

Magnetic Resonance Imaging of the In-vivo Human Tympanic Membrane

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Background: To obtain magnetic resonance images of the in-vivo human tympanic membrane to avoid radiation exposure.

Methods: Images of the in-vivo human tympanic membrane were obtained by magnetic resonance imaging (MRI). The differences in resolution of the images obtained by multi slice single echo (MSSE) and 3-dimensional (3D) SNAP sequences were then compared.

Results: The resolution of the 2D MR images acquired by MSSE sequences was higher than that obtained by 3D SNAP. The voxel size of the MR images was smaller than that with 3D SNAP because of the narrower slice thickness. Therefore, the spatial resolution of the 3D SNAP sequenced images was better than that of MSSE images. The scanning time for MSSE and 3D SNAP were 12 minutes and 40 seconds and 1 minute and 42 seconds respectively. The signal-to-noise ratio (SNR) of MR images with 3D SNAP was 0.32 decibels higher than that with MSSE.

Conclusion: In this study, MR images of the in-vivo human tympanic membrane could be obtained with a 9-cm surface coil with MSSE and 3D SNAP sequences. The spatial resolution of MR images acquired with 3D SNAP was better than that with MSSE. The scanning time with 3D SNAP was shorter than that with MSSE based on similar SNRs. The structure and geometry of the tympanic membrane can be observed clearly, which would be helpful for diagnosis in clinics and can avoid radiation exposure.

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Key words: human tympanic membrane, magnetic resonance imaging, surface coil, computed tomography

The cone tympanic membrane is 9-10 mm long, 8 mm wide and 0.1 mm thick. The tympanic membrane is divided into three layers. The outer layer is squamous epithelium, the medial layer is fibrous tissue, and the inner layer is cuboidal mucosal epithelium.⁽¹⁾ The tympanic membrane conducts sound vibration to the middle ear, then the inner ear, to elic-

it neural activity which passes on the auditory nerve to the primary auditory cortex. Therefore, it is important to visualize the 3-dimensional (3D) structure of the tympanic membrane when hearing impairment is suspected.

Computed tomography (CT) images of the anatomic structure of the temporal bone can be

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shown by high-resolution computed tomography (HRCT) in clinics.⁽²⁻⁴⁾ HRCT scans are also utilized to examine ossicular disruptions and middle ear disease.⁽⁵⁻⁷⁾ However, radiation exposure is a concern with CT scans. Magnetic resonance imaging (MRI) is mostly utilized to examine soft tissue and middle ear disease, and does not carry the radiation concerns of CT.⁽⁸⁻¹¹⁾ Unlike CT, MRI does not use ionizing radiation, but uses radio waves in a powerful magnetic field to align the nuclear magnetization of hydrogen atoms in water in the body. Images of the structures of the canine middle and inner ear, such as the cochlear duct, semicircular ducts, vestibule and facial nerves, have been obtained by MRI with a stable gradient echo and 0.9 mm slice thickness.⁽¹²⁾ However, no practical sequence for obtaining the MR images of the structures of the human tympanic membrane has been reported in previous studies. Hence, this study developed techniques for imaging of the in-vivo human tympanic membrane using MRI.

METHODS

A high-resolution computed tomography scanner (Aquilion TSX-101A, Toshiba Medical Systems Corporation, Japan) was utilized in this study. CT images of a healthy ear of a 25-year-old woman were studied.

MR images from 8 subjects, 4 men and 4 women between 20 and 26 years old were studied. This study involving humans was approved by the Institutional Review Board of Chang Gung Memorial hospital. A 3-Tesla MR system, Bruker S630 was utilized. A 9-cm-diameter surface coil was developed. Multi-slice-single-echo (MSSE) and 3D SNAP (a software application used to segment structures in 3D medical images) were the sequences used to acquire the MR images.⁽¹³⁾ The radio-frequency (RF) for spin-echo with MSSE was 90 degrees for the excitation pulse and 180 degrees for the refocusing pulse. The RF pulse for gradient-echo with 3D SNAP was 180 degrees.

The repetition time (TR) of the pulse for MSSE was 1480 ms, the echo time (TE) was 40 ms, and the field of view (FOV) was 130 mm × 130 mm. The scanning time for MSSE was 12 minutes and 40 seconds. The TR of the pulse for 3D SNAP was 12.5 ms, the TE was 5.0 ms, and the FOV was 150 mm ×

80 mm × 30 mm. The flip angle was 20 degrees. The scanning time for 3D SNAP was 1 minute and 42 seconds. The signal-to-noise ratio (SNR) for MRI was obtained using the following equation:

$$SNR = 20 \log_{10} \left(\frac{m_a}{S_n} \right)$$

where

m_a : Average brightness of the region of interest
 S_n : Standard deviation of noise

RESULTS

The images of the in-vivo human tympanic membranes were obtained by HRCT and MRI based on the experimental parameters in this study. The acquisition matrix of the CT images was 512 × 512, the pixel size was 0.19 mm × 0.19 mm, and the slice thickness was 0.30 mm. Fig. 1 shows the CT image of a human tympanic membrane in the transverse plane.

For MRI, the acquisition matrix of the MSSE sequences was 512 × 512 and the pixel size was 0.25 mm × 0.25 mm. The slice thickness was 2.20 mm and the voxel size was then 0.25 mm × 0.25 mm × 2.20 mm. The scanning time for the MSSE sequences was 12 minutes and 40 seconds. The SNR was 18.72 dB. Fig. 2 shows an MR image of a human tympanic membrane using MSSE sequences in the coronal plane.



Fig. 1 CT image of a human tympanic membrane (arrow).

The acquisition matrix of the 3D SNAP sequences was $256 \times 128 \times 64$, the pixel size was $0.59 \text{ mm} \times 0.63 \text{ mm}$ and the voxel size was $0.59 \text{ mm} \times 0.63 \text{ mm} \times 0.47 \text{ mm}$. Note that the slice thickness was 0.47 mm. The scanning time for the 3D SNAP sequences was 1 minute and 42 seconds. The SNR was 19.04 dB. Fig. 3 shows an MR image of a human tympanic membrane acquired by 3D SNAP in the coronal plane. The Table 1 shows a comparison of the MSSE and 3D SNAP sequences.



Fig. 2 MR image of a human tympanic membrane using MSSE sequences (arrow).



Fig. 3 MR image of a human tympanic membrane using 3D SNAP sequences (arrow).

Table 1. Comparison of MSSE and 3D SNAP MR Images

Sequence method	MSSE	3D SNAP
Voxel size (mm)	$0.25 \times 0.25 \times 2.20$	$0.59 \times 0.63 \times 0.47$
Scanning time	12 minutes and 40 seconds	1 minute and 42 seconds
SNR (dB)	18.72	19.04

Abbreviations: MSSE: Multi slice single echo; 3D SNAP: 3-dimensional ITK-SNAP (sequencing software); mm: millimeter; SNR: signal-to-noise ratio; dB: deciBel.

DISCUSSION

An otoscope or video-otoscopy from the external auditory canal can be used for analysis of pathological changes in the tympanic membrane.^(14,15) A side-viewing needle otoscope also facilitates visual inspection of the inside of the middle ear through a perforation in the tympanic membrane.^(16,17) But an otoscope can only offer a sagittal plane 2D image of the tympanic membrane. In patients with external auditory canal stenosis, it is difficult to observe the ear drum in detail with an otoscope. A 2D image is not capable of evaluating the real position of the tympanic membrane because it forms an obtuse angle with the posterior wall of the external ear canal, and an acute angle with the anterior wall.⁽¹⁸⁾

Primary acquired cholesteatomas arise as the result of tympanic membrane retraction. If cholesteatoma is suspected, a further image study such as CT or MRI is needed to evaluate the retracted tympanic membrane, whether the retracted ear drum is primary or secondary to previous surgery. Tympanic membrane lateralization is a condition in which the visible surface of the tympanic membrane is located lateral to the bony annular ring and loses contact with the ossicular chain in the middle ear. Most cases are related to previous tympanoplasty. Tympanic membrane lateralization may be associated with significant otological morbidity, including cholesteatoma and conductive hearing loss.⁽¹⁹⁾ Surgical repair is often necessary. MRI is helpful in confirming a diagnosis of tympanic membrane lateralization.

CT and MRI can both accurately assess the middle and inner ear. But the radiation exposure delivered by CT scanning may be related to increased cancer risks in adults and particularly in children.⁽²⁰⁾ Radiation exposure of the eye lens is an especially serious problem in children since the development stage predisposes to a high risk for radiation disorder.⁽²¹⁾ The radiation dose is often expressed as an equivalent dose in millisieverts (mSv). The radiation doses of a chest X-ray, a temporal bone HRCT and a MRI scan are around 0.1 mSv, 1 mSv and 0 mSv respectively.^(20,22) The actual time and total time for a CT scan are about 15-30 seconds and 3-6 minutes whereas an MRI takes about 30-60 minutes. Therefore, sedation for uncooperative children may be needed for MRI scanning.

The objective of this study is to develop techniques for imaging of the in-vivo human tympanic membrane by MRI non-invasively and non-destructively. MRI is capable of imaging relevant structures within and neighboring the inner ear, such as the cochlear duct, semicircular ducts, vestibule, facial and vestibulocochlear nerves, and temporal sinus. Kneissl, et al. concluded no applied sequence allowed identification of the canine auditory ossicles or tympanic membrane.⁽¹²⁾ Based on the study by Virapongse et al., the anatomic structure of the temporal bone can be shown with HRCT.⁽²⁾ The dry bone and the complete ossicular chain are scanned in the axial direction. Although microscopic examination is the most important aspect of the initial evaluation of the tympanic membrane, ossicular chain and supporting tissue,⁽²³⁾ CT images also offer much information about these structures. The structure of the in-vivo human tympanic membrane can be clearly seen in Fig. 1 with the thin collimation, high resolution and continuous slices of HRCT. Additionally, MR images of the structures of the tympanic membrane and inner ear can be obtained with surface coil with MSSE and 3D SNAP sequences as shown in Fig. 2 and 3. Consequently, the resolution of MR images acquired by MSSE sequences, based on the pixel size, was higher than that with 3D SNAP sequences. However, the slice thickness with 3D SNAP was much thinner than that with MSSE. Therefore, the voxel size of MR images acquired by 3D SNAP was smaller than that acquired by MSSE. Hence, the spatial resolution of MR images acquired by 3D SNAP was better than that with MSSE. The scanning time

with 3D SNAP was 10 minutes and 58 seconds faster than that with MSSE. The SNR of MR images with 3D SNAP was 0.32 dB higher than that with MSSE.

Conclusion

Radiation exposure is a concern in computed tomography scans. In this study, MR images of the in-vivo human tympanic membrane could be obtained with a 9-cm surface coil using MSSE and 3D SNAP sequences. The spatial resolution of MR images acquired by 3D SNAP was better than that with MSSE. The scanning time with 3D SNAP was shorter than that with MSSE based on a similar signal-to-noise ratio. Therefore, with MRI assistance, the structure and geometry of the tympanic membrane can be observed clearly, which would be helpful for diagnosis in clinics and can avoid radiation exposure.

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以核磁共振檢查重組人類活體耳膜影像

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背景： 尋求低輻射之影像學檢查，以重組之核磁共振影像，評估人體耳膜構造。

方法： 人類活體之耳膜構造，由核磁共振檢查取得影像。影像之重組由兩種軟體進行，分別為 MSSE 以及立體 3D SNAP 兩種程式，並探討兩種軟體在重組時間以及解析度上之差異。

結果： 以 3D SNAP 軟體處理之核磁共振影像，因為較為細切，因此立體解析度比 2D MSSE 軟體處理所得的影像要好，雖然 MSSE 所得到的單一水平影像之解析度要比 3D SNAP 為佳。3D SNAP 重組時間為 1 分 42 秒，MSSE 則需要 12 分 40 秒。而 3D SNAP 影像之訊號雜訊比則較 MSSE 強 0.32 分貝。

結論： 在此研究中，人體耳膜的核磁共振影像，能夠藉由 9 公分長的表面線圈，經 MSSE 以及 3D SNAP 兩種程式重組而成。利用此方法，將來能夠使用無輻射的核磁共振檢查，在臨床上針對人體耳膜的幾何構造，提供更詳盡的觀察與診斷。
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關鍵詞： 人體耳膜，核磁共振，表面線圈，電腦斷層

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