Computer–Aided Simulation of Mastoidectomy

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Abstract Objective To establish a three–dimensional model of the temporal bone using CT scan images for study of temporal bone structures and simulation of mastoidectomy procedures. Methods CT scan images from 6 individuals (12 temporal bones) were used to reconstruct the Fallopian canal, internal auditory canal, cochlea, semicircular canals, sigmoid sinus, posterior fossa floor and jugular bulb on a computer platform. Their anatomical relations within the temporal bone were restored in the computed model. The same model was used to simulate mastoidectomy procedures. Results The reconstructed computer model provided accurate and clear three–dimensional images of temporal bone structures. Simulation of mastoidectomy using these images provided procedural experiences closely mimicking the real surgical procedure. Conclusion Computer–aided three dimensional reconstruction of temporal bone structures using CT scan images is a useful tool in surgical simulation and can aid surgical procedure planning.

Key words three–dimension reconstruction, CT scan, surgery simulation

Introduction

Computer–aided three dimensional reconstruction using CT scan images is a useful non–invasive tool in the study of the anatomy and physiology of human organs. It is especially helpful for studying delicate structures with complex anatomical relations and important functions. It has been successfully utilized in disease diagnosis, surgery planning and surgery simulation.

In this study, high–speed spiral scanning CT images of the temporal bone from 6 normal subjects were used to reconstruct three–dimensional images. The reconstructed model was used in mastoidectomy simulation with satisfactory results.

Materials and methods

Temporal bone CT scan images were obtained from 6 normal volunteers (12 temporal bones) using a Hispeed CT/I scanner (GE, USA). Pre–scan X–ray was used to locate scan target that included the entire temporal bone. The subject’s head was restrained from motion during scanning. Scan thickness was 5 mm with the table moving at a speed of 7 mm/s.

A computer work station running on the Advantage Windows software was used for three–dimensional reconstruction and surgery simulation. Metal artifact shadows were removed during image processing. The thickness of reconstruction sections was 0.5 mm. Arbitrary colors were assigned to the following structures: red for cochlea, pink for Fallopian canal, yellow for internal auditory canal, and blue for jugular bulb, sigmoid sinus and posterior fossa floor. The anatomical relations of these structures inside the temporal bone were restored in the reconstructed model.

Results

The reconstructed three–dimensional temporal bone model provided clear views of structures inside the temporal bone. Visualization of the mastoid allowed pre–operative determination of areas of surgical resection in surgery simulation. Mastoidectomy was simulated on this model using the regional volume removal feature provided by the imaging software, which allowed step–by–step exposure of the sigmoid sinus, posterior
fossa floor, horizontal semicircular canal, Fallopian canal, posterior semicircular canal, superior semicircular canal and cochlea (Fig. 1–Fig. 6).

**Discussion**

**Impact of surgery simulation on the advances of surgery**

The latest advances in technology and inter-discipline research have brought increasing application of new engineering technologies in the clinic. Traditionally, surgeons rely on their eyes and hands in complicated surgical procedures. However, visualization of organs is restricted to exposed structures to the surgeon, making surgery an empirical experience to a certain extent in many cases. Lack of quantitative description of anatomical structures and their relations has limited preoperative planning. Surgeons often have to make empirical analyses and decisions in the middle of a procedure when facing unexpected anomalies. This can result in unnecessary procedural difficulties and delays and may affect surgical outcomes.

The development of CT, MRI and PET scan technologies has greatly extended a surgeon’s vision, allowing visualization of structures beyond body surface in a sequence of sectional images. These images can be used to reconstruct three-dimensional anatomical models on a computer with certain image-processing capability. With interactive software, such models can be used for preoperative planning and intraoperative guidance, which help predicting the surgical process and outcomes. Such computer-aided simulation has been used in maxillofacial plastic surgeries. Preoperative simulation familiarizes the surgeon of the surgical procedure, while intraoperative guidance helps the surgeon navigating through complex anatomical relations. The advent and advance of these technologies are revolutionary to the development of surgery.

**Significance of three-dimensional reconstruction of CT images and surgery simulation in otology**

The complicated anatomical relations among temporal bone structures make literal and pictorial description of these organs difficult. Three-dimensional demonstration of temporal bone structures has been developed using...
histological sections and computer reconstruction technologies. The three-dimensional relations can be restored on a computer when images of histological sections are grouped together in accordance to their original sequences [7–10]. However, this is a complex, multi-procedural and time-consuming process. It is expensive and not practical for clinical application. Three-dimensional reconstruction using CT scan images is an advance based upon the histological section technology. It can be used to measure tissue volume (useful for monitoring organ development [12]), help detect anatomical anomalies and their relations to diseases, guide surgical procedures in congenital middle ear deformities, and predict surgical outcomes [13, 14].

The three-dimensional model of the cochlea and related structures developed in this study allows an easy visualization of the anatomical location, features and relations of these organs. The model can be rotated for viewing from different angles. To our knowledge, this study is the first to report simulation of otological surgeries, which not only helps predict surgical process and outcomes, but is also useful in training young otologists.

With its ability to provide complete and accurate visual description of anatomical structures and allow preoperative simulation, computer-aided three-dimensional reconstruction will play an important role in research, teaching and patient care. It should be noted that the high cost and equipment requirement involved in three-dimensional reconstruction with CT images may limit its use in the clinic. Another drawback is the increased amount of radiation exposure needed to obtain thin section high resolution CT images which are critical for high-quality three-dimensional reconstruction. Also, metal object in the CT field can generate artifacts that compromise image quality. Three-dimensional reconstruction with CT images therefore should be used in selected patients.

**References**


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