

# Imaging the “Windeby Child”

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**KEY WORDS:** bog bodies, Germany, imaging, three-dimensional (3D) printing, 3D modelling

## Abstract

***During conservation, the skeletal material was removed from the Windeby Child, a bog body from northern Germany. As part of a recent project to completely re-examine six bog bodies from the Archäologisches Landesmuseum, Schloss Gottorf, Schleswig Germany, the skull of the Windeby Child was scanned using Multislice Computed Tomography (MSCT). The images were then examined for diagnostic and reconstructive purposes using both Mimics 7.3 and 3D-Doctor. This paper will explore the use of both software products for three-dimensional reconstruction, using the images of the skull of the Windeby Child.***

## Introduction

In 1952, two Iron Age bodies were recovered from a peat bog in northern Germany. One of these bodies, often referred to as “Windeby Girl” or “Windeby Child”, was nearly complete and had generally good soft tissue preservation throughout the body. The second body was completely flat due to severe demineralization of the bone. As part of a recent re-analysis of six bog bodies at the Archaeologisches Landesmuseum Schloss Gottorf in Schleswig, northern Germany, the skull and pelvis of the “Windeby Child” (officially Windeby I) were subjected to Multi-slice Computed Tomography (MSCT) scanning. This paper is a comparative report of the use of two software packages for the three-dimensional reconstruction of the skull of Windeby I.

## Material and methods

Although Windeby I is currently on display at the

Archaeologisches Landesmuseum, the majority of the skeletal material, including the skull, was removed during conservation and is stored in another part of the museum. The body that is on display has remaining soft tissue over the head, shoulders (covered by a fur cape), arms, legs and feet. Some skeletal material is visible through the open thoracic cavity. Artificial peat has been mounded over the abdominal and lower thoracic regions of the body. The body is now very heavy and substantially reconstructed; it was felt that MSCT scanning would not provide any additional information. The cranium and mandible of Windeby I were scanned in the head cradle of a Siemens Somatom Sensation 16 MSCT unit at the Institute for Diagnostic Radiology at the Kiel University Clinic, in Kiel, Germany.

The data acquired by MSCT are a series of 2D image files that are processed by the CT scanner from raw data to the DICOM standard (Digital Imaging and Communications in Medicine). DICOM files are a series of 2D images that contain header information about the data acquisition and subject. This is advantageous for maintaining continuity and organization of data. The DICOM files can then be processed into 3D images using a variety of software packages. The Windeby I files were converted to DICOM at the point of scanning in Kiel, Germany.

The type of software used to manipulate the DICOM images and create 3D representations of the subject can have significant implications for the researcher. Processing software is the most variable aspect of working with CT data; researchers should be aware of the advantages and limitations of the software they choose and balance this against their research objectives. One of the objectives for the Windeby I project was to create a 3D model of the skull. Two different software packages were evaluated for the creation of the 3D model that was printed using a 3D printer; 3D Doctor produced by Able Software, and Mimics by Materialise. The advantages and limitations of each piece of software are discussed below.

Soft tissue was first removed from the original 2D slices using both software packages respectively in preparation for the creation of the 3D model of the skull. The Windeby I skull was rendered into 3D using both the 3D Doctor and Mimics software packages, and exported to the 3D printer using the Stereolithography (STL) format. The STL format is a common file type to use between 3D medical

imaging software and 3D printers.

The 3D printer used was a Z-Corp Z-406 printer. This printer uses plaster and binder to recreate an object layer by layer. The Z-406 has the ability to create objects in both colour and monochrome, although monochrome was used for the creation of the Windeby I skull. The printer operates by laying down a thin layer of plaster in the build chamber. A print head then moves over the plaster layer spraying a binding solution in the shape of a 2D cross section of the object. This process is repeated until an entire object is recreated in 3D, the object is then excavated from the build chamber and excess plaster is removed. The model is then infiltrated with a resin for stability and coated with a wax for a shiny appearance, preparing it for extensive handling or display. The model created from this process is extremely accurate and representative of the original bone. In particular, the plaster material gives the model a texture and weight that is similar to actual bone.

## Results

The original skull and mandible are intact and well-preserved; excellent quality images were obtained from the CT scanner with very few imaging artefacts. The scanning of the Windeby I skull resulted in approximately 400 two-dimensional (2D) images. The skull created in Mimics was both accurate and easy to produce, but a manual re-ordering of slices (2D images) was necessary to produce a good model in 3D Doctor.

The full-size virtual 3D models in both Mimics and 3D Doctor were bisected sagittally using the cutting plane feature common to both packages. It was also possible to create physical three-dimensional models of the skull and mandible of Windeby I using the Z406 rapid prototyping unit. A three-dimensional model of the Windeby I skull, following 3D rendering and a sagittal cut in each software package, is seen in Figure 1. The half-skull created in 3D Doctor displayed in-filling of the majority of the cranial region, while the half-skull created in Mimics provided an

unobstructed and accurate rendering of the inside of the skull of Windeby I. When examining the facial region of models generated in Mimics and 3D Doctor, the Mimics model was more precise (see Fig. 2).

The 3D printed sagittal-cut model, created to scale of the original, provided the opportunity to examine the inside of



Fig. 2 - Comparison of plaster model of the facial area of the Windeby I skull, generated in 3D Doctor (left) and Mimics (right).

the skull of Windeby I in detail, which was not possible with the original skeletal material. The brain of this individual was preserved at excavation, although the current location of the organ is unknown. Since the skull was opened to extract and cast the brain, it was thought that there may be evidence of this process on the inside of the skull. Through the imaging, and by using a sagittal section to examine the inside of the Windeby skull, it was clear that the brain had not been returned to the skull after conservation. There were small traces of plaster adhering to the internal surface of the skull (visible in Fig. 3). There was evidence of the cut mark from where the cranium had been opened to access the brain. This mark is virtually invisible on the surface of the original skull.

## Discussion

Table I shows a comparative summary of Mimics and 3D Doctor. For this research, both Mimics and 3D Doctor were able to generate accurate 3D virtual models, although the Mimics models were better for 3D printing. Furthermore, Mimics was more user-friendly and intuitive, although the cost of the software is prohibitive for most institutions. Both software packages provided the opportunity to import multiple file formats and offered accurate surface measurement features. The montage window and quick animation of 3D Doctor was especially useful for a slice-by-slice view, while Mimics offers a multiplanar view that is valuable during editing. Both packages have several features not included in the preparation of the models for this paper. Use of the "pseudocolours" feature in Mimics allowed easier

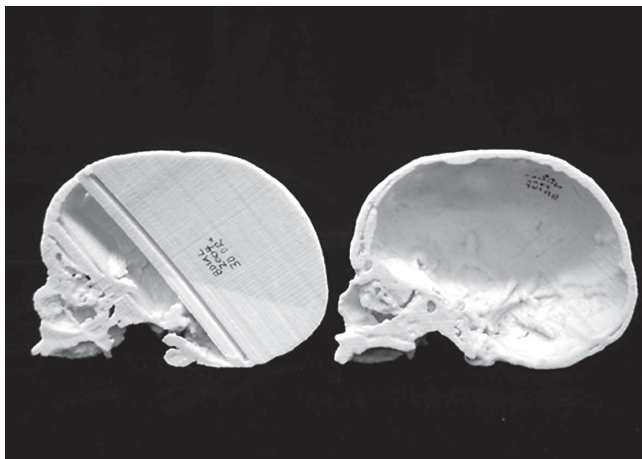


Fig. 1 - Internal structure of a plaster model of the Windeby I skull (sagittal cut), generated in 3D Doctor (left) and Mimics (right).

distinction of bone from soft tissue and enabled clearer visualization of artefacts to be removed. The editing and reconstruction process is both laborious and highly time intensive. Hundreds of hours of editing may be needed to remove artefacts or soft tissue in order to provide a clear

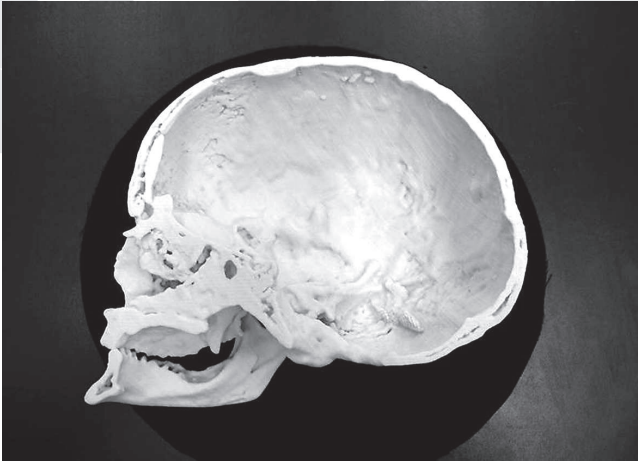


Fig. 3 - Plaster model of the Windeby I skull, inside view.

three-dimensional reconstruction. Although a segmentation algorithm exists within the Mimics software, this algorithm was designed to work with medical imaging of living humans. The skeletal material of the bog bodies displayed varying degrees of demineralization and the soft tissue had become desiccated. It was, at times, very difficult to identify differences in density between some soft tissues, areas of bone and other structures, including the bases on which the body rested for imaging. Effective editing in this respect also has a significant impact on the quality and usefulness of the printed 3D model.

Mimics has been used extensively for the imaging of other bog body material during one author's (HGR) research with the Schloss Gottorf bodies and has proven to be an excellent tool for bog body image analysis. Additional publications on the imaging of the Schloss Gottorf bog bodies are expected in the near future.

## Conclusion

The choice of software should be dependent upon the goal of the image analysis. For simple 3D rendering without rapid prototyping, and for surface measurement of volumetric analyses, 3D Doctor offers a good, affordable option. For complex 3D rendering, visualization on multiple planes and high quality rapid prototyping, Mimics is a better option. In the case of highly demineralised bog body bone, Mimics is much more effective for visualization. The use of the pseudocolours feature and the multiplanar views of Mimics vastly improved the quality and simplicity of image editing and analysis for bog bodies.

## Acknowledgements

- Archaeologisches Landesmuseum, Schloss Gottorf, Schleswig, Germany
- Institut für Diagnostik Radiologie – Kiel
  - Dr. Heller (Director), Dr. Biederer and Dr. Bolte
- Dr. Robert Hoppa, Canada Research Chair in Skeletal Biology
- Bioanthropology Digital Imaging Analysis Laboratory (BDIAL), University of Manitoba
- Able Software and Materialise Technical Support Teams

FEATURE	3D DOCTOR	MIMICS
<b>Company</b>	Able Software	Materialise
<b>Approximate price</b>	Approximately \$4,800 U.S. All inclusive price Academic discount available	Approximately \$17,000 U.S. for base module only Other modules available at additional cost, including: STL+ for rapid prototyping - \$,8000 U.S. Academic discount available
<b>Ease of use</b>	Training recommended (often provided free)	Very user-friendly
<b>Advantages</b>	Montage viewing window 3D Wizard Import and export a wide variety of images (eg. DICOM, TIFF, JPEG, BMP, STL, VRML) 3D volume rendering Quick animation of slices Accurate in 2D and 3D surface and volume rendering	Easily imports DICOM images Series of masks for editing and segmentation Pseudocolours feature for editing Project management list Instant 3D rendering Able to look at multiple image planes easily Accurate in 2D and 3D surface measurements Excellent STL algorithm for rapid prototyping
<b>Limitations</b>	Manual import of multiple image files can be problematic Slices may need to be re-ordered to render 3D model Model rendering may be slow Plaster models may be in-filled internally	Creates proprietary image files that can be difficult to export

Table 1 - Comparative summary of the software packages used for this research.

# JOURNAL OF BIOLOGICAL RESEARCH

## Imaging the "Windeby Child"

- Dr. Niels Lynnerup, Panum Institute
- Research funded by:
  - Support for this research was provided in part by Dr. Robert Hoppa, Canada Research Chair in Skeletal Biology
  - Deutscher Akademischer Austausch Dienst (DAAD)/German Academic Exchange
  - Duff Roblin Fellowship, University of Manitoba
- Conference travel funded by:
  - Faculty of Graduate Studies Conference Travel Award (University of Manitoba)
  - Faculty of Arts Graduate Student Conference Travel Award (University of Manitoba)
  - University of Manitoba Student Union SIGPAC Fund
  - Support for this research was provided in part by Dr. Robert Hoppa, Canada Research Chair in Skeletal Biology