Facial Reconstruction and the Uppsala Mummy Survey

Geoffrey Metz & Silvano Imboden.

Contributors: Anders Magnusson, Marilina Betrò and Roberto Gori.

Introduction

The Uppsala Mummy Survey (UMS) is a joint research project between the Victoria Museum of Egyptian Antiquities, which is now a section of Museum Gustavianum, the section of Egyptology at the Department of Archaeology and Ancient History, and the section of radiology at the Department of Oncology, Radiology and Clinical Immunology at the Uppsala Academic Hospital, all of which are connected to Uppsala University in Sweden. The survey is directed by Geoffrey Metz, the curator of Egyptian antiquities at Uppsala University, who is currently attempting to track down all the mummified material and human remains from ancient Egypt in the various collections and institutions of this country. The purpose of the survey is essentially to document and preserve the material, as well as to make it available to science and the general public. The wide selection found in obscure collections, together with the more well known examples of mummies in major museums are being studied from various angles with the help of non-destructive and non-invasive techniques, such as computer tomography (CT).

The preliminary results of the survey were presented in an exhibition at Museum Gustavianum from October 2001 to September 2002 entitled The Legacy of the Mummies. Movies and pictures made from the CT scans of the mummies were very useful tools in illustrating their age and gender, as well as the methods of mumification that had been utilized in each individual case (MUSEUM GUSTAVIANUM).

One of the most interesting visual enhancements used for presentation was a digital 3D reconstruction of the possible physiognomy of an adult mummy from the Uppsala collections (VM363). The reconstruction was performed by a multi-disciplinary team of Italian specialists that consisted of Dr. Marilina Betró, an Egyptologist from the University of Pisa, Roberto Gori, a computer specialist from the University Supercomputing Center of CINECA (Bologna), and Silvano Imboden, a computer specialist from the Department of Information at the University of Pisa. The final reconstruction, along with an introduction to the methods used by the team, was a highlight of the exhibition.

The CT analysis of VM363

In 1893, H.R.H. Crown Princess Victoria of Sweden (1862-1930) donated a fine coffin (VM153) containing a wrapped mummy (VM363) to the Egyptian collection at Uppsala University. The coffin bears the name and titulature of a priestess, the Chantress of Isis Tau-her and can be dated on stylistic grounds to the middle of the 21st Dynasty (Fig. 1) (NIWINSKI, 397, p. 174).²

Ever since 1893, the “mummy of Tau-her” has been the main attraction of the collection and has been seen by countless visitors and schoolchildren. As such, it has been the pedagogical focus for teaching about the funerary beliefs of the ancient Egyptians. Radiological analysis performed during the 1950s supposedly confirmed that there was a woman inside the wrappings who had died at about the age of 50. Sadly, no trace of this study can be found in the museum archives. The connection between the mummy and coffin has always been taken for granted, possibly due to the “royal” provenance, and no questions were raised until a few years ago, when the UMS was created more or less by accident.

It all began one evening in late May of 1999, when the Uppsala Academic Hospital was throwing a staff party at the museum. When the party was winding down, the professor of radiology Dr. Anders Magnusson came into the workroom to thank the museum staff. Geoffrey Metz was working late that evening and they began talking. G. Metz inquired into the possibilities of X-raying a mummy from the museum and Dr. Magnusson was very interested in the idea. He suggested G. Metz bring one to the hospital and scan it using Spiral CT for the best results. They agreed on the mummy of Tau-her as it was central to the permanent Egyptian exhibit and was the only intact adult mummy in the collection.

The mummy of Tau-her is partially unwrapped, with the outer layers of linen missing and the inner layers adhering to the body with resin. The face as well as the ears and toes have been revealed at some time, possibly causing the extensive damage to the soft tissues of the face (Fig. 2). Unrollers of the 19th century often attempted to unveil the face of a mummy so the audience or museum visitor could see the features of the

² Largely due to this donation, and as a gesture of its appreciation, the University applied in 1895 to the Royal Family for permission to name the collection in honour of the Princess. Permission was granted and from then on the collection has been known internationally as the Victoria Museum of Egyptian Antiquities (STARCK, pp. 11 - 12).
Mummies were often stripped of their outer bandages during the hunt for amulets as well (IKRAM & DODSON, pp. 69 - 71). Although the facial features of Tau-her are largely destroyed, other protruding areas, for example the ears, show that the mummy is very well preserved beneath the remaining wrappings. Good preservation is also confirmed by its strong musky scent, pleasantly reminiscent of dried flowers, aromatic gums and incense.

Before the mummy could be brought to the hospital, a special transport case had to be made that would protect it for the short journey and also keep it safe from curious eyes. After careful preparation and packing, the mummy was brought to the Department of Radiology at the Academic Hospital in Uppsala on the 11th of June 1999. Many heads turned as the coffin-sized plywood box with twin padlocks was wheeled through a back entrance, up an elevator, down the hall, and through the waiting room of the radiology department. The eyes seemed to say: “are those padlocks to keep people out or the contents in?”

The next day, Dr. Magnusson and G. Metz met at the hospital after hours, together with Marianne Almgren, the head radiology nurse, who volunteered to run the machine in her free time. They discussed what was previously known about the mummy and the reputed X-ray examination from the 1950s. G. Metz was hoping to confirm this earlier study, as well as shed light on the methods of mummification used on this particular example, and hopefully find clues indicating the cause of death. Dr. Magnusson and Marianne in turn explained the procedure in more detail and demonstrated the technique by showing images from living individuals.

---

For a discussion of techniques used in handling and transporting mummies: MELVILLE, pp. 81 – 82.
Computer Tomography (CT) is a specialized X-ray technique for creating images of the internal structures of the body. The images are cross-sections or “slices” of the body that can be virtually stacked into a volumetric dataset in order to generate 3D images on a computer, where everything of a certain density receives the same colour and is connected in space. The patient, or mummy, lies on a table that moves through the short tunnel of the CT machine during the scanning process (Fig. 3). Earlier generations of machines obtained images by a time-consuming “stop and shoot” method. The table would move an increment and stop, and then the X-ray tube of the CT would revolve one revolution around the subject creating a single image or slice. Today, scans can be made without pausing between slices using spiral or helical CT. The X-ray tube rotates continuously around the subject as the table is moved through the tunnel.

Fig. 3: Mummy of “Tau-her” on CT machine.

The machine used for our initial studies at the Academic Hospital was a Siemens Somatom Plus 4 Spiral CT Scanner, which can obtain images of slices down to a thickness of 0.5 mm. This was linked to Silicon Graphics computer with software from Siemens for compiling, viewing and manipulating the slice images. The software is capable of combining the two-dimensional slices into detailed 3D images of any part of the subject that is of interest.

Although G. Metz had brushed up on the subject, mummies were not his main field, not to mention medicine. Dr. Magnusson and M. Almgren were new to the field of Egyptology and they had never scanned an entire “patient” before, as the levels of radiation would be very dangerous and possibly fatal for a living subject. They were all somewhat in the dark, but were very excited and watched with eyes glued to the computer screen as slice after slice of the mummy appeared.

The entire mummy was scanned at a resolution of 1 mm per slice, making a total of 1661 slices from head to foot. They quickly ran into difficulties, as the machine was unable to scan the entire mummy in one package. Instead, it was necessary to divide the mummy into three virtual sections, which could later be joined on a different computer (Fig. 4). Over the following days, Dr. Magnusson worked together with his son Petter Magnusson, a computer engineer and specialist in CT imagery, to produce
pictures of the mummy of Tau-her from different angles and of specific details of interest.

Dealing with the press is a factor that should not be ignored when performing experiments of this kind. Public interest in the subject of mummies is great, a phenomenon that can be highly beneficial but is also unpredictable and can become problematic.\(^4\) The one day that the mummy was missing from the museum, a journalist became curious about the label in the case, which read, “Temporarily removed for analysis”. She asked in the reception and was told that the mummy was at the hospital being X-rayed. This would no doubt make for a good story, so she contacted me for the details. Before G. Metz could even confirm the fact to her, he had to talk to Dr. Magnusson as the publicity was a potential problem, and they had tried to keep the lid on for the time being. Dr. Magnusson wanted to be discreet due to an incident a few years earlier when a dying hippopotamus baby had been scanned in a last attempt to diagnose its illness. This had caused somewhat of a scandal as critics felt that an animal should not have been allowed to cut in line to the machine before human patients. The media had not been very interested in the fact that the staff had volunteered their free time after hours and that no one was waiting to use the machine at the time. What would happen if the same critics got wind of a mummy cutting in line, even if work was only performed when there were no patients waiting? A chance had to be taken as the cat was already out of the bag. It was decided to cooperate with the journalist, so G. Metz told her about the mummy and the experimental analysis and put her in contact with Dr. Magnusson so she would get the technical facts straight. A photographer came to the museum the next day to take pictures of the mummy before it was returned to its case and an article appeared the following day in the local Uppsala newspaper. It seems the critics were elsewhere as no one made a scandal – instead, the article generated many visitors to the museum, who came to see the “mummy of the

\(^4\) In May 1972, a mummy from the Pennsylvania University Museum (PUM 1) was to be autopsied. The museum’s Public Relations Dept. released this information to the press causing an unexpected media storm, resulting in unnecessary problems for the team and endangering the well being of the mummy (David & Archbold, p. 91).
priestess”. G. Metz and Dr. Magnusson felt very lucky that a serious problem had been avoided and they learned to be more careful in choosing when and where to invite the media so that publicity could be used to their advantage in a controlled manner.

A few days after the mummy had returned from the hospital, Dr. Magnusson contacted the museum with very interesting news. After looking at reconstructed images of the cranium and pelvis, he had realized that something was not as it was supposed to be (Fig. 5). He showed the images to several other physicians and they all confirmed his suspicion – the mummy of the Chantress of Isis Tau-her was not a woman. The shape of the eye-sockets was far too square to be female and the jaw was also very masculine. The pelvis had a typically masculine form, with a hole of triangular shape instead of the ovoid feminine equivalent. In order to confirm our suspicions, images of the soft tissue in the pubic region were made, which clearly indicate the male sex of the mummy (Fig. 6). The penis had not been seen at first, as both hands were placed before it in protection. The arms could easily be removed from the virtual reconstruction, revealing what lay beneath. The size of the penis suggests that it may be a simulation made of resin soaked linen. Some male mummies had this member ceremonially amputated, a ritual clearly connected to the dismemberment of Osiris and the regenerative magic of Isis. Further analysis is necessary to show if the appendage of this particular mummy is real or false. Many questions were immediately raised by this discovery. If our mummy wasn’t Tau-her and he wasn’t a woman, then who was he and how had he ended up in her coffin? Furthermore, how had this fact been missed by the X-ray analysis of the 1950s? More information was needed before these questions could be answered. Back at the museum, the question of what to call the mummy was now raised. As it had gone by the name of Tau-her for so long, it was decided to continue to do so for no other reason than tradition, instead of finding a nickname or calling him VM363 (except in scientific articles).
The methods with which a mummy was embalmed can be used to determine the period of interment and sometimes even the social status of the individual (Dunand & Lichtenberg, p. 120). In this case, decerebration had been performed successfully via the nose, as shown by the broken ethmoid bone, and the thick layer of resin and dried chunks of remaining cerebral tissue at the back of the head. The angle at which the resin has solidified shows that it was left tilted slightly to one side while or after this operation was performed. The majority of the brain was removed, and the cerebral tissue at the back of the head is just out of reach if a straight rod is passed into the cranium, perhaps explaining why it still remains in situ (Fig. 7).

The abdominal and thoracic cavities are almost entirely eviscerated with the exception of a shrunken structure in the center of the thorax, which may be the partial remains of the heart (Fig. 8). The body cavities were otherwise completely empty and devoid of any packing material, and no abdominal incision could be found. Instead, evisceration had been performed via the anus, which was left greatly dilated (Fig. 9). When anal evisceration was performed, the thoracic organs above the diaphragm were
often left in place and the diaphragm intact, however in this case there is no trace of
the diaphragm or lungs remaining. Herodotus only mentions nasal decerebration in
connection with evisceration via an abdominal incision. Evisceration per ano on the
other hand, belonged to a cheaper method, and was not combined with decerebration
according to his description. This particular combination is very rare (Smith &
Dawson, p. 125). The evidence of this mummy confirms that there were more
techniques in use than the three described by Herodotus (Book II, §§ 85-88).

![Fig. 8: Chest section showing thoracic cavity and possible remains of heart.](image)

Evisceration per ano was only rarely used prior to the Late Period (c. 713-332 BC,
25-30 Dynasty), indicating that this mummy is most likely from a much later date
than the coffin of Tau-her (Ikram & Dodson, p. 129 etc.). A Late Period date is also
suggested by the position of the hands over the pubic region. Perhaps the coffin was
usurped in ancient times, yet the name of the original owner is extant in several places
on it and has not been replaced by another, nor has it been rebuilt or redecorated in
any way for use by a man. It is more likely that the mummy was combined with the
coffin in the late 19th century in Egypt, before they were given to H.R.H. Princess
Victoria as a gift by the Egyptian authorities.

![Fig. 9: The highly dilated anus indicating the method of evisceration. To the left the orifice is seen from the outside and to the right from the inside, sliced through the hip.](image)
The tomb-robbers, dealers or early Egyptologists who stripped this anonymous mummy of his outer shrouds missed at least some of what they were looking for. Several objects are still hidden below the remaining inner sheets and bandages. Two long thin necklaces consisting of what seems to be tubular beads of faience are draped around the neck and hang down to the abdomen (Fig. 10). A few amulets are either attached to the ends of the necklaces or have slipped from the breast and down the shrunken slope of the collapsed abdomen below the ribcage. An amulet depicting the god Horus in falcon form wearing the double crown is clearly visible just above the wrists, and what may be a heart amulet lies to one side together with another unidentified object. A very dense object was also located below the little finger of the left hand, which may be a scarab or ring-bezel (Fig. 11).
The body itself is in very good condition with no skeletal damage or signs of injury with the exception of the damaged face and a missing toe, which was broken off long after death. The osteological analysis was hampered by the fact that many of the joints have lost their density and do not show up well in the CT-images. The age of an adult individual can, for example, often be determined by examining marrow deterioration in a section of the upper femur. This proved very difficult in the case of our mummy although what little remains does not contradict the earlier approximation of 50 years of age (Fig. 12). Closer analyses of his teeth and skeleton will no doubt give a clearer picture of this individual’s health and age at his time of death.

The first experimental radiological analysis at Uppsala University using CT was deemed a success. The major methods of mummification had been determined as well as the period to which the mummy belonged. It was also clearly shown that the mummy did not belong to the coffin in which it had arrived in 1893. G. Metz and Dr. Magnusson were in the mood for more and decided to cooperate on a more official basis and form a team. This was the first step toward the foundation of the Uppsala Mummy Survey.

The purpose of the survey is manifold and will develop as time goes on and different specialists get involved with the project. The initial goals are location and preservation of all the extant material so that the corpus can be studied from various angles and be made available to other researchers in the field. This step has for the most part been achieved, however more material tends to pop up when least expected. Most of the specimens have undergone basic documentation and cleaning, and in some cases emergency conservation. The majority of the material is skeletal and consists largely of cleaned crania from mummies, all of which will undergo osteological and dental analyses. The main methods used so far on the wrapped and/or well-preserved mummies have been radiological, in order to obtain an internal survey of each specimen using only non-destructive means. All the connected collection documentation and history of the material is also being re-examined in order to better understand why so much was brought to Sweden.

The documentation and scientific analysis of the material is not the only purpose of the survey. Mummies are very useful from the standpoints of popular-science and museology. The subject of Egyptology can only exist in a country like Sweden if there is enough public interest to support it and the same goes for the exhibition or even storage and upkeep of the Egyptian collections. Public interest in mummies is very high and their pedagogic potential should not be overlooked. The Egyptomania of the early 20th century along with Hollywood horror-movies have only added to the
mystique surrounding everything Egyptian – a phenomenon that can be traced back for thousands of years. As museums compete for visitors and institutions fight for their existence, subjects like this can be used to elevate popular interest and generate support for more research and positions in the field.

The Facial Reconstruction of VM363

Facial reconstruction used to be a technique only applied within forensic science as a means of identifying unrecognisable corpses. It was developed by anthropologists and sculptors who would model soft tissues in clay over plaster casts of crania. Its use within archaeology is a more recent development pioneered by Richard Neave at Manchester University (PRAG & NEAVE). Dr. Marilina Betrò, Roberto Gori and Silvano Imboden have developed a new method of virtual modelling based on spiral CT data, which they instead use to create visualizations of archaeological and anthropological material, especially ancient Egyptian mummies.

In 2000, the UMS contacted the Italian team about the possibility of having a reconstruction made of one of the Uppsala mummies as a visual enhancement for our upcoming exhibit, and they agreed to help. In order to allow the team to choose the best candidate, CT scans of three heads were sent to Pisa and that of M363 was chosen due to its superior condition.

The first step was the conversion of the CT images from the original DICOM (ACR/NEMA) format to a VTK dataset. This conversion was done using Hipcom, an application developed by R. Gori. It was noticed that despite the 0.5 mm resolution of the CT head slices, the device had interpolated two out of three of them, i.e. the actual axial resolution of the dataset was 1.5 mm. The non-interpolated slices were manually selected by S. Imboden and used to build a volumetric dataset with spacing between slices of 1.5 mm. In the new format, the slices were combined into a 3D volume in which points with the same density value could be connected to form an isosurface. This step allowed 3D visualization of the cranial and soft-tissue remains of the head, which could now be viewed and sectioned interactively on a standard PC using software developed by the team (Fig. 13).  

5 Applications were designed using VTK (The Visualization ToolKit), a public domain library for scientific visualization available at http://www.kitware.com/. See also SCHROEDER, W., AVILA, L. S. et al. The Visualization ToolKit User’s Guide, Version 4.0.
The continued work forced S. Imboden to extensively rewrite the programs used for the team’s previous facial reconstruction. It was felt that a new approach based on surface instead of volumetric reconstruction would give better results. The earlier volumetric approach relied heavily on a close correspondence between the reference model and the cranium of the mummy. Problems occurred in the previous reconstruction due to the fact that the mouth of the mummy was slightly open and that of the reference model was not. The mouth of VM363 is also somewhat open and the only way to virtually close it was to work with surfaces. This technique creates many new possibilities and the warping procedure is now totally different than before.

The head of VM363 still needed to be worked on before a final facial reconstruction could be realized. There were multiple unnecessary objects that had to be removed, largely consisting of resin-impregnated linen adhering to the cranium in several areas, especially at the apex of the head. These objects were removed and the areas of interest were isolated using 3Dstudio Max, after which the resulting holes were filled in (Fig. 14). Most of the vertebrae were also cut away as they were unnecessary to the final reconstruction and their removal would decrease the size of the dataset and make it easier to handle on a standard PC. Reconstruction was also hindered by missing teeth, areas of the maxilla that were broken away and the open position of the mouth mentioned previously. Despite the missing teeth, two molars gave S. Imboden clues that helped him close the mouth and position the virtual maxillary prostheses correctly. The first step was to isolate the mandible from the rest of the cranium. The anchor points of the jaw were clear enough that it could then be rotated until its remaining teeth met with those of the maxilla above. Ad hoc
maxillary prostheses were cut away from the digital reference cranium, scaled to fit and “pasted” into the new model (Fig. 15) These areas of the maxilla were only necessary as “landing points” for the placement of dowels at a later stage, so a high level of precision was not considered necessary.

The next step in the procedure was the preparation of the digital reference model. For the best results, a reference model of similar morphological type should be used, which would entail having a broad selection at hand. However, only one example was available to S. Imboden at the time. The nose of the reference model was bent and one ear was broken (Fig. 16). In order to remedy this problem and improve the results from the previous reconstruction, the model was cut sagitally into two halves and the side with the good ear was mirrored and used to replace the defective side, straightening the nose in the process. The dataset was also re-sampled to a resolution of 1.5 mm in order to fit with the dataset from VM363.

The initial stage of the reconstruction procedure was to warp the reference model in such a way that its cranium would match that of VM363. The identical transformation was then applied to the soft tissue of the reference model. The new soft tissue model was fit over the skull of the mummy creating a hybrid model and completing the first step. This procedure consists of four steps: 1/ the location of a set of corresponding features on both skulls; 2/ the generation of a scattered vectors field that maps the corresponding features; 3/ the diffusion of the vectors field over each vertex of the surface; 4/ the warping of the surfaces. In the team’s previous work, point 1 was addressed using a feature-tracking algorithm. In order to improve the final results, a
A different approach was used in this case that is based to some degree on a surface reparametrization algorithm.

- A set of landmarks is positioned over the skull following the Manchester Thickness Table, with the addition of additional landmarks for a total of 68 points (Fig. 17).
- The landmarks are connected into a mesh (Fig. 18).
- The cells of the mesh are subdivided (Fig. 19).
- The mesh is collapsed onto the cranium of VM363: every vertex of the subdivided mesh is projected onto the skull surface (Fig. 20).
- The same steps are repeated for the cranium of the reference model (Fig. 21).
- The scattered vectors field is generated by the differences in the positions of corresponding points of the mesh (Fig. 22). This is facilitated by the two collapsed meshes sharing the same topology and vertex numbering.

Some of the points of the cranial surface did not make reliable candidates for correspondences. These areas were avoided, creating “holes” in the mesh, but some vertices of the collapsed mesh still fell within the orbits as seen in Figs. 20 & 21. The incorrect points could be discriminated by the shape of the relative cells: long and
narrow cells were discarded in computing the field. Details of the results of this warping procedure can be seen in Figs. 23 – 25.

The following step in the reconstruction procedure was the constrainment of the soft tissue thickness using data taken from the average measurements listed in the Manchester Thickness Table (Fig. 26).\(^6\) This step involved another warp of the skin surface similar to that described previously. However, the scattered field was instead generated by forcing the thickness of the soft tissue to conform to what was specified in the table.

At this stage it was possible to choose from different tables, representing emaciated, normal or obese male individuals. It was agreed on an arbitrary basis to continue the facial reconstruction using the emaciated model (Fig. 27).

The final step in the reconstruction was the application of a surface texture in order to provide the model head with colouration and details in agreement with the suspected age and ethnicity of the individual. High-resolution images were taken of a volunteer from different angles. They were then manipulated so that contours of facial features such as the nose and ears would not show up on the final reconstruction. This new surface was then mapped onto the 3D model, giving it a more realistic and aesthetic appearance (Figs. 28 & 29). It should be noted that the shape of the ears and nose is largely based on the reference model.
Many museum visitors find themselves ill at ease in the presence of a mummy, especially one with a face as damaged as that of VM363. The completed physiognomic reconstruction of VM363 (Fig. 29) was of great use as a visualization tool in the exhibition of this mummy, and elevated the understanding and compassion of the museum visitors, allowing them to see the mummy as a human being instead of a museum object.

The ancient Egyptians believed that a person’s soul would live on only if his or her identity was preserved. VM363 had lost both face and name, a terrible fate for an Egyptian: We will probably never know who he was, but at least it is now possible to look him in the eye.

Fig. 30: Final physiognomic reconstruction.

Bibliography


London, Archetype Publications.


**Internet Publications & Websites**


