Virtual endoscopy of the middle ear

Abstract Virtual endoscopy is a computer-generated simulation of fiberoptic endoscopy, and its application to the study of the middle ear has been recently proposed. The need to represent the middle ear anatomy by means of virtual endoscopy arose from the increased interest of otolaryngologists in trans-tympanic endoscopy. In fact, this imaging method allows the visualization of middle ear anatomy with high detail, but it is evasive and is essentially used for surgical guidance. Virtual endoscopy provides similar perspectives of the tympanic cavity but does not require the tympanic perforation. In the study of the middle ear, specific attention is given to the retroperitoneum. This region contains elevations of the medial wall (pyramidal eminence and ridge, styloid eminence and ridge, subiculum, ponticulus) and depressions (sinus tympani, posterior sinus tympani, facial sinus, fossula of Grivot, oval window fossula), which can be effectively displayed by virtual endoscopy. Virtual endoscopy is foreseen as a useful tool in preoperative management of patients who are candidates for middle ear surgery, since it can predict with high detail the patient’s specific anatomy by imaging perspectives familiar to otosurgeons.

Key words Temporal bone · CT · Virtual images

Introduction
The middle ear is a little aerated cavity with a complex anatomy, difficult to access by the direct human vision. The unique, uninvasive method that allows visualization of the tympanic cavity is represented by otoendoscopy performed through the external auditory canal. In this case the tympanic membrane remains a barrier between the endoscope and the middle ear structures, which can be illuminated through an intense light source which crosses the transparent membrane. The indirect visualization of the middle ear and the fixed position of the endoscope, which reduces the field of view, represent the main limitations of this imaging method. Despite these issues, otoendoscopy is still the easiest and fastest uninvasive method for visualizing the tympanic cavity that can be used by every otolaryngologist for the screening of pathologies which affect the middle ear.

For the aforementioned reasons the diagnostic work-up of middle ear pathologies often includes the use of high-resolution computed tomography (HRCT) whereas MR imaging plays a role in the characterization of specific CT findings or when the study of the inner ear is required.

The possibility of using thin collimation with helical scanners allows the study of very small structures, such as the ossicular chain, with a submillimetric resolution. Moreover, the volumetric acquisition provides the suitable data sets for dedicated simulation of the endoscopic vision. Such simulation is called virtual endoscopy (VE).

Actually VE represents the unique uninvasive method for the direct 3D visualization of the anatomical...
structures of the middle ear, since the use of fiberoptic endoscopy for visualizing the middle ear is reserved to the guidance of otosurgical interventions through a transtympanic access (trans tympanic endoscopy, TE) [1].

Although the understanding of HRCT images is easy for radiologists, it is not taken for granted by otolaryngologists who are closer to three-dimensional surface anatomy of the middle ear. Furthermore, the middle ear presents some peculiar anatomical landmarks which are difficult to reproduce through bi-dimensional images. For this, VE could represent an ideal radiological tool for visualizing the anatomy of the middle ear from the point of view of the endoscopist, reducing the existing gap between radiologists and otologists in the interpretation of three-dimensional anatomy.

The aim of the present paper is to describe the VE anatomy of the middle ear.

Study of the middle ear: image acquisition and post-processing

High-resolution CT represents the imaging modality of choice when external otoscopy fails to identify or characterize pathologies which affect the middle ear. The increased spatial resolution, related to a thinner collimation and a volumetric acquisition, allows study of very small components of the tympanic cavity such as the ossicular chain. The study of the superstructure of the ossicles has relevant interest for assessing their integrity in cases of pathologies which potentially cause erosion, or in case of developmental anomalies.

However, the interest for the study of the middle ear with HRCT has been enhanced by better knowledge of the surgical anatomy of the middle ear and by use of TE as guidance for interventions. In fact, this imaging method allows detailed evaluation of either the ossicles and the wall of the tympanic cavity. The otoendoscopist evaluates this latter by following many anatomical landmarks which guide localization of pathologies or identification of the surgical field. A typical example is represented by the study of the retrotympanum. In this case HRCT can be useful to predict the presence or absence of some surgical landmarks of interest when a posterior tympanotomy or a retro-facial approach are planned [2, 3].

Caldemeyer et al. demonstrated that a submillimetric and isotropic imaging of the middle ear can be obtained with helical CT, with 0.5 mm of collimation, single volumetric scan in the axial plane, 0.2 mm of reconstruction spacing, and coronal image created with multiplanar reformations [4]; therefore, the isotropic imaging obtained by helical CT allows not only the detailed evaluation of anatomical details on native images, but even the reconstruction of oblique planes. These reformations of the data sets acquired by the scanner can be directed along planes crossing through the structures of interest [5, 6, 7, 8, 9].

An interesting application of reformatted planes in the study of the middle ear is represented by the imaging of recurrent post-operative cholesteatoma. In this case the combined use of axial native images as well as coronal and sagittal reformations allows evaluation of the shape of the tissue filling the middle ear, which, in case of recurrent cholesteatoma, can be identified by the prevalent scalloped limits [10].

Finally, since the helical CT data sets are obtained in a volumetric manner, they can be processed with dedicated software for 3D reconstruction and visualization, based on surface- and/or volume-rendering methods [11]. Among these methods VE is the most recent and it promises interesting applications in the study of the middle ear [12, 13, 14, 15].

Virtual endoscopy: technical aspects

Virtual endoscopy is a computer-generated simulation of fiberoptic endoscopic perspective which allows simulation of the presence of a human eye within the anatomical spaces of the body. The virtual-eye can be moved in any direction to simulate a navigation [11].

In principle, VE is based on techniques for surface and volume rendering that allow, respectively, to display the surface or the content of the volume reconstructed in three dimensions. In the first case the amount of voxels represented in the final image is strongly reduced by application of binary thresholds which allow generation of a 3D contour or surface, directly visualized with the virtual endoscope. Even in case of volume rendering the surface can be displayed, but differently from surface rendering, the CT density of the image voxels is still represented in the final perspective and the operator can control the contribution of individual voxels to the image by assigning opacity values to particular densities. Dealing either with surface- and volume-rendering methods, visualization of the middle ear requires electronic identification of the air-filled spaces before positioning the virtual endoscope (Fig.1).

Although accurate clinical validation of VE should be performed by a comparison with fiberoptic endoscopy, the case of the middle ear appears difficult, since the introduction of the endoscope within the tympanic cavity requires perforation of the tympanic membrane. This therefore explains the interest for noninvasive procedures which allow representation in three dimensions of the inner structures of the middle ear.