

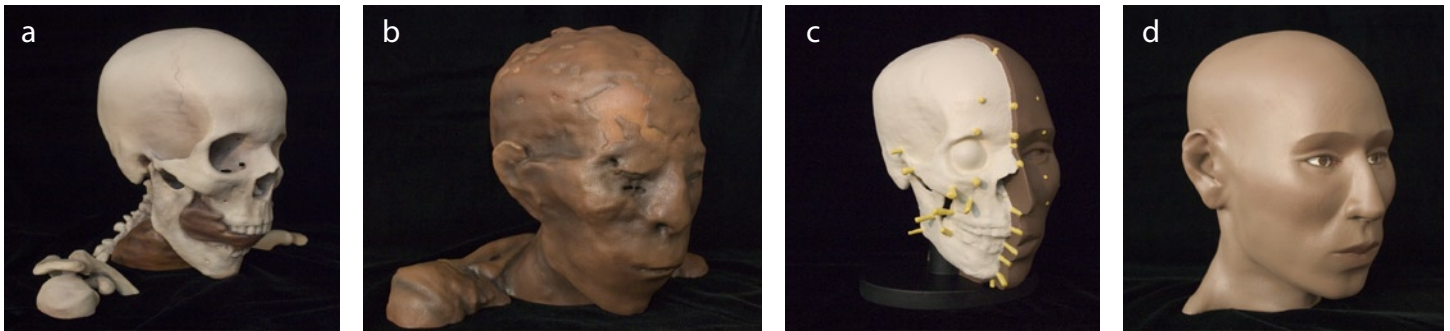
The Denver “Rich Mummy” Reconstruction Project: A novel use of “digital sculpting” techniques and 3D printing

March 9, 2005

Christensen, AM Humphries, SM Vermilye, TL

Several years ago the Denver Museum of Nature and Science (DMNS) and University of Colorado Health Sciences Center (UCHSC) cooperated in a unique effort to study an intact 3,000 year old Egyptian mummy using medical imaging techniques. High resolution computed tomography (CT) scans were acquired through the entire length of the mummy enabling a detailed and non-invasive view inside the wrappings. The CT images effectively create a three-dimensional digital database of the anatomy and structure of the specimen which provided a basis for computer renderings that are currently on display at the DMNS.

Medical Modeling LLC in Golden, Colorado specializes in the fabrication of custom anatomical models using medical image data and rapid prototyping techniques. Working with the DMNS and UCHSC, the company has created solid replicas of the skull and head of the mummy using the available CT data. Further, a facial reconstruction has been performed using a published forensic technique¹ and strictly digital design tools. The four models currently on public display at the DMNS and shown in pictorial form below represent a) the skull of the mummy as revealed by CT scans, b) the appearance of the mummy’s skin segmented from CT scans, c) the skull with tissue depth markers for forensic reconstruction, and d) the final facial reconstruction. Each of these models was constructed based on the electronic CT data using software design tools and solid replicas made with 3D Printing technology (Z Corporation, Burlington, MA).



Use of mummy specimen by permission of the Rosemount Museum in Pueblo, Colorado and the Denver Museum of Nature and Science in Denver, Colorado.

CT scan data courtesy of the University of Colorado Health Sciences Center.

1. Taylor, KT: Forensic Art and Illustration, 2001, CRC Press LLC



Photograph of the “Putting a Human Face on an Ancient Mummy” display. Image courtesy the Denver Museum of Nature and Science. Models and images on display courtesy Medical Modeling LLC, Golden Co.

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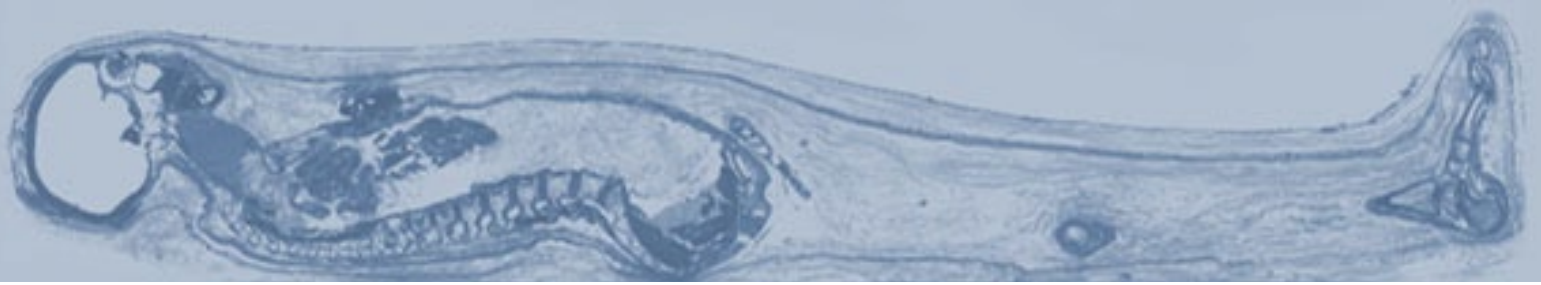
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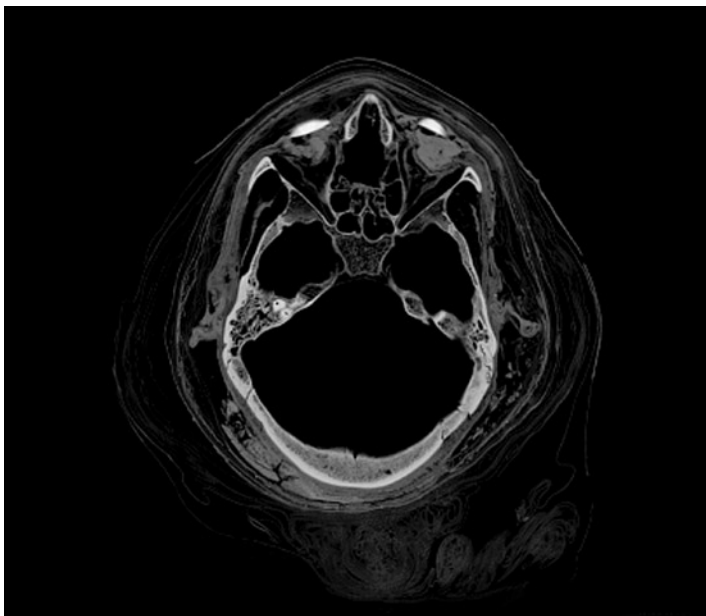
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Step by step project overview

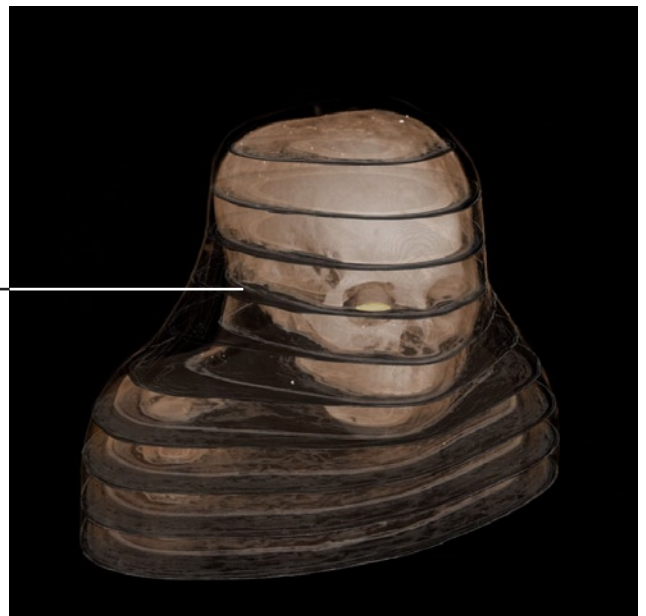
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Step 1: CT scan acquisition

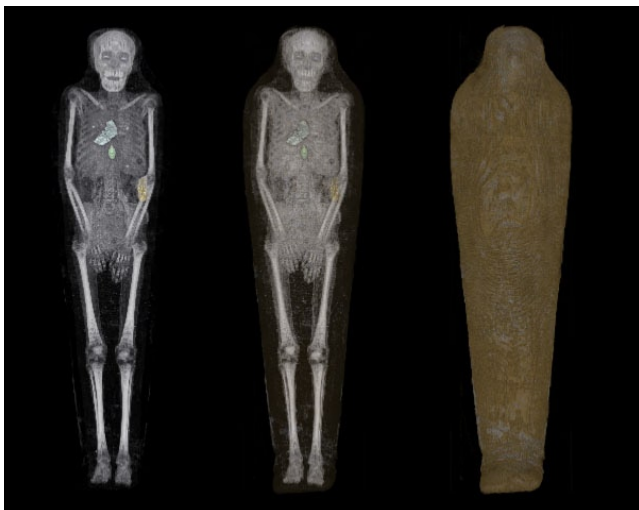
In order to create a digital representation of the "Rich Mummy" on display at the Denver Museum of Nature and Science, medical image data in the form of CT needed to be obtained. In February of 1998, High resolution CT scans were performed on both mummies displayed at the DMNS. These scans show a detailed "slice" every 1mm from head to toe. Medical Modeling used sophisticated software to stack the individual slices and create virtual 3D representations on an advanced computer system. The images below depict individual slices as well as on-screen reconstructions from the data.



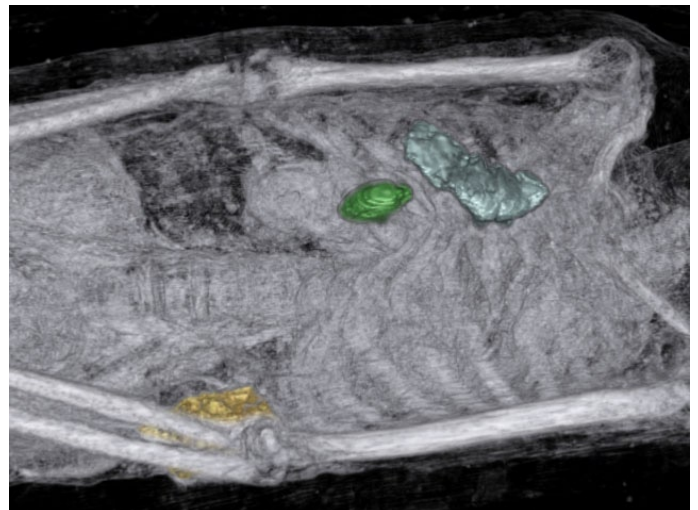
CT slice through the head and eyes (note corresponding slice in image on the right).



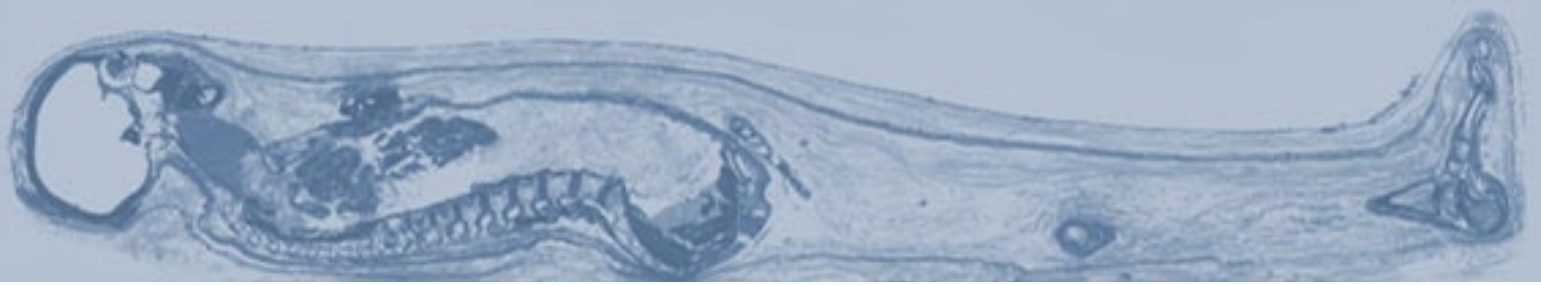
Virtual 3D reconstruction showing slices mixed with skull volume.



Virtual 3D reconstruction showing bone and artifacts (left), bone with transparent wrappings (middle) and overall wrappings (right).



Virtual 3D reconstruction showing a detail of bone with artifacts (note scarab beetle in green).



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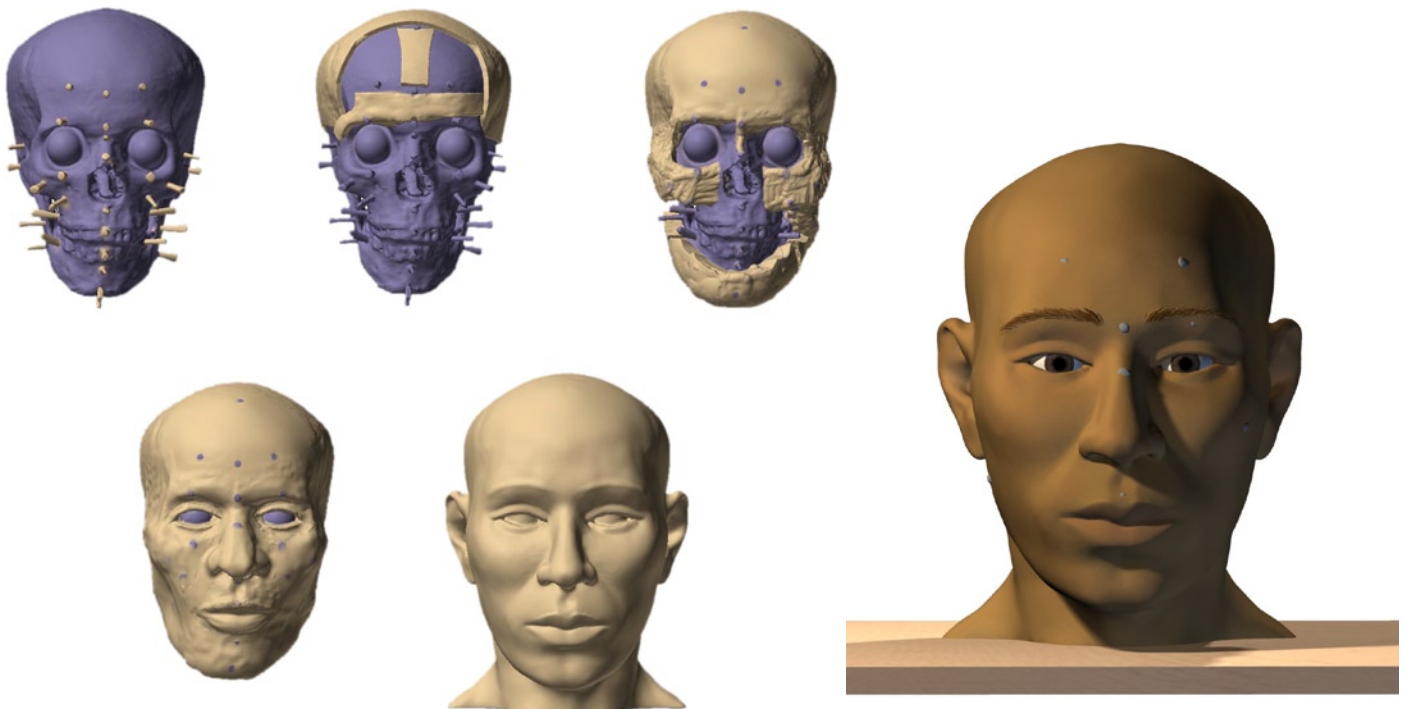
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Step 2: "Digital Sculpting"

After the CT scan images were processed, digital 3D files representing the bone and skin surfaces were created (see images below). A digital 3D model of the mummy's skull was used as a base for creating a facial reconstruction of what the mummy may have looked like in life. The technique, as described in chapters 11-13 from Karen T. Taylor's book, *Forensic Art and Illustration, 2001, CRC Press LLC*, was used with one integral difference: Instead of using traditional clay on a plaster skull, Medical Modeling used "digital clay" on a digital skull. Sophisticated software and touch-based hardware known as haptics were employed to mimic the way real clay would have been used. The result is a completely digital and extremely versatile reconstruction model (see images below). Virtual 3D models allow the use of rendering software to add pigment to the skin, change the lighting environment, rotate the model to any angle, quickly send images via email, and even add hair and clothing without endangering the original sculpture.

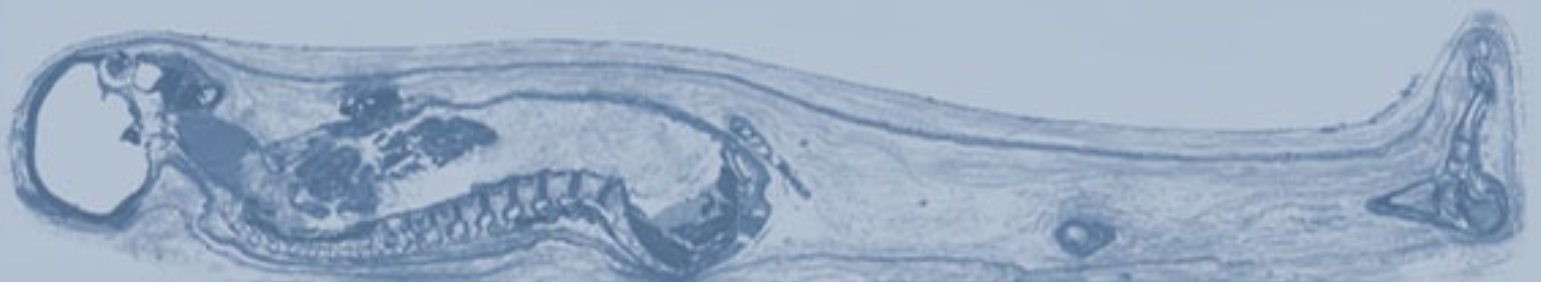


Digital renders of the mummy's bone & resin (left) and of the mummy's skin (middle and right).



Screen captures of the reconstruction process.

Render of final digital reconstruction



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Step 3: 3D Printing

Once the digital models were created, Medical Modeling output them to a Z-corp 3D printer (Z Corporation, Burlington, MA) to create the physical models that would be on display at the DMNS. This form of rapid prototyping uses inkjet print heads to print layers of liquid binder on plaster powder. After each layer is printed a thin layer of new powder is spread over the surface to allow the next layer to be printed. Thousands of layers are stacked this way to produce the final model (see illustration below). The printed models are then dried and hardened for the next step (see model images below).

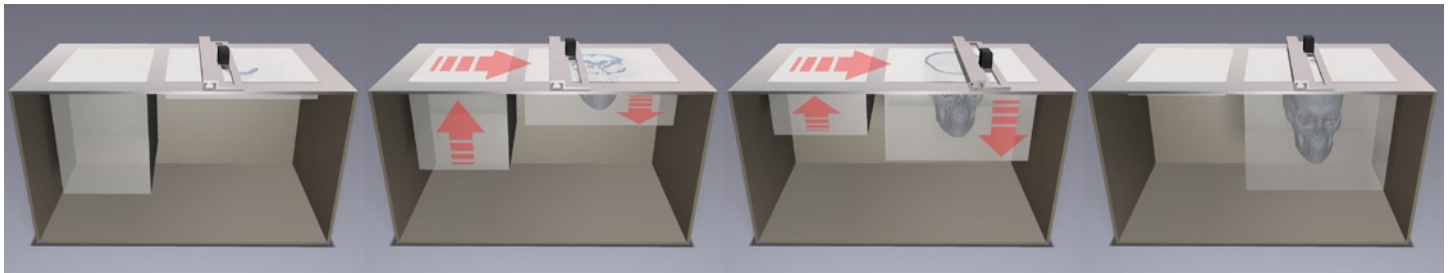


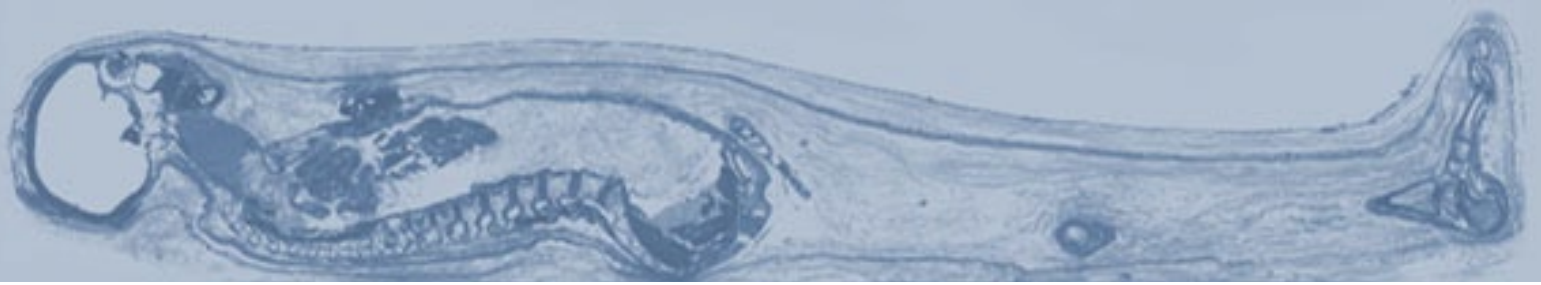
Illustration of the 3D printing process as occurs with Z-Corp 3D printers (Z Corporation, Burlington, MA).



Photograph of the mummy models being removed from the Z-Corp machine. The plaster powder surrounding the models is recycled into the machine for the next print.



Photograph of the mummy models immediately after removal from the machine. Note the loose plaster powder on the surface; this will be removed with forced air during the finishing process.



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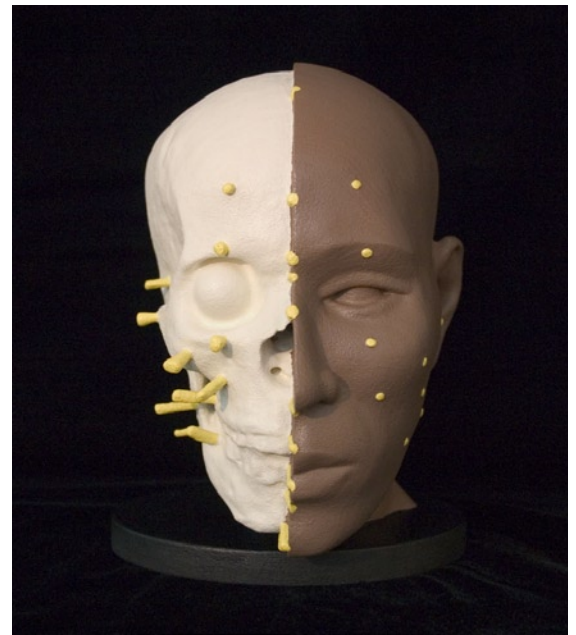
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Step 4: Painting

The last step in the process was to paint each model using traditional painting techniques to give a more life-like appearance. Photographic references of modern Egyptian women were used as a guide for skin tone on the facial reconstruction model. Photos of various mummies and skulls found on the web were used as a reference for the color choices on the mummy skin and bone models. The final models as seen on display at the DMNS are shown below.



Model showing the bone and resin as it exists inside the mummy's wrappings



Model showing the tissue depth markers on the skull and on the surface of the skin



Model showing the skin as it exists inside the mummy's wrappings



Model of the mummy as she may have looked in life