3-D CAT-scan: Anthropology, Archaeology and Virtual Reality

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Abstract: The use of CAT-scanning and three-dimensional image rendering is a powerful tool in the documentation, analyses and exhibition of human remains. Human remains may be CAT-scanned to ensure a complete documentation of the specimens. Furthermore, such documentation is easily stored and shared on computers, allowing researchers access to otherwise non-accessible materials. CAT-scanning is also an important method for osteological analyses, yielding cross sectional and composite data of bones.

Most importantly perhaps, CAT-scanning allows visualisation of hidden structures, a case in point being mummy studies, were skeletal structures may be visualised without opening the mummy wrappings. Furthermore, we have been able to visualise non-excavated skeletal structures, thus pointing to a wholly new avenue of archeological and preservational methods.

Finally, using so-called stereolithography, we have produced 1:1 models of CAT-scanned structures directly from the computer visualisations, detailing structures at a 1mm resolution. This has some very evident uses for exhibits.

Key words: CAT-scan, 3-d image, visualisation, stereolithography, human remains

Introduction

The introduction of CT-scanning by Hounsfield in the early 1970s represented a major improvement within the field of radiology. Unlike conventional X-ray images, the regions of interest in CT-scannings are presented without disturbing superimpositions of juxtapositional structures. The special characteristics of the CT-images allow three-dimensional (3-D) reproductions of the objects examined. Furthermore, the continuos refinements of equipment and techniques have made the production of plastic models a realistic and promising option, with interesting prospects for the future in a wide range of fields of anthropology.

A 3-D analysis starts with a CAT-scan of the item, done however with a close scan slice setting, preferably 2 mm or less. CAT-scanners are usually confined to hospitals, but are gradually becoming available at bigger research institutions. The Department of Anthropology of the National Museum of Natural History, the Smithsonian Institution, is an example of the latter.

After acquisition of the images, these are usually transferred to workstations or powerful PCs, equipped with software, which allows reading of these files and editing of the single images, and finally 3-D rendering. The 3-D renderings may further be used to build solid models by the technique called stereolithography (see below).

We will illustrate the various applications of these methods by some examples of the analyses we have carried out using these methods.

Documentation: King Gorm the Old of Denmark

Documentation may in many ways be viewed as the most basic use of these techniques. CAT-scanning and 3-D rendering allows items to be "virtually" accessible at any workstation. More importantly, it means that a complete documentation exists of the items, literally covering every square millimetre, including accurate representation of internal structures. This level of documentation may be especially important when the items in question are very valuable or when they may not be accessible at all times.

When excavation was undertaken in the Viking Age Jelling Church, the archaeologists found a crypt containing a skeleton underneath the church. The research team thought, after thorough investigation, that it was possible they could be the bones of King Gorm the Old (died 958/959 A.D.), transferred from one of the tumuli outside the church. Last year (2000) the bones, after being CAT-scanned, were replaced in the crypt as part of a ceremony that also marked the introduction of Christianity into Denmark. Thus, although the bones themselves are no longer immediately available for further investigation, the research team could at any time "assemble" the image sections and make 3-D reconstructions to serve as a basis for, e.g., determination of bone size and morphology (fig. 1).

Anthropological analysis: The skull from Hedegård, Denmark

CAT-scan may of course also be used directly for detailed analyses. The Hedegård skull was found by radiocarbon dating to be almost 8000 years old, making it one of the oldest human remains found in Denmark. When it was analyses at our lab, we noticed a couple of indentations of the skull surface, probably the result of healed fractures. CAT-scan allowed us to section the skull "virtually" at these lesions, thus allowing us a more detailed view of the bony changes (fig. 2). Indeed, using the 3-d rending techniques, we can section, i.e. cut, the specimen at any angle we wish.

Non-invasive and non-destructive: Mummy mismatch.

The founder of the Ny Carlsberg Glyptotek Museum in Copenhagen, Denmark, Carl Jakobsen, like many wealthy men of his time, had acquired an Egyptian mummy complete with sarcophagus. The names of two male priests were inscribed on the sarcophagus, which was said to date from circa 1100 B.C. It was decided to "look inside" virtually, by use of 3-d CAT-scan. Special focus was put on the head and hip region, and by examining the pelvis of the visualised remains inside the embalming material; it was possible to say with relative certainty that the mummy was a female (fig. 3). This may not be so surprising, as we know there was once a brisk trade in mummies and sarcophagi, a veritable "souvenir industry", in which mummies and sarcophagi were mixed up in the effort to ensure that the customer got a "full set".

Exhibition purposes: The face of the Mummy

Another mummy from the collections of the New Carlsberg Glyptotek Museum is decorated with the portrait of a young man, presumably depicting the embalmed individual. The portrait is considered one of the finest of its kind in the world, and naturally the question arose whether the portrait really bore a resemblance to the now mummified person. After the mummies skull had been rendered in 3-D, a solid 1:1 plastic model was made using stereolithography. The basis of stereolithography is the process of polymerization, i.e., the formation of larger molecules from the bonding of many, identical oligo- or monomers. This is achieved by guiding a laserbeam into a vat of liquid, i.e. monomeric, plastic resin. The laser generates heat when it strikes the monomers, which then bond, i.e. polymerise, and thus become solid. The laser beam is in turn guided by the 3-dimensional item rendered in the computer. In this fashion a polymeric model of the mummy skull was produced. This skull model was then used by forensic anatomical artists to produce a face of the deceased (fig. 4). These reconstructions in turn served as exhibition objects, allowing the public to compare the mummy portrait with a likeness of the real once-living person.

Non-invasive archaeology: Excavating without excavating

When the Danish Khapur Expedition undertook the excavation in 1990-1995 of an approximately 7000-year-old Sumerian settlement, Tell Mashnaqa in Syria, the archaeologists found numerous graves. The bones in the graves were, however, very badly preserved, and those that could be uncovered were very fragile. To get round this, the archaeologists came up with a technique for casting the entire cephalic region of a grave in plaster. Using this technique the grave could be lifted out in its entirety and flown to Denmark for CAT-scanning. The scan showed, among other things, an intact mandible that could be visualised in 3-D by the computer. Using lasers and a highly photosensitive plastic polymer – a technique called stereolithography – the computer's 3-D images were rendered as a solid model. Thus an accurate model could be produced on an not yet excavated item (fig. 5).

Not just bones

It should be noted that while the above cases all pertain to bones, as this is our field of research, the techniques are not thus limited. Indeed, wooden objects, clay and stone, also show up on CAT-scanning, and may be likewise visualised (fig. 6). This may have some implications for archaeologists working with such materials and objects. Metal more or less blocks X-rays completely, thus also disturbing other materials in an item, but fine metal objects may be probably be visualised also.

Computers and software

The computers used to run the software for these kinds of analyses used to be high-end workstations and machines capable of running UNIX. However, given the rapid development of machine power, the software now runs on ordinary, albeit powerful, PCs.

The software in question are usually specific kinds of software made for medical imaging, ranging from low cost (Digital Dr. ®) to high end (Materialise®) products. A product such as Mimics by Materialise® furthermore has the possibility of formatting the data to allow stereolithographical modelling.

Stereolithographical modelling is made possible by machines built for industrial purposes (as a whole, the field is called Rapid Prototyping, as the idea is to allow for a rapid generation of solid, 1:1 models of products, ranging from valves to mobile phones). As such, these machines are very expensive, but can be accessed through industrial research centres. In the above-presented cases, all models were made by the Danish Institute of Technology, which carries our research of such innovative techniques for the benefit of industrial purposes.

References

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Figures

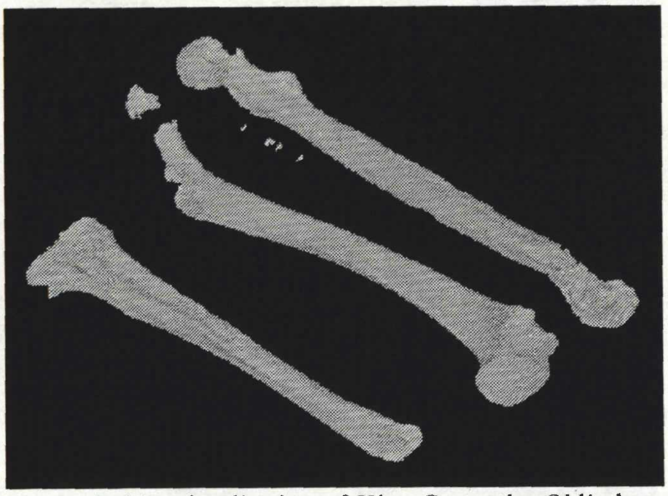

Figure 1: 3-D visualization of King Goem the Old's long

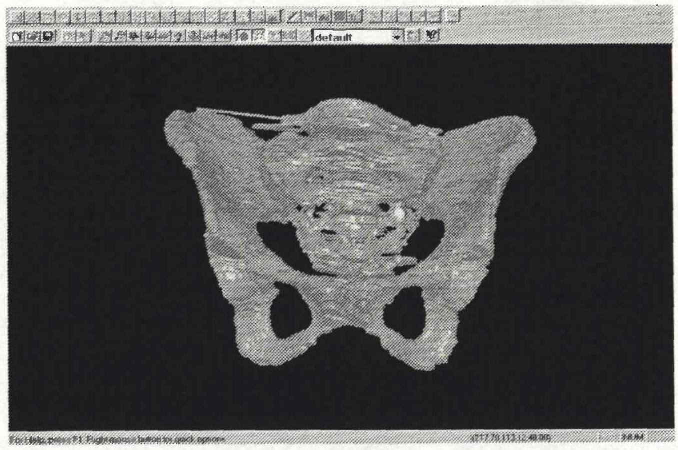

Figure 3: 3-D visualization of bone structures of an Egyptian mummy. The hip morphology indicates that the mummy is of a female.

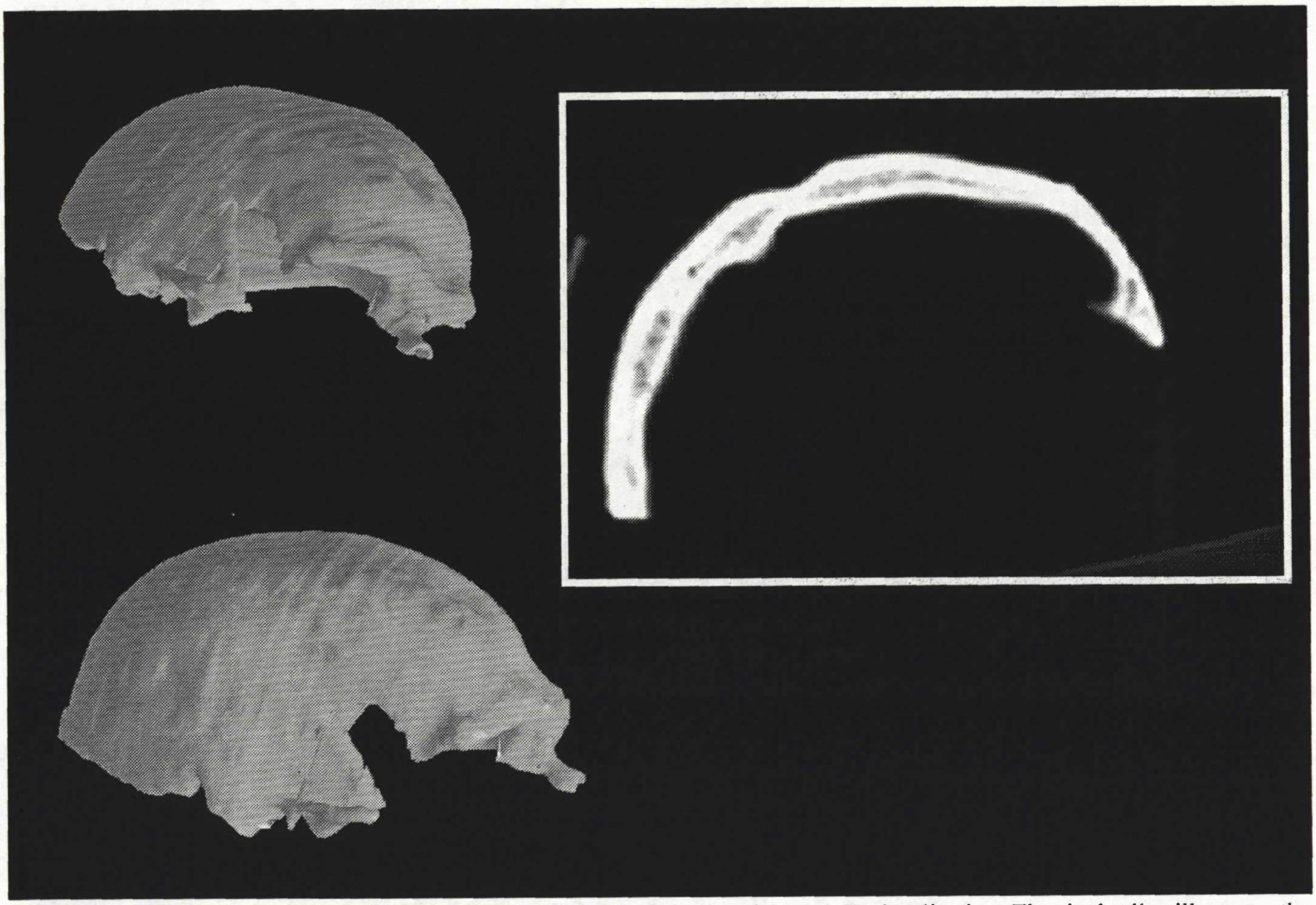

Figure 2: The skull cap from the Hedegård find. Note lesion in frontal region on 3-D visualisation. The single slice illustrates the lesion on a "virtually" cut surface.

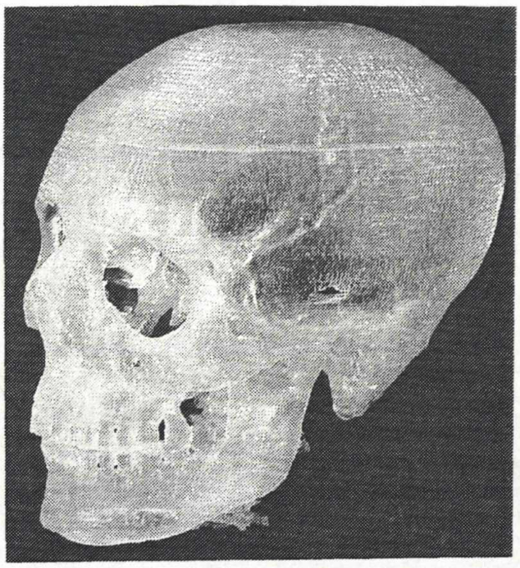

Figure 4: Stereolithographical model of mummy skull.

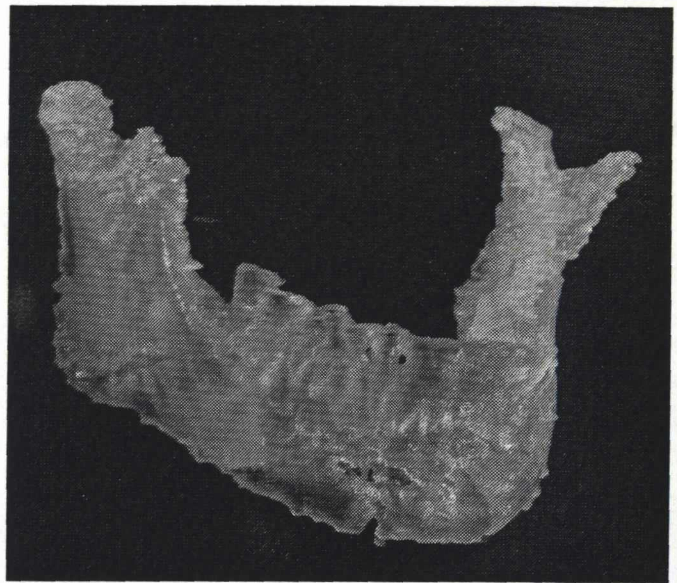

Figure 5: Stereolithographical model of un-excavated human mandible.

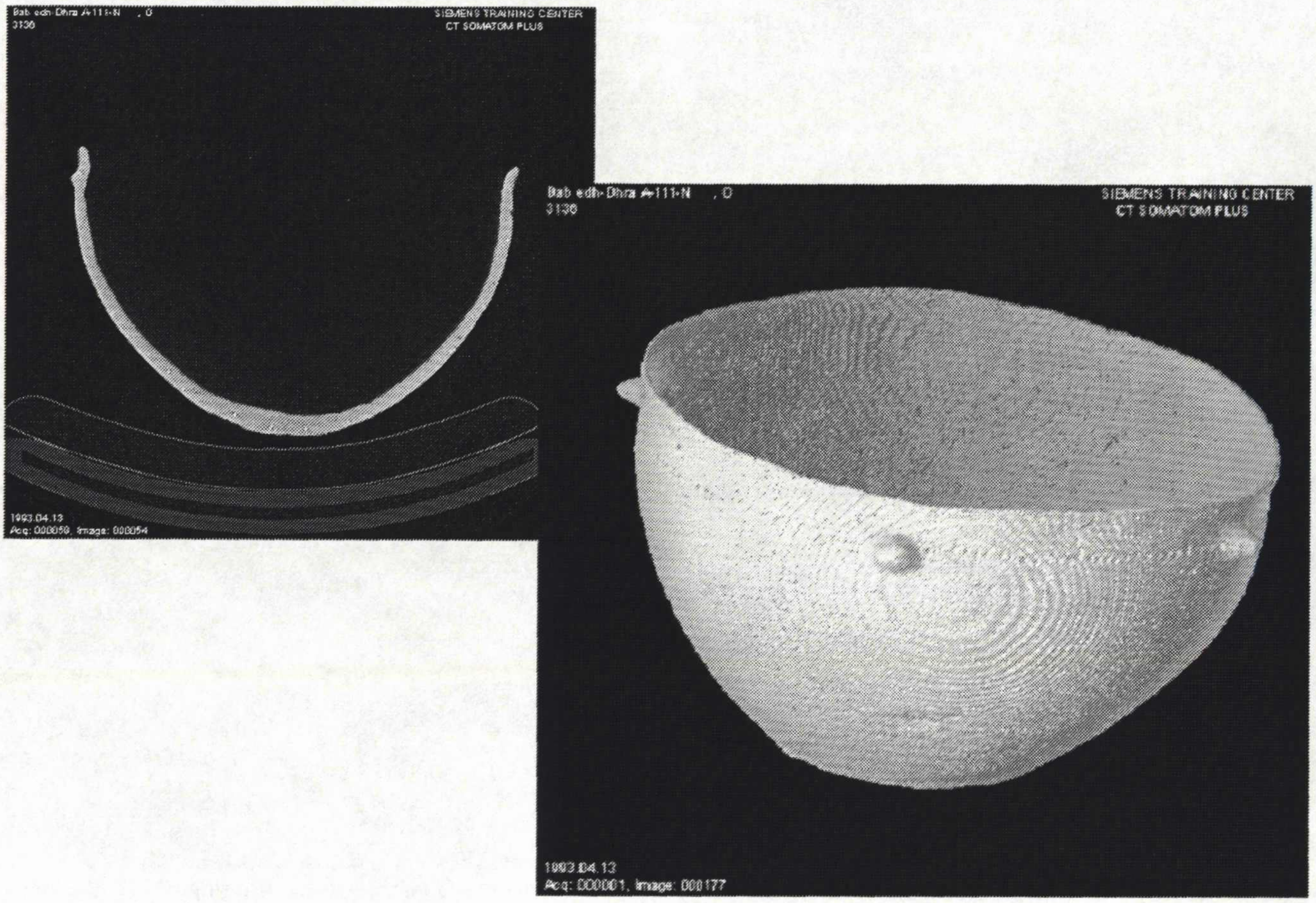

Figure 6: 3-D visualisation of pottery ware.