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ORIGINAL COMMUNICATION

Preliminary Study on Digitized Nasal and Temporal Bone Anatomy

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The purpose of this study was to explore a feasible method for the reconstruction of the nasal and temporal bone structures of the Chinese virtual human project and provide a more accurate and facilitated way view them three-dimensionally (3D). The 3-D Slicer software was used to reconstruct the anatomic structures of the human nose and temporal bone. Segmentation and extraction of the contours of the ROI (region of interest) in each single slice were conducted and the processed volume data was transferred into the 3-D Slicer. After resegmentation, a set of labeled maps of the ROI were produced. Based on these maps, the 3D surface models of the tissues of interest were constructed. Four groups of paranasal sinuses, nasal septa, middle and inferior turbinates, temporal bones, tympanic cavities, mastoid air cells, sigmoid sinuses, and internal carotid arteries were reconstructed successfully. These models show spatial relationships and orientation between them. The results show that the 3-D Slicer may be used for the 3D visualization of parts of anatomic structures in the nose and temporal bone based on the first Chinese virtual human data, and thus, can facilitate the observation and understanding of the anatomic structures in this area. Clin. Anat. 19:32–36, 2006. © 2005 Wiley-Liss, Inc.

INTRODUCTION

The rapid development of modern computer technology and computer image processing techniques have promoted the creation and development of many new areas of scientific research. The establishment of the Visible Human Project (VHP) (Spitzer et al., 1996; Ackerman, 1998), initiated by the National Library of Medicine in the United States is an example of this. The VHP aimed to build a dataset complete with high resolution three-dimensional (3D), colorized human models, and at the same time, scientists further advanced the concept of a virtual human being.

At present, the research of the virtual human being remains at a developmental stage. The emphasis thus far has been on applying image registration techniques, colored image segmentation techniques, surface reconstruction of anatomical structures, multi-resolution display of reconstructed surfaces, and interactive browsing of rendered volume results onto these datasets. Due to the complexity of otorhinolaryngological structures, many learners have been challenged by the spatial relationships. Three-dimensional reconstruction of these structures should enhance such understanding. Although there have been many reports demonstrating 3D reconstruction of nasal and temporal bones from CT and histological images (Harada et al., 1988; Lutz et al., 1989; Mason et al., 2000; Dong et al., 2003; Chen et al., 2003), we failed to find reports of such reconstructions based on frozen histological slices. This study

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uses the Chinese virtual human dataset to reconstruct structures in this area to accumulate experience for the Virtual Human Being project.

MATERIALS AND METHODS

Frozen sectional histology data from a fresh cadaver head (Zhong et al., 2003) was acquired through a collaboration with members of the Chinese Virtual Human Project and the Anatomy Institute of the First Military Medical University (Guangzhou, China). The individual was a 19-year-old female who died of food poisoning and was frozen shortly after her death, after written consent from her relatives. Using a high precision numerical control milling machine (milling accuracy = 0.2 mm), successive cross-sectional layers from head-to-feet of the female cadaver were milled and photographed with a digital camera (Fuji FinePix S2 Pro, 6.49Mb pixel resolution) at −25°C in a low temperature laboratory. A total of 8,556 slices were photographed. This dataset has the advantage of high precision without distortion of color and displacement of tissue. Slices 380–760 were used for this study.

The anatomical structures of interest for reconstruction were outlined using the lasso tool in Photoshop (7.0). These structures were rendered with the same gray scale values, and the gray scale differences between these and background were increased so that different anatomical structures could be extracted. The order of the 2D images were maintained by using specific extension names. This volume data was then transferred automatically to the 3-D Slicer software. This is a downloadable (www.slicer.org) surface rendering software program developed by Harvard Medical School and the MIT Artificial Intelligence Lab and is based on Medical Reality Modeling Language. It carries out the following functions: induction of original volume data automatically, half-automatic image segmentation, produce 3D surface models of segmented structures, and 3D visualization and quantitative analysis. Once the volume data was transferred it was reconstructed to produce the other two vertical sets of planar data for each original image. The extracted outlines of the original data were revised according to the reconstructions. The transferred volume data and segmented images were further edited by threshold selection to improve the precision and reliability of the segmentation. Algorithms were calculated to smooth noise and sharpen borders of the interested structures before their labeling.

Fig. 1. Original sectional image of slice 600 through the temporal bones. [Color figure can be viewed in the online issue, which is available at www.interscience.wiley.com.]

Surface models of pertinent structures were produced automatically using the 3-D Slicer software by selecting labeled images of interested tissue. This allows reconstructed organs and tissues to be observed from different angles. In addition, because the 3D window can also interact with three vertical sets of 2D plane windows, sectional images with different positions can be displayed by cutting the model on different planes.

RESULTS

Three-dimensional surface models of anatomical structures of the nose and temporal bone were constructed based on histologic images from unfixed, frozen tissue. These models included nasal sinuses, turbinates, nasal septum, internal carotid artery, temporal bone, mastoid process, and the sigmoid sinus. A surface model of the head was made, and the reconstructed structures were placed in it to show their relationship (Figs. 1–6).

Specific areas of interest can be selected freely and the spatial relationships between different structures can be displayed. At the same time, multiplanar anatomical structures can be sequentially viewed from superficial to deep. Reconstructed structures can also be rotated in different angles to observe special relationships between various anatomic structures and displayed 3D.

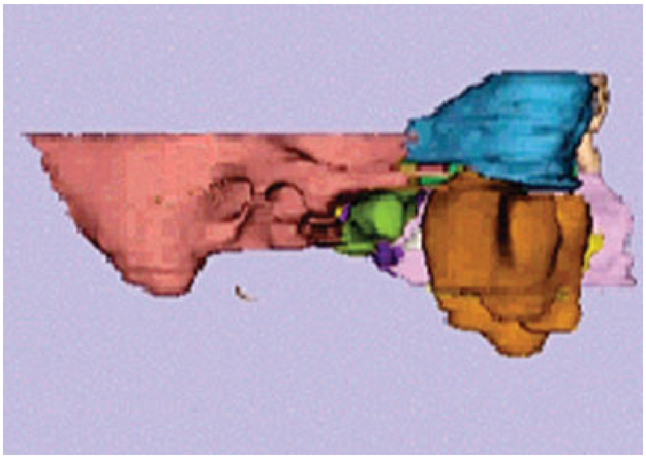

Fig. 2. Lateral view of reconstructed right temporal bone and paranasal sinuses. [Color figure can be viewed in the online issue, which is available at www.interscience.wiley.com.]

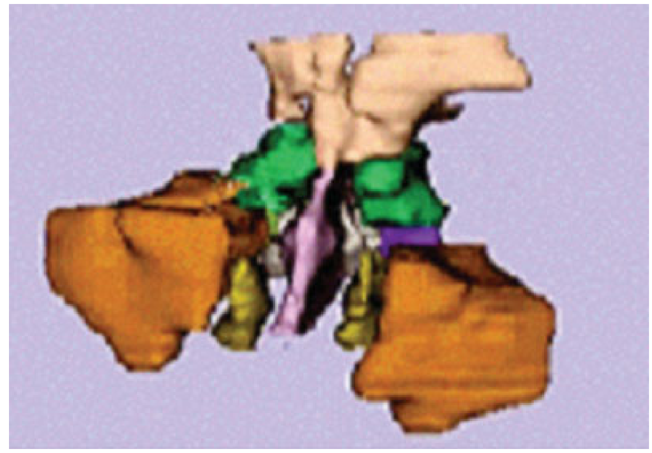

Fig. 4. Anterior view of reconstructed nasal cavity and paranasal sinuses. [Color figure can be viewed in the online issue, which is available at www.interscience.wiley.com.]

DISCUSSION

The virtual human being refers to a complete and systematic interactive digitized human model that includes anatomy, physical characteristics, physiological and biochemical function. This digital model will provide continued opportunities for research in medical education, physical diagnosis, and treatment of disease. Currently, there are many virtual human research projects being undertaken internationally, and much progress has been achieved. Famous among these include the VHP, the Virtual Korean Project (VKP), and the Voxel-Man, developed at Hamburg University in Germany. Each of these has variously focused on the development of datasets from which sophisticated 3D anatomical models can be produced, where virtual reality techniques can be applied and where simulated surgeries can be carried out.

Reconstruction of human anatomical structures has great significance for understanding spatial relationships between complicated anatomical structures and for research on operative approaches and operation simulations. This has become a worldwide research topic that has attracted much interest in the last 10 years and has produced such educational operation simulation software as mastoidectomy (Pflesser et al., 2002; Chen et al., 2003) and endoscopic surgery (Rudman et al., 1998).

Fig. 3. Internal view of reconstructed right temporal bone and paranasal sinuses. 1, frontal sinus; 2, ethmoid sinus; 3, maxillary sinus; 4, sphenoid sinus; 5, orbit; 6, temporal bone. [Color figure can be viewed in the online issue, which is available at www.interscience.wiley.com.]

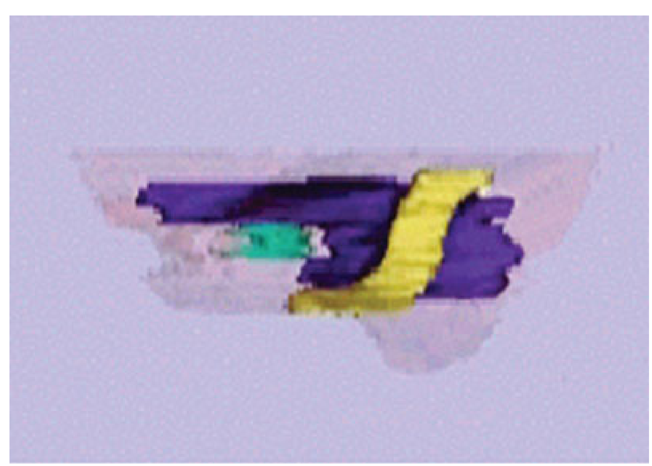

Fig. 5. Transparent right temporal bone viewed from behind demonstrating the tympanic cavity (green), mastoid air cells (blue), and sigmoid sinus (yellow). [Color figure can be viewed in the online issue, which is available at www.interscience.wiley.com.]

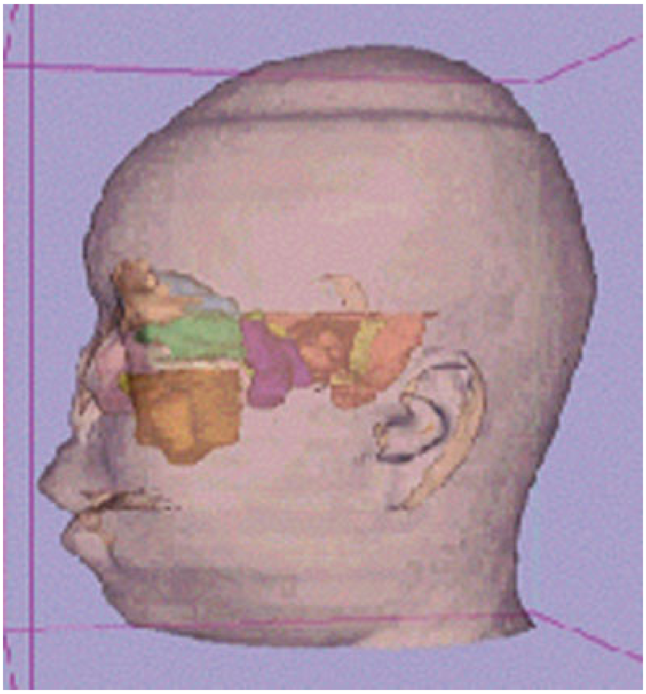

Fig. 6. Position of reconstructed structures in the head. [Color figure can be viewed in the online issue, which is available at www.interscience.wiley.com.]

The complicated anatomy of the nasal region and temporal bone has been challenging for learners. Ideal ways of reconstructing these structures have not been fully realized yet. To date, reconstruction of these areas has been largely based on CT images (Chen et al., 2003; Dong et al., 2003). Inherent limitations of such source material (e.g., indirect structural information, lack of color to aid in distinction of different tissues, and thicker sections) prevent optimal reconstruction of fine, detailed structures. Past efforts to create reconstructions from sequential histological slices have been hampered by technical challenges in tissue preparation (tissue shrinkage or displacement), and frequent use of some magnification system (e.g., projection of tissue images) to permit delineation and outlining of structural contours. Such technical problems have introduced error in the reconstructions (Harada et al., 1988; Lutz et al., 1989; Mason et al., 2000).

Since the advent of the VHP project in the United States, acquisition of images from frozen histologic slices via the milling technique has generated considerable interest. First, this technique greatly reduces displacement of tissue. Second, using digital photography further reduces error in image acquisition and allows all anatomical structures to be captured. Colored image segmentation techniques, however, currently lag far behind 3D reconstruction capabilities. This has necessitated high-end computer hardware, powerful image processing and extraction software, and multidisciplinary cooperation between anatomists, computer scientists, and experts in image processing.

In this study, we attempted to reconstruct complicated otorhinolaryngological structures using the first virtual Chinese female dataset. Three-dimensional morphology of and spatial relationships between paranasal sinuses and temporal bone were clearly demonstrated. This work has advanced the goals of our visible human research efforts and has laid the foundation for future research into operation simulations. Our results fall short, however, of the ideal method for extracting detailed tissue information. For example, fine structures, such as ossicles and elements of the inner ear could not be reconstructed due to low resolution of the original images. Errors could not be avoided because the outlines of some structures, or parts thereof, were not clearly discernible. Potential solutions to this problem may include the use of thin, histologic sections or plastinated sections. Sorensen et al. (2002) used histologic sections to create a ''visible ear'' that clearly showed semicircular canals, the cochlea, the ossicles, and ligaments. Qiu et al. (2001), using plastinated sections of temporal bone and a surface rendering method, were able to produce reconstructions that showed the anatomic relationships between the facial nerve canal, the sigmoid sinus, the ossicles, and the bony labyrinth of the inner ear. Although our reconstruction efforts, based on histological slices are yet limited, future reconstruction based on histologic sections will prove to be superior to those derived from CT images along with further development and refinement of image capturing and processing technology. This will further enhance our efforts to optimize protocols for development of otorhinolaryngological operation simulation systems.

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