ANNALES
UNIVERSITATIS MARIAE CURIE-SKŁODOWSKA
LUBLIN-POLONIA
VOL. LX, N 1, 73 SECTIO D 2005

Department of Radiology, Department of Otolaryngology, Head and Neck Surgery
Medical University of Lublin

AGNIESZKA TROJANOWSKA, ELŻBIETA CZEKAJSKA-CHEHAB, PIOTR TROJANOWSKI, WITOLD OLSZAŃSKI, ANDRZEJ DROP, WIESŁAW GOŁĄBEK

Visualization of the middle ear and adjacent structures using reconstructed multi-slice CT datasets, correlating 3D images and virtual endoscopy to the 2D cross-sectional images

Multi-slice computerized tomography (MSCT) is considered to provide superior image quality.The recently introduced MSCT technology has improved spatial resolution in the Z axis as well as scan speed in computed tomography. Three-dimensional rendering of high-resolution MSCT data of the petrous bone may be expected to provide endoluminal views of superior image quality, thus competing with transtympanic endoscopy (otoendoscopy).

Virtual endoscopy is a computer-generated simulation of fiberoptic endoscopy, and its application to the study of the middle ear has been proposed in a few recent papers. The need to represent the middle ear anatomy by means of virtual endoscopy arose from the increased interest of otolarygologists in transtympanic 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.

This work uses a new programme for producing 3D radiological images acquired by means of computed tomography (CT), which enables the internal surfaces of the examined structures to be visualized. This new method, which is able to navigate inside organs in a similar way to fibreoptic endoscopy, is known as virtual endoscopy. We applied this new technique to the middle ear because this anatomical area is characterized by favourable contrast, in order to achieve detailed information concerning ossicular chain and tympanic cavity.

MATERIAL AND METHODS

This study was conducted at the University Teaching Hospital No 4 in Lublin. Fifty-eight ears were examined during 10-month period (from 1 October 2003 until 1 August 2004). All patients came from the Department of Otolaryngology Head and Neck Surgery, University Teaching Hospital in Lublin, with the initial diagnosis of conductive hearing loss. CT examinations of the petrous bone were obtained using 1.25 mm thick coronal axis slices, with 1 mm table feed, 120 kV, 140–170 mA and 2 s scan time. All examinations were performed using multislice CT equipment (8-row GE Light Speed Ultra Advantage). The images were reconstructed with the high resolution algorhythm for bony structures and a small field of view (9.6 cm), separately for the right and left petrous bone. The images were then transferred on a separate workstation and proc-

essed with the Navigator virtual endoscopic software (General Electric, Advantage Workstation 4.2). A threshold value ranging from 350 to 600 HU was applied.

Post-processing was performed using the in-house software, applying thresholding and manual segmentation. 3D models of the individual anatomical structures were generated and displayed in different colours. The display of relevant anatomical and pathological structures was evaluated in the greyscale 2D slices, 3D images, and the 2D slices showing the segmented 2D anatomy in different colours for each structure. Correlating 2D slices to the 3D models and virtual endoscopy helps to combine the advantages of each method.

RESULTS

Assessment of middle ear structures was initially made upon evaluation of axial slices, so-called basic images (Fig.1). Virtual endoscopy of the tympanic cavity and 3D images of the ossicles were generated using surface and volume rendering. Qualitative assessment of the representation of anatomical structures was performed in normal patients. In all cases 3D imaging was possible using the standardised approach. All elements of external, middle and bony elements of internal ear, as well as the ossicular chain and soft tissue structures of the tympanic cavity were visualised in all patients (Fig. 2, Fig. 3).

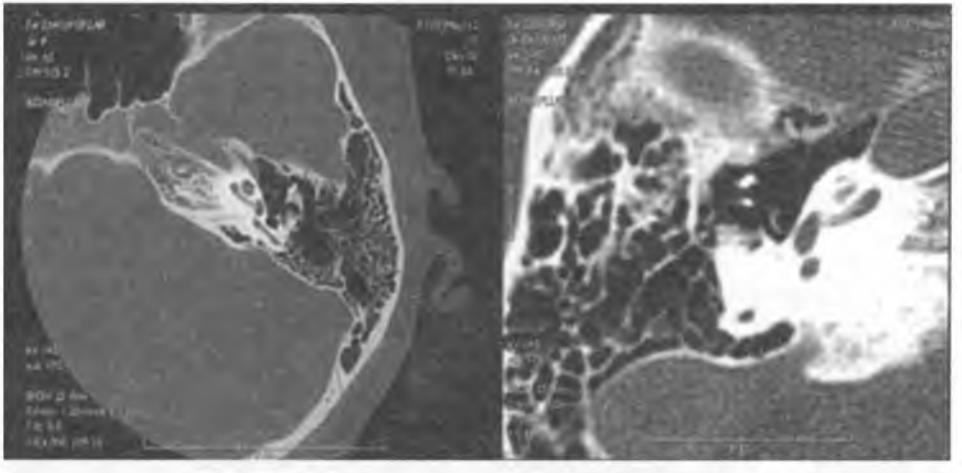

Fig. 1. Normal anatomy of the middle ear structures based on cross-sectional axial scans

A series of images was acquired as the virtual endoscope moves from the external auditory canal to the middle ear cavity. Images of the anterior, medial, and posterior surfaces of the middle ear were achieved. Different views of the ossicles were also possible to generate. High quality images were always obtained for the middle ear structures, including the ossicles and their connections (Fig. 4, Fig. 5).

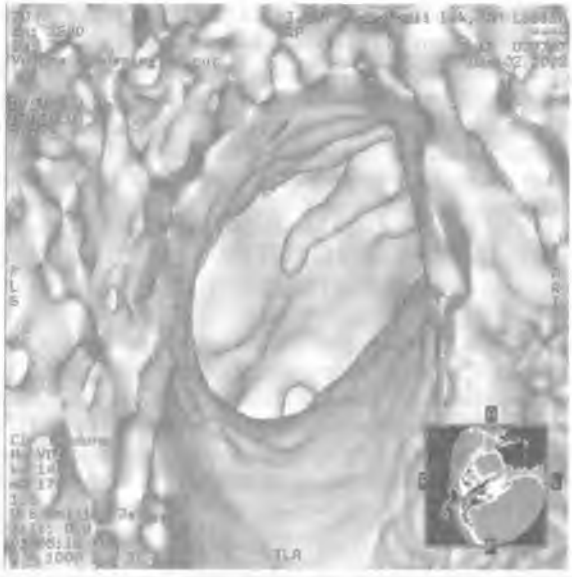

Fig. 2. Three-dimensional visualization of the external auditory canal with the handle of malleus visible

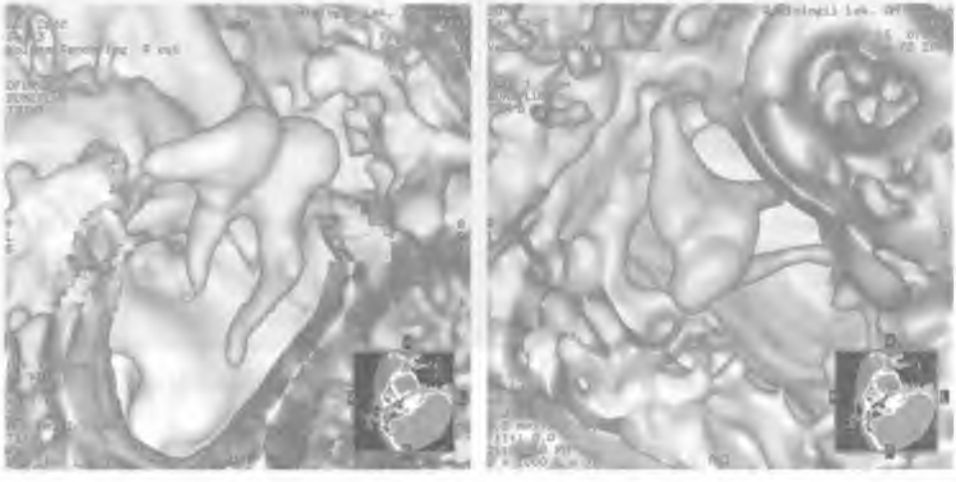

Fig. 3. 3-dimensional visualization of the ossicular chain and the walls of the tympanic cavity, lateral (3a) and superior (3b) view

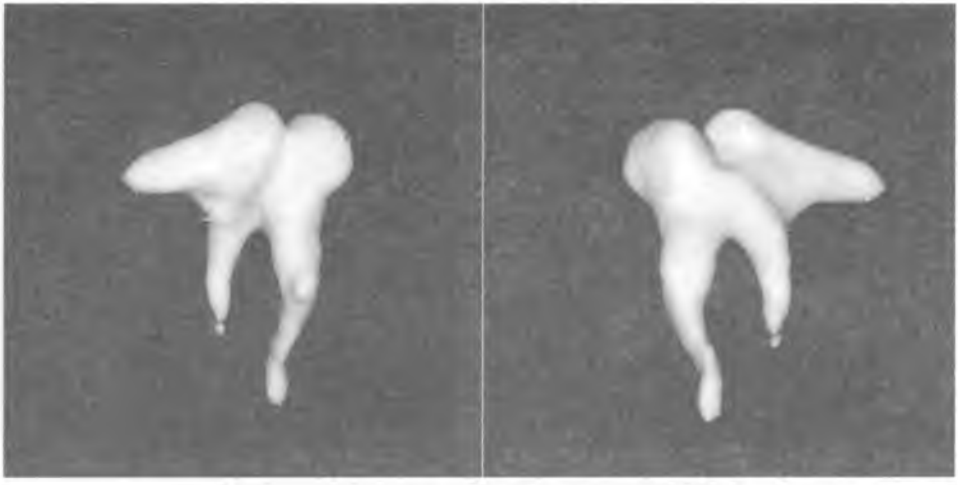

Fig. 4. Virtual endoscopic view of the ossicular chain extracted from tympanic cavity. Malleus, incus and stapes are visible together with malleo-incudal and incudo-stapedial joint

Fig. 5. Suprastructure of stapes in virtual endoscopic examination. Standardized anterior (4a) and posterior (4b) views were achieved

CT endoscopy of the middle ear provided a new view of the anatomy of this complex area. In addition, to demonstrate tympanic cavity and its contents, it proved to be useful in visualisation of bony structures of the inner ear as well. It was an excellent method to show the first three segments of the facial nerve and allowed its careful evaluation (Fig. 6).

Fig. 6. Reconstructions of the facial nerve canal in curved planes

The method had obviously some advantages and disadvantages; the former can be summarized as follows: demonstration of areas which are difficult to show with endoscopy because of the presence of membrana tympani; the virtual endoscope can be placed in several positions and therefore, it can be inserted in all sites and tortuous places of anatomical cavity; nice and effective demonstration of the ossicular chain including the stapes. The disadvantages were related to the fact that the endoscopic reconstruction (such as any other three-dimensional reconstruction) is a representation of surfaces where different densities are necessarily homogenized, therefore it proved impossible to apply virtual endoscopy in cases of fluid presence in the middle ear cavity.

With regard to intermediate and high-density structures, virtual endoscopic images, based on MSCT data, yielded endoluminal views closely resembling corresponding otoendoscopic views. Based on these results it can be expected that virtual endoscopy will seem useful for imaging ossicular pathologic conditions such as dysplasia and chain disruption as well as for assessing patient status before and after otosurgery.

DISCUSSION

In the study of the middle ear, specific attention is given to the retrotympanum. 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 (3, 4, 5, 6)

The 3D imaging of the middle ear facilitates better understanding of the patient's anatomy. Cross-sectional slices, however, often allow a more accurate evaluation of anatomical structures, as some details may be lost through post-processing (1, 2, 7, 8).

As generating 3D models can be extremely time-consuming, this approach can be a clinically applicable way of gaining a 3D understanding of the patient's anatomy by using models as a reference (9). Furthermore, it can help radiologists and otolaryngologists evaluating the 2D slices by adding the correct 3D information that would otherwise have to be mentally integrated. The method can be applied to radiological diagnosis, surgical planning, and especially, to teaching (8, 9).

CONCLUSIONS

Virtual endoscopy is a term used to describe computer simulated endoscopy procedures derived from high resolution images of patient anatomy. By simulating the endoscopic examination, the patient is spared the discomfort and possible complications of an actual examination. The physician also has more flexibility in a virtual endoscopic examination of 3D patient data in comparison to a real endoscopic examination.

Virtual endoscopy removes the physical and physiologic constraints of real endoscopy and can create views that are not possible in an actual endoscopic examination. This may enhance the performance of actual endoscopic examinations. Virtual endoscopy may also be used to perform "numerical biopsies" and anatomic measurements such as size, distance, shape, and density. Virtual endoscopy allows the physician to comprehensively explore the patient anatomy using an intuitive and interactive interface.

Acknowledgements. This study was totally financed from a State Committee for Scientific Research grant no 3PO5C06626

REFERENCES

1. Calhoun P.S. et al.: Three-dimensional volume rendering of spiral CT data: theory and method. Radiographics, 19, 745, 1999.
2. Casselman J.W.: Temporal bone imaging. Neuroimaging Clin. North. Am., 6, 265, 1996.
3. Hermans R. et al.: Spiral CT of the temporal bone: value of image reconstruction at submillimetric table increments. Neuroradiology, 37, 150, 1995.
4. Howard J.D., Elster A.D., May J.S.: Temporal bone: three-dimensional CT. I. Normal anatomy, techniques and limitations. Radiology, 177, 421, 1990.
5. Karhuketo T.S. et al.: Virtual endoscopy imaging of the middle ear cavity and ossicles. Eur. Arch. Otorhinolaryngol., 259, 2, 77, 2002.
6. Klingebiel R. et al.: Virtual endoscopy of the tympanic cavity based on high-resolution multislice computed tomographic data. Otol. Neurotol., 22, 803, 2001.
7. Morra A. et al.: Usefulness of virtual endoscopic three-dimensional reconstructions of the middle ear. Acta Otolaryngol., 122, 382, 2002.
8. Rodt T. et al.: Virtual endoscopy of the middle ear: experimental and clinical results of a standardised approach using multi-slice helical computed tomography. European Radiology, 12, 1684, 2002.
9. Rodt T.: 3D visualization of the middle ear and adjacent structures using reconstructed multi-slice CT datasets, correlating 3D images and virtual endoscopy to the 2D cross-sectional images. Neuroradiology, 44, 783, 2002.

SUMMARY

The aim of the article was to assess the value of high-resolution multislice computed tomography (MSCT) for the visualization of ossicular chain and middle ear cavity. The study consisted of 56 ear examinations of 28 consecutive patients with conductive hearing loss. The examination was performed using multi-slice helical CT scanner – 8-row Light Speed Ultra Advantage. The data were transferred to a workstation for post processing, with the use of software Volume Rendering (GE) in order to generate standardized virtual endoscopic views and multiplanar reconstructions. As a result, virtual surgical views of the middle ear cavity were obtained, as well as accurate 3D images of ossicular chain. Virtual endoscopy allowed identification of the anatomy of ossicles. Ossicular chain elements were successfully investigated, as well as middle ear cavity walls and

adjacent structures. Unfortunately, virtual endoscopy could not demonstrate soft tissue and changes of the tympanic membrane. CT multiplanar reconstructions and virtual endoscopy clearly demonstrated a two-and three-dimensional image of auditory ossicular chain. It proved to be useful in evaluating anatomical details. Clinical applications of this method still have to be defined, though it might play an important role in presurgical evaluation and diagnosis.

Obrazowanie ucha środkowego oraz struktur przyległych z zastosowaniem wielorzędowej tomografii komputerowej oraz korelacja obrazów 3D i wirtualnej endoskopii z przekrojami poprzecznymi 2D

Celem pracy była ocena możliwości diagnostycznych wielorzędowej tomografii komputerowej wysokiej rozdzielczości (MSCT) w obrazowaniu łańcucha kosteczek słuchowych oraz jamy ucha środkowego. Wykonano 58 badań u 28 pacjentów z niedosłuchem spowodowanym zaburzeniami przewodzenia. Badania przeprowadzono przy pomocy aparatu wielorzędowej tomografii komputerowej LightSpeed Ultra Advantage 8-row. W celu dalszej analizy dane przesyłane były na konsolę diagnostyczną, gdzie przy użyciu oprogramowania Volume Rendering (GE) uzyskiwano obrazy 3D w opcji wirtualnej endoskopii oraz rekonstrukcje wielopłaszczyznowe. Uzyskano wirtualne obrazy jamy ucha środkowego, jak również dokładne, trójwymiarowe obrazy kosteczek łańcucha słuchowego. Wirtualna endoskopia umożliwiła identyfikację oraz ocenę anatomii kosteczek słuchowych. Poddano dokładnej ocenie elementy łańcucha słuchowego, ściany jamy ucha środkowego oraz przyległe struktury. Niestety, wirtualna endoskopia nie pozwoliła na zobrazowanie tkanek miękkich oraz zmian patologicznych błony bębenkowej. Wielopłaszczyznowe rekonstrukcje tomografii komputerowej wraz z wirtualną endoskopią umożliwiają uzyskanie dwu- i trójwymiarowych obrazów kosteczek słuchowych. Rekonstrukcje wielopłaszczyznowe i trójwymiarowe mogą być bardzo użyteczne do oceny szczegółów anatomicznych ucha środkowego. Chociaż zastosowania kliniczne tego typu badań nie zostały jeszcze ostatecznie ustalone, mogą one odgrywać w przyszłości istotną rolę w ocenie zmian przed zabiegiem chirurgicznym.