TECHNICAL REPORT

Ultrashort echo time imaging of normal middle ear ossicles: a feasibility study

K Yamashita, T Yoshiura*, A Hiwatashi, H Kamano and H Honda

Department of Clinical Radiology, Graduate School of Medical Sciences, Kyushu University, Fukuoka, Japan

Objective: The aim of this study was to assess the feasibility of ultrashort echo time (UTE) imaging in the visualization of middle ear ossicles in normal subjects.

Methods: 12 young adult volunteers (males/females = 6/6, age 25–44 years, mean 30.3 years) with normal hearing levels underwent MRI studies using a 3.0 T clinical unit with an eight-channel SENSE head coil. For each subject, the whole head was imaged using a three-dimensional dual-echo UTE imaging sequence with radial trajectory and the following parameters: field of view, $240 \times 240 \times 240$ mm; matrix, 320×320 ; flip angle, 7° ; repetition time/echo time (TE)₁/TE₂, 8.0 ms/0.14 ms/1.8 ms; acquisition voxel size, $0.75 \times 0.75 \times 0.75$ mm; number of signals averaged, 1; imaging time, 27 min 20 s. Subsequently, subtraction images were obtained by subtracting long TE (1.8 ms) images from short TE (0.14 ms) images. By using these three images, the visibility of the bilateral middle ear ossicles was evaluated. Moreover, as a reference for the UTE findings, CT images of the temporal bone were obtained in one volunteer.

Results: In all subjects, the middle ear ossicles were clearly visualized as a high signal intensity spot surrounded by a signal void of air on short TE images bilaterally, while they were not visible in long TE images in any of the subjects. The subtraction images provided better contrast of the ossicles.

Conclusion: We demonstrated the feasibility of UTE imaging of the middle ear ossicle in normal subjects.

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Introduction

CT scanning has been an essential imaging modality available for evaluation of the middle ear ossicles. However, high-resolution CT techniques involve considerable exposure of the lenses, thyroid and salivary glands of patients to radiation, and therefore CT dose reduction is required when feasible.¹ On the other hand, MRI has been unable to visualize bony structures owing to the extremely short T_2 of compact bone, whereas it is completely non-invasive and is known to provide useful information in detecting temporal bone disease such as middle ear cholesteatoma.^{2,3} Visualization of middle ear ossicles and other bony

structures in the temporal bone region would lead to accurate anatomical localization of cholesteatoma pre-operatively. Therefore, MR visualization of the middle ear ossicles in normal subjects would be an important first step in the evaluation of the temporal bone without radiation exposure.

Ultrashort echo time (UTE) imaging is an MRI method that allows for direct visualization of tissues with very short T_2 that are invisible on other types of MR images. UTE imaging enables signal acquisition from cortical bone ($T_2 = 0.4$ – 0.5 ms) before substantial signal decay.⁴ UTE imaging has been used to evaluate bones and other connective tissues such as tendons, ligaments and menisci, and new clinical applications for it are being discovered, but it has never been used to image the middle ear ossicles.^{4–11} Our purpose was to assess the feasibility of UTE imaging of the middle ear ossicles in normal subjects.

*Correspondence to: Dr Takashi Yoshiura, Department of Clinical Radiology, Graduate School of Medical Sciences, Kyushu University, 3-1-1 Maidashi, Higashi-ku, Fukuoka 812-8582, Japan. E-mail: tyoshiu@radiol.med.kyushu-u.ac.jp

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Materials and methods

Subjects

This study was approved by the institutional review board of our university hospital. Written informed consent was obtained from each participant. 12 healthy Japanese subjects with normal hearing and without a history of temporal bone diseases (males/females = 6/6, age 25–44 years, mean 30.3 years) were prospectively enrolled in this study. Subjects who had any history of otitis media, hearing loss, head trauma or malignant disease were excluded.

MRI

MR images were obtained using a 3.0T MR imager (Achieva Quasar Dual™; Philips Medical Systems, Best, Netherlands) with an eight-channel SENSE head coil. For each subject, images were obtained using a three-dimensional (3D) dual-echo UTE imaging sequence with a radial trajectory.^{12,13} A quadrature technique was utilized to shorten echo time (TE). The imaging parameters for UTE imaging were as follows: field of view, 240 × 240 × 240 mm; matrix, 320 × 320; flip angle, 7°; repetition time (TR)/TE1/TE2, 8.0 ms/0.14 ms/1.8 ms; read out bandwidth, 910.7 Hz per pixel; acquisition voxel size, 0.75 × 0.75 × 0.75 mm; NSA, 1; imaging time, 27 min 20 s.

In order to highlight the short T_2 components, subtraction images were obtained by subtracting the long TE (1.8 ms) images from the corresponding short TE (0.14 ms) images.

CT imaging

To obtain an anatomical gold standard for the evaluation of UTE findings, CT images of the temporal bone were obtained in one volunteer using a 64 detector row CT scanner (Aquilion™; Toshiba Medical Systems Corporation, Tochigi, Japan) with 0.5 mm collimation and a 512 × 512 matrix. Transverse scans were acquired in a plane parallel to the orbitomeatal plane in the

helical mode using the following parameters: 120 kV, 250 mAs, 1 s rotation time, 0.5 mm section thickness, beam pitch of 0.625 and field of view of 240 mm. The obtained image data were displayed at a window centre of 400 HU and a window width of 4000 HU.

Registration of UTE and CT data

To closely compare UTE and CT images, fusion of the subtraction images and CT images was performed by automated rigid registration and subsequent manual fine-tuning by a board-certified neuroradiologist with 9 years of experience in head and neck radiology using the rigid fusion mode on Fusion 7D™ (Mirada/Siemens, Erlangen, Germany). In manual fine-tuning, CT images were moved and rotated relative to the UTE images to correspond exactly with the bilateral petrous apex (Figure 1). Fused images were created by overlaying semi-transparent UTE images onto the CT images. The matching of corresponding structures in both data sets was assessed by another board-certified neuroradiologist with 21 years of experience in head and neck radiology.

Image assessment

By comparing three MR images (short TE images, long TE images and subtraction images), two neuroradiologists with 9 and 7 years of experience in head and neck radiology independently determined whether the ossicles were visualized in the epi- or mesotympanum of the right and left temporal bones for each subject.^{14,15} For all subjects, the final decision regarding the visualization of the middle ear ossicles was made by consensus. Fused images were used to confirm the spatial agreement of corresponding structures in one subject.

Results

In all subjects, the middle ear ossicles were clearly identified as a high signal intensity structure surrounded by signal

Figure 1 Image registration and fusion of CT and MRI. Semi-transparent CT images are overlaid onto the MRI images by moving and rotating the CT relative to the MRI

Figure 2 Left middle ear ossicles (arrow) can be visualized on the short echo time (TE) image (left) and much better visualized on the subtracted image (right), whereas they are not visible in the corresponding long TE image (middle)

voids of air on short TE images bilaterally, while they were not visible on long TE images in any of the subjects (Figure 2). The subtraction images provided better contrast for the ossicles (Figure 2). Moreover, the CT–MRI fusion images confirmed that the high signal intensity structure on the short TE images and the subtraction images coincided with the middle ear ossicles (Figure 3); specifically, they coincided with the complex of the malleus and incus at the incudomalleolar joint.

Discussion

Our study demonstrated that the middle ear ossicles could be visualized using UTE imaging. To our knowledge, this is the first report of MR visualization of the middle ear ossicles in normal subjects.

Bony tissues including ossicles have very short T_2 .^{4,6} In addition, there is strong magnetic field inhomogeneity in the region of temporal bone, which results in rapid T_2^* signal decay. We speculate that in UTE,

signal loss due to both T_2 and T_2^* decays was minimized by the immediate acquisition, enabling signal detection from the ossicles.⁵

With its high sensitivity to minerals as well as high spatial resolution, CT has been considered to be the gold standard imaging modality for the evaluation of the middle ear. The diagnostic value of MRI is limited by the strong susceptibility artefact in the temporal bone region. Moreover, conventional MR techniques are unable to detect signals from bony structures, which are the key elements of temporal bone imaging. However, recent studies have shown that MR is superior to CT in detecting middle ear lesions, especially cholesteatoma. Direct visualization of bony structures by UTE imaging would provide an anatomical frame for the imaging of cholesteatoma, which would be useful for surgical planning. Additionally, the destruction of bony structures such as ossicles, semicircular canals and tegmen tympani may be evaluated in the same MR examination. When cholesteatoma abuts an osseous structure, it is difficult to distinguish between the bone and cholesteatoma by conventional

Figure 3 Comparison with CT image (left) confirms that the high signal intensity spot in the epitympanum on the short echo time images (middle) corresponds to the complex of the malleus and incus at the incudomalleolar joint (arrows in middle and right-hand images). The CT–MRI fusion image (right) further confirms their spatial agreement

MRI. UTE imaging may solve this challenging problem in the future.

Another major advantage of MRI over CT is the lack of radiation exposure, especially of the lens. Further development of the MR techniques for temporal bone imaging would be beneficial especially for infants and paediatric patients.

Although the feasibility of MR ossicular imaging was demonstrated, our UTE imaging technique is not yet ready for clinical use. Only the complex of the malleus and incus was visualized in this study. In addition, the

imaging time for UTE was over 27 min, which is unacceptable in actual clinical settings. A two-dimensional UTE slice selection technique may reduce signal acquisition time, although it causes a partial volume effect which results in image degradation. Further technical developments are necessary before this technique is ready for clinical use.

In conclusion, with UTE imaging, MR visualization of portions of normal middle ear ossicles is feasible. This technique may lead to a new application of diagnostic MRI of the temporal bone.

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