Hughes, Stephen W. and Wright, Richard and Barry, Mark D. (2005) *Virtual reconstruction and morphological analysis of the cranium of an ancient Egyptian mummy.* Australasian Physical and Engineering Sciences in Medicine, 28(2). pp. 122-127.

TECHNICAL NOTE

Virtual reconstruction and morphological analysis of the cranium of an ancient Egyptian mummy

S. Hughes[1], R. Wright[2] and M. Barry[3]

[1]*Department of Physical and Chemical Sciences, Queensland University of Technology, Brisbane, Australia*
[2]*Shellshear Museum, Department of Anatomy and Physiology, University of Sydney, Sydney, Australia*
[3]*High Performance Computing Centre, Queensland University of Technology, Brisbane, Australia*

Abstract

A mummy of an Egyptian priestess dating from the 22nd dynasty (c. 770 BC), completely enclosed in an anthropoid (human shaped) coffin, was scanned on a CT scanner. An accurate reconstruction of the cranium was generated from 115 × 2 mm CT images using AVS/Express on a SGI computer. Linear measurements were obtained from six orthogonal cranial views and used in a morphometric analysis software package (CRANID). The analyses carried out were both linear and nearest neighbour discriminant analysis. The results show that there is a 52.9% probability that the mummy is an Egyptian female, with a 24.5% probability that the mummy is an African female. Thus the technique confirms that the coffin contains an Egyptian female, which is consistent with the inscription on the coffin and the shape of the pelvic bones as revealed by plain X-rays. These results show that this technique has potential for analysing forensic cases where the bones are obscured by soft tissue and clothing. This technique may have an application in virtual autopsies.

Key words egyptology, mummy, morphological analysis, discriminant analysis, CRANID, virtual autopsy, forensic medicine

Introduction

The British Museum in London, UK, contains a collection of about 80 Egyptian mummies. One mummy on display in the museum is an Egyptian priestess dating from the 22nd dynasty (c.770 BC). The mummy was first X-rayed by Dawson and Gray[1] in the 1960's. The original report by Gray states that the mummy within the coffin is a "priestess, aged 25-40, in cartonage[a], named Tjentmutengebtiu[b], daughter of Khnonsmes and Mehenmutemhat". Tjentmutengebtiu was a priestess in the great temple at Karnak, near modern day Luxor on the River Nile. Tjentmutengebtiu arrived in the British Museum (BM), London in 1891. Her provenance is unknown, although she probably came from one of the tombs cut into the cliffs at Thebes. The style of Tjentmutengebtiu's coffin indicates that she most probably lived in the period of the 22nd dynasty.

Tjentmutengebtiu was the first mummy in the BM collection to receive a whole-body X-ray CT scan. This particular mummy was selected for scanning as the 22nd dynasty is considered to be the period when the art and science of embalming reached its peak[c]. Therefore Tjentmutengebtiu should be a good example of the work of the best Egyptian embalmers. The results of the initial analysis of the X-ray CT scans and 3D reconstructions have been previously reported elsewhere[2-4]. This paper reports on further work done on the morphometric analysis of Tjentmutengebtiu's cranium carried out in Australia, where one of the original investigators (SH) now resides. CT scans of the mummy's head were used to produce a 'virtual cranium' from which accurate dimensions could be taken to enable morphometric analysis to be performed.

To take physical measurements from Tjentmutengebtiu's skull would entail cracking open her anthropoid coffin of linen and plaster and removing the wrappings around her head, which would obviously be very destructive.

As Tjentmutengebtiu is called a daughter we presume that the body within the coffin is that of an Egyptian female. The shape of the pelvic bones as revealed by plain X-rays also indicates that the coffin contains a female body. While there is no reason to doubt the inscription on the coffin, this paper reports on another method of verifying the likely physical ancestry of the person within.

Corresponding author: Stephen Hughes, Department of Physical and Chemical Sciences, Queensland University of Technology, Gardens Point Campus, Brisbane 4001, Queensland, Australia.
Tel: 07 3864 2327, Fax: 07 3864 1521
Email: sw.hughes@qut.edu.au
Received: 7 April 2004; Accepted: 24 March 2005

[a]*A light-weight mixture of linen and plaster*
[b]*A translation of the hieroglyphics*
[c]*Personal communication, Jeffrey Spencer of the Department of Egyptian Antiquities of the British Museum*

Material and methods

A computer program has been developed by one of the authors (RW) called CRANID for the morphometric analysis of the skull from 29 measurements. A description of an earlier version of CRANID is given by Wright[5]. The CRANID database includes measurements of 2,802 individuals from around the world. It is a slightly expanded version of the database originally collected by W.W. Howells[6-7]. The crania are only those of modern *Homo sapiens*. Most date from the last 1,000 years. They come from 33 geographical samples, most of which are divided by sex. This results in 64 samples for analysis. Among the new samples in the database are two that are particularly relevant to the analysis of the mummy, namely males and females from the Iron Age site of Lachish in Israel. The output of the program is a series of probabilities that the person is from a particular geographical sample within the database.

Tjentmutengebtiu was scanned on a Siemens DRH Somaton scanner (Siemens AG, Erlangen, Germany) (figure 1). In total, 115 CT images were acquired of Tjentmutengebtiu's head. Slices were 2 mm thick with an image size of 512 × 512 pixels. Images were acquired contiguously so that the centre of each slice was separated by 2 mm. Pixels were 0.5 mm on a side and 12 bits deep (i.e. 4096 grey scale levels). The X-ray tube potential was 125 kV and the current 210 mAs. Figure 2 shows the AP and LAT topogram views and figure 3 shows a CT image at the level of the orbits. No residual brain tissue was seen inside the cranium.

The original X-ray CT images were transferred onto a Silicon Graphics super-computer in the High Performance Computing and Research Support (HPC) facility at Queensland University of Technology in Brisbane, Australia. The computer used for this work was an SGI Origin 3000 computer server with 60 processors, 30GB of RAM and a peak performance of 52 Giga Flops. Matlab (The MathWorks, MA, USA) was used to read the 2D image data into a 3D grid structure and output it in a format suitable for the scientific visualisation package AVS/Express (Advanced Visual Systems, Inc, MA, USA).

The reconstruction images were created using the

Figure 1. *Tjentmutengebtiu on a Siemens Somaton DRH CT scanner at St. Thomas' Hospital, London.*

(a)

(b)

Figure 2. *(a) AP and (b) LAT topograms (scout views). The radio-opaque objects over the neck and chest are amulets.*

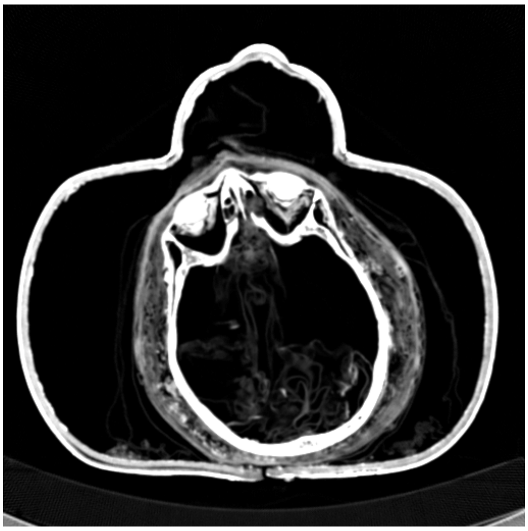


Figure 3. *CT image through Tjentmutengebtiu's cranium.*

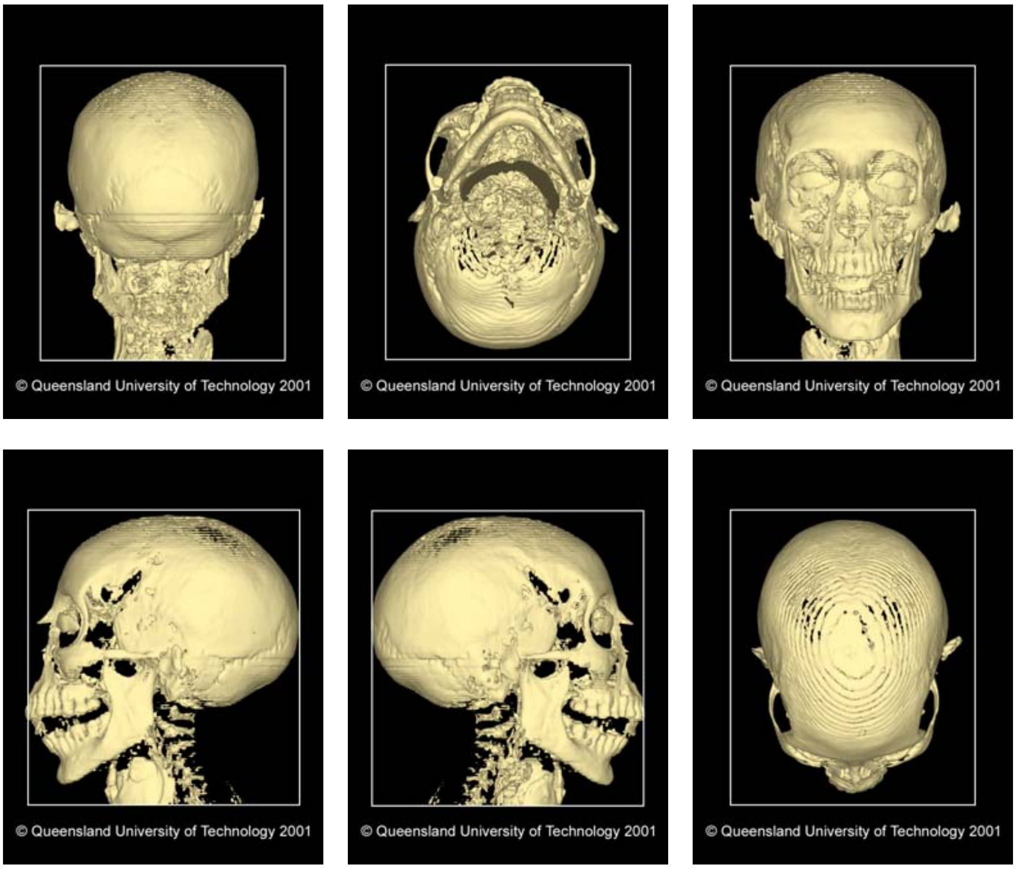


Figure 4. *Six orthogonal views of the cranium required for obtaining morphometric measurements. (a) Back, (b) bottom, (c) front, (d) left, (e) right, (f) top. (The apparent hole in the skull above and behind the eye orbits is probably due to the partial volume effect in combination with the thin bone in the temple region of the skull).*

AVS/Express isosurface module. This module extracts a surface from the volume data at a particular pixel value. A rotating 3D image of the virtual skull and a 3D image of the head showing the mummified skin fading into the bone surface are available for download at: http://www.its.qut.edu.au/hpc/showcase/mummy/

Normally measurements would be taken from a real skull using callipers. However, in this case the virtuals kull was used to extract measurements. Six views of Tjentmutengebtiu's cranium were generated, as shown in figure 4. In each image the skull was rendered with no perspective so that accurate dimensions could be obtained. 27 measurements of Tjentmutengebtiu's skull were obtained - two measurements fewer than the 29 normally used in CRANID, but enough to obtain good results. The estimated measurements in mm obtained from the mummy, using the codes defined by Howells[6], are shown in table 1.

The multivariate methods of identification, used in the analysis of the mummy, fall under the general heading of discriminant analysis. A comprehensive account of the various approaches in discriminant analysis is given by Krzanowski and Marriott[8].

The program CRANID first applies canonical variates analysis to the 27 measurements. This procedure maximises the morphological difference between the samples of crania and can be thought of as a principal components analysis of samples - not of individuals. Canonical variate scores of the individual 2,802 crania are then computed.

Using these canonical variates scores, the identification of the mummy proceeded by two distinct methods of discriminant analysis:

(a) linear discriminant analysis, which measures the distance of the unknown from canonical variates sample means and computes the probabilities of the unknown coming from each of the samples in turn; for this exercise the numbers in each sample are assumed to be equal; in computing these probabilities linear discriminant analysis makes parametric assumptions about the data, including the normal distribution of the variables and the equality of the sample covariance matrices;

(b) nearest neighbour analysis, which reports the *nearest neighbours* of the unknown in the hyperspace of canonical variates scores; this classificatory procedure makes no parametric assumptions about the data; all that the analysis is doing is reporting which of the 2,802 crania are most like the unknown cranium in terms of morphology; it seems that this computer intensive approach has not previously been applied to morphological data, but it is widely used in computerised pattern recognition[9].

Table 1. *Howells' code dimensions in mm taken from Tjentmutengebtiu's virtual cranium. The error in the length measurements is estimated at ± 0.5 mm since pixels were 0.5 × 0.5 mm. For more information on the meaning of the codes refer to Howells' papers*[6,7].

Measurement	Howell's code	Length (mm)
Glabello-occipital length	GOL	175
Nasio-occipital length	NOL	175
Basion-nasion length	BNL	91
Basion-bregma height	BBH	117
Maximum cranial breadth	XCB	134
Maximum frontal breadth	XFB	108
Biauricular breadth	AUB	105
Biasterionic breadth	ASB	101
Basion-prosthion length	BPL	91
Nasion-prosthion height	NPH	65
Nasal height	NLH	50
Orbit height, left	OBH	35
Orbit Breadth, left	OBB	38
Bijugal Breadth	JUB	102
Nasal Breadth	NLB	26
Palate breadth	MAB	59
Bimaxillary breadth	ZMB	87
Bifrontal breadth	FMB	94
Biorbital breadth	EKB	94
Interorbital breadth	DKB	18
Cheek height	WMH	18
Frontal Chord	FRC	93
Frontal subtense	FRS	17
Parietal Chord	PAC	112
Parietal subtense	PAS	22
Occipital chord	OCC	93
Occipital subtense	OCS	23

Table 2. *Results of linear discriminant analysis showing the probability of Tjentmutengebtiu being from certain locations in the Middle East. (The Dogon are an indigenous tribe who occupy a region of Mali in sub-Saharan Africa; Lachish is an Iron Age site in Israel).*

Sample	Number	Probability
Egypt 26-30 Dynasty Female	53	52.9%
Dogon West Africa Female	52	24.5%
Lachish West Asia Female	20	16.9%
Egypt 26-30 Dynasty Male	58	2.0%
Dogon West Africa Male	52	1.6%

Table 3. *Result of nearest neighbour discriminant analysis. The expected column shows the result expected if a value was picked out of the database at random.*

Sample	Number	Hits	Expected
Egypt 26-30 Dynasty Female	53	10	1.0
Egypt 26-30 Dynasty Male	58	7	1.1
Dogon West Africa Female	52	6	1.0
Lachish West Asia Female	20	3	0.4
Dogon West Africa Male	52	3	0.9

The results for discriminant analysis are reported as the probability of the mummy coming from one of the samples within the database.

The results for nearest neighbours analysis are reported as the number of hits made on each sample, together with the numbers expected by chance, given the varying sample sizes. A total of 53 nearest neighbours are sought. The number 53 is the square root of the 2,802 individuals in the CRANID database - an arbitrary, but convenient, stopping rule in the search for nearest neighbours.

Results

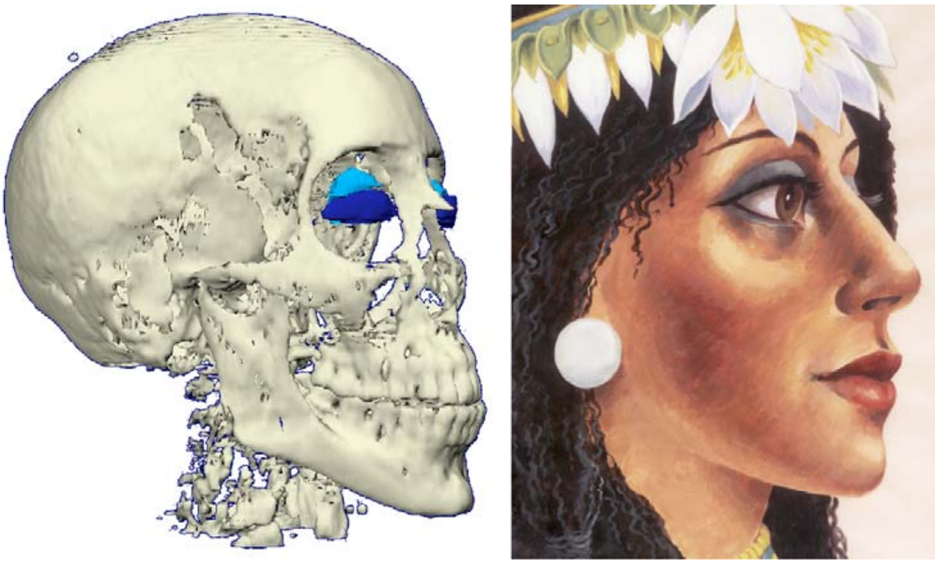
Linear discriminant analysis identifies the mummy as most likely an Egyptian female, with a probability of 52.9%. This result, together with less probable contenders, are included in table 2 (samples reported are only those with a probability greater than 1.0%). There are 64 samples within the database (two samples are Egyptian females and males, the remaining 62 are non-Egyptian), so the probability of getting the result of Egyptian female by chance alone is 1.6%. The actual probability of 52.9% is therefore a very strong result.

As already mentioned, linear discriminant analysis makes parametric assumptions about the data. In case the particular result for the mummy is an artefact of an assumption not being met, the non-parametric nearest neighbours discriminant analysis method was also applied (table 3). It also identifies the mummy as most likely an Egyptian female (samples with hits of three and above reported).

We see that the result by nearest neighbour analysis strengthens the case for an Egyptian identification, while still retaining a preference for female. By chance alone, we must expect only one Egyptian female on average from 53 hits. The fact that there are 10 such nearest neighbours is a very strong result.

We can also see that there are three hits for Lachish females, even though the sample total is as low as 20 - resulting in an expected frequency of only 0.4 hits. From this relative point of view the mummy is finding more female West Asian (Iron Age Palestinian) nearest neighbours than West African.

Armed with the knowledge that Tjentmutengebtiu was very probably an Egyptian female, it is interesting to consider what she may have looked like during life. Figure 5 shows an artists impression based on an oblique view of the reconstructed skull. It is interesting to compare the artist's impression with the painting of Tjentmutengebtiu on her coffin (figure 6). Coffin paintings often appear to be of an idealised or generic nature; therefore we would not expect the painting on the coffin to be an accurate portrait of the person. Although of limited scientific use, such impressions are useful in giving us some idea of what the individual may have looked like in life.



(a) (b)

Figure 5. *Artist's impression of what Tjentmutengebtiu may have looked like in life based on an oblique view of the reconstructed skull. (a) 3D reconstruction of skull, (b) artists impression (courtesy of Maureen Hart, UK).*

Figure 6. *Tjentmutengebtiu as depicted on her coffin. Tjentmutengebtiu is seen kneeling on a mat while the Egyptian gods Horus and Thoth purify her with streams of ankh and was symbols rather than water. (Image courtesy of the British Museum, London, UK).*

Discussion

The results are highly consistent with the mummy being an Egyptian female. Alternative, but less probable, identifications are for regions likely to have been historically associated with Egypt.

Knowing the geographic origin of an unidentified person may speed up the process of identification in forensic cases. The convincing result reported here was obtained without physically uncovering the wrappings from the mummy's cranium. Indeed the mummy was still in its coffin. The technique therefore has forensic potential. Corpses are often obscured by decomposed and burnt tissue, which it may be undesirable to disturb from the evidentiary point of view. A CT image can facilitate craniometric measurements, and thereby identification, without disturbing the biological and cultural material evidence that obscures an unidentified individual. The technique demonstrated here could also have an application in virtual autopsies. For example, the linear dimensions and volumes of internal organs could be obtained without physical intervention, apart from performing a whole-body CT scan. There is increasing interest in the use of virtual autopsies in cases where conventional autopsies cannot be performed for religious reasons[d]. The existing craniometric database is comprehensive enough to enable reliable estimates of ancestry of any unknown individual in terms of major geographical areas, e.g. Europe/Mediterranean, S. Asia, E. Asia, sub-Saharan Africa, Australia/Melanesia, New World and Pacific Islands. At the moment, the LDA computer program CRANID is unable to compute errors for the percentage values. More research in this area would be useful. Another point to note is that although 2mm image slices were used in this study, all CT scanners are able to produce finer slices than this (e.g. 1 mm) which could further improve the accuracy of this technique.

[d]*Personal communication with staff of the Victoria Institute of Forensic Medicine (VIFM), Melbourne, Victoria, Australia*

References

1. Dawson, W.R and Gray, P.H.K., *Catalogue of Egyptian antiquities in the British Museum: 1 mummies and human remains*, British Museum Press, London, 8, 1968.
2. Hughes, S.W., Sofat, A., Baldock, C., *CT imaging of an Egyptian Mummy*, British Journal of Non-Destructive Testing, 35:369-374, 1993.
3. Hughes, S.W., *3D reconstruction of an ancient Egyptian mummy*, British Museum, Occasional paper, No.114:211-225, 1996.
4. Baldock, C., Hughes, S.W., Whittaker, D.K., Taylor, J., Davis, R., Spencer, A.J., Tonge, K., *3-D Reconstruction of an ancient Egyptian mummy using X-ray computer tomography*, J. R. Soc. Med., 87:806-808, 1994
5. Wright, R.V.S., *Correlation between cranial form and geography in Homo sapiens: CRANID - a computer program for forensic and other applications*, Archaeology in Oceania, 27:105-112, 1992.
6. Howells, W.W., *Cranial Variation in Man: a Study by Multivariate Analysis of Patterns of Difference Among Recent Human Populations,* Papers of the Peabody Museum, Harvard University, Vol.67, 1973.
7. Howells, W.W., *Skull Shapes and the Map: Craniometric Analyses in the Dispersion of Modern Homo.* Papers of the Peabody Museum, Harvard University, Vol.79, 1989.
8. Krzanowski, W.J. and Marriott, F.H.C., *Multivariate Analysis Part 2: Classification, Covariance Structures and Repeated Measurements*, Arnold, London, 1995.
9. Devijver, P.A., Kittler, J., *Pattern Recognition: a Statistical Approach.* Prentice/Hall International, Englewood Cliffs, New Jersey, 1982.