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Research article

Digital data recording and interpretational standards in mummy science

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ABSTRACT

Beginning during the late19th century, paleoimaging has played an ever-expanding role in mummy science. Increasingly during the 21st century, digital radiographic data collected through imaging efforts have become significant. The rapid influx of imaging data raises questions regarding standardized approaches to both acquisition and interpretation. Reports using digital data presented without contextual considerations commonly lead to interpretational errors. Digital data recording and interpretation require rigorous methodology and standards in order to achieve reproducibility, accuracy and minimization of inter- and intra-observer error. Researchers applying paleoimaging methods in bioarchaeological research must understand the significant limitations inherent in data collection and interpretation from various digital data recording methods. Currently, vast amounts of digital data are being archived, allowing greater potential for hypothesis-based research and informed diagnosis by consensus. Digital databases hold great potential in preparing both radiologists and bioarchaeologists in the appropriate application and interpretation of digital data.

1. Introduction

Mummy Science has become an established aspect of biomedical, paleopathological, and bioarchaeological study (Aufderheide, 2003). In many contexts, medical imaging plays an important role in the non-destructive analysis of mummified remains. New imaging methods, primarily borrowed from biomedical sciences, continue to be adapted to bioarachaeological investigations of the past. Notable among these newer methods are multi-detector computed tomography (MDTC) (Beckett and Conlogue, 2010) and magnetic resonance (MR) (Posh, 2015; Rühli, 2015), as well as experimental techniques such as terahertz imaging (Thz) (Öhrström et al., 2015). With both these newer and more standard technologies however, it is critical to understand the importance of rigorous adherence to scientific methodology during both data acquisition and data interpretation.

The rigor of mummy science and the role of imaging data are perhaps best exemplified in the critical concept of context as described in the following paragraphs. Similar to the crime scene in a forensic case, context is critical. Without context we have little hope of meaningfully interpreting data collected in mummy science studies. Original contexts may be disrupted or impacted by post-depositional, taphonomic changes, both natural or created by human interaction. The many variables associated with the original context must be carefully considered when making any interpretations. We will focus here on two aspects of context in considering the rigors of imaging data collection and interpretation, external and internal contexts.

The initial features associated with context are those of the external context. The archaeological findings are critical to our understanding of what is being studied. To improve the accuracy of imaging data interpretations, the researcher must consider place, time, climate change over time, water table changes, erosions, endemic disease patterns (if known), structures, materials used, tombs and other burial styles along with their created microenvironments. All available archaeological and historical data, along with social theory are additional aspects of the bioarchaeoogical context. If the study is conducted away from the point of discovery, in a museum collection room, for example, the current context and resultant environmental conditions also need to be considered along with any records describing the original context and the means of transport to the alternate location.

An equally important construct is the internal context. Imaging studies are well suited to provide internal information inaccessible other than by autopsying or otherwise opening the object or mummy, both destructive procedures. The internal context as it relates to imaging applications is described as the condition and

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bioanthropological information derived from within closed artifacts or mummified remains. Paleoimaging helps to collect data regarding the internal context by being able to 'see' within a wrapped mummy or 'see' within a mummy that is unwrapped but still encased in its mummified integument. A variety of bioanthropological questions can usually be addressed using imaging methodologies. In a setting where direct access to the body is not possible without disrupting the enclosure or wrappings, imaging can be employed to acquire data regarding sex, age at death, dental health, presence of some paleopathologies, as well as evidence of pre or perimortem trauma or injuries. These data have the greatest meaning if collected at the point of discovery (POD). Understanding the internal context can inform researchers regarding the internal structures associated with the burial be they archaeological or biological in nature. Another important point is that the POD data can be used to understand post depositional changes within the subject if transport has occurred. Without the POD information, interpretation of imaging data risks being severely compromised.

1.1. The role and contribution of collected imaging data to bioarchaeological interpretation efforts

Imaging methodologies have been very helpful in answering specific anthropological and archaeological questions. The data derived from imaging methods are of significance particularly when the mummified remains are within a burial chamber, enclosure, or wrapped in textiles, bandages or other presentations that decrease the efficacy of macroscopic visual inspection alone. Given that imaging can 'see what can't be seen' a variety of questions can be answered that assist in the reconstruction of lives as described above. In addition, imaging is useful in ascertaining the presence/absence of medical interventions, such as trepanation, and are instrumental in conducting tissue targeted biopsies.

Regarding the archaeological perspective, imaging can provide data that may allow interpretations related to the use of and type of artifacts present and other evidence of both funerary and burial practices. Objects discovered may potentially assist with understanding the temporal context and imaging may also guide additional research by assisting in artifact retrieval.

As we consider the significance of digital data recording and interpretation, it is critical that the concepts be placed in the bioarchaeological construct. Buiksrta, (2006) defines bioarchaeology as the attempt to reconstruct human histories with focused effort on anthropological problem solving and inquiry with integration of archaeological data. To reconstruct life experiences, imaging data must be carefully collected and scrutinized in consideration of the external and internal contexts of the archaeological and biological findings. Only in this manner are we able to reduce unfounded assumptions and speculations and thus reconstruct human histories with a greater degree of accuracy and confidence.

I begin with a brief overview of paleoimaging and its use in mummy sciences. This is followed by a discussion of the need for rigor in digital data recording, including sections on standards development, image acquisition, image interpretational phase, and in digital archiving and its significance for bioarchaeological research.

2. Overview of the evolution of imaging in mummy sciences

Soon after the discovery of the x-ray in 1895 by William Roentgen, the technology was used to image mummified remains. In March of 1896, Carl George Walter Koenig (Koenig, 1896), a German physicist, published a paper "14 Photographs with X-rays Taken by the Physical Society of Frankfurt am Main"(1896). Koenig presented the first x-rays involving mummies including x-ray images on an Egyptian mummified cat and the knees of an Egyptian child mummy (Beckett and Conlogue, 2010). Over 80 years later, the first CT scans were conducted on mummified remains (Lewin and Harwood-Nash, 1977).

Magnetic resonance imaging (MR) was first thought to not be useful in mummy studies due to the need for free hydrogen ions (Notman, 1983), which are not present in dehydrated mummies. Recent advances in both technology and technique have allowed researchers to obtain images from mummified remains using MR (Beckett and Conlogue 2010; Conlogue et al., 2008; Öhrström et al., 2013; Posh, 2015; Rühli, 2015). While MR images have been acquired, additional research is needed to assure that these images add value to bioanthropological research (Öhrström et al., 2013). Terahertz imaging is a newer method that has been applied to mummified remains. Research continues to advance regarding this method as it is applied to mummified remains (Öhrström et al., 2010; Öhrström et al., 2015). Additional imaging methods, such as endoscopy, have been applied to mummy science studies since their inception (Tapp et al., 1984; Beckett and Conlogue, 1998; Beckett and Guillen, 2000; Beckett, 2015). Initially endoscopy applications followed the medical model of guided biopsy and more recently its use has been expanded to collecting systematic data following the bioarchaeological model. Endoscopy is also useful when combined with micro-sampling in order to provide further lines of evidence in support of specific and general research questions. Given the ever-increasing use of imaging methods in bioarchaeological research, scientific rigor in the application of imaging modalities and interpretation of the data collected is critical as we strive for meaningful and accurate interpretations of past cultures.

A more extensive discussion of the evolution of the use of imaging methods in mummy studies can be found in Aufderheide (2003), Chhem and Brothwell (2008), Beckett and Conlogue (2010), and Lynnerup (2010).

3. Rigor in digital data recording

In the context of this paper, rigor can be defined as the quality or state of being very exact, careful, or strict in the collection of digital data. Rigor in all sciences requires intellectual honesty about one's interpretations, which should be based upon objective observations, as free as possible from preconceptions. Data must be collected through vigorous application of the scientific method. Hypothesis formulation, methodological reproducibility, data collection accuracy, with careful attention to inter and intra-observer error, further describe aspects of scientific rigor required in digital data recording.

Standards development is designed to create a science that is reproducible, as accurate as feasible given technology limitations, and understandable by the varied communities of interest. Standards are a starting point and should evolve as technique, technology, and interpretations are validated. This requires a consistent approach, with newer methods building upon past approaches. Standards are needed in both the acquisition and interpretational phases of digital data collection.

When considering the rigor of digital data recording, the subject can be considered broadly within three categories: rigor in image acquisition, rigor in interpretation, and rigor in data archiving. We will examine each of the phases in turn and then consider future implications.

3.1. Rigor in image acquisition

Standards related to the technology associated with digital data collection are considered in terms of both instrumentation and

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