3D RECONSTRUCTION OF THE TEMPORAL BONE IN COCHLEAR IMPLANT SURGERY

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Introduction

In the preoperative evaluation of prospective cochlear implant patients high resolution computed tomography (CT) is routinely performed\(^1\). Sectional images of the temporal bones in the axial or coronal plane can give essential information about cochlear or mastoid pathology that will enable the surgeon to select a side for operation and alert him to surgical obstacles he might encounter\(^1,4\).

Even with the help of serial CTs it has always been very difficult to visualize the complicated anatomy of the normal temporal bone. In particular, in a patient with a malformation or a previous operation, even an experienced otologic surgeon cannot always avoid unwelcome surprises. In analyzing the CT films he must still try to form a 3-dimensional image in his mind by looking through a large number of different pictures\(^5\). Consequently, to make it easier to understand, a lot of effort has been put into the development of 3-dimensional (3D) imaging of the object. A variety of 3D graphics systems that provide multi-angled surface renderings from serial CT images have become available in recent years and proved to be useful in craniofacial reconstructive, orthopedic and neurosurgical planning\(^6-8\).

We applied our own image analysis technique to produce three-dimensional reconstructions of temporal bones in patients and in isolation on a personal computer\(^9\). We focused on the use of this method for the preoperative examination and surgical planning for cochlear implantation as well as for our research purposes. This system and the results are presented here.

Methods

Input for the reconstructions can be any series of CT scans. The images are usually stored on X-ray films or can be saved onto magnetic tapes or floppy disks. In most cases we use CT images saved on tape. On our own VAX computer these files are converted into a standard format (GIF) and can be transferred to a personal computer on a floppy disk.

Alternatively the films can be viewed on a light-box with a video camera. These video images are digitized and stored on the personal computer. By transferring the image data onto our independent work-station we overcome the problem of blocking valuable scanning time on the CT-scanner computer. The same system can also be used for the reconstruction of histological sections.

In a first step the program displays the CT images on the screen by color coding the different gray levels approximately representing the density (Hounsfield Units). Depending on the resolution and the intervals of the consecutive “original” CT-scan images, a variable number of slices can be interpolated between them. The program allows now for either automatic, interactive or manual edge detection in the CT images. By using the original image data, there is absolutely no loss of resolution in the reconstruction. The user can select certain regions of interest in the surfaces as boxes and store them as separate features or objects. This means, that any feature detected on a particular scan can be easily recognised in the following 3D recon-

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Fig. 1 The distances of anatomical points of interest yielded after 3D reconstruction are correlated with direct calliper measurements after anatomical dissection of the same specimen. The correlation coefficient for 574 measurements is 0.9452, the slope is 0.867 with an intercept at 1.38. T(572)= 69.25.

Fig. 2. Photograph of the lateral aspect of a temporal bone (age 17 years).
3D reconstruction of the temporal bone

structure. For instance the ossicles, the round window, the facial recess etc. can later be highlighted by being plotted alone or in a different color than the surrounding bone.

Within the display mode of the reconstruction program the user can rotate the object around all axes, zoom and move it, cut off a section at any level, or "drill" a hole to display otherwise hidden structures. The images can be labeled and stored for documentation. By defining points of interest with the computer mouse, distances and angles can be calculated even after additional rotations, magnifications, drilling etc. To enhance the 3D appearance of the object shading can be added with a virtual light source from any angle and at any intensity. The most plastic 3D appearance image however can be achieved by producing a video imitating rotation of the object.

In addition to its use in examining the temporal bone in patients and to determine the accuracy of our 3D reconstruction system the CT-scan images of six cadaver temporal bones from children ranging from three months to 18 years were recorded, digitized and transferred onto our microcomputer. We selected several anatomical and surgical landmarks relevant for cochlear implant surgery in children, including the round and oval windows, the promontory, the lateral semicircular canal, the fossa incudis, the mastoid tip, the sinudural angle and others. The distances between these points were measured using our reconstruction program and compared to those yielded by direct calliper measurements after anatomical dissection of the same bone.

Results

The correlation between the two sets of data was very good and yielded a regression coefficient of 0.9452 (Fig. 1). Examples of the 3D reconstructions from these temporal bones are shown in Figs. 2 and 3.

Fig. 3 The same temporal bone as in Fig. 2 after reconstruction using the original CT data.
Fig. 4. Reconstructed image of a seven-year-old girl with a bilateral Mondini's syndrome after implantation of a Cochlear 22 multichannel implant. The lead-wire of the implant can be seen in the mastoid cavity, forming a loop to accommodate expected skull growth.

Fig. 5. The same child as in Fig. 4. Only the cochlear implant and the ossicles are plotted, displaying the orientation of the electrode array in the inner and middle ear.
On a patient with a bilateral Mondini's malformation of the inner ear a postoperative CT scan was performed and the images used for reconstruction (Figs. 4 and 5). By only displaying the electrode array, the ossicles and the inner ear spaces, the orientation of the Nucleus Mini 22 multichannel cochlear implant inside the inner and middle ear becomes obvious. The intracochlear part of the electrode follows the basal turn of the rudimentary cochlea. Even the thin platinum wire we use for the fixation of the electrode array at the fossa incudis in children is visible.

Discussion

The presented concept with its ability to visualize the complicated anatomy of the ear and to make accurate measurements of the various structures in it can provide important information for the surgeon planning the cochlear implant operation. For instance, the relationship of a bulging sigmoid sinus to the facial recess can be assessed more accurately and, by detecting the cranial sutures in a child prior to the operation, the surgeon can try to avoid the placement of the package across these sutures.

For research purposes, we are examining the growth pattern of the temporal bone during early childhood in order to make the cochlear implant available for small children. Cadaver temporal bones from children are not easy to come by. On the other hand, CT scans are performed routinely on all our cochlear implant candidates including the increasing number of small children. So now these CT-scan series are used for our measurements.

By its nature the 3D reconstruction can only detect features already present on the plain two-dimensional CT scan. But it facilitates significantly the conceptualization of the complicated anatomy of the ear and is supplementing plain CT scans.

With the present program we believe we have achieved a relatively cheap and effective system, providing the surgeon and researcher with a rapid and accurate method to examine a patient's temporal bone.

Therefore we will continue to use the 3D reconstruction for the preoperative evaluation in cochlear implant surgery and for the collection of data on the growth pattern of the temporal bone.

References

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