 for the Mac and RadiAnt Dicom Viewer v3.2.3 (64-bit) for the PC. Imaging staff at Advanced Radiology Services of Grand Rapids, affiliated with Butterworth Hospital, created 3D models also with the use of a medical workstation. Detailed results of this analysis can be located in the report prepared for and submitted to the GRPM in September of 2016 (See Appendix B). The following is a summary of those findings made through the use of the 2D CT slices (Figure 4) and 3D models (Figure 5).

An inventory of the condition of Nakhte's skeleton was conducted by Dr. Quick and myself. The right ulna and radius, all wrist and hand bones, the sixth cervical vertebrae, and the hyoid were not present. The mandible was not scanned, but is located in collections. There were

numerous fractures to the skeleton, primarily from the waist up. All of the fractures were attributed to postmortem damage and some were estimated to be saw cuts. Nakhte's female sex was confirmed via her pelvis and skull using methods from Buikstra and Ubelaker (1994). Although these methods are intended to be used on skeletal remains, they were applied to the 2D slices from the CT scan and 3D reconstructions of Nakhte's bones. Some assessments were easily made while the articulation of the skeleton did not allow for all techniques to be used. Her young age at death was confirmed and estimated to be between 17-19 years through dental eruption methods as outlined in Buikstra and Ubelaker (1994). Nakhte's stature was estimated to be about 4'10" tall using the negroid female formula by Trotter (1970). This method is not exact since these formulas are based on modern populations, however they are used by many bioarchaeologists studying ancient skeletons for broad comparisons. Her short stature was compared to two populations of female mummies compiled by Habicht et al. (2015). Analysis through Z-scores indicate Nakhte's height was -1.5940cm below the mean height of 15 royal mummies from various time periods and -2.4166cm below the mean height of 20 commoner burials exclusive to the Third Intermediate Period (Habicht, 2015). No evidence of periosteal reaction from infectious disease or other changes could be observed on the bone surface. No evidence of dental disease was found although RM^3 was found to be congenitally absent. Dr. Quick identified sclerosis on Nakhte's iliac bones, indicating mechanical strain to the area occurred during life. One cause of sclerosis in this region is the stress and changes to the pelvis from pregnancy although this possibility could not be confirmed with secondary indicators. Several mummification techniques supported the estimation of the 22^{nd} Dynasty in the Third Intermediate Period, including bilateral brain removal, the use of visceral packets and granular filling in the abdominal cavity, and lack of subcutaneous packing. A foreign object, possibly

wood, was located near the left acetabulum. A foreign wire like material was also wrapped around the lower half of the body. Both items remain unidentified and may have been added to Nakhte during mummification, looting, or the unwrapping event in 1910, or they may be an attempt at early conservation. Using density measurements, two of the amulets lying on Nakhte's chest were determined to be made from metal and the third is likely stone or faience.

Process of CT analysis

Coming to the above determinations was a time consuming process that required the learning of Dicom viewing software, the consultation of professionals, and research on paleoradiological interpretations of mummies. The process of this analysis is now described to highlight the strengths and challenges a museum should consider when pursuing the CT scanning of their mummy. It also serves to outline my contributions to this analysis.

Consultations. Initially I had hoped to make all of the clinical assessments by myself, using programs, scholarly articles, and reference books to diagnose. I soon realized that the 3D models I created from the CT scan were not refined enough to see fine details on bone and skin surfaces. Additionally interpretation of 2D slices was very challenging. Therefore my initial research of the scan slices served mainly to inventory the skeleton and identify large features such as the packing inside the mummy and areas of interest to study further. To ensure that the mummy was studied thoroughly I reached out to a forensic pathologist in Grand Rapids, Dr. Stephen Cohle, a contact provided to me by committee member Dr. Gwyn Madden. Dr. Cohle was very interested in participating in the analysis, however had limited CT experience, so offered to contact a few radiologists. Dr. John Quick, a radiologist at Butterworth Hospital contacted me soon after and we made plans to meet in the radiology department to look over Nakhte's CT scan. During the process I was informed that Nakhte's scan is the largest they had

ever had in the hospital's system. Staff confirmed that the scan's size was taxing even for their system, so it is not surprising that I had computer latency issues myself.

Over a few hours Dr. Quick examined the CT slices in 2D form on a professional grade hospital workstation. Dr. Quick asked me what I wanted to know and I started down my prepared list. I was initially surprised that the clinical assessments were taken entirely from the 2D CT scan slices and learned that in fact there was a separate imaging department that created the 3D models. Remembering that patients are normally alive during CT scans, helps to make sense of why 3D models are not often needed for clinical diagnoses. Patients are often able to describe their symptoms and medical history to their doctors. This was a reminder of how Nakhte's CT scan in many ways needed to be approached differently than one of a living patient. After seeing the ease at which Dr. Quick was able to examine the CT scan for broken bones and pathologies, I was thankful he was able to assist. The books and articles that I was using as guides were absolutely essential to knowing what to look for, but a trained radiologist is the best person to make those assessments and or confirm findings.

At the close of the session, Dr. Quick offered to send a list of my requested 3D models to the offsite imaging department Advanced Radiology Solutions. I requested models of anatomical areas where we found interesting results in anticipation that 3D representations would allow for more interpretations to be made as well as be used by the GRPM in media. These models were ready to be picked up a few weeks later and were provided to me on a Dicom formatted disc.

A few features in the CT scan required additional consultations. There was some question as to whether or not Nakhte's third molar was erupted or not. To try and clarify this issue I contacted Sara VanHorn, a surgical dental assistant, to ask the opinion of someone who is experienced in reading dental panoramic radiographs. To possibly shed light on some of the

cultural items inside Nakhte and her wrappings, I consulted with other museums. I contacted Dr. J.P. Brown at the Field Museum, who had offered assistance previously, to see if he had any insight in identifying the amulets, the foreign object near the pelvis, and the beadlike material wrapped around the lower half of the body. Dr. Brown has been involved with multiple CT scans of mummies for the Field Museum. The amulets and foreign object were not identifiable to him, but it was suggested that what I thought might be decorative beading may in fact be 19th century wire that was used to either secure or display the mummy. Dr. Brown had seen a similar material in a Peruvian mummy CT scan. I had no success locating a mummy study that showed a similar wire like feature, or a source that discusses 19th century museum methods. I consulted with James Draper, Registrar at the Gerald R. Ford Presidential Museum, to see if he was aware of any 19th century related practices or could identify the material, but he was unable to. Draper did confirm that museum "standardization of preventive conservation or mounting" did not occur until late in the 20th century. He also said it was not uncommon to see rather destructive methods used even into the 1970's. Since there were not standard practices until the late 20th century it is likely each museum used a variety of methods and materials.

My Determinations. There were several ways in which I was able to make additional determinations about Nakhte's health and mummification procedure. I was first able to use previous mummy studies and texts to anthropologically explain the clinical findings of the scan. For example, I was able to compare the broken cranial bones to what is typical in each type of Egyptian brain removal technique to determine the route of excerebration. I also researched the other findings such as sclerosis and missing third molar so that I could present theories to the GRPM on their causes. In addition to this general research of the clinical findings, I also continued to study the 2D CT scan slices. I resorted to using two viewing programs because each

had its own strengths and weaknesses. Some of these factors included ease of usability and quality of images. Using these programs I was able to take density readings of the visceral packets, amulets, and other materials found inside Nakhte. After consulting between guides and the Hounsfield unit (HU) measurements taken, I was able to estimate what some of these materials may be. In this type of assessment you can omit materials from the list of possibilities or make suggestions based on what is most commonly recovered from Egyptian mummies. Unfortunately in this type of study these relative determinations are all that can be made. For example, a moderately radiodense granular substance was used to fill Nakhte's body cavity, but whether it was sand, soil, or sawdust, is unclear since all were used in this period and sometimes a combination of them. Conversely, it was clear that neither resin (highly radiodense) nor loose linen (low radiodensity) was used to fill the abdominal cavity. The density tools on these programs were a relatively simple and effective tool for making interpretations about the cultural material.

Density measurements taken of the tissue and bone were less effective at answering questions about Nakhte. Since taphonomic processes have affected the soft tissue and bone, there is a very wide range of what could be considered a normal reading of attenuation. These measurements could tell me areas where a lot of bone loss had occurred, but this is not indicative of any pathology. This technology did allow me to suggest that there may have been organs in the visceral packets (assuring they were not just folded linen), since the density at the center was greater than the perimeter. During this time period organs were often coated in resin before being wrapped and returned to the body, which could account for these more radio-dense regions towards the center.

These viewing programs were also a valuable tool used to create images for the GRPM. I

was able to denote areas of interest and density readings, and save them in either Dicom or a picture format such as jpg. This assured that the museum would have plenty of images to incorporate into their exhibit or other media that corresponded to the health and mummification findings.

The viewing programs used also allowed for 3D reconstructions or models to be created which were also made available to the GRPM. I was able to create several full body models of Nakhte using filter settings which highlighted different features (Figure 6). These included models showing the surfaces of the skin, wrappings, and skeleton. Some features inside the mummy were better visible in the 3D models, such as the wire like material wrapped around the lower body (Figure 7) and the foreign piece near the pelvis. Although I could not determine with any degree of certainty what these were, I was able to give better images to the museum to use in future research and for media purposes. I was hoping to match the amulets with known types used in the period, but the models provided by Advanced Radiology Services showed little more detail than in the 2D slices. This I determined was due to their metallic quality, which is known to obscure radiological images with a classic streaking pattern (Figure 8) (Hawass & Saleem, 2016). The models I created were also able to be saved in movie format which showed them rotating to a chosen degree and speed. These were also made available to the GRPM. The education department has already been able to use them in their children's *Science Tuesday* program by loading them onto an iPad.

Overall, the 3D models were an interesting feature of this project, but are of more benefit to the media purposes of the museum and less for diagnosing pathology. All of the images produced from the CT scan, the 3D models, and movies were organized into folders and supplied to the GRPM through Dropbox and on a USB drive. I also placed two viewing programs in the

folder. I have extended an offer to the museum to assist them in viewing any files if they have trouble. I also have been in touch with the education department, offering my services in helping to create or provide information for future media, such as the brochure I suggested in my report. To date, I have presented on Nakhte and her CT scan analysis at a thesis competition at Western Michigan University. I presented my findings as a poster at the 23rd annual Midwest Bioarchaeology and Forensic Anthropology Conference in October of this year. I have also offered to present these findings at the GRPM, although currently no plans have been confirmed.

Discussion

There were many issues that prevented or hindered absolute determinations to be made about Nakhte's health and burial assemblage. Most of these issues are obstacles other museums may face as well, so will be discussed at length below for the benefit of future researchers. Along with these challenges come in some instances helpful solutions or positive outcomes such as increased networking. For many of these specific areas of concern, there are research methods the GRPM may choose to employ to answer these questions.

A main issue that is common in bioarchaeological study, was that of established provenance. Frequently during the analysis I had to consider the unwrapping event in 1910 as a source of damage and alteration to the mummy. There are no detailed transcripts of what took place during this event, which makes it difficult to determine the state of the mummy prior to this time. There is also the possibility that damage and alterations occurred while the mummy was at the shop in Cairo. During the 19th century mummy dealers sometimes had controversial practices such as selling mummies and coffins together that do not belong (Richards, 1996). It is possible that the store owner manipulated the body to either remove valuables or to present it in better condition than what it was (wiring). Since looting occurred even in ancient times, the damage

observed could even have occurred shortly after burial. A letter from the owner Mr. Lowe to the GRPM does indicate some damage occurred during Nakhte's travel by ship to the United States, but this would not account for the missing bones, nor for the unusual additions found. Without a full skeleton and the mandible not being scanned, there is quite a bit of lost knowledge. Consideration must be given that these regions of the body may have contained pertinent information that is missing from this study. Without knowing all of Nakhte's history since death, it is difficult to clear up some of these mysteries, however some future avenues of research may be able to clarify findings.

The unknown wire-like material and foreign object near the pelvis were discovered in this CT analysis, but their origins remain unknown. There is even the possibility that these objects were additions made by Nakhte's embalmers. There are studies that have identified odd additions to mummies and speculate this was the source (Čavka et al., 2012, Jackowski et al., 2008). I did not find any examples of a wire like material in ancient mummy CT studies, however their use of several metals in jewelry making is commonly observed. One solution would be to unwrap a portion of the mummy again or send an endoscope in to examine these features which is a less destructive method (Beckett, 2015; Čavka et al., 2012). A tiny piece of each of these materials could be removed for analysis, but additional manipulation to this mummy would likely cause damage, and the possible rewards not worth the risk. Even with a piece to radiocarbon date there may be the issue of cross-contamination since Nakhte was possibly handled during the unwrapping or looting. Similarly, unwrapping to identify the amulets is not suggested. The use of micro CT on these areas could provide a more detailed image which could help with identification of all the unknown cultural objects. Micro CT could also be applied to study the cut marks on the bones to identify a pattern of tool which could help date

that cutting event. Additionally, if C6 is in collections it may have a cut mark that can be examined macroscopically.

Another dilemma in this analysis was the technical difficulty involved with examining CT scan slices and using Dicom viewing programs. When the GRPM CT scanned Nakhte they received a few initial results from the technicians and doctors present, however receiving explanations for those results in any great detail was difficult for them. It is possible that radiologists are hesitant to make concrete statements since diagnosing pathology in dry bone is different from diagnosing live bone. There is no conscious patient to request a life history from, or many clues left in the desiccated soft tissue. For these reasons an anthropologist who is experienced with bioarchaeological and osteological interpretive methods is a necessity for CT scan analyses. The anthropologist is able to help decipher what formations are indicative of a paleopathological condition and what may be caused by damage or taphonomic processes. A radiologist is absolutely necessary though, unless the anthropologist has formal education or experience reading a CT scan. After a year of studying Nakhte's scan, I can say that I have learned a great deal about these viewing programs and how to read a CT scan, however anything that I uncovered I would want to get a second opinion by a radiologist. It is very easy to think you are seeing an anomaly when in fact it is something normal. My collaboration with Dr. Quick and all of my consultants provided a much more well-rounded analysis and thorough approach.

In addition to the technical difficulty of interpreting the CT scan, I encountered some issues running the viewing programs. Particularly, when creating 3D models I would have latency issues and timeouts. This was due to the enormous file size of Nakhte's CT scan of over 8,000 slices. The software was also difficult to run without formal training. I was able to learn through experience and online tutorials however the technical prowess required to create models

of individual features was beyond my capability. I had hoped that my 3D models would allow for precise examination of the surface condition of bones and even skin, but I found that the clarity I could achieve was not very effective for this. Large anomalies would be noticeable, but fine details may have been obscured. Interestingly though, the 3D surface rendering models that were created by the staff at Advanced Radiology Solutions, were also less refined than I hoped (Figure 9). The strength in their models was their ability to isolate and increase in size certain features. Either both our software settings required additional manipulation to produce better quality images or the settings used in Nakhte's CT scan may have needed to be more specialized to view ancient mummified remains. Whichever the reason, this leads me to believe and confirm what the adjustment of CT scan settings and viewing program settings plays a significant role in the quality of the view achieved (Conlogue, 2015). Fortunately I may have the opportunity to find out if these models can be improved, as the creators of the IMPACT mummy database have offered to assist in reviewing Nakhte's CT scan and my report, if the GRPM so chooses. To clarify, the 3D models did aid in interpretations and provided wonderful visuals for the GRPM to use. I had just hoped to be able to use them to make more determinations about Nakhte's health than what ended up being possible. Specifically, no cause of death could be determined and fine details of bone surface were not visible.

In regards to Nakhte's health during life and cause of death there are still questions. Sometimes a CT scan of a mummy can give clear indications of why or how that person died (Saleem & Hawass, 2014). In our case, it seems we are left with more questions than before the scan. This is not a failure though; it is the opportunity for the GRPM to continue their research. Even though her provenance is somewhat questionable there are many avenues for new information to be uncovered. DNA can be analyzed for diseases that are not visible on the

remains. Isotope analysis of Nakhte's teeth could provide information about her diet and mobility during life similar to studies by Lacovara et al. (2015), Proefke et al., (1992), and Touzeau et al. (2014). As mentioned above there are also other paleoradiological techniques such as micro CT and MRI that can be used to view internal structures better. There are many options, yet the financial means to carry out expensive research practices can be a limiting factor. This financial burden can sometimes be viewed as a blessing to mummy studies. If these technologies were more affordable (and they are moving in that direction) then too many unnecessary samples may be taken. Considering Nakhte's case study, I think it is a positive idea to explore some of these options in research. Since her mandible is in collections, there is no need to disturb the rest of her remains for bone and teeth samples. The CT scan did not uncover any tissue related anomalies of interest nor did we identify particular organs, so there is not much reason to explore histological biopsy at this time.

As long as there is the potential for new information to be uncovered, especially through noninvasive or minimally destructive methods, research should continue. Invasive techniques should be used sparingly. For new research to be carried out, there should be the possibility of new information as well as confirming previous findings. For example, confirming sex is not a sufficient reason to conduct DNA analysis. The different types of methods should be researched and the proper tests found for the mummy in question. To help the GRPM decide which of these techniques to pursue or understand what their colleagues are pursing (i.e. trends), I sent a questionnaire to other Midwestern Museums that curate Egyptian mummies. The questionnaire also served to identify how these museums used their CT data in their exhibit displays and for educational purposes. Below I will describe the results of this questionnaire and the additional research collected through website and in-person visits on the practices of these museums.

Midwest Museum Practices

Methods

To identify the practices of other museums in regional proximity to the GRPM a short questionnaire was distributed to 20 museums in the Midwest. A copy of the questionnaire and a list of these museums is located in the appendix of this paper (See Appendix C). The Midwest for this project was defined as the states of Ohio, Indiana, Illinois, Michigan, Wisconsin, Minnesota, Iowa, Missouri, Kansas, and Nebraska (American Heritage, 2011). The museum selection was based on preliminary website research that indicated their collections included an Egyptian mummy. The questionnaire was delivered through an email link, using the survey generating website QuestionPro. The emails of the directors, curators, and collections managers that appeared to be most associated with the Egyptian collection were selected to participate. In the case of smaller museums with less specialized staff, the questionnaire was sent to the general curator of the museum. Nine museums responded to the questionnaire. The individuals who responded identified themselves as curators of archaeology, curators of history and anthropology, collections managers, a conservator, director, and an executive director of their respective museums. After receiving questionnaire results and identifying museums that have incorporated CT scans into their exhibits, four locations were visited in person to gain additional perspective on their display practices. Additionally, the museums that online articles and databases suggested may have used CT scanning on a mummy, were examined closer through their websites to gain information on their practices.

The gathering of this information had two purposes. The first was to provide knowledge and

examples to the GRPM of the ways museums are using their CT data. The second was to form a better outlook from the consensus of professionals, as to the overall process of museum CT scanning Egyptian mummies and its outcomes. An advantage that was not expected from the questionnaire was offers of assistance in this project by some participants.

Questionnaire Results

Of the nine museums that responded, all but one had CT scanned an Egyptian mummy in their collection; half of those had scanned two or more. This response is valuable since most of the participating museums will have experience to offer, yet also unfortunate because the reasons why museums that do have mummies and have *not* CT scanned could not be explored thoroughly. It is possible that museums that have not CT scanned did not find the questionnaire relevant to them and perhaps that is one reason for their lack of response. Since over half of the museums chose to scan more than one mummy, this tells me that either the procedure on the first was deemed at least relatively successful enough to pursue a second scan or there is the possibility that they were scanned at the same time. Two museums planned to scan an additional mummy in their collection and one did not. The museum that is not choosing to scan gave additional insight that perhaps as technologies keep evolving they would consider another CT scan, but currently there are no plans. The remaining six had no further mummies to scan.

The participants were asked to select all of the reasons why they chose to CT scan their mummy. The most popular response which received 100% consensus was to *increase knowledge about their mummy*. More than half of the museums desired to *change or update the mummy's exhibit* as well as *provide data for researchers or mummy databases.* I think in part all three of these choices speak to a core museum responsibility of researching their collections and disseminating the knowledge gained. The least popular response selected by only two museums

was to *increase visitation to the museum*. This question may have insinuated a monetary motive that respondents did not agree with although I think it should not be taken negatively as attendance is a necessity for museums to survive. Other possibilities for the lack of selection of this 'reason' are increasing visitation may not be a concern to professionals in more specialized roles at larger museums or to museums that do not struggle with attendance.

It was asked of those who have CT scanned, what additional research methods will be or already have been employed. None of the museums selected *dissection* or *unwrapping*, showing a clear preference for less invasive methods. The techniques that were selected were *endoscopy, DNA analysis,* and *isotopic analysis*. This shows a growing comfort and greater availability of outsourced technical procedures being pursued by museums. Two museums also expressed interest in radiocarbon dating through the *other* option, which may be beneficial for confirming dates, especially for mummies with little provenance. There are many reasons a museum may not desire to do additional research after a CT scan, including a lack of funds or lack of necessity, but these results at least give a sample of what some museums are opting for.

The second half of the survey asks questions that relate more to the use of the collected CT data by these museums. Seventy-five percent or 6 of the 8 museums who have CT scanned, incorporated these CT scans into their Egyptian exhibits. These museums said that the incorporation of these images was aimed at educating *all ages*. One museum kindly relayed in comments that their key audience is grade 5 and older, which seems like a traditional standard for museums of natural history. Since human remains on display can be a controversial subject, I was interested in finding out if any museums saw a marked difference in negative feedback after CT scans were incorporated into their display. Only two museums of nine reported any experiences with negative feedback and neither indicated any change occurred after the CT scan

installation. Comments indicate that these were very isolated experiences and not a common reaction to their mummy exhibit. Among the seven museums currently displaying their mummies, only one provides an area for comment cards near their mummy. The final question to be reviewed asks whether the data from the CT scan of these mummies has been added to the IMPACT database or any other mummy research database. Only two museums answered yes. The other six had not contributed their data and half of these were unaware that such databases existed.

Exhibit Research

The questionnaire discussed above was sent to twenty museums in the Midwest that supposedly housed at least one Egyptian mummy. In preliminary research 11 of these museums were identified as having already CT scanned a mummy in their collection (eight of whom responded to the questionnaire). These were identified during initial museum website visits, online newspaper article hits, and the website *mummylist.com*. Although a helpful website, there is no indication when it was last updated and I found many discrepancies during my research. Four of these museums were visited in person and observations from these will be discussed below. In the hopes of gathering more information about the other seven museums' exhibits and CT scan use, their websites were examined. For each website I first looked for an *exhibits* or *exhibitions* link and examined them for Egyptian collections. If no information was found on their Egyptian mummy, then I used their search engine to find pages with “mummy” and “mummy CT.”

I could not find any website information about a mummy in the collection of two of these museums, although that does not prove that they do not have one. In fact one of these museums answered the questionnaire and indicated that they have incorporated CT images into their

Egyptian display. A third museum mentions a mummy in its collection but no information about CT activity and no pictures were present. The remaining four museums all had at least a short explanation of the CT process performed on their mummy(ies) and some excelled in their coverage. One museum used a blog section of their website to detail through pictures and story, the event of their mummy's CT scan. Although highly effective in design and content, the only critique is that the webpage was much harder to locate than information on other museums' websites. Perspective researchers may know to search for this page by using key word searches, but a visitor using the website to examine the current exhibits may miss it.

The Ohio History Connection, located in Columbus, which actually is a network of multiple museums and heritage sites has an enormous amount of information about the CT scan of their mummy on their website. This includes multiple website pages, videos of the process, videos of presentations about findings, and videos showing the 3D models created (Ohio History Connection, 2016). Through questionnaire answers, it was confirmed that they have incorporated CT scans into their exhibit as well, although I could not find that explicitly mentioned online or shown in a picture. The Milwaukee Public Museum (2016), of Wisconsin, has a wonderfully informative video that depicts the entire creation of their exhibit "Crossroads of Civilization." The caption for this video specifically says, "Visitors can now peer inside MPM's two Egyptian mummies through CT scan imagery," and it is again mentioned in the video although not seen (Milwaukee Public Museum, 2016).

My aim in examining these museums websites was to see visuals of what was offered at their Egyptian mummy exhibits. These views could help me present ideas to the GRPM on how to update their display. This was largely unsuccessful, as I did not find any websites that showed actual pictures from their exhibit that contained CT imaging or descriptions. There are many

reasons why a museum may not show the CT scans on their website such as they are planning on updating the site or display but have not yet, or simply choose not to display CT scans on such as public forum (website) for mummy privacy reasons.

I visited four museums in person, to examine their exhibit's design. These were chosen for their close proximity to the Grand Rapids area. Each museum had differences in collection size and approach, but all shared some similarities as well. Overall their exhibits used very dim lighting which likely serves several purposes, that is, to set an ambiance, promote respect for the human remains on display, as well as protect artifacts from unnecessary light damage. The Field Museum of Chicago, Illinois, is a world renowned institution. They have CT scanned several Egyptian mummies and my expectations were high on this visit. Unfortunately it was learned through conversation with a docent, that the mummies in their collection that have been CT scanned are currently on loan in a traveling exhibit, along with much of the CT information. As of August 2016, their permanent Egyptian exhibit did have other mummies on display and did have one area that discussed and showed CT scan images. This area was an interactive station consisting of a TV monitor and touch screen standing unit (Figure 10). The TV monitor displayed what was being shown on the touch screen device. The station allowed museum visitors to closely inspect a 3D model created from the CT scan of the mummy known as the Gilded Lady. Patrons can select different areas of the model to learn specifics about her wrappings, skin, and skeleton and see specialized views (Figure 11). The Oriental Institute Museum in Chicago, IL, also had a similar station. Their touch screen device was affixed to the wall and provided images of their mummy Meresamun, who was in her coffin nearby (Figure 12.). Patrons could explore the anatomical regions of 3D models and 2D slices while learning about the research findings. The CT scan 2D slices shown had been annotated to show points of

interest (Figure 13). There was also a video that depicted the CT scan event itself. In addition to this station, a placard on the display case of a second mummy Petosiris described his provenance and CT findings and also included 2D slice views (Figure 14).

The Kelsey Museum in Ann Arbor, MI, has an unidentified child mummy on display, which they have CT scanned. On the wall near the mummy, is information about the child's provenance and the CT scan conducted in 2002 (Figure 15). This includes images from the CT scan slices, a 3D model, the CT scan event, and a polymer-resin model created (Figure 16). Between this display board and the mummy is a case that contains the polymer-resin model. The Kalamazoo Valley Museum of Michigan also used what could be considered more traditional museum display techniques. They incorporated views of CT scan slices of their mummy Tjenet-Nefer into what I would describe as a wing of their mummy exhibit. They used 2D slices to explain the pathological and mummification findings (Figure 17). Sometimes multiple consecutive slices were shown (Figure 18). They also had a small TV which provided video of the mummy and her CT scan. Although no method of display observed is inherently wrong, in my opinion the exhibits that employed traditional signs and wall descriptions in their displays relayed a feeling of permanence to their exhibit. Interestingly, although the use of new technologies such as touchscreens allow more interaction with the exhibit, they were not found to be a necessity to effectively convey the CT scan data to the audience.

Discussion

The questionnaire data confirms the type of research that is being conducted in the region and the continued interest in mummy studies by Midwest museums. Museums that have CT scanned mummies seemed to employ the science foremost for knowledge's sake and expressed interest in continuing the study of their mummies through minimally destructive methods. The

method most were planning to or already have used was endoscopy which does have the potential to cause damage, but very little if done properly (Beckett, 2015). This procedure may be appealing since it can be done on site and is considered by most to be minimally invasive (Beckett, 2015). Other methods being pursued such as DNA, isotopic, and radiocarbon testing have become minimally destructive in recent years (small sizes needed), and are less expensive to perform.

Midwest museums are using the data from their CT scans to update their exhibits, but many are either choosing not to or have yet to update their websites to show this. Advertising is important and the perusal of websites showed that the use of exhibit previews and museum blogs are an excellent way to keep the public informed of the ongoing research conducted there. It can also be a missed opportunity useful in attracting visitors to their museum. These museums were interested in researching their mummy(ies) to learn more about them and share this with the public, but very few had contributed this data to a mummy database such as IMPACT or had even heard of them. Hopefully this project served to enlighten some museums to this important possibility, especially since it has the potential to allow them to reach a national audience, benefitting the museum by attracting visitors and researchers.

The in-person visits were the only effective method used to observe how museums are presenting their CT scan data in mummy exhibits. Both the touchscreen interactive stations and the traditional display techniques were effective in explaining how medical procedures are being applied to ancient bodies and the types of medical and cultural information that can be gleaned. Although the interactive displays were fun and full of content their drawback is they can only be used by one or two people at a time, while wall displays can be viewed by many. Children may benefit the most from interactive stations since it may be easier for this age group to

conceptualize the internal findings of a mummy through a 3D model rather than 2D CT scan slices. Overall, the vocabulary used in all of these displays was kept simplistic when possible, avoiding technical jargon, which made the concepts easier to understand. A positive aspect of the wall displays was how they felt more permanent and better integrated into the exhibit. For the museums that do not incorporate their CT scans or data, this may be because it is costly to redesign exhibits and/or it may be scheduled for a future time. Other possibilities include an unwillingness to change the design and/or there is a lack of space available. Lastly, the CT scan may not have produced results the museum thought necessary to display.

Conclusions

Every Midwest museum I observed through in person visits, the questionnaire, and website perusals had a different ambience, size, history, and agenda. Even those similar in scale had different focuses for their collections. For all their aesthetic differences they had at least two things in common, an Egyptian mummy and a Midwestern location. I believe this highlights the universal appeal that the Egyptian mummy still has today. Being able to advertise to a local community that they can now come and see images of what is inside of an ancient Egyptian mummy is very exciting. There may be even greater interest when the mummy has been on display in that museum for a long time. However, since exhibiting human remains is still a controversial subject, there should be adequate justification for their display. The mummy should not be on exhibit just to be a spectacle. Incorporating CT data into exhibits that have been anthropologically and clinically analyzed helps to understand a mummy in a more educational way, just as the cultural artifacts that surround it. The cost of adding CT scan images and research to exhibits is a consideration that curators should keep in mind when choosing to scan. Museums do not need to install high-tech viewing systems although they are appealing;

traditional displays serve the purpose just as well. Disseminating mummy CT scan research to the public should be a priority. Museums should update not only their exhibits but also their websites to help guide visitors to their location and accurately depict what their museum has to offer. Websites are also an excellent tool to display information that cannot fit in the display.

There are many reasons why CT scan images and data may not be incorporated into exhibits and websites of the Midwestern museums I researched. Perhaps they are planning on updating in the near future, there is currently funding restrictions, or simply this action is not a priority. The aim of this portion of the internship research was to highlight the practices that were observed to be the most successful at disseminating knowledge to the public, but it is understood that the goals, focus, and funding, of every Midwestern museum is unique. But just as it is important to publish research with negative findings, it is important to show the public the research a museum is conducting. Many visitors who go to museums do not realize that collections are still being studied by museum staff and visiting researchers. Incorporating CT research shows another side to the museum as an institution that is employing new technologies to conduct valuable research, helping to dispel the notion they are just the keepers of old artifacts.

These new technologies as shown above through the CT scan case study of Nakhte may be a technically difficult process, but the positives outweigh any negatives. A CT scan analysis requires a team of professionals to adequately decipher what information the ancient mummified remains hold. The best team would include a radiologist that can clinically diagnose the scan, and an anthropologist knowledgeable in bioarchaeological skeletal analysis and ancient Egyptian culture. Even then, the need to consult with other professionals in the medical and museum fields may arise. Finding professionals interested in helping with these interpretations can be

challenging, since it is usually unpaid work. Yet I found many people willing to donate their time out of sheer interest in the project. These working relationships that are formed provide a network of people the museum can possibly call on in the future. The relationships I formed can be used to continue research on Nakhte or possibly be revisited for different projects in the future. It is an asset to the museum to form these working relationships and have people to call on when questions arise.

The practice of museums using CT scanning on mummies, also has the potential to benefit the field of anthropology as a discipline on a larger scale. This is done by incorporating this CT scan data into a mummy database that researchers around the world can access. By doing this, anthropologists can study how Egyptian health and mummification techniques changed over time. They can reveal patterns about a population instead of only features of one individual. Museums also benefit from donating their data through possible exposure from additional research. Studies like these have the opportunity to reach national and even international audiences through peer reviewed publications and conferences.

The GRPM wanted to learn more about their mummy Nakhte and this CT scan analysis did allow for some new information to be uncovered. It seems that many other questions have also been raised as well. Museums have a responsibility to research their collection to its fullest potential and using noninvasive methods such as CT scanning is a valid way to fulfill this mission (goal?). Hopefully the GRPM will choose the best additional procedures to conduct on Nakhte that are the least destructive and have the best potential to provide new information.

As described above the CT scan analysis of a mummy can be used to inspire public interest in a museum through advertising, blogs, exhibit displays, and peer reviewed research publications. Although all of the museums in the questionnaire were mostly interested in

increasing knowledge of their mummies, increasing foot traffic and possible financial gain is a positive outcome as well. It would be ideal if all museums were free, but the reality is that it is expensive to house and preserve artifacts. Mummy CT scan research and subsequent display of this research can bring in visitors, which should benefit the entire museum. It is not unethical to use mummy research to increase visitation as long as the least invasive methods are used and not recklessly or without foresight. Many museums are struggling to retain proper funding from year to year. Similarly many university anthropology departments are facing the same challenges. Displaying and disseminating CT scan research can educate the public on their local mummy and simultaneously the valuable work of anthropologists. This interdisciplinary study of Egyptian mummies helps museums and anthropology connect with biomedical fields and technologies, allowing them to continue to produce meaningful research.

The outcomes of this internship were somewhat surprising. My focus shifted more and more away from justifying CT scans on mummies, to justifying what is done with the final product (i.e., data). The infatuation with Egyptian mummies and subsequent research is not going to end. Unless there is a major realigning of the Western morals and ethics that permit us to study and display the deceased, efforts to responsibly conduct and disseminate research should be the priority. The questionnaire proved personally valuable to me similarly as it was described above for the museum. I was able to network with multiple professional curators and collections managers, some of whom offered suggestions for additional or different survey questions, assistance in interpreting the CT scan, and valuable extra comments on their practices. These connections may benefit me in the future. In return, I will offer the data from the questionnaire to the museums that participated. The CT scan analysis of Nakhte allowed me to practice skills of osteological interpretation, learn to use Dicom programs, and taught me paleoradiological

interpretation techniques. I was not able to discern Nakhte's cause of death, which was disappointing, but I feel confident that my effort on the project revealed new information and revealed new avenues of research for the GRPM. Although I cannot call myself an expert in interpreting a CT scan, I now have a model and skills that could assist me in helping other museums complete such a project. This experience should be an asset to my CV and increase my prospects of gaining employment in the highly competitive museum field.

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Appendix A

Figure 1. The Third Intermediate Period mummy Nakhte-Bastet-Iru (GRPM, 2016).

Figure 2. Map showing the location of the ancient city of Thebes in Egypt (Encyclopedia Britannica, Inc., 2016).

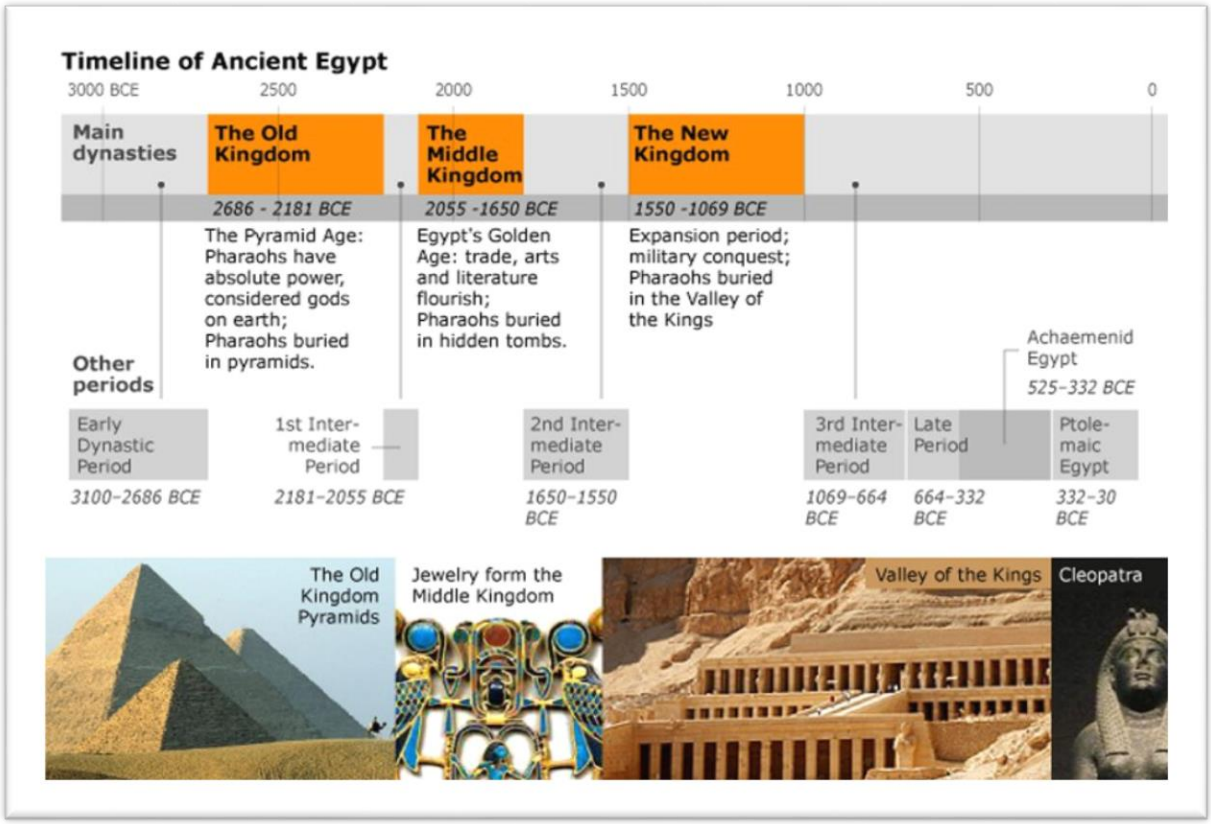

Figure 3. Major time periods of ancient Egypt (Fanack, 2016).

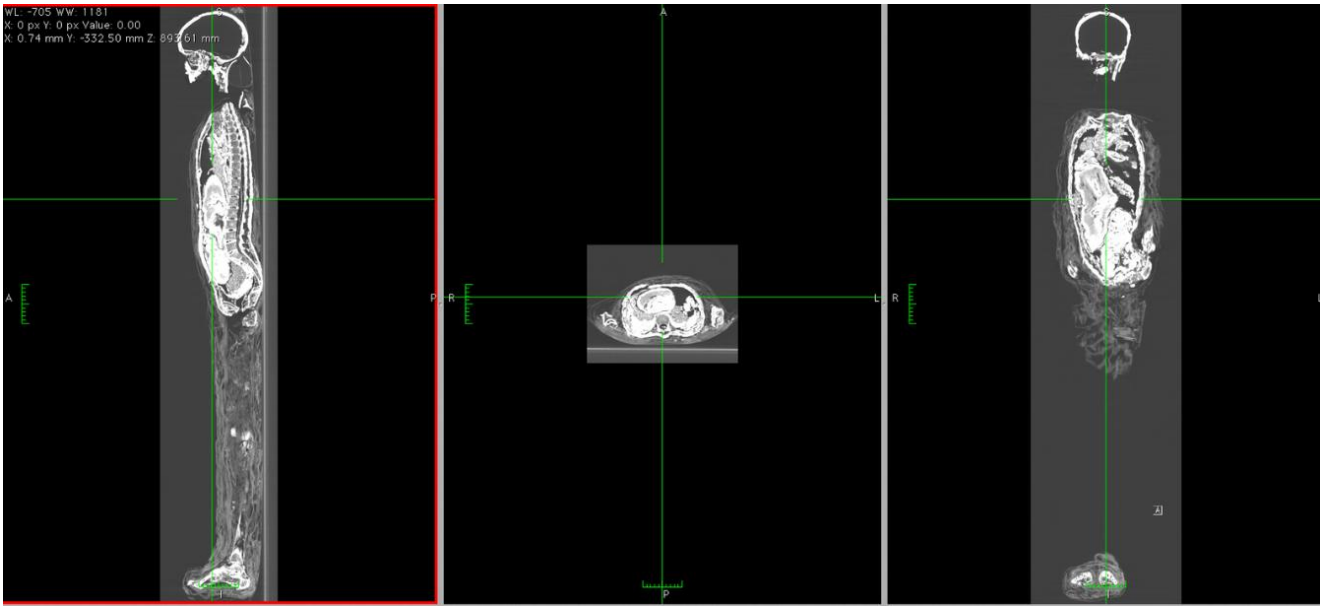

Figure 4. Example image of 2D CT scan slices of Nakhte

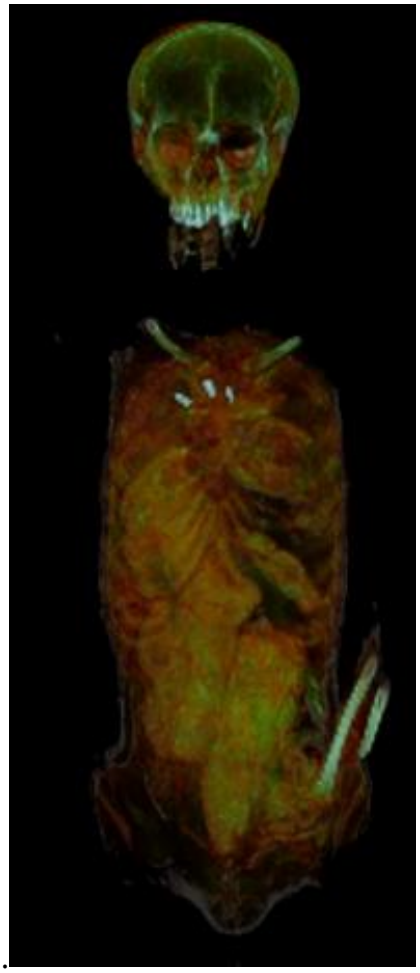

Figure 5. Example image of a 3D model created from Nakhte's CT scan.

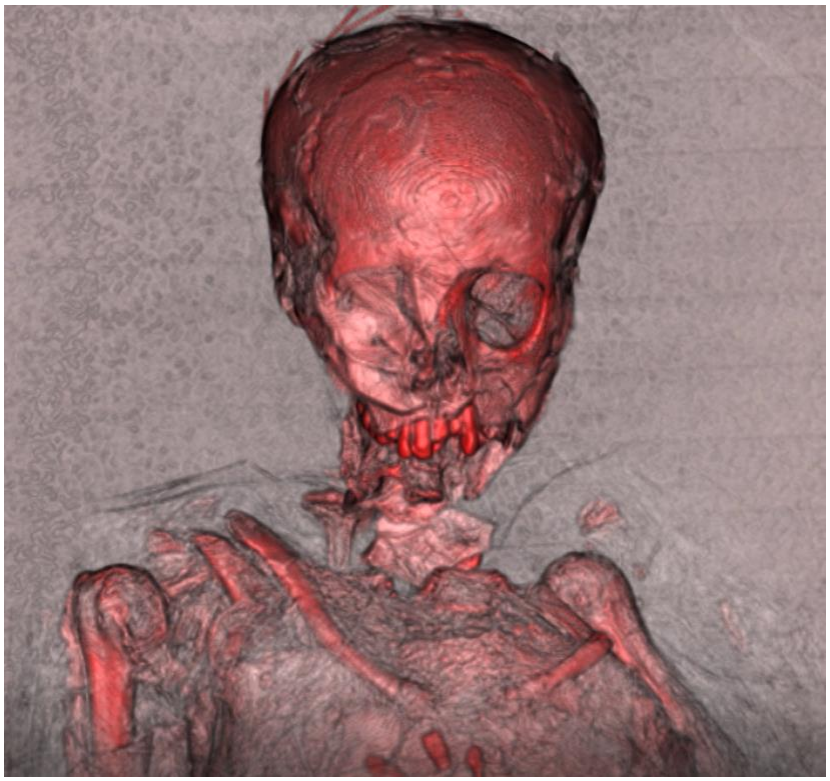

Figure 6. Image of a filtered 3D model of Nakhte showing skeleton and wrappings.

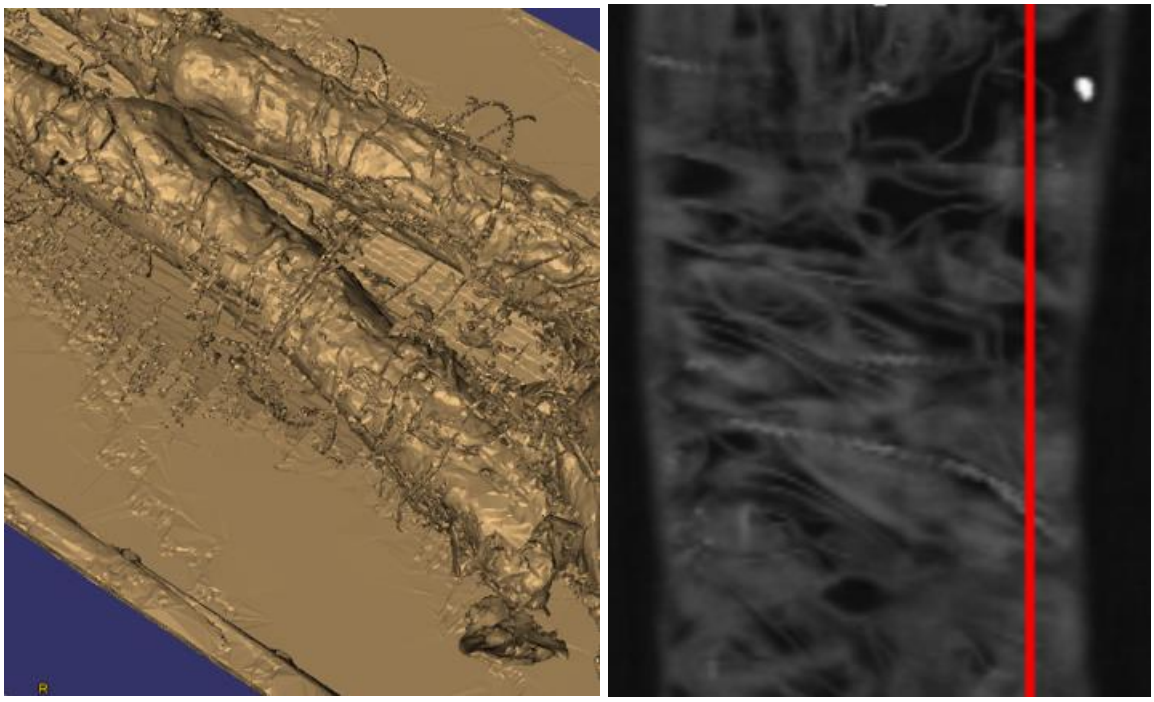

Figure 7. Image of a 3D model showing wire like material (left); Image of a 2D CT slice view of wire like material (right).

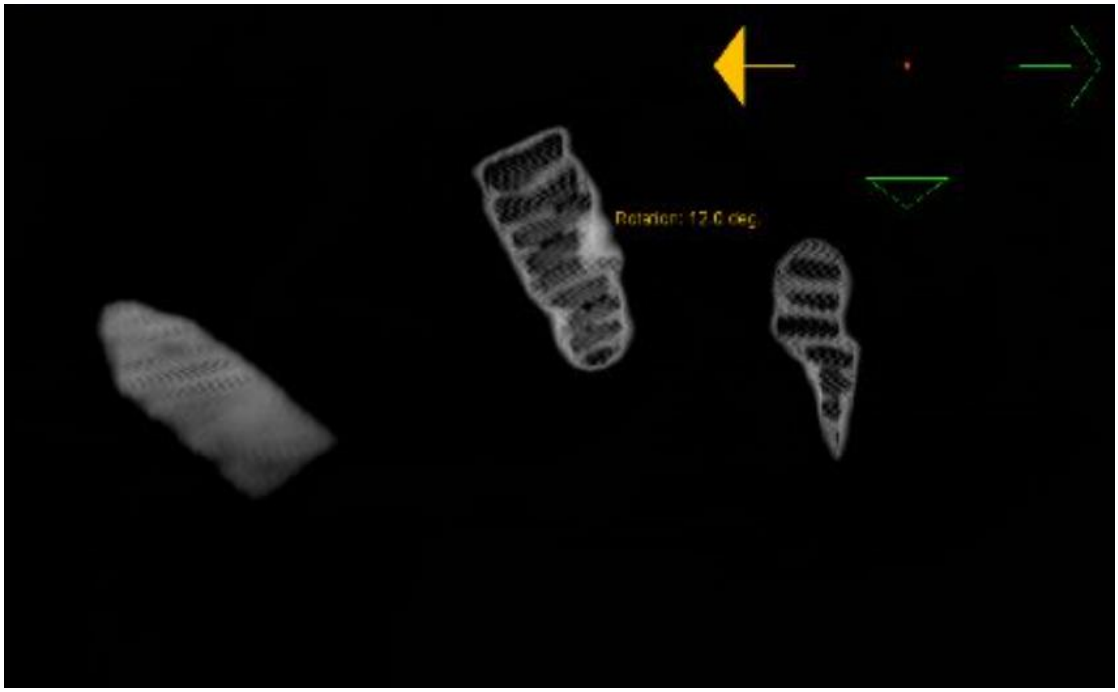

Figure 8. Image of a 3D model of Nakhte's amulets, showing the classic streaking pattern observed in CT scans of metallic objects.

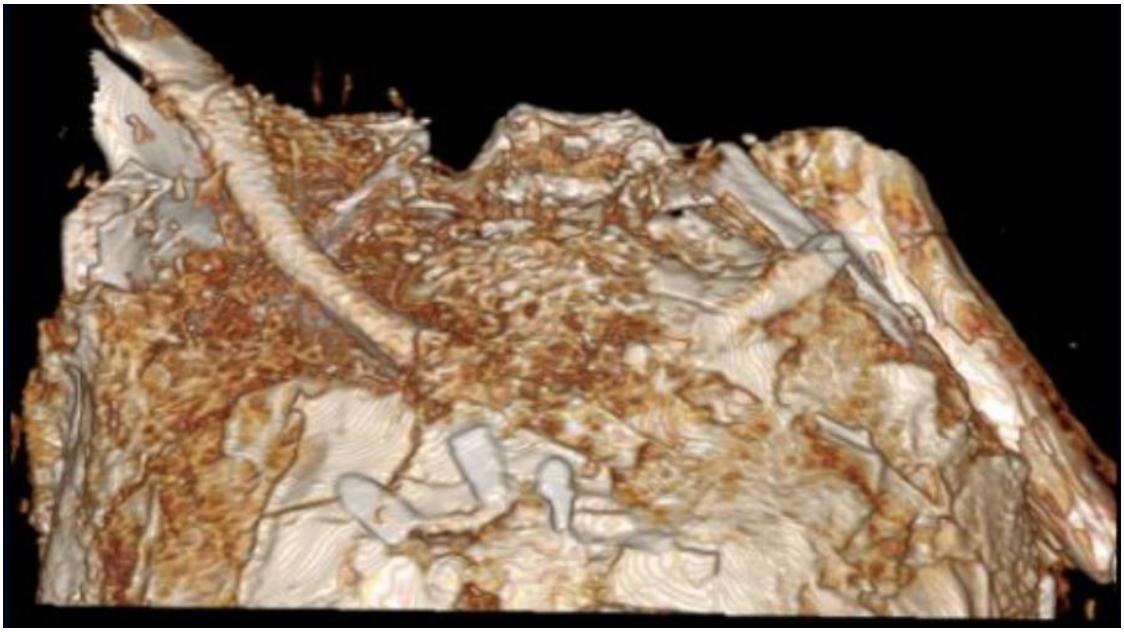

Figure 9. Image of a 3D surface model of Nakhte's chest showing lack of fine details, produced by Advance Radiology Services.

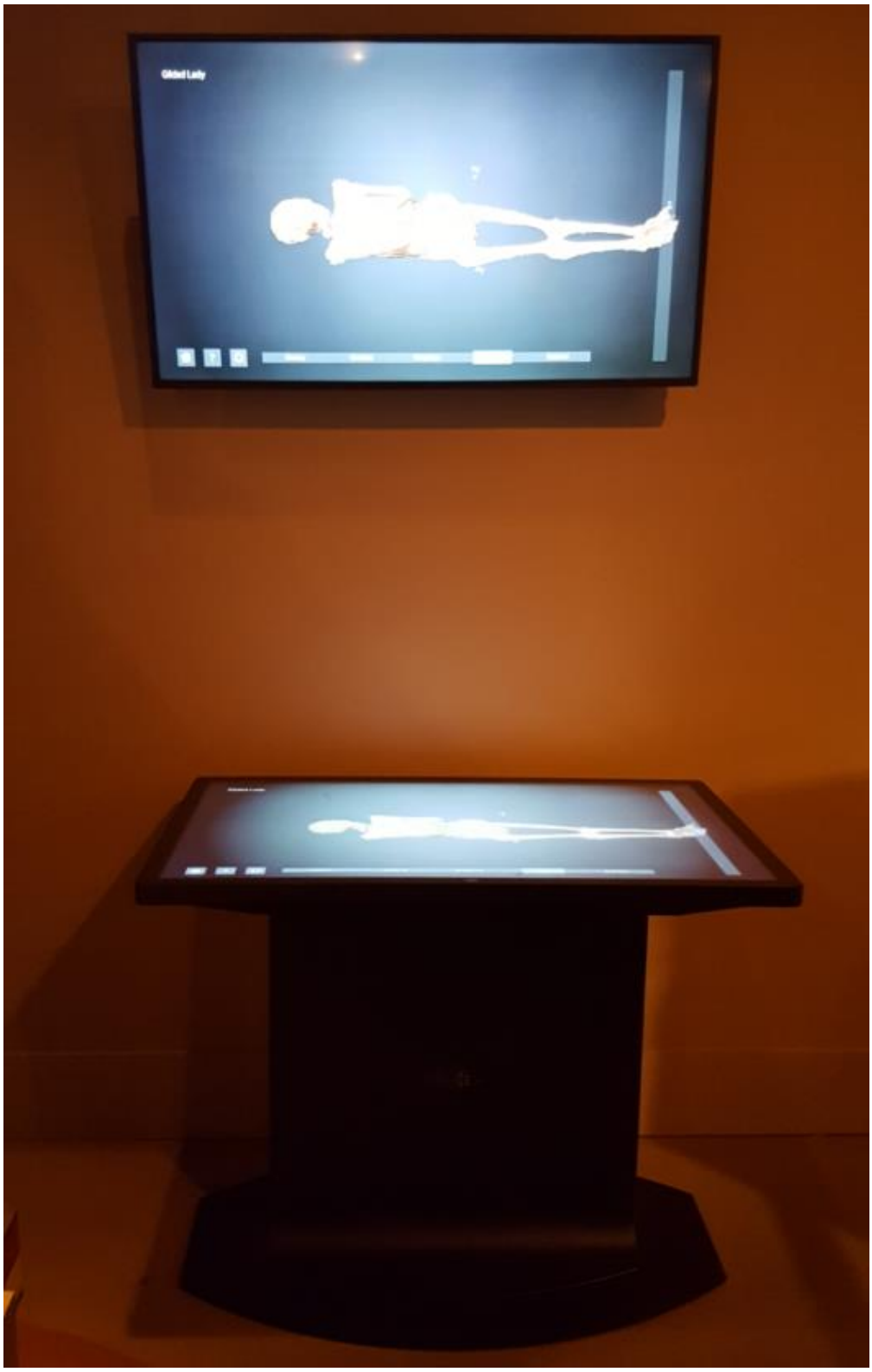

Figure 10. Photograph of the interactive station in the Egyptian exhibit at the Field Museum in Chicago.

Figure 11. Photograph of a close-up view of a 3D model from the interactive station at the Field Museum in Chicago.

Figure 12. Photograph of the mummy Meresamun and the interactive station that displays her CT scan data; at the Oriental Institute Museum in Chicago.

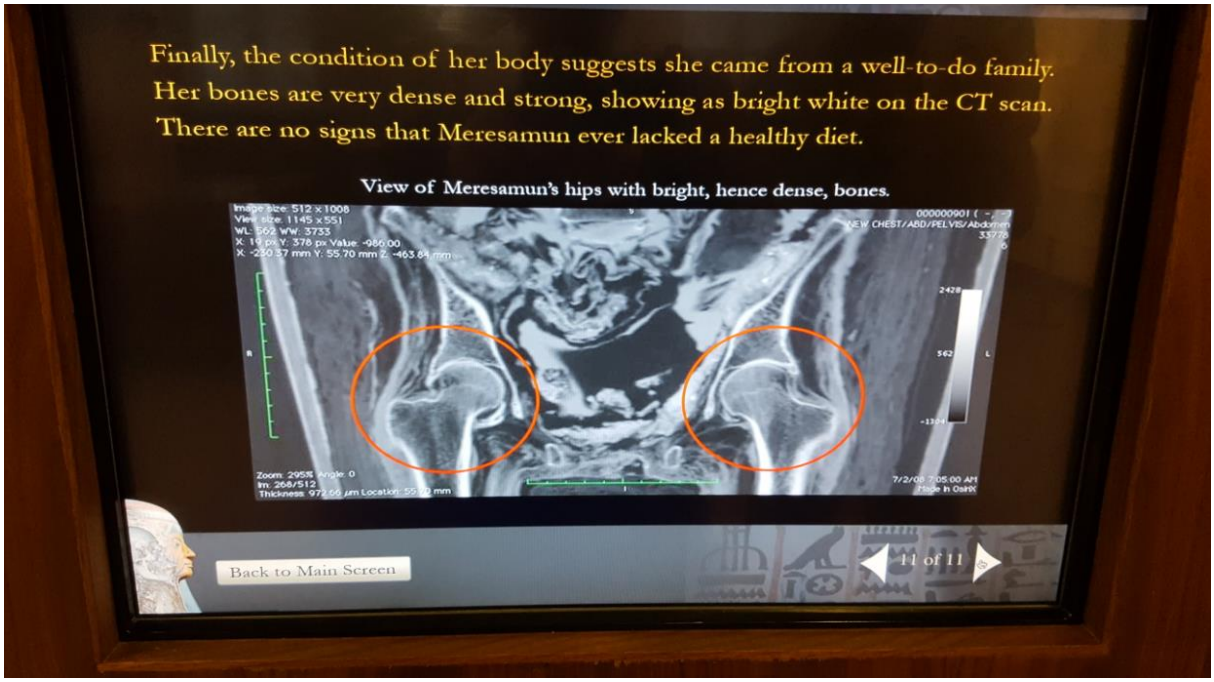

Figure 13. Photograph of a 2D CT scan slice denoted and explained on the interactive station at the Oriental Institute Museum in Chicago.

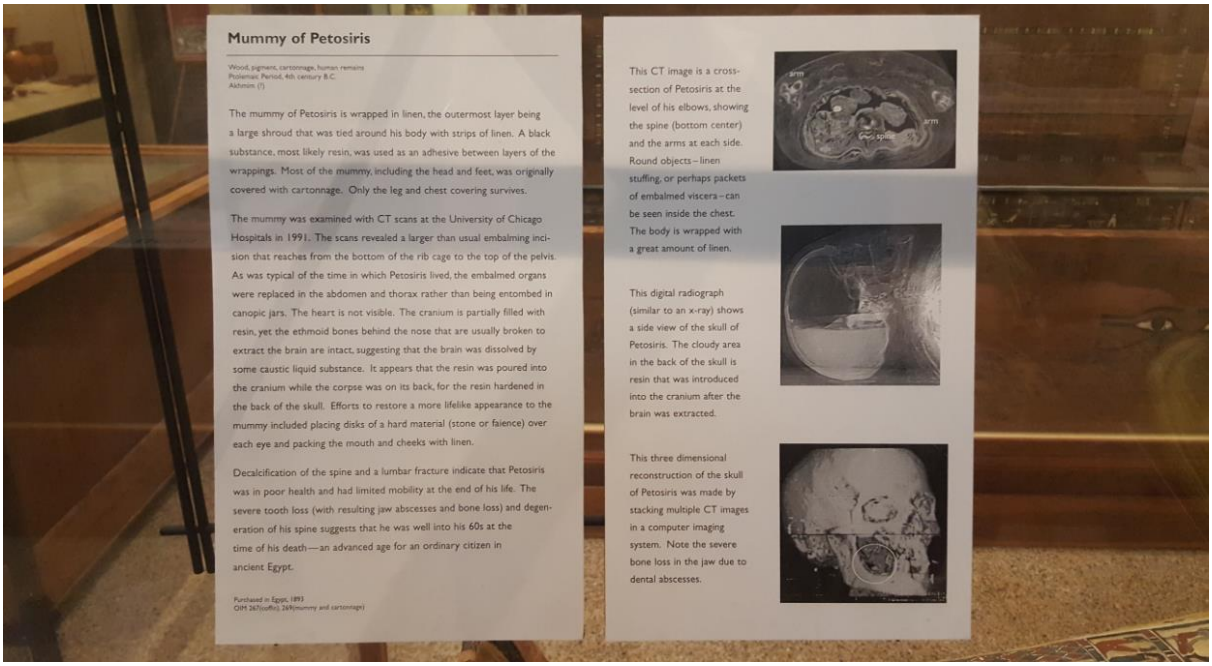

Figure 14. Photograph of the informative placard on the display case of the mummy Petosiris, including 2D CT slices and a 3D model, at the Oriental Institute Museum in Chicago.

Figure 15. Photograph of the mummy case built into the wall (far left), polymer resin model, and CT scan display at the Kelsey Museum in Ann Arbor.

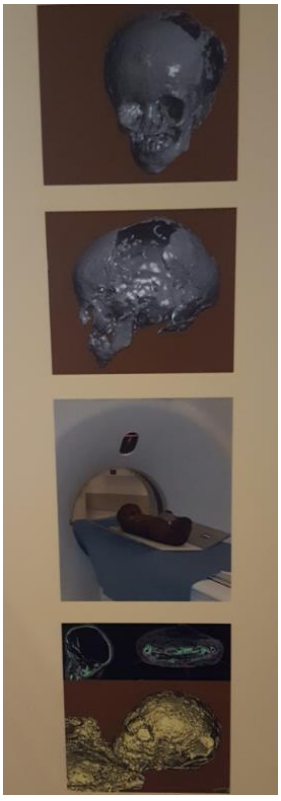

Figure 16. Photograph of a close-up view of the CT scan display images at the Kelsey Museum in Ann Arbor.

Figure 17. Photograph of a 2D CT scan slice explaining age estimation, on display at the Kalamazoo Valley Museum.

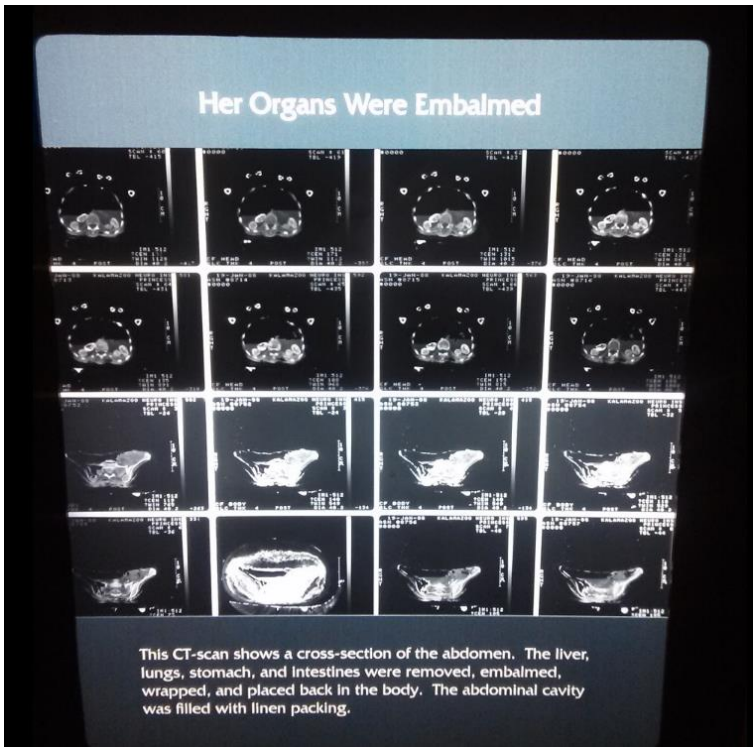

Figure 18. Photograph of multiple sequential CT scan slices on display at the Kalamazoo Valley Museum.

Appendix B

2016 CT Analysis of Mummy Nakhte-Bastet-Iru

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Report submitted to Grand Rapids Public Museum

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Author Note

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Introduction

The following is a report for the Grand Rapids Public Museum (GRPM) that describes the condition and health of their Third Intermediate Period (1069-664 BC), 22nd Dynasty (946-712 BC) Egyptian mummy, known as Nakhte-Bastet-Iru. This research was conducted using the Computed Tomography (CT) scan taken in March of 2015; no physical access to the mummy occurred. The clinical assessments were made by a radiologist at Butterworth Hospital in Grand Rapids, MI. These assessments were made from the two dimensional slices of the CT scan, using a profession medical workstation. Additional measurements and interpretations were made by myself using both 2D images and 3D models, sometimes with consultation from professionals. Some of the 3D models were created by imaging staff at Advanced Radiology Services (ARS) of Grand Rapids, MI, also with the use of a professional medical workstation. The other models and images were created using Horos v1.1.2 for the Mac computer and RadiAnt Dicom Viewer v3.2.3 (64-bit) for the PC.

Research Context

The goal of this report is to provide new information about the life and death of Nakhte-Bastet-Iru through examination of the first full body CT scan of her bones, tissue, and the mummification process used. This information builds on previous research by Dr. Janet Richards who prepared a report based on Nakhte's coffin, cartonnage, and outer wrappings in 1996, a bioarchaeological examination of skull x-rays by Dr. Brenda Baker in 1996, and a facial reconstruction by Jennifer Fillion in 2000. I am a graduate student in the Department of Anthropology at Western Michigan University with a research focus on skeletal biology in museum contexts. This report is the result of a year long internship that has included extensive research of Third Intermediate Period mummification and museum CT practices. New

information about Nakhte's health and burial assemblage was discovered. Previous findings were reviewed, explained in greater detail, and supported with additional evidence through my analysis of the CT scan. This report will also be submitted to a graduate committee at Western Michigan University to fulfill requirements for a Master's of Arts Degree in Anthropology.

Nakhte-Bastet-Iru

Nakhte-Bastet-Iru's mummified remains were donated to the GRPM in 1909 by Edward Lowe. The Grand Rapids native had acquired the mummy while on vacation from a well-known shop in Cairo, Egypt. Interpretation of the hieroglyphics on her coffin and cartonnage indicate that Nakhte was the daughter of a priest who worked in the temple of Amon in Karnak, which is located in Thebes. Her father was not a high priest, which would have been a role of great power during this period, but his status would still be considered upper-class. This is also evident by Nakhte's high quality linen wrappings and finely decorated coffin and cartonnage. Dr. Richards used these cultural items to date the mummy to the Third Intermediate Period. The cartonnage particularly indicates the 22nd Dynasty. Dr. Baker confirmed female sex by observing facial features of the skull x-ray. She used the maxillary dentition to age Nakhte at between 18 and 21 years at her time of death. I was asked to provide further description of Nakhte's sex and age determination as well as insight into her health through examination of her bones and tissue visible through the CT scan (Figure 1).

Inventory/Condition of Bones

While a mummy may be expected to have been buried with all bones, the following bones were not located inside Nakhte: the right radius, right ulna, and both hands including all of the carpals, metacarpals, and phalanges. It is possible that some tiny higher density pieces in the

wrappings may be fragments of these hand bones, but the imagery was not strong enough to determine this.

Nakhte has numerous broken bones which has been previously attributed to improper care prior to her arrival at the museum. The following includes a summary of the general condition and breaks but it is not an all-inclusive list since there are too many to discuss individually. Those omitted from discussion are mainly fractures of the upper limbs, scapulae and clavicles that appear to have been crushed in several locations from rough handling. The breaks focused on are those of the undisturbed lower limbs and large breaks throughout the body. The skull is in fair condition. The mandible is separated from the cranium. The top of the left ramus and mandibular condyle are still attached to the cranium. The mandible was not CT scanned, and is not included in this report. The nasal bones are fractured. There is damage to the sphenoid and nearly all of the ethmoid is missing, which will be discussed further under the 'Mummification' section of this report. The middle ear bones are intact. The dentition of the maxilla is *in situ*, but there are breaks on LI^1, LI^2, LM^2, and RC^1, additionally RM^3 is not present. The cranium has been separated from the rest of the body at the cervical (C) spine and the first section of vertebrae have become misaligned. There are fractures to C5 and C6 is absent. C7 is mostly intact and remains with the lower spinal column. The thoracic and lumbar vertebrae, sternum, and all of the ribs are accounted for and show no visible damage. The hyoid is not present, likely it was lost during the decapitation or may have disintegrated due to its extreme fragility. The clavicles and scapulae are fractured, and not in anatomical position although in the general area. Both humeri have complete breaks at mid-shaft. The left ulna and radius are incomplete on their distal ends and contain fractures. The right femur has several breaks at mid-shaft. The left femur is broken at the neck. The left tibia has a fracture at the upper mid-shaft.

The patellas are in good condition with no fracturing. The pelvic girdle is in good condition with no visible fracturing. The feet and ankle bones are in good condition, except for distal phalange 1 (big toe) of the right foot, which is protruding through the wrappings. The left humerus has been returned to the mummy upside down. The misalignment of this and other bones in the torso is likely a result of the unwrapping in 1910 or a previous disturbance, and or the tight wrapping of the body during mummification. Several complete fractures throughout the skeleton appear to be the result of deliberate postmortem human modification and will be discussed further in the next section.

Taphonomy

Although many bones are present and *in situ*, there is evidence that taphonomic processes have affected the 3,000 year old remains. The desiccation and manipulation by mummification can make it quite difficult to differentiate between organs and stuffing material, due to tissue shrinking (Rühli et al., 2004). Additionally, the bones may look ideal in some instances, but are actually hollow or less dense than in live or recently deceased individuals. A Hounsfield Unit (HU) is the term of measurement used to describe the density of material in a CT scan, also referred to as attenuation. The standard calibrated reading for air in a CT scan is at -1024HU (Villa and Lynnerup, 2012). After this calibration, traditional (from living bodies) HU ranges cannot be applied to clinically interpret mummified tissue (Villa and Lynnerup, 2012). For example, trabecular bone, the spongy inner bone, is less dense in Egyptian mummies than in forensic bodies, showing significant loss has occurred through time (Villa and Lynnerup, 2012). This is a common occurrence in desiccated mummies (Rühli et al., 2004). Nakhte's vertebrae for example had a reading in one location of -442HU, meaning the marrow space is now hollow and air-filled. There are several sources of HU ranges for bone, tissue, and foreign material found in

Egyptian mummies that were used as reference in this project (Gostner et al., 2013; Raven & Taconis, 2005; Villa & Lynnerup, 2012). Some of the highest attenuation readings come from Nakhte's teeth and long bones; these areas usually survive the best in archaeological conditions. The passing of time, the unwrapping in 1910, and other manipulation since mummification, may all contribute to increased degradation of her tissue and bone. It is also possible to get higher density readings than normal because of the addition of resin to the body and wrappings from the mummification process (Rühli et al., 2004). It is important to understand these differences of density in mummies versus the living, so that HU's or attenuation readings are not interpreted as pathological conditions or the incorrect material.

Some of the fractures on Nakhte's skeleton appear to possibly be saw cuts. These include at C7, the neck of the left femur (Figure 2), and the shaft of the left humerus. It is the opinion of the radiologist that these breaks look too clean and neat to be made by accident. Seeing as the skull was detached, it is possible this occurred intentionally through C6 and C7. The cuts were possibly made during the unwrapping of Nakhte in 1910. If notes from this event can be located, this could shed light on the occurrences of that day, including whether or not the missing hand and arm bones were present at that time. If the saw cuts and missing bones occurred before 1910, then these alterations are likely a result of earlier looting or the mummification procedure. Plundering of Egyptian tombs and mummies began in ancient times, so it would be difficult to estimate when this occurred.

Sex

The sex of the Nakhte was previously determined female using the hieroglyphics and illustrations on the outside of her cartonnage and coffin. For further explanation of this cultural analysis, Dr. Richards' report can be located in Nakhte's museum file. Although cultural

indicators can be an excellent means of determining sex, a biological determination is important since controversial merchant practices existed, including selling mummies with cultural artifacts that did not belong together, to fetch a higher price. Physical anthropologist Dr. Baker analyzed x-rays of the cranium taken in the 1990's and reached the conclusion of female, but no formal explanation of this finding is currently present in the GRPM's file, except for mention in an email. For the potential use by the museum in future educational materials or display, sex was confirmed and the determination of female explained further.

Upon examination of a 3D model there is no outward indication of male or female genitalia. Although the absence of male genitalia would be the immediate indicator of sex, several studies find this method unreliable, with less than a 50% success rate (Rühli et al., 2004). Shrinking tissue, skin folding, and the use of resin contributes to this difficulty. The CT scan images of the pelvis and skull were sexed using methods from Buikstra and Ubelaker (1994). These are standards for the macroscopic interpretation of bone, but are applied here as best as possible when views allow. The supraorbital margin and mental eminence were unable to be scored. The mastoid process and glabella score female. The nuchal crest scores ambiguously. Estimated sex from cranial features is female. The preauricular sulcus, ischiopubic ramus ridge, and ventral arc of the pelvis were unable to be scored. The greater sciatic notch and subpubic concavity strongly scored female. Estimated sex from pelvic features is female. The general wide and ovoid shaped pelvic girdle also indicates female.

Age

To confirm age at death, the sutures of the skull were examined using methods from Buikstra and Ubelaker (1994), and although there was not enough detail in the 3D models to score each closure, a view of the lambdoidal and sagittal sutures shows very little closure,

indicating a young individual (Figure 3). The pelvis was not used to age since the pubic symphysis and auricular surface are obstructed from view due to articulation of the bones. Dental age was estimated using methods in Buikstra and Ubelaker (1994). Dental features indicate an age between 15 and 21 years of age based on the upper left third molar (LM^3). This molar is at or near the gumline (Figure 4). After consultation with a dental surgical assistant, it appears that the occlusal surface of LM^3 is in line with the cervical root of LM^2, indicating the wisdom tooth had likely not erupted the gumline yet. The root of LM^3 appears to be approximately half way grown, indicating an age possibly closer to the mid of that range, or 17-19 years old. The right third molar is not present so could not be used for aging (Figure 5). Radiology also confirmed that all of the long bones are fully fused as well as the iliac crest apothysis, further eliminating subadult.

Stature

Calculations for stature were made using the "negroid" formulae for females by Trotter (1970), which is traditionally used in ancient Egyptian studies. The stature formulas by Trotter (1970) were created using modern American populations and are applied with the understanding that they are not population specific. A recent study that attempted to create new formulas confirms that ancient Egyptian body proportions are closer to "blacks" than "whites" but are not identical (Raxter, 2008). Much debate continues to exist on the "race" of ancient Egyptians, but Trotter's formula is used here since it continues to be applied in some of the most recent mummy studies published (Bianucci et al., 2015; Brier et al., 2015; Habicht et al, 2015). The maximum length of the right femur (better condition than left) measured approximately 38.5 cm, giving a stature estimation of 4'8"-4'11". The left tibia measured approximately 31.6cm, giving a stature estimate of 4'9"-5'0". Measurements were also taken from the top of the cranium to the feet and were approximately 146.5cm or 4'9.5", although this method does not take into consideration

shrinkage of tissue and muscle or movement of bones from handling. Combining these averages it is estimated that Nakhte was around 4’10” tall. This may seem very short by present day standards yet a recent study by Habicht (2015) gathered height information from a sample of 259 Egyptian mummies. Both royal females and commoner females had an average height of over 156cm, or 5’1” (Habicht, 2015). Although a small sample size when considering the time span, it appears Nakhte was short for her time as well, but not abnormally. Over all time periods royal women were found to be shorter than commoner women and this is attributed to sexual selection in less stature being more attractive among this population (Habicht, 2015). Although Nakhte is not known to be royalty, she was the daughter of a priest and from a wealthy family. Perhaps her shorter than average stature was a result in part to her elite status. There are other circumstances that can contribute to small stature, including illness or poor nutrition in childhood, which cannot be discounted as well.

Pathological Conditions

No evidence was found to support that any of the breaks on Nakhte’s bones occurred prior to (antemortem), or near the time of her death (perimortem). Typically in a bioarchaeological investigation ancient trauma and modern breaks can be discerned by examining the color of the exposed broken bone (Buikstra and Ubelaker, 1994). This is not possible to see with the CT scan images. Also examined, are signs of remodeling on the bones, a signal that healing was beginning or occurred. There was no evidence of remodeled bone, either from very old injuries or recently acquired. Children’s bone can remodel so perfectly by adulthood that any sign of an early fracture may not be visible, so it cannot be said that Nakhte never broke a bone in her lifetime. There is a possibility that a fracture or fractures occurred causing death so abruptly that there was no time for any healing to begin. There is no evidence

for this idea though. If a massive trauma had occurred you would likely find different kinds of fractures on the bones, such as evidence of weapon piercing, partial breaks (greenstick), compression, or depression fractures (Buikstra and Ubelaker, 1994). All of the breaks on Nakhte's bones appear to be simple breaks resulting in two fragments with jagged edges, suggesting post-mortem damage as the cause. Additionally, a large trauma may be visible on the tissue, but there is no evidence of that either.

No evidence of infection was found on Nakhte's bones. The 2D CT slices are not able to identify small abnormalities such as pitting or areas of osteitis (inflammation). The 3D models created also lacked fine detail, making it difficult to identify small imperfections, however a large abnormality would have been noticeable. A chronic disease or infection can leave markers on bone, but if the condition killed Nakhte quickly there may not be any evidence on her body (Wood et al., 1992).

Nakhte's dental health, by evidence of her maxillary dentition, was rather good. There are no signs of cavities, abscesses, or wear. Her youth may attribute to this good condition. Her broken teeth are the result of postmortem damage. If the breaks were a result of antemortem or perimortem trauma, there would be other indications of this to her maxilla, especially on the alveolus. Her teeth show no overcrowding and a slight maxillary prognathism, which is a common feature of ancient Egyptian dentition (Cockburn et al., 1998). It was noted above that LM^3 is near the gum line, however RM^3 is not present in the maxilla (Figure 5). The two possibilities for this missing tooth are that it was extracted well before death and the alveolar process was able to fully remodel or it is a congenital anomaly. Consultation from the dental surgical assistant indicates it is more likely the latter. There is no sign of bone loss, also known as resorption, which occurs when a tooth is removed and the socket is allowed to heal

completely. It is more likely that Nakhte was born without this tooth. Both the evidence for ancient Egyptian dentistry practices (i.e. extraction) and naturally occurring missing teeth have been well documented in Egyptian mummies (Cockburn et al., 1998).

On Nakhte's pelvis there is an indication of sclerosis on the iliac bone near the sacroilliac joint, more prominent on the right side (Figure 6). This is represented by areas of denser bone near the joint and is a result of "mechanical strain causing premature arthritis" (Mitra, 2010, pp.293). Other differential diagnosis include metastatic disease or ankylosing spondylitis (Mitra, 2010), however neither evidence of tumors nor bone deformation of the spine was found in Nakhte so these conditions are not likely. There is no single cause for trauma to this location of the pelvis, but since Nakhte was very young and wealthy, degenerative arthritis caused from old age or years of hard work can be excluded. It is possible that an unknown condition or trauma afflicted Nakhte. It is also common for this condition to appear in females during and following pregnancy (Mitra, 2010). This sclerosis can be caused by stress from the motion of walking while pregnant. During pregnancy the joints in the pelvis loosen due to the presence of hormones which allows the baby to pass through the birth canal. The condition can also start after pregnancy if the ligaments and joints do not tighten up promptly after giving birth causing arthritis in the joint. Patients with this condition, pregnant or not, usually complain of low back pain (Mitra, 2010).

To further examine the possibility that Nakhte had birthed a child, the symphysis pubis was examined. The symphysis pubis does not show widening and there are no arthritic changes in this region. This contradicts the idea of parturition. There is considerable critique as to the effectiveness of these factors or any skeletal alterations in confirming childbirth (Ubelaker and De La Paz, 2012). Many other conditions can cause similar skeletal anomalies, even in males

(Ubelaker and De La Paz, 2012). Some of these differential diagnoses can be omitted due to Nakhte's young age at death, however neither the sclerosis nor the pubic symphysis can be used to indisputably declare a pregnancy did or did not occur (Ubelaker and De La Paz, 2012). The best way to make a case for a finding of parturition is to look for multiple indicators present throughout the skeleton, however we did not find a second indicator. The possible causes of sclerosis on the pelvis is an unknown trauma or pregnancy.

Nakhte's spine is in great condition and good health, with exception to the postmortem damage on the cervical vertebrae discussed above. It is also of note that no arthritic changes in the patella and joint of the right knee was found, which contradicts initial findings reported to the GRPM. The most recent radiological interpretation is that the skeletal degeneration is from postmortem damage, not arthritic changes.

Mummification

Nakhte's brain was removed through her nasal aperture (Figure 7). The ethmoid bone has been nearly completely destroyed. Both sides of the sphenoid (although greater on the left) have been broken indicating bilateral brain removal. Throughout the torso and in the cranial cavity is material used to help the body retain its shape. These include what appear to be pieces of folded linen, visceral packets, resin, and low-density granular substances (Figure 8). A visceral packet is created by removing the internal organs, covering them in resin, wrapping them in linen, and then returning the packet to the abdominal cavity (Dunand & Lichtenberg, 2006). The grainy substances could be sawdust, lichen, clay, sand, soil, rocks, or a combination of these (Dunand & Lichtenberg, 2006; Raven & Taconis, 2005). The attenuation in these grainy regions were usually in the -300HU to -500HU range suggesting that it is more likely sawdust or other very low density material. It may be a mixture of many as there appears to be higher density pieces

which could be tiny rocks present in soil. There are no clear fluid levels from resin being poured in, which is often seen when large amounts are used, so it is more likely that it was used to a lesser degree or not at all to fill the body cavity (Hawass & Saleem, 2016).

Nakhte's eyes have been removed and a wad of linen remains stuffed in the right orbit, but the left is now empty. This linen was likely soaked in resin, evident by its moderate density (Figure 9). There is also some packing at the back of the cranium, although the material is not clear. The mode of evisceration is by incision on the left abdomen (Figures 10 & 11). The asymmetric filling of the abdominal cavity and overflow at the incision region are evidence of this (Loynes, 2015). Additionally, there is no evidence of a perianal or foramen magnum approach, the other less common evisceration techniques.

There is no evidence of subcutaneous packing in the limbs. There appears to be a foreign object near the left acetabulum and left femur head (Figure 12). It looks similar to a piece of wood, and the attenuation of 200-300HU support this possibility although it could be another material as well (Gostner et al., 2013). The size and morphology omits the possibility of it being a bone fragment from Nakhte's skeleton. It is possible that this object is an alteration from the unwrapping or earlier tampering, or from the mummification process itself. There are published findings of wood found in mummies, attributed to embalming practice. Two mummies had wooden sticks removed from their sphenoid sinus, one of which was radiocarbon dated as 2200 years old (Čavka et al., 2012; Jackowski et al., 2008). Two child mummies, one dated between the 22nd and 23rd dynasty, were found with wooden poles used to straighten their bodies (Cesarani et al, 2003).

Around the outer layers of wrapping there are numerous small high density objects (Figures 13). It was mentioned above that they could be missing phalanges. These may have

come to be there during the rewrapping in 1910 or an earlier looting. It is also possible some of these high density pieces may be beads or additional amulets that were placed purposely in the wrappings during embalming (Hawass & Saleem, 2016).

Tissue

The examination of mummified tissue is problematic due to shrinkage from desiccation and the addition of resin to the surface of Nakhte's skin and wrappings. The 3D models that were created were not sensitive enough to pick up small details of the skin. Some mummy research has been able to identify the skin incision(s) from evisceration and even pierced earlobes, however neither could be located during this project. Radiological investigation was able to identify the presence of some costal cartilage of the ribs, with nearly no calcification, which also supports the finding of young age at death. One of the visceral packets contained what looked similar in appearance to intestines. The density of the visceral packets were examined to attempt to identify if organs were in fact inside. Figure 14 shows the attenuation of a visceral packet found in Nakhte's right abdomen. Organs were often coated in resin during this period, before being wrapped into linen. The more radiodense center of this packet suggests this technique was used. These findings suggest that at least some of Nakhte's organs were returned to her body and the packing inside is not just folded linen, however, specific organs could not be identified.

Cultural Material

There are three decorative pieces on Nakhte's chest (Figure 15). The CT images show that they are between 1.5cm and 2cm long and share a similar outline (Figure 16). The 3D reconstructed shape does not match any well-known amulets that are common to ancient Egyptian mummies, although degenerate forms of amulets, those lacking great detail, were

common in all periods (Andrews, 1994). These ‘amulets’ may actually be characterized as a plaque which contains raised reliefs or inscriptions, or as a jewelry item. I will continue to refer to them as amulets since that is the most common finding and also sometimes used as a blanket descriptor.

In an email in Nakhte’s file, from Dr. Richards, there is reference to “three small porcelain ornaments... imbedded in the bitumen” from the *Director’s letter to Mr. Lowe*. Dr. Richards suggested in her report to locate these ornaments in collections, which she explained were more likely glazed faience than porcelain. It is possible that these three amulets *are* the “ornaments” and that they were never removed from Nakhte since they were affixed in the resin, or they may be additional pieces.

The density readings of these amulets are extremely high, two are over 3,000HU (Figures 17 & 18). Her center and left amulets are definitely metal, although the type cannot be ascertained (Gostner et al., 2013). Amulets made from gold, silver, bronze, copper, iron, and other metals have been found in Third Intermediate Period and more specifically 22nd Dynasty mummies (Andrews, 1994, d'Auria, Lacovara, & Roehrig, 1988). These precious metal amulets are rarer than those of faience and other glazed composites. Nakhte’s right amulet was slightly less dense, although still had attenuation of over 2,000HU indicating stone or faience (Hawass & Saleem, 2016). Some mummy CT studies claim that HU’s over 3,000 are “likely gold” although I have not found an explanation for why this is assumed. Possibly this is because of a preference for the use of gold by ancient Egyptians in their burial assemblages.

Intertwined in Nakhte’s wrappings, from around the thighs to the feet is an unidentified material (Figures 19 & 20). By color you can tell that it is denser than the surrounding wrappings, but an attenuation was not able to be measured. One possibility is that this material is

a string of beaded jewelry, or decorative linen trim, which is encased in the wrappings. Upon consultation with a conservator from the Field Museum, Chicago, IL, it was suggested that the material looks similar to late 19th century museum display wire seen in a Peruvian mummy. Museum display practices were not standardized until well into the 20th century, so any type of wire could have been used. If it is 19th century wire, it might have been weaved in and out of the mummy, and there may be evidence on the outside of the wrappings. There are also numerous modern pins around the head, which may be from the unwrapping, prior care by the seller in Egypt, or conservation attempts.

Discussion

No cause of death for Nakhte-Bastet-Iru was determined. There was no skeletal evidence found of a catastrophic injury that caused death, however with the multitude of breaks and limited visibility, trauma cannot be ruled out. Even a relatively minor trauma that only affected the soft tissue could have been enough to kill someone in this time period, especially if infection set in. There were no signs of infection or other disease on the skeleton, however a pathology could have killed her before any skeletal changes developed (Wood et al., 1992). Additionally, the CT technology and 3D modeling programs used may not have been precise enough to pick up tiny bone imperfections. This is one research area where examining the bones and tissue macroscopically or by dissection is most effective. The strength of the CT technology was identifying arthritic changes in the pelvis, and conducting density readings. Although it is more likely that Nakhte's sclerosis is from pregnancy, other mechanical stress cannot be excluded. It is certainly a possibility that she died during or as a result of childbirth since the danger of giving birth was equal among all classes of women and their leading cause of death in this time period (Graves-Brown, 2010).

The mummification techniques revealed by the CT scan reinforces the estimation that Nakhte lived during the 22nd Dynasty of the Third Intermediate Period. The left abdominal incision is seen most frequently among mummies from this Dynasty (Loynes, 2015). Nakhte's abdomen contained visceral packets which was the standard for this period. Filling the body cavity was common practice in the 22nd Dynasty, but subcutaneous packing in the appendages had begun to decline (Ikram, 2003; Raven, M. & Taconis, 2005). It is also more common to find granular material as packing rather than resin in this period (Loynes, 2015). This matches the findings of packing only in Nakhte's torso and head, and the use of very low density granular substances. Excerebration through the nose was the norm prior to this period and beyond (Ikram, 2003). Nakhte's excerebration was through the ethmoid and sphenoid; this method, as well as through ethmoid or sphenoid only, has been found in 22nd Dynasty mummies (Loynes, 2015). Loynes (2015) says there was a movement towards using the horizontal approach (ethmoid/sphenoid perforation) beginning in the Third Intermediate Period.

The existence of precious metal amulets confirms that Nakhte was an upper class individual. The density of these amulets and other material should be considered a guide, since there is overlap in the attenuation of many substances. For example, the high attenuation of metal excludes other substances, but does not tell us what kind it is. Likewise, the abundance of types of packing materials makes it possible to narrow the list but not always specify exactly what was used. Similar attenuation made it difficult to discern some features from the CT scan, such as how many visceral packs there were and if other objects were desiccated tissue or packing material. Some ambiguousness may also be attributed to the unwrapping in 1910 and other damage done to the mummy.

Recommendations

If the GRPM chooses to continue researching the life and death of Nakhte-Bastet-Iru, there are many options available. These options should be weighed based on the potential of harm to the mummy and the possibility of meaningful information to be retrieved. DNA analysis could be employed to examine her genetic information. A pertinent study to consult would be that of Otzi the Iceman. Researchers have used DNA from his intestines to examine his last meal (Rollo et al., 2002) and mapped his entire genome which revealed amazing detail such as eye color and lactose intolerance, as well as the location of his closest living relatives (Saey, 2012). Isotopic analysis of Nakhte's teeth, could be performed using the mandible that is located in collections. Isotopic analysis could reveal information about her diet and if she was native to Thebes. Since the mandible has been likely exposed to human activity in collections and possibly handled in earlier times, consultation from professionals should be considered before moving forward with these type of analyses.

Macroscopic examination of the mandible by a dental anthropologist or bioarchaeologist could give more insight into dental pathologies and overall health. It would also be interesting to see if the third molar congenital abnormality seen on the maxilla exists on the mandible. If cervical vertebrae (C6) is present in collections, examination for cut marks could confirm the intentional separation of the cranium from the body by saw. Characteristics of the cut mark itself may also provide insight to the type of saw or tool used and possibly the time period in which it occurred. An examination of the surface of Nakhte would be beneficial to look for signs of the beading or possible wire seen in her wrappings. This may help to clarify if this material is an alteration to the mummy or part of her burial assemblage. If more information can be found on what took place during the unwrapping event in 1910, this could shed light on if the beading/wiring and the foreign object (possibly wood) found near her hip are modern additions

or from the ancient embalming. Records could also indicate if the body was more intact prior to the unwrapping or if looting damage or mummification mishaps occurred.

There is a technique called Micro-CT that can focus on small areas of the body and provide very detailed images of tissue and tiny objects (Wanek et al., 2011). This technology could be employed to get a better view of the morphology of the amulets, stick, possible beads, and other areas of interest. There is also special software that can help to better process images of metal in CT scans to retrieve more detail, such as "MDT: Metal Deletion Technique" (Hawass & Saleem, 2016, p.236). There are specific CT calibrations that should be used in mummy research that will produce the best images and models. Good sources that give recommendations for settings for future scans include Conlogue (2015) and Hawass & Saleem (2016).

In addition to this report, the Dicom disc created by Advanced Radiology Services and digital copies of all other images, models, and moving graphics created, will be provided to the GRPM. This material could be incorporated into the mummy exhibit. During recent visits to the Field Museum and the Oriental Institute Museum, Chicago, IL, it was observed that both locations have an interactive touchscreen display that allows patrons to examine the inside of a mummy by toggling through 2D CT slices. This would be an exciting way to allow visitors to interact more with the display.

It may also be beneficial to the public to understand who is performing mummy CT research and the larger questions it helps to answer. It would be a beneficial addition to the exhibit or possibly in the form of an educational pamphlet, to describe more of the current research of bioarchaeologists, paleopathologists, and Egyptologists. Topics of interest could include how these disciplines increase our understanding of current diseases, help recreate patterns of health and disease in ancient populations, and the bioarchaeological techniques of

bone interpretation. As the social sciences continue to see drops in funding across university departments and less grants for field research, it is important to show the public the valuable work being performed by anthropologists and their colleagues. Probably the most influential action to take with Nakhte's CT scan would be to permit access to it by other researchers. The largest CT database currently being compiled is the IMPACT Radiological Mummy Database (Nelson & Wade, 2015). Contributing Nakhte's scan would assist in more meaningful comparative and population based studies to be performed in the future.

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Appendix

Figure 1: Full body model of Nakhte-Bastet-Iru.

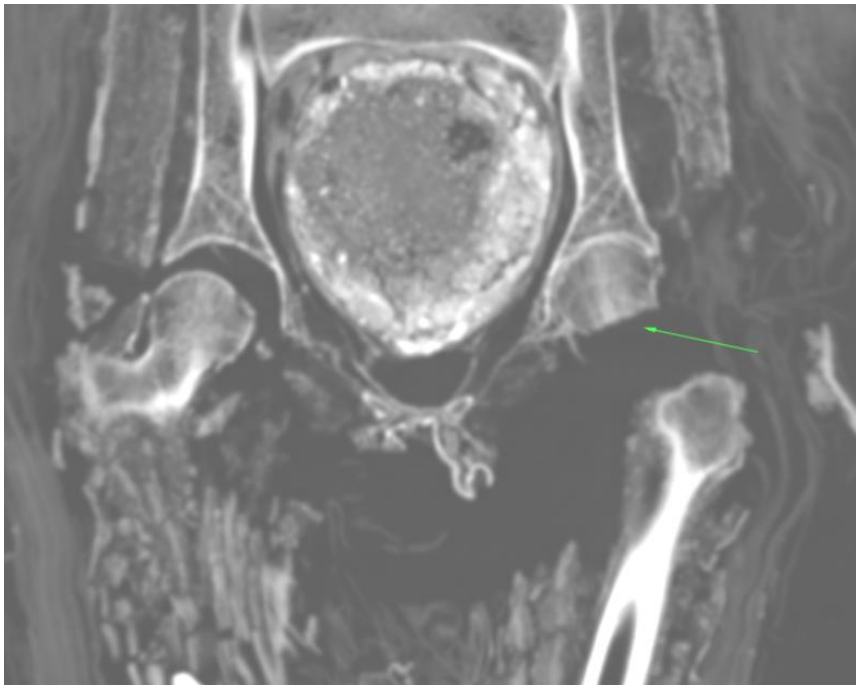

Figure 2: Possible saw cut on left femur.

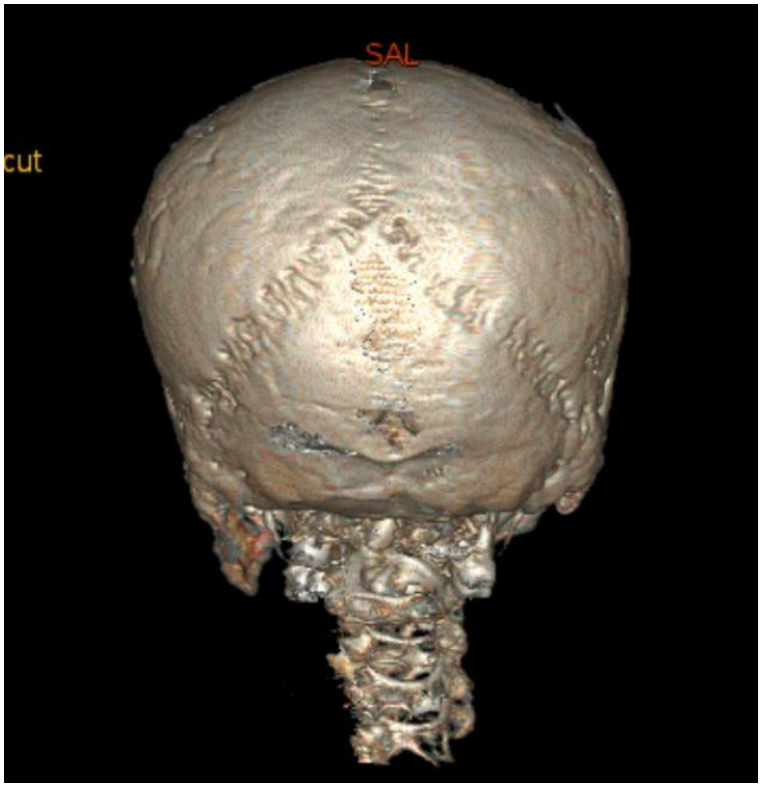

Figure 3: Lambdoidal and sagittal sutures (ARS, 2016).

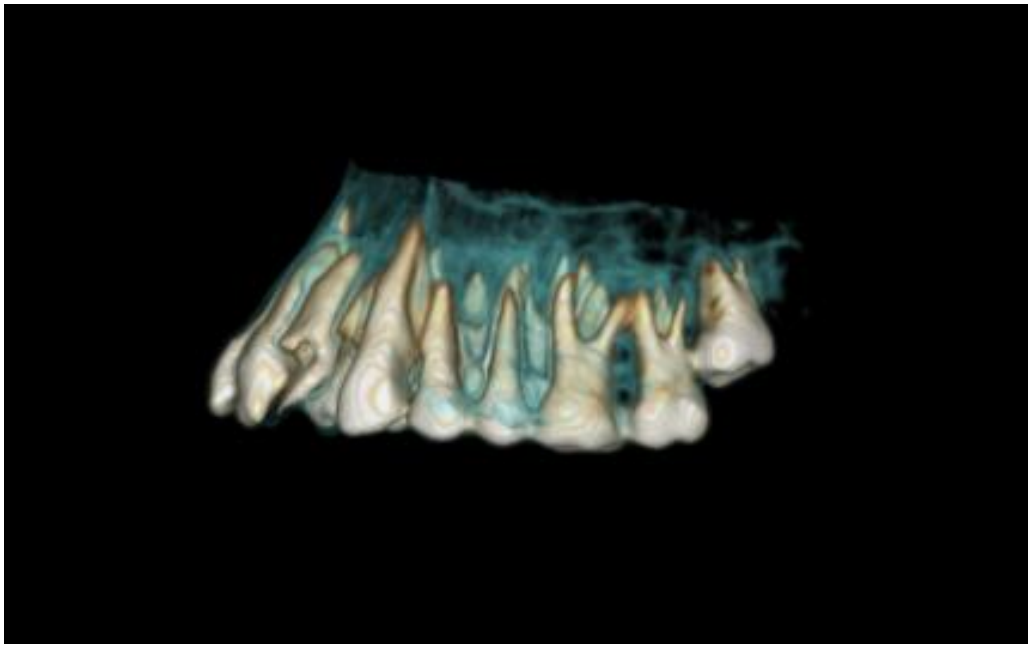

Figure 4: 3D model of maxilla, showing LM^3 near the gumline (ARS, 2016).

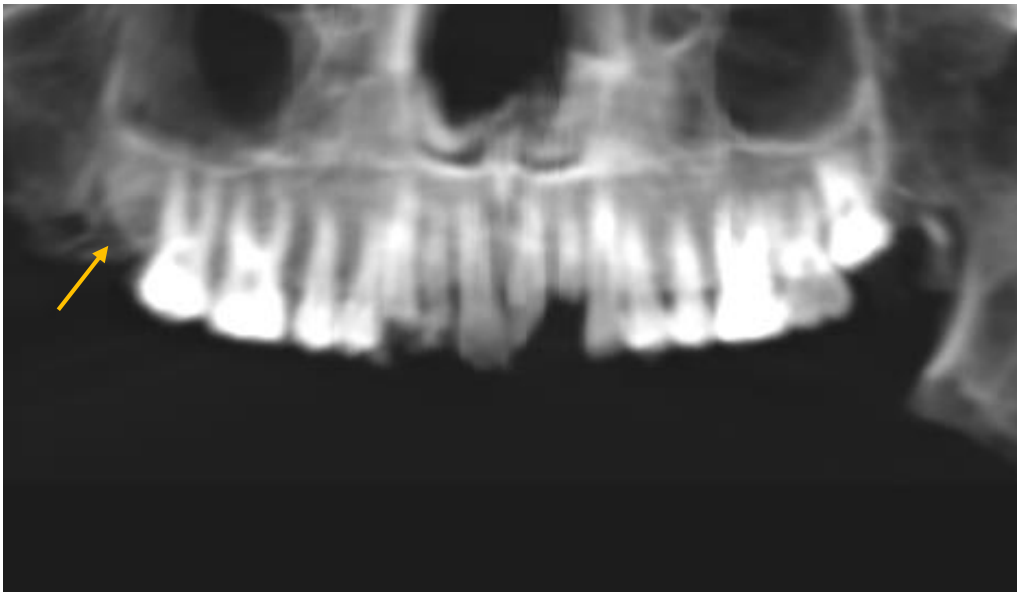

Figure 5: View of missing RM^3, and fractured teeth (ARS, 2016).

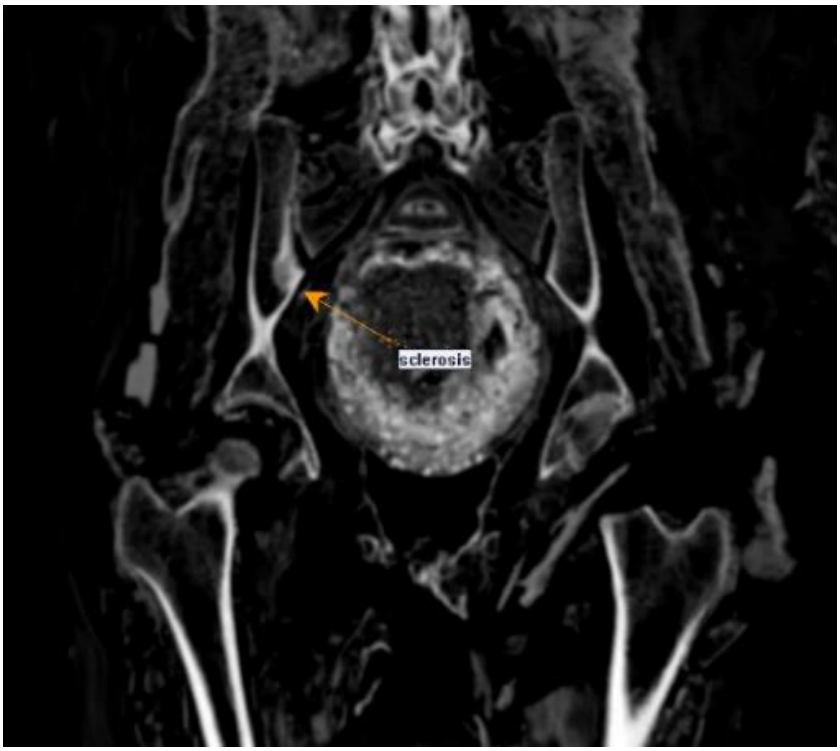

Figure 6: Sclerosis of the right ilium pelvic bone.

Figure 7: Excerebration route.

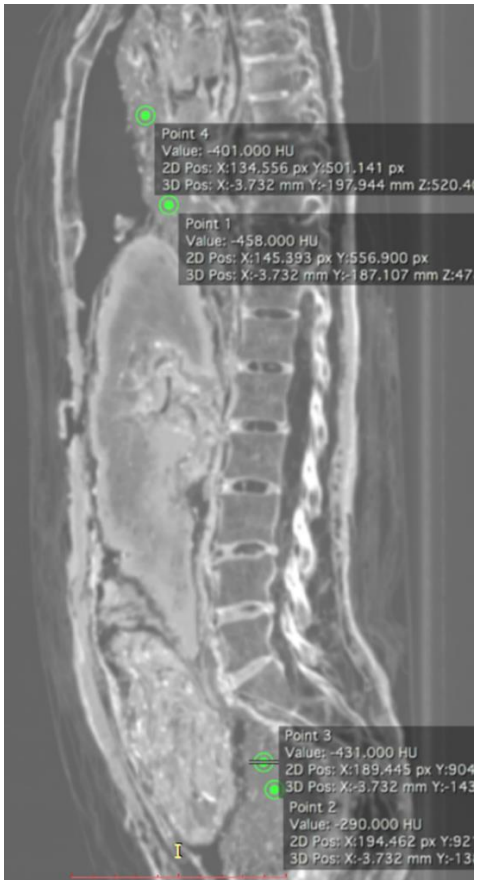

Figure 8: Sagittal view of torso showing attenuation of granular packing material.

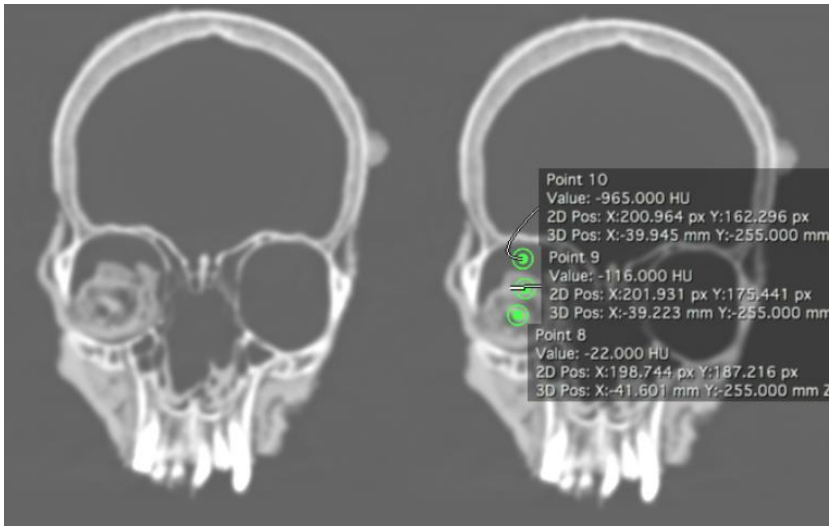

Figure 9: Coronal view of linen packing in the right eye orbit and density readings of hollow space (upper), and the packing material (two lower).

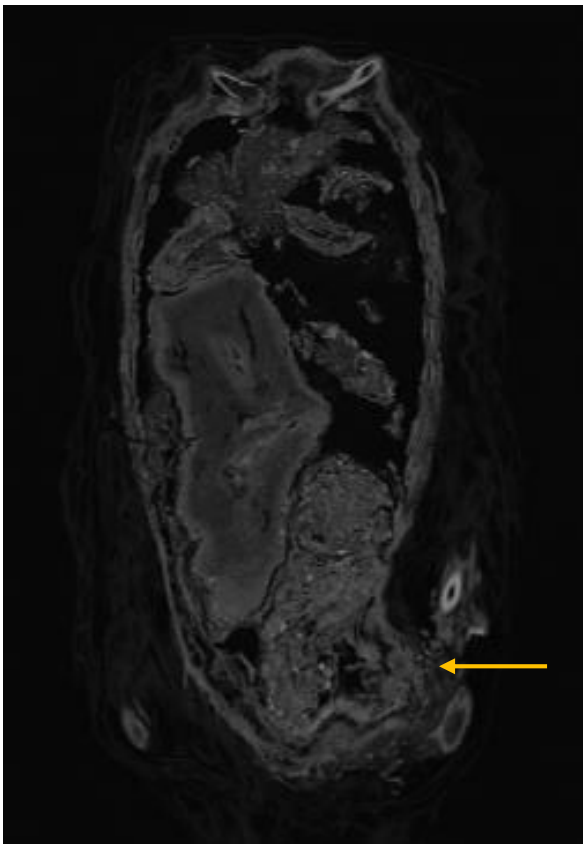

Figure 10: Coronal view of left abdominal incision area.

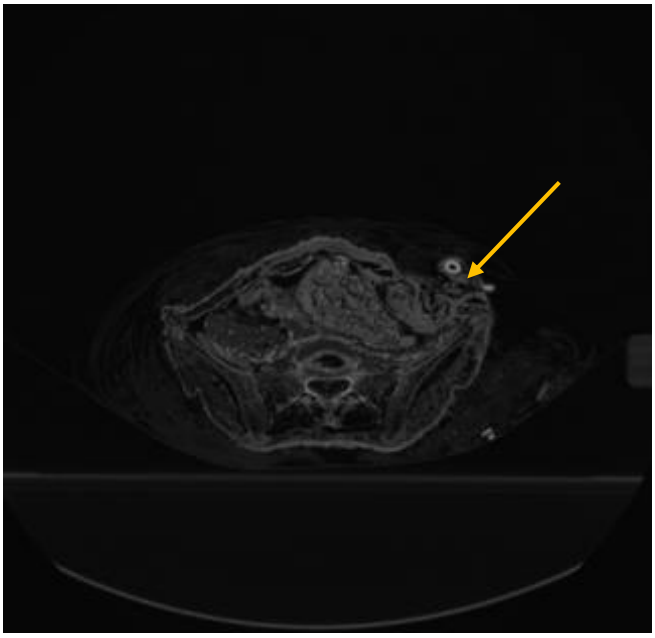

Figure 11: Axial view of left abdominal incision area.

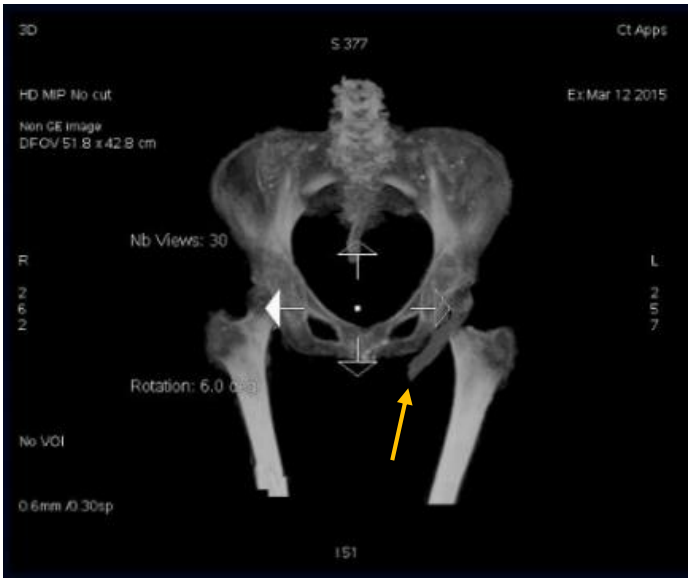

Figure 12: 3D model showing foreign object between pelvis and left femur (ARS, 2016).

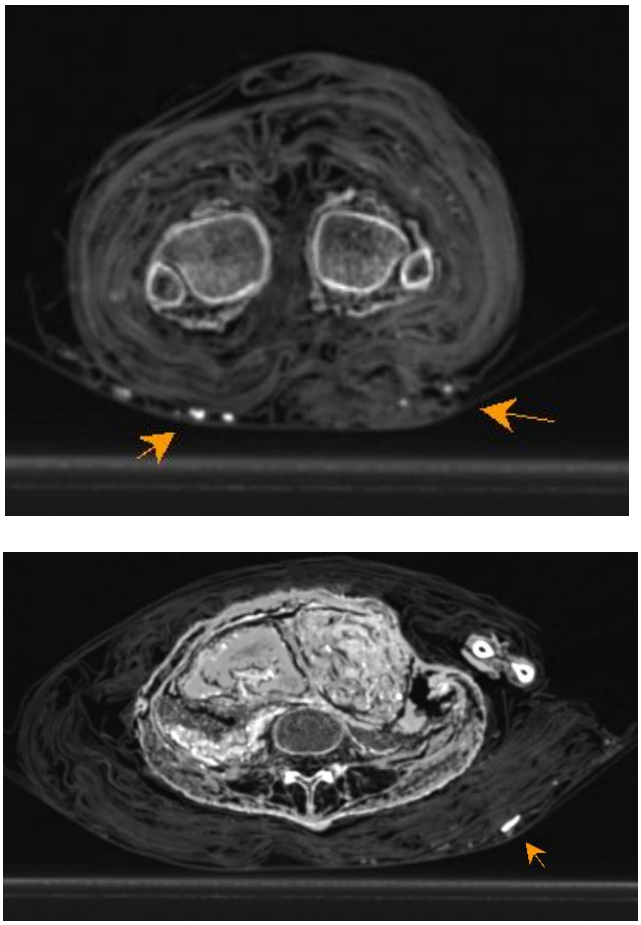

Figure 13: Axial views of small dense objects in wrappings.

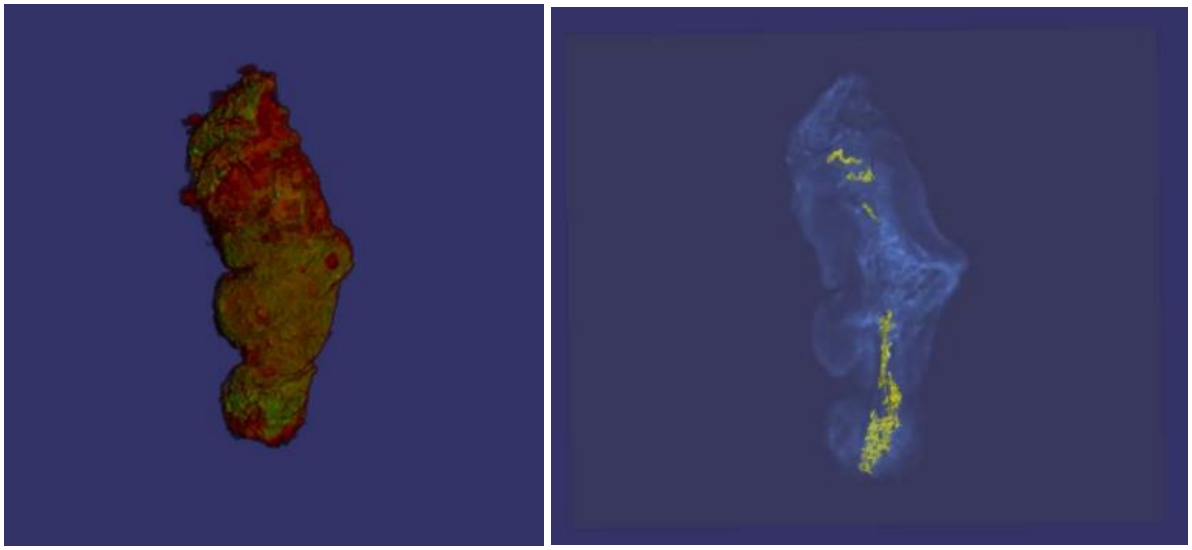

Figure 14: 3D model of visceral packet, and visual of dense material at the center.

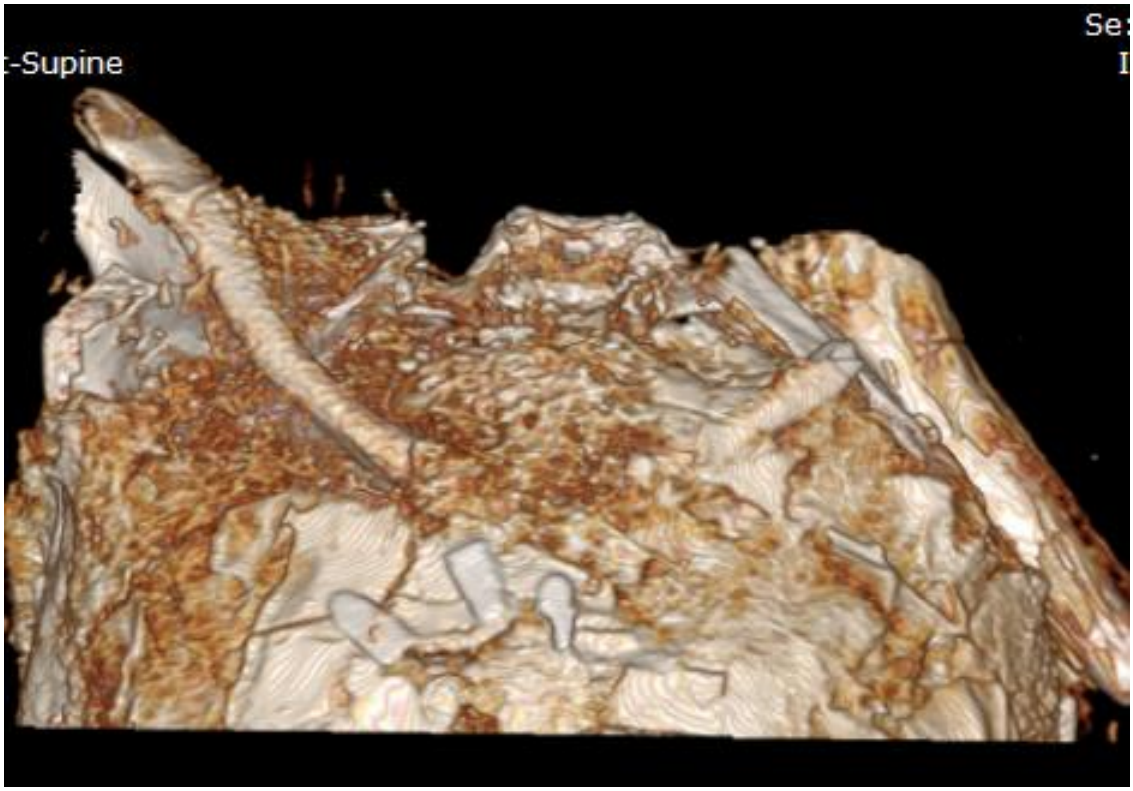

Figure 15: 3D model of upper torso showing three amulets (ARS, 2016).

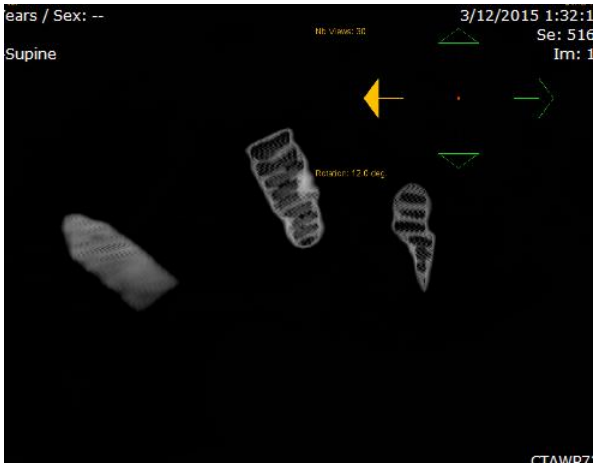

Figure 16: 3D model of amulets (ARS, 2016).

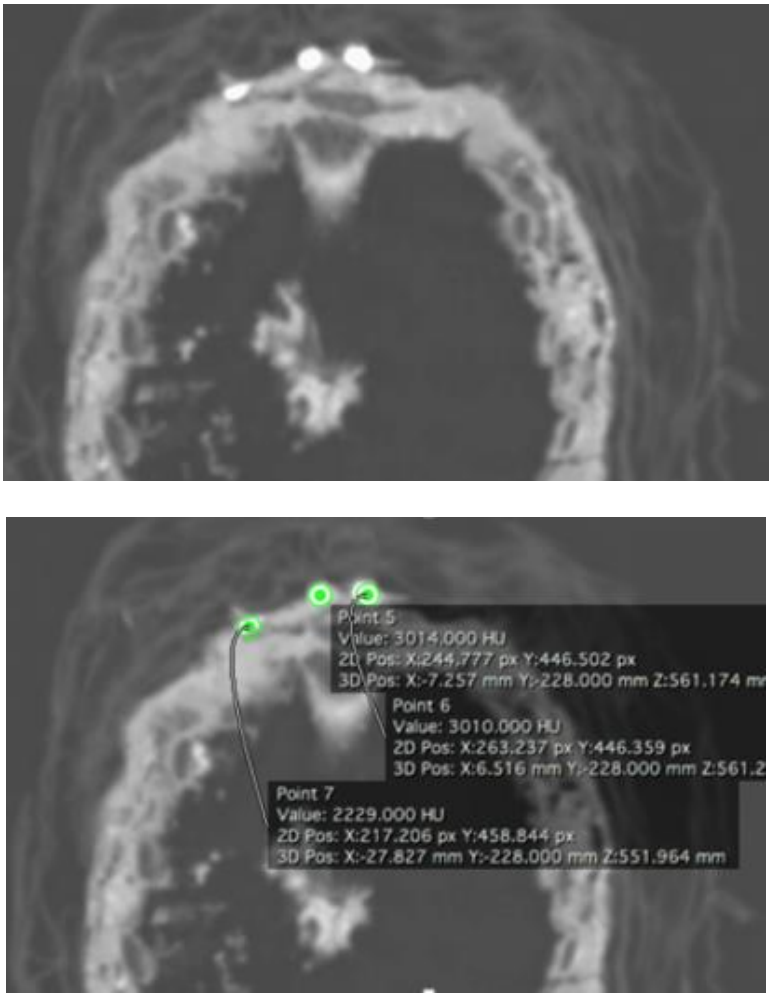

Figure 17: Coronal views of three amulets and there Hounsfield Units.

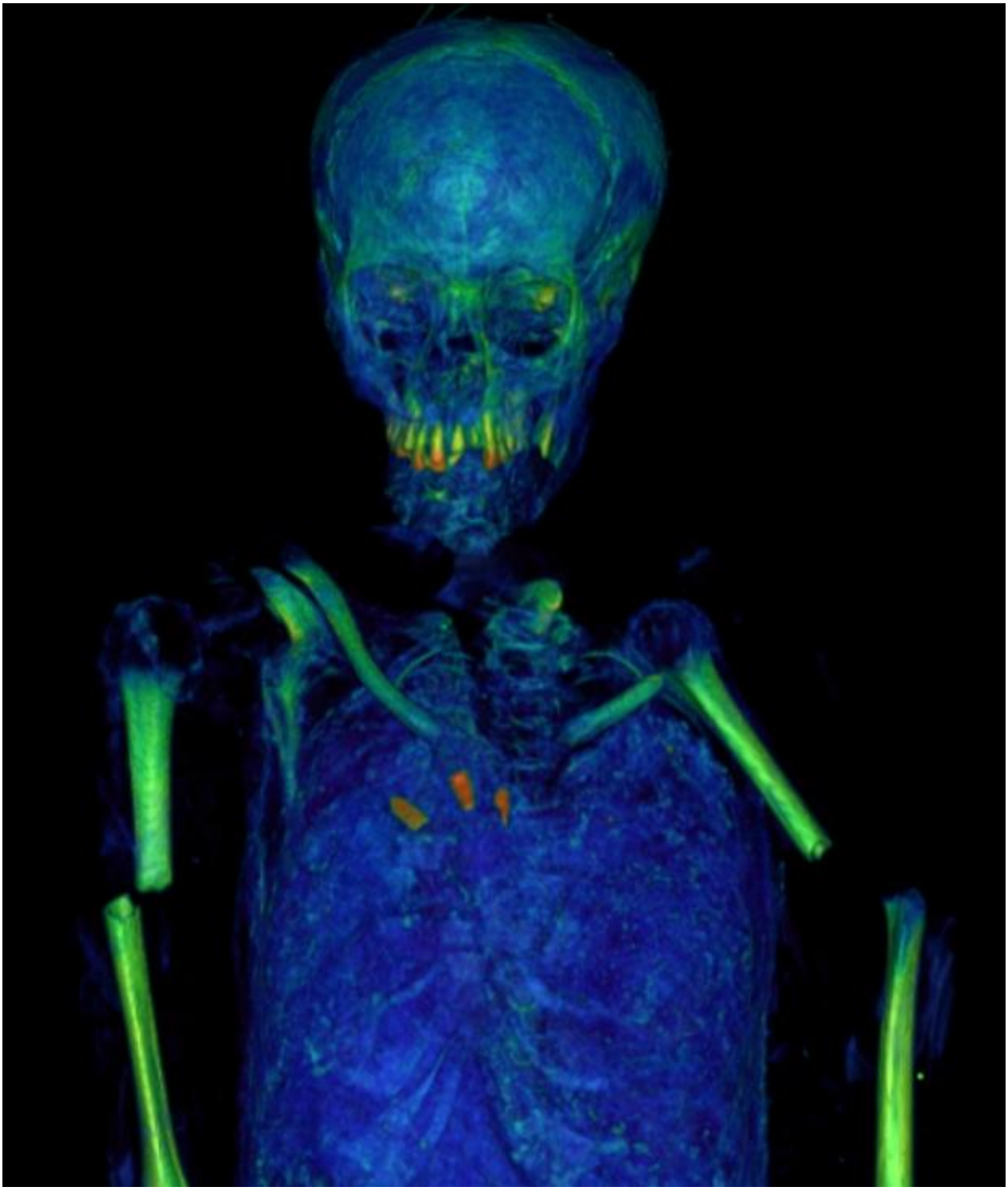

Figure 18: 3D model showing the highest density locations in orange.

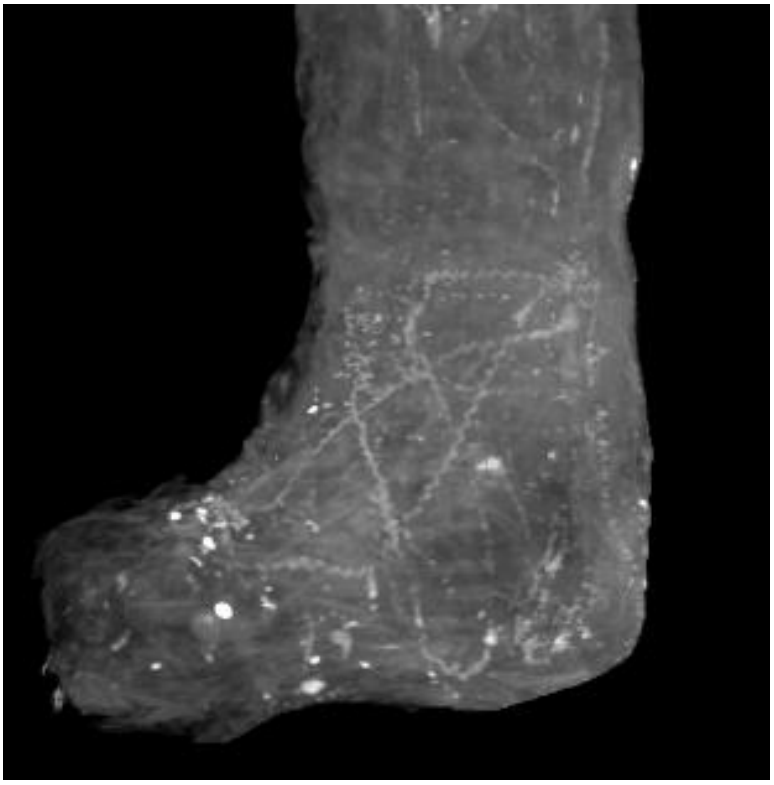

Figure 19: 3D model of beading or wire in the wrappings of the feet (ARS, 2016).

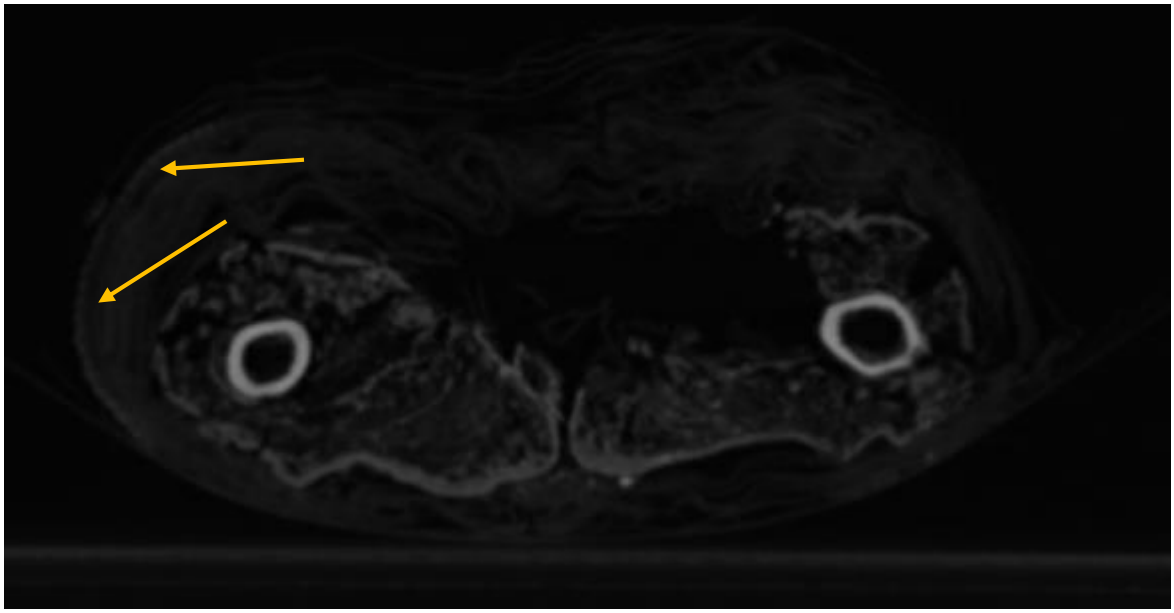

Figure 20: Axial view of beading or wire on the outer wrappings near upper femur.

Appendix C

Midwest Museums List

(Michigan, Ohio, Illinois, Indiana, Minnesota, Wisconsin, Iowa, Missouri, Nebraska, Kansas)

Questionnaire (*Have definitely used CT on Egyptian mummy)

1. Michigan
    - *Kalamazoo Valley Museum http://www.kalamazoomuseum.org/
    - *Kelsey Museum of Archaeology (child and on display) https://www.lsa.umich.edu/kelsey/
    - Detroit Institute of Arts http://www.dia.org/object-info/becf2401-3f73-4a91-8b78-af5ed44f85f0.aspx?position=1
2. Ohio
    - *Ohio History Connection https://www.ohiohistory.org/search?s=mummy
    - Cleveland Museum of Natural History (Senbi in Hammond-Todd Collection)
3. Illinois
    - *Field Museum http://www.fieldmuseum.org/
    - *Oriental Institute Museum https://oi.uchicago.edu/museum-exhibits
    - *Spurlock Museum http://www.spurlock.illinois.edu/search/index.php?q=mummy&Search=Search&n=&a=&g1=All&g2=&g3=&g4=&g5=&c1=All&c2=All&c3=All&cl=&cr=&date=&mat=&man=
4. Minnesota
    - *Science Museum of Minnesota

https://www.smm.org/100objects/archaeology/mummy

- Minneapolis Institute of Arts http://new.artsmia.org/?s=mummy

5. Indiana
    - Joseph Moore Museum http://www.earlham.edu/joseph-moore-museum/
    - Wayne County Historical Museum http://waynecountyhistoricalmuseum.org/permanent-exhibits
6. Wisconsin
    - Racine heritage Museum http://www.racineheritagemuseum.org/?s=mummy
    - *Milwaukee Public Museum http://www.mpm.edu/search/apachesolr_search/mummy
7. Iowa
    - *Putnam Museum http://www.putnam.org/Exhibits/History/Unearthing-Ancient-Egypt
8. Missouri
    - The Nelson-Atkins Museum of Art http://www.nelson-atkins.org/collections/search-Results.cfm
    - * (according to mummylist.com) St. Louis Art Museum http://www.slam.org/
    - *St. Louis Science Center http://www.slsc.org/
9. Nebraska
    - University of Nebraska State Museum http://museum.unl.edu/research/anthropology/collections.html
10. Kansas
    - Museum of World Treasures http://www.worldtreasures.org/

Questionnaire

Survey: Human Egyptian Remains

Hello:
You are invited to participate in the survey *Human Egyptian Remains and CT Scanning*. In this survey, approximately 20 museums will be asked to complete a survey that asks up to 12 multiple choice questions. It will take approximately 10 minutes to complete the questionnaire.

Some questions allow for multiple answers to be selected.
Your participation in this study is completely voluntary. There are no foreseeable risks associated with this project. However, if you feel uncomfortable answering any questions, you can withdraw from the survey at any point. If you have questions at any time about the survey or the procedures or need the survey to be reset, you may contact Kate Peterson at 616-706-0735 or by email at mary.k.peterson@wmich.edu.

Thank you very much for your time and support. Please start with the survey now by clicking on the Continue button below.

First Name

Last Name

Museum Name *

Job Title *

Has the museum had any of its human Egyptian mummies CT scanned? If so, how many?

- o Yes, 1
- o Yes, 2
- o Yes, more than 2
- o No

Why has the museum chosen not to pursue CT scanning of your mummy(ies)?

- o Too expensive
- o Uninterested
- o Unaware of the practice
- o Unsure what to do with the scans/ how to interpret them
- o Unable to find a facility willing to perform the procedure
- o Other(s)

Why did the museum choose to CT scan the mummy(ies)?

- To increase knowledge about the mummy
- To change or update the mummy's exhibit
- To increase visitation to the museum
- To provide data for researchers or mummy databases
- Other(s)

Does the museum plan to CT scan additional mummies in your collection?

- Yes
- No
- No, because there are no additional mummies

What additional procedures is the museum considering or has already performed *because* of the results of the CT scan?

- Endoscopy
- Dissection
- Unwrapping
- DNA analysis
- Isotopic analysis
- Other(s)

Has the museum ever received negative feedback from patrons because of human Egyptian remains on display?

- Yes
- No

Does the museum provide an area for comment cards near your Egyptian mummy display?

- Yes
- No
- Mummy not currently on display

Has the museum incorporated actual CT scan images of the mummy into its display?

- Yes
- No
- No, but plan to in the future

How has negative feedback changed since incorporating CT scanned images into the display?

- Increased
- Decreased
- No change

Has data from the CT scans of the mummy(ies) been added to the IMPACT database or any other mummy research databases?

- Yes
- No
- No, unaware that they existed

If the museum is hoping to enhance the mummy exhibit by incorporating CT scans into the display, is there a particular key audience you are focusing on educating?

- Yes, children
- Yes, teens
- Yes, adults
- All ages
- No
- Not planning on incorporating CT scan data into the display
- Other

Any Additional Comments or Questions you may have about this questionnaire and/or CT scanning of Egyptian mummies?