Original Article

Virtual Temporal Bone Anatomy

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Background The Visible Human Project (VHP) initiated by the U.S. National Library of Medicine has drawn much attention and interests from around the world. The Visible Chinese Human (VCH) project has started in China. The current study aims at acquiring a feasible virtual methodology for reconstructing the temporal bone of the Chinese population, which may provide an accurate 3-D model of important temporal bone structures that can be used in teaching and patient care for medical scientists and clinicians. **Methods** A series of sectional images of the temporal bone were generated from section slices of a female cadaver head. On each sectional image, SOIs (structures of interest) were segmented by carefully defining their contours and filling their areas with certain gray scale values. The processed volume data were then inducted into the 3D Slicer software (developed by the Surgical Planning Lab at Brigham and Women´s Hospital and the MIT AI Lab) for resegmentation and generation of a set of tagged images of the SOIs. 3D surface models of SOIs were then reconstructed from these images. **Results** The temporal bone and structures in the temporal bone, including the tympanic cavity, mastoid cells, sigmoid sinus and internal carotid artery, were successfully reconstructed. The orientation of and spatial relationship among these structures were easily visualized in the reconstructed surface models. **Conclusion** The 3D Slicer software can be used for 3-dimensional visualization of anatomic structures in the temporal bone, which will greatly facilitate the advance of knowledge and techniques critical for studying and treating disorders involving the temporal bone.

Keywords 3-D reconstruction; temporal bone; Chinese Virtual Human

Introduction

The rapid development of modern computer technology and computer image processing techniques has promoted emergence and development of many new scientific research areas. The Visible Human Project (VHP) [1-2] initiated by the United States National Library of Medicine is one good example. VHP aims at building a complete dataset of high resolution, 3-dimensional, color human anatomy models. At the same time, the concept of virtual human being has been put forward,, which provides a unified platform for building models of the human life system that will facilitate transition of medicine from empirical to theory- and evidence- based science and from microscopic subsystem studies to macroscopic systemic studies.

At present, research of the virtual human being is limited to morphological studies, and key points currently under study include image registration, color image segmentation, surface reconstruction of anatomical structures, multiresolutional indication of reconstructed surfaces, and interactive browsing of volume rendering results. We have reconstructed selected temporal bone

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structures based on the first Chinese virtual human dataset for the purpose of gaining practical experiences and collect needed data for the Virtual Chinese Human (VCH) project.

Material and method

Acquisition of sectional image data[3-4]

In collaboration with the Anatomy Institute, First Military Medical University (Guangzhou, China), 0.2 mm cadaver head sections were produced using a high precision milling machine. A total of 2128 successive cross- sections were photographed using a digital camera. Images generated in this manner were free from color distortion and structure displacement.

Data processing

Image segmentation

1) On each sectional image, contours of SOIs were marked on the Photoshop software platform.
2) For each OSI, an identical grey scale value was assigned to the entire area representing the structure on each single sectional image. For the same structure, its assigned grey scale value on each sectional image varied systematically from the background. SOIs were extracted based upon their assigned grey scale values.

Induction and processing of two- dimensional images:

All sectional images were saved as a series of computer files with numerical extension names representing the order of the images. The files were then inducted into the 3D Slicer software, which reconstructed sectional images on the other two perpendicular planes using inducted data. Data on the newly constructed two planes were also used to refine definition of SOI contours on the original sectional images for improved visual effects. Volume data were edited and segmentation refined through adjusting thresholds in order to increase segmentation precision and reliability and to produce a series of color-labled SOI images. Data of labeled images were subjected to additional computing to smooth surface image noise and sharpen their borders.

Three-dimensional reconstruction and visualization:

Surface models of SOIs were generated using the 3D Slicer software by selecting color-labeled volumes of various SOIs. The linked 3-D and 2-D windows in the software allow viewing sectional images of preference along selected axes.

Results

1. Three- dimensional surface models of several structures in the temporal bone were reconstructed, including the temporal bone, mastoid, and sigmoid sinus. Surface model of the head was also reconstructed to demonstrate the orientations and positions of the SOIs within the head(Figure1-4).
2. SOIs could be selected to be viewed and spatial relationship between different structures could be visualized. "Stripping" browsing of various structures was also available. Reconstructed structures could also be rotated in all angles, allowing enhanced observation of various structures.

Discussion

Introduction to Virtual Chinese Project

Virtual human being refers to building a complete, systematic and interactive digital human model representing the anatomy, physics, physiology and biochemistry of the human body, to meet the needs in medical education and clinical research for improvement in diagnosis and treatment of diseases. Multiple virtual human research projects are currently underway and much progress has been made. Some of

Figure 1. Lateral view of reconstructed temporal bone.

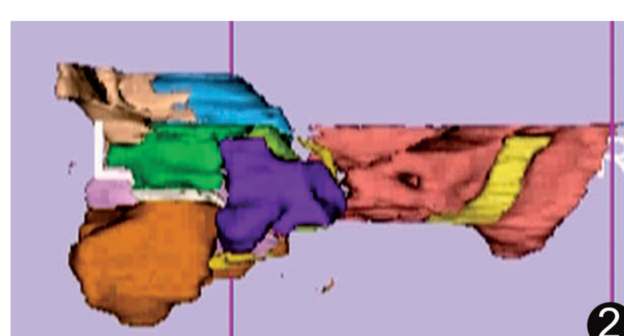

Figure 2. Internal view of Reconstructed temporal bone

Figure 3. Transparent view of tympani cavity(green)、mastoid(blue)and sigmoid sinuses(yellow)in the temporal bone. **Figure 4.** Indicate positions of reconstructed structures in the head

such projects include the VHP, Visible Korean Project and Voxel-Man project at Hamburg University in Germany. The goals of these projects are to build accurate 3-dimensional anatomical models using virtual computing technologies and to integrate these models into development of new surgical techniques. Different technical approaches have been adopted in these projects in dataset acquisition and application. Considering racial differences and the different goals between these projects and the CVH project, datasets used in the existing projects may not be completely appropriate for the VCH project. Therefore, there is a need for building datasets based on information collected from the Chinese race[5].

The VCH project was officially initiated in China as part of the so-called "863 Plan", which is a state sponsored national effort to boost advances in science and technology in China. The project is assigned to the Institute of Computing Technology at Chinese Academy of Science, the First Military Medical University, Capital University of Medical Sciences and Huazhong University of Science and Technology. So far, datasets of three fresh cadavers, including one male, one female and one female fetus, have been acquired.

Comparison between CT scan- and histological slices-based reconstruction

Reconstruction of human anatomical structures has great significance for understanding the complex spatial relationship among different structures and is a useful tool for developing new surgical approaches and for surgery simulation. It has become a worldwide fruitful research hot spot for the past 10 years. Training simulation softwares for surgical procedures in the ear, nose and throat including mastoidectomy and rhinoendoscopic procedures have been developed in Germany and the U.S.

There have been a number of studies both in China and other countries on reconstruction of anatomical structures using CT images [6-8]. However, because CT images are derivative information, with false color representation and relatively coarse section thickness, they are inadequate for reconstruction of high-precision models. Reconstruction using traditional histological slices have also been less than satisfactory, due to the overwhelming complexity of the process and the inherent problem of tissue displacement.

Since the time of initiation of the U.S. VHP, frozen section data acquisition technology has aroused much interest for researchers around the world. Frozen section greatly minimizes the tissue displacement problem. In addition, the application of digital photography further reduces errors in image acquisition. More importantly, frozen section allows much thinner sections compared to CT scans while preserving information of all anatomical structures. Reconstruction of high-resolution structure models puts high demands on technologies in image processing, structure extraction and, ultimately, computing capacity of the computer. Color image segmenting techniques do not yet meet the requirements of 3-dimensional reconstruction. Multidisciplinary cooperation is required for breakthroughs in this research area.

Comprehending the complex temporal bone anatomy has always been a challenge for researchers and clinicians. Satisfying reconstruction of temporal bone structures has yet to be developed. Reconstruction using frozen section slices can be an important advance in this area, although by no means an easy task. Compared to the numerous reports on CT-based reconstruction, reports on reconstruction using frozen section slices are rare. Harada[9] is among the earliest to report temporal bone reconstruction using histological slices, followed by Lucz [10], Their success was limited by available slicing techniques, computer technology and reconstruction computing techniques at the time. Partial temporal bone reconstruction using histological slices were later attempted by other researchers. In 2000, Mason[11] tried reconstructing the temporal bone using 630 histological slices. In his work, the omission of labeling acquired images created tremendous difficulties for re-aligning structures at later reconstruction stages.

In this study, we attempted to reconstruct the complex temporal bone structures using data from the VCH dataset No. 1. Three-dimensional images of main structures in the temporal bone were successfully reconstructed with good viewing effects. This is an important supplement to the VCH project and lays a foundation for future surgical simulation research. Our work is limited by the lack of an ideal method for extracting mastoid air cells and subtle structures such as the ossicles and inner ear structures. This is due to the relatively low resolutions of the images acquired from frozen section slices. Extraction errors are inevitable in the presence of ambiguous borders between structures. Qiu et al[12] reported temporal bone reconstruction using surface rendering method that resulted in improved demonstration of relationship among the fallopian canal, sigmoid sinus, ossicles and labyrinth. We suggest that imaging of thin histological slices from a single fresh temporal bone may be required to accurately reconstruct fine structures such as the semicircular canals, cochlea, ossicles and middle ear ligaments. Sorensen[13] has established a temporal bone dataset from 605 sectional images that were acquired through digitally photographing 25 μm fresh frozen temporal bone slices. He, however, has not yet reconstructed the structures. Bernhard[14] has developed a mastoidectomy simulation system based on CT images. Chen[7] has also reported his preliminary works on CT image-based mastoidectomy simulation. It has to be acknowledged that, at this stage, reconstruction based on histological slices is not completely satisfying and is yet to surpass the quality of reconstruction based on high resolution CT images. However, it is expected that, as technologies of image capturing and processing improve, the results of histological slice-based reconstruction will eventually exceed those of CT-based reconstruction. Continued research in this area is therefore critical. We intend to continue the present work toward the goal of developing a otolaryngological surgery simulation system that reflects the unique characteristics of the Chinese race and is suitable for clinical application.

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