3-D Reconstruction of an ancient Egyptian mummy using X-ray computer tomography

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Keywords: mummies; Egyptian, computer tomography; 3-D reconstruction

Summary
Computer tomography has been used to image and reconstruct in 3-D an Egyptian mummy from the collection of the British Museum. This study of Tjentmutengebtiu, a priestess from the 22nd dynasty (945-715 BC) revealed invaluable information of a scientific, Egyptological and palaeopathological nature without mutilation and destruction of the painted cartonnage case or linen wrappings. Precise details on the removal of the brain through the nasal cavity and the viscera from the abdominal cavity were obtained. The nature and composition of the false eyes were investigated. The detailed analysis of the teeth provided a much closer approximation of age at death. The identification of materials used for the various amulets including that of the figures placed in the viscera was graphically demonstrated using this technique.

Introduction

In recent years research groups have used radiological techniques to examine Egyptian mummies. An advantage of using these techniques is their noninvasive nature. Invaluable information of a scientific, Egyptological and palaeopathological nature may be obtained without mutilation and destruction of the painted cartonnage case or linen wrappings. The radiological techniques to date have included film radiography[1], xeroradiography[2] and computer tomography[3-5]. The latter technique has been used to reconstruct images in 3-D[6-8]. To date reconstructed images have been limited by computer facilities and quality of the graphic displays available.

We undertook a study using 'state of the art' facilities normally used clinically to image and reconstruct in 3-D an Egyptian mummy from the collection of the British Museum. Radiological techniques of investigation were used which included those not applied to previous studies of mummies. These included establishing the age at death of the mummy by analysis of the apices of the teeth. The composition of the various amulets, including the false eyes, placed during the mummification process was also analysed.

Figure 1. Tjentmutengebtiu, an Egyptian mummy from the 22nd dynasty (945-715 BC) being scanned at St Thomas' Hospital

Methods

An Egyptian mummy from the collection of the British Museum was scanned using a Siemens Somatom DRH computer tomography (CT) X-ray scanner at St Thomas' Hospital (STH), London (Figure 1). The mummy called Tjentmutengebtiu, a priestess from the 22nd dynasty (945-715 BC) was chosen by the British Museum as an example of the period when the mummification process had reached its optimum. The mummy had previously been Xrayed using film radiography[9] and so a direct comparison of the results of this study could be made with the previous findings. 600 CT slices (2 mm thickness through the skull, 1 mm through the teeth, 4 mm thickness through the rest of the body) were produced and stored on magnetic tape. The images were transferred to a Titan graphics supercomputer (Kubota Pacific Computer Inc., Santa Clara, CA, USA). A suite of dedicated computer programmes developed over several years for planning neurological[10] and orthopaedic[11] surgical operations were used to analyse the data. The programmes enabled CT slices chosen from topogram views to be manipulated and reconstructed in 3-D using surface finding algorithms. The composition of the various amulets present were investigated by analysing the 'CT numbers' of the amulets. The CT number of a particular material is the fractional difference of the material's linear attentuation coefficient relative to water.

Results

3-D reconstruction of the mummified soft tissue of the face is shown (Figure 2). The soft tissue was more radio-opaque than normal tissue. This may be explained through the use of Natron (a naturally occurring substance consisting of NaCl, Na_2CO_3, $NaHCO_3$ and NaP_2SO_4) being used as a dehydration agent and also the application of various resins to the skin during

the mummification process. The ears appeared to be well preserved although the nose appeared displaced. 3-D reconstruction of the skull indicated how the lower jaw had been displaced at the temporomandibular joint resulting in an elongated appearance of the face.

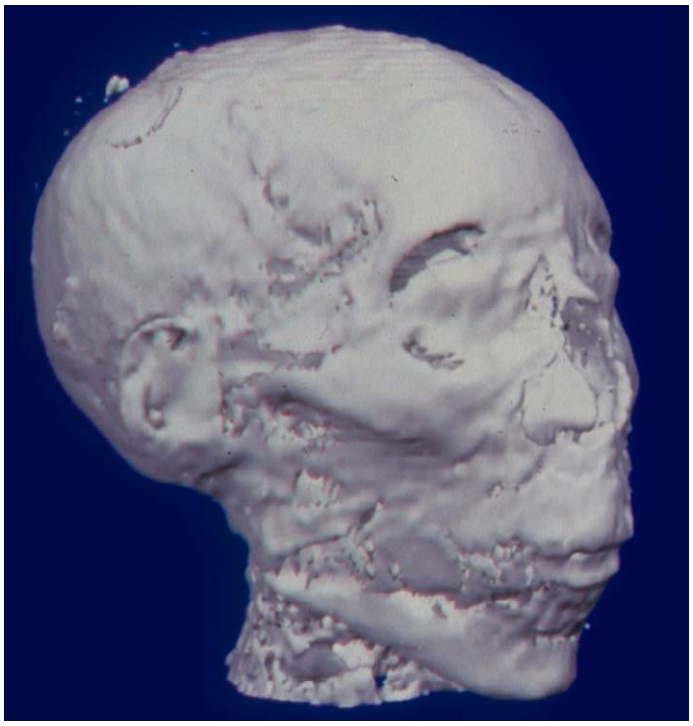

Figure 2. 3-D reconstruction of the head shows mummified soft tissue of the face

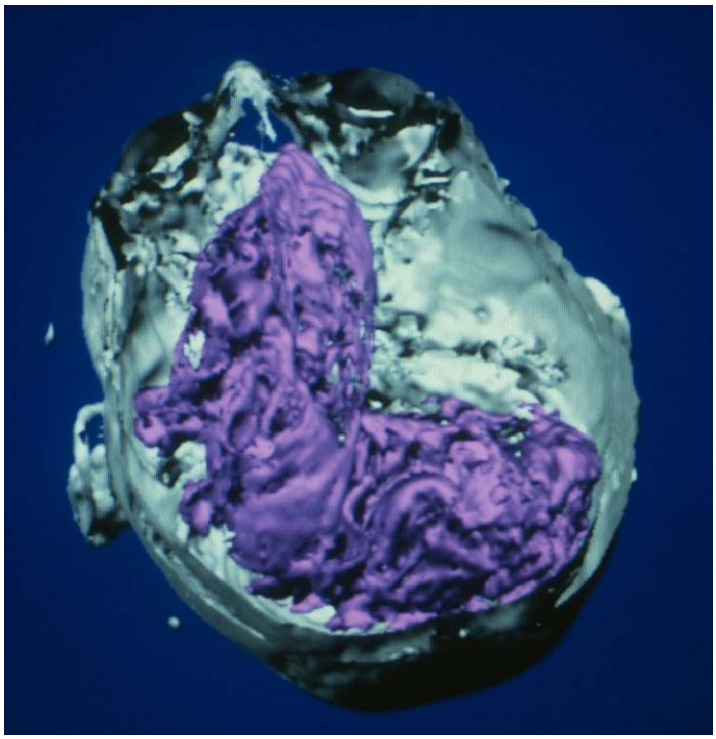

Figure 3. 3-D reconstruction of the cranial cavity shows linen placed within the cavity converging into the right nasal cavity confirming that the brain was removed via the nose

Figure 4. 3-D reconstruction of first, second and third apices. The third apex is slightly open compared to the first and second

3-D reconstruction of the artificial eyes (placed during the mummification process) showed them to be made in two components. Analysis of the front component indicated a further composition of two sections. The CT numbers were compared with each of those from a representative sample of amulets obtained from previous unwrapped mummies and scanned separately from this Tjentmutengebtiu (Table 1). The CT numbers of the front components of the eyes (2346, 2422) compared closely with the glazed eye of Horus (2251). The CT numbers of the back components of the eyes (523, 525) corresponded closely to those of the glass (501).

During the mummification process it was usual to remove the brain. 3-D reconstruction of the cranial cavity showed linen placed within the cavity converging into the right nasal cavity confirming that the brain had been removed via the nose (Figure 3). Damage to the nasal septum and ethmoid bone was clearly visible.

Small specimens of Romano-British teeth and jaw bone (400 AD) were scanned to obtain suitable CT numbers for 3-D reconstruction of the teeth rather than bone. Separated dentine and enamel specimens were used along with fragments of alveolar bone. Using CT numbers for these specimens it was possible to image full upper and lower dentitions in 3-D. This enabled occlusal surfaces of the molar teeth to be assessed for attrition patterns. In addition the molar teeth were imaged separately and the images rotated and magnified to allow inspection of the status of apical development (Figure 4). The incomplete nature of the third molar apices in all four quadrants was much more striking and seen as a classical 'funnel shaped' orifice produced by the growth pattern of the sheath of soft tissue responsible for growth of tooth roots. Apices of contemporary third molars close between the ages of 16-22 years[12,13] suggesting an age at death of the mummy between 19-23 years. The occlusal surface of the third molars in each quadrant did not show evidence of attrition whereas those of the first and second molars were worn. This suggested recent eruption into functional

occlusal of the third molar but also a rapid rate of attrition following eruption - probably occasioned by silica particles in the diet. These dental features, considered together, suggested an age at death of less than 23 years. The 'mummy was previously thought to be between 25 and 40 years of age at death.

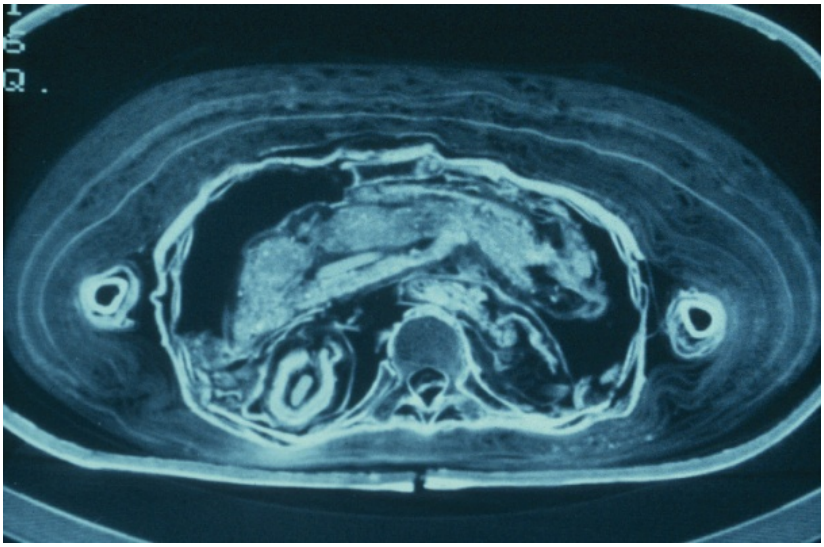

Figure 5. Computerized tomography slice showing wrapped viscera replaced in the thorax and each containing a small object

Several amulets were identifiable in the tomograms. A winged goddess was visible on the anterior surface of the neck. A hawk had been placed across the sternum and an unidentified object was attached to the left arm. A small object was visible over the umbilicus. A four-sided plate covered the abdominal left flank incision where the liver, stomach, lungs, and intestines had been removed (the heart was usually left in place during mummification).

Table 1. Mean computerized tomography numbers for a representative sample of amulets retrieved from previously unwrapped mummies and scanned separately from Tjentmutengebtiu with standard deviation (SD). (n) is the number of data points measured in each amulet

Amulet	**Description**	**Mean**	**SD**	**n**
Girdle of Isis	Jasper	1562	210	229
Heart	Carnellian	1456	58	164
False eyes	Glass	1695	122	53
Head rest	Haematite	3095	0	0
Two finger amulet	Obsidian	1164	80	108
Heart scarab	Seperntine	2596	122	1866
Bead	Glass	501	27	8
Eye of Horus	Glazed	2251	129	43
Papyrus column	Glazed	791	17	80
Djed pillar	Glazed	960	25	124

The viscera were subsequently wrapped and replaced in the thorax, which was typical of the embalming procedure of that period. The four individually wrapped organs could be seen in the abdominal cavity, each containing a small object (Figure 5). It was usual for the embalmers to place a wax figure of one of the Sons of Horus inside each wrapped organ in mummies of 22nd dynasty. A comparison of the CT numbers of the figures and a scanned wax test object (Table 1) indicated that the figures were made of wax. An object, probably the heart, could be recognized in the chest cavity. A winged figure (possibly a vulture) covered the pubis and a winged scarab covered the feet.

Discussion

Computer tomography and 3-D reconstruction has proved to be an extremely useful technique in the investigation of ancient Egyptian mummies which have not been unwrapped. It enables non-destructive investigations to be undertaken revealing invaluable information of internal structures of mummies.

It is clear that the techniques used in the current study add a whole new analytical dimension to them examination of mummified remains and extends the information obtained from the earlier radiological study of Tjentmutengebtiu[9]. Details of the composition of the various amulets present could only be obtained by analysis of the CT numbers in the current study. In the previous study the presence of false eyes were noted but no estimation could be made of their composition. The current techniques used to investigate the teeth have established the age at death as 19-23 years rather than the previous estimate of 25 and 40 years. There was no indication from the previous study of how the brain had been removed from the cranial cavity. 3-D reconstructions, however, indicated linen placed within the cavity converging into the right nasal cavity confirming the route of removal of the brain. The site of incision to facilitate removal of viscera was clearly demonstrated along with the presence of wax figures inside the wrapped organs.

The authors hope to continue this work with further studies of British Museum mummies in the future.

Acknowledgments: The authors would like to acknowledge the contribution to this work from the staff of the Departments of Medical Physics and Radiology, St Thomas' Hospital and the Department of Egyptian Antiquities, British Museum which was undertaken out of normal working hours.

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