Imaging Endolymphatic Hydrops at 3 Tesla Using 3D-FLAIR with Intratympanic Gd-DTPA Administration

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Purpose: Visualization of endolymphatic hydrops by 3-dimensional fluid-attenuated inversion recovery-FLAIR using conventional turbo-spin-echo (3D-FLAIR-CONV) after intratympanic injection of Gd-DTPA has been reported in patients with Ménére’s disease. Compared to 3D-FLAIR-CONV used in previous studies, the addition of a variable flip-angle technique (3D-FLAIR-VFL) enables very long echo trains and, therefore, shorter scan times. We evaluated whether 3D-FLAIR-VFL could replace 3D-FLAIR-CONV in detecting endolymphatic hydrops after intratympanic Gd-DTPA administration.

Methods: Eleven patients were included in this study. Twenty-four hours after Gd-DTPA injection, we performed 3D-FLAIR-CONV and 3D-FLAIR-VFL imaging at 3T. We compared the contrast-to-noise ratio (CNR) between cochlear fluid and the cerebellum between the 2 FLAIR sequences. We subjectively scored the size of the endolymphatic space in the cochlea and vestibule for each patient and correlated the scores with the clinical diagnoses.

Results: The CNR of 3D-FLAIR-CONV was significantly higher than that of 3D-FLAIR-VFL. Scores for the size of endolymphatic space in the vestibule were identical between the 2 sequences; however, those in the cochlea disagreed in 3 cases. 3D-FLAIR-CONV correlated better with the clinical diagnoses.

Conclusions: Currently, we may not be able to replace 3D-FLAIR-CONV with 3D-FLAIR-VFL, at least not with the scanning parameters used in the present study.

Keywords: 3D imaging, advanced imaging techniques, magnetic resonance imaging, temporal bone disease

Introduction

Visualization of endolymphatic hydrops by magnetic resonance (MR) imaging after intratympanic injection of gadolinium-diethylene-triamine pentaacetic acid (Gd-DTPA) has recently been reported in patients with Ménére’s disease. In these patients, on 3-dimensional fluid-attenuated inversion recovery (3D-FLAIR) obtained with a conventional turbo spin-echo (3D-FLAIR-CONV) technique used in previous studies, the enlarged endolymphatic space without Gd-DTPA distribution has been recognized as an area of low signal intensity partly surrounded by high-signal perilymphatic fluid with Gd-DTPA distribution.1 Although the in-plane resolution was relatively high at 0.42 mm × 0.42 mm, the scan time was rather long, 15 min, even when applying a parallel imaging technique and utilizing slices 2-mm thick.

On the other hand, 3D-FLAIR covering the entire labyrinth can be obtained in 5 to 6 min with a near isotropic resolution of 0.67 mm × 0.67 mm × 0.8 mm by using a variable flip-angle turbo-spin-echo (3D-FLAIR-VFL) technique.2 This voxel volume is almost identical to that of the conventional turbo-spin-echo 3D-FLAIR (3D-FLAIR-CONV) used in previous studies.1,3 The shorter scan time of 3D-FLAIR-VFL enables its routine use in clinical settings. Thus, 3D-FLAIR-VFL has been used to evaluate various inner ear disorders.4–10 The pre-contrast 3D-FLAIR-VFL scan was used to detect subtle changes in labyrinthine fluid composition, and the post-contrast 3D-FLAIR-VFL scan
We evaluated whether 3D-FLAIR-VFL could replace 3D-FLAIR-CONV for detecting endolym-
phatic hydrops after intratympanic Gd-DTPA ad-
ministration.

Materials and Methods

Patients

Eleven patients (5 men, 6 women, aged 24–74; eight with clinically diagnosed Ménière’s disease, one with sudden sensorineural hearing loss, one with fluctuating sensorineural hearing loss, and one with delayed endolymphatic contralateral-type hy-
drops) underwent intratympanic administration of gadolinium-diethylene-triamine pentaacetic acid-
bis (methylamide) (Gd-DTPA-BMA; Omniscan, Daiichi-Sankyo Pharmaceutical Co. Ltd., Tokyo, Japan). These patients were scheduled for intra-
tympanic injection therapy with gentamicin or, for the patient with sudden sensorineural hearing loss, a steroid. Written informed consent was obtained from all patients. This study was approved by the institutional review board of our university hospit-
al.

Intratympanic gadolinium injection

The detailed methods for intratympanic gado-
linium injection have been reported.1 In that study, a delay of 24 hours between the intratympanic gad-
olinium injection and MR imaging was found to be optimal to allow the gadolinium to distribute wide-
ly in the perilymphatic space of the labyrinth. Gd-DTPA-BMA was diluted 8-fold with saline (v/v 1:7) and injected intratympanically using a 23-G needle and a 1-mL syringe after the patient was placed in the supine position with head turned approximately 30° away from the sagittal line toward the healthy ear. The diluted Gd-DTPA-
BMA was injected until a backflow of fluid into the external ear was observed through a microscope, resulting in an injected volume of 0.4 to 0.5 mL per patient. After the injection, the patient remained in the supine position for 60 min with head turned approx-
imately 60° away from the sagittal line toward the healthy ear. Gentamicin or steroid was not in-
jected at the same time.

MR imaging

All scans were performed on a 3T MR imaging scanner (MAGNETOM Trio, Siemens Medical So-
lutions; Erlangen, Germany) using a receive-only, 12-channel, phased-array coil. T1-weighted 3D-
FLASH (fast low-angle shot) and 3D-FLAIR-
CONV images were acquired 24 hours after intra-
tympanic injection of diluted Gd-DTPA-BMA.

In addition, T2-weighted 3D-CISS (constructive interference in the steady state) imaging was per-
formed to obtain reference images of the labyrinth fluid-space anatomy.

The parameters for 3D-FLASH were: repetition time (TR), 4.3 ms; echo time (TE), 1.97 ms; flip angle, 10 degrees with radiofrequency (RF) spoiling; matrix size, 256 × 256; 96 axial 0.8-mm-thick slices covering the posterior fossa with a 16-cm2 field of view (FOV); and number of excitations (NEX), 2. Total scan time was 2 min 51 s.

The parameters for 3D-CISS were: TR, 11.42 ms; TE, 5.71 ms; flip angle, 50 degrees; matrix size, 320 × 320; 48 axial 0.8-mm-thick slices; FOV, 16 cm2; and NEX, 1. Scan time was 3 min 42 s.

The parameters for 3D-FLAIR-CONV were: TR, 9000 ms; TE, 128 ms; flip angle, 180 degrees (constant) for the turbo-spin-echo refocusing echo train; echo-train length, 23; matrix size, 384 × 384; 12 axial 2-mm-thick slices covering the labyrinth; FOV, 16 cm2, acquired using the generalized autocal-
ibrating partially parallel acquisition (GRAPPA) technique with an acceleration factor of 2;11 and NEX, 1. The scan time was 15 min.

The parameters for 3D-FLAIR-VFL were: TR, 9000 ms; effective TE, 638 ms; variable flip-angle echo train with an average flip angle, 151 degrees; echo-train length, 171; matrix size, 384 × 384; 48 axial 0.8-mm-thick slices covering the labyrinth; FOV, 25.6 cm2; acceleration factor, 2 using the GRAPPA technique;11 voxel size, 0.67 mm × 0.67 mm × 0.8 mm; and NEX, 2. The total scan time was 5 min 26 s. The readout bandwidth was 592 Hz/pixel, and the echo spacing was 3.64 ms. Non-
selective inversion pulses and slab-selective excita-
tion pulses were used. The features of this variable flip-angle sequence have been reported else-
where.12–14 This sequence allows the use of very long echo-train lengths, in the range of 150 to 220, without severe blurring and while maintaining con-
trast similar to that of 3D-FLAIR-CONV, even with a long effective echo time. To achieve short echo spacing, field of view was larger than with other sequences.

Image evaluation

Qualitative evaluation

The size of the endolymphatic space in the vesti-
bule was scored subjectively: a score of 3 indicated that the entire vestibule was occupied by endo-
lymph; 2, more than half was occupied by endo-
lymph; 1, from 30 to 50% was occupied by endo-
lymph; and 0, less than 30% was occupied by endolymph.

The size of endolymphatic space in the cochlear basal turn was scored subjectively: 3: the cochlear duct was larger than the perilymphatic space of the scala vestibule; 2: Reissner's membrane was bulging toward the scala vestibuli, though smaller than the perilymphatic space of the scala vestibule; 1: no bulging of Reissner's membrane; and 0: bulging of Reissner's membrane toward the scala media or no visualization of endolymphatic space. Two radiologists independently scored the size of the endolymphatic space. 3D-FLAIR-CONV and 3D-FLAIR-VFL were evaluated separately with an interval of 7 days. If a discrepancy existed between the two, consensus was obtained after discussion.

The probability of endolymphatic hydrops was scored tentatively from clinical records: 3, high; 2, moderate; 1, slight; and 0, low. This probability was scored subjectively based on the ratio of the summating potential to the action potential (SP/AP) on an electrocochleogram. The vestibular evoked myogenic potential (VEMP), audiogram frequency and fluctuation patterns, and clinical history. A positive VEMP response is considered to be a normal sign of vestibular function, especially in the perilymph space, allowing separate visualization of endolymphatic space. Two radiologists independently scored the size of the endolymphatic space. 3D-FLAIR-CONV and 3D-FLAIR-VFL were evaluated separately with an interval of 7 days. If a discrepancy existed between the two, consensus was obtained after discussion.

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Qualitative analysis

The scores for the size of the endolymphatic space in the vestibule were identical between the 2 sequences (Fig. 1). On the other hand, the scores for the size of the endolymphatic space in the cochlea disagreed in 3 cases (Fig. 2). In these 3 cases, 3D-FLAIR-VFL showed a score of 0 for the patients with a positive probability score.

Quantitative analysis

The CNR between the basal turn of the cochlea and the cerebellum was significantly higher with 3D-FLAIR-CONV (34.1 +/- 21.5) than with 3D-FLAIR-VFL (21.1 +/- 18.2) (P < 0.01); however, CNR per scan time was not significantly different.

Discussion

Intratympanically injected Gd-DTPA is thought to be absorbed through round window membrane into labyrinthine space. Gd-DTPA distributes mainly in the perilymph space, allowing separate visualization of the endo- and perilymph space. A variable flip-angle turbo-spin-echo (VFL) sequence enabled the acquisition of images with a very long echo train (> 100) and very long effective echo time (> 300 ms) while keeping T2-contrast and blurring at levels similar to that using a conventional turbo-spin-echo sequence with an echo train length of 15 to 30.

A VFL sequence using a non-selective excitation pulse can image the whole brain with 1-mm isotropic resolution in a scan time of several minutes. However, the 3D-FLAIR-VFL protocol employed in the present study used a slab-selective excitation pulse to reduce the imaged volume and scan time while obtaining sub-millimeter isotropic voxels.

This slab-selective 3D-FLAIR-VFL protocol can obtain images with a voxel volume comparable to that of 3D-FLAIR-CONV in a far shorter scan time. Scan time of 15 min by 3D-FLAIR-CONV is too long to include in routine practice in most hospitals. However, the CNR of cochlear fluid was significantly lower on 3D-FLAIR-VFL, and the in-plane acquisition spatial resolution was also lower. The effective in-plane resolution may be lower still as a result of blurring induced by the very long echo train, even though the variable flip-angle technique reduces blurring compared to a constant flip-angle echo train of the same length.

It might have been possible to compare reformatted 2-mm-thick 3D-FLAIR-VFL images made from 0.8-mm-thick data and 2-mm-thick 3D-FLAIR-
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<th>contrast-to-noise ratio</th>
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<th>probability of endolymphatic hydrops from clinical records</th>
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SP/AP = summating potential/action potential on electrocochleography
VEMP = vestibular evoked myogenic potential
3D-FLAIR-CONV = 3-dimensional fluid-attenuated inversion recovery (FLAIR) using conventional turbo-spin-echo
3D-FLAIR-VFL = 3-dimensional fluid-attenuated inversion recovery (FLAIR) using variable flip-angle technique
Fig. 1. A 46-year-old man with Ménière’s disease. On both 3-dimensional fluid-attenuated inversion recovery using conventional turbo-spin-echo (3D-FLAIR-CONV) (a) and using variable flip-angle technique (3D-FLAIR-VFL) (b), the size of the endolymphatic space in the cochlea (arrows) and vestibule (short arrows) were scored as 3, although endolymphatic space in the cochlea is more clearly depicted on 3D-FLAIR-CONV. Almost no Gd-DPTA is seen in the vestibule in this case, whereas the vestibule is filled with lymphatic fluid on 3D- constructive interference in the steady state (CISS) (short arrows, c). On T₁-weighted 3D-fast low-angle shot (FLASH) (d), signal enhancement of perilymphatic fluid is quite faint; thus the discrimination between perilymph and endolymph is impossible.

CONV. However, increasing the reconstruction slice thickness of 3D-FLAIR-VFL would have resulted in the further degradation of the performance by 3D-FLAIR-VFL because the newly reconstructed voxel size of 3D-FLAIR-VFL was far larger than that of 3D-FLAIR-CONV.

The performance of 3D-FLAIR-VFL in detecting endolymphatic hydrops in the vestibule was comparable to that of 3D-FLAIR-CONV. In the cochlea, however, the 3D-FLAIR-CONV protocol was better, probably because of its higher in-plane resolution and higher CNR, as stated in the previous paragraph. The diameter of the cochlear duct (cochlear endolymphatic space) is smaller than the dimensions of the endolymphatic space in the vestibule, and the cochlear duct is in contact with surrounding bone tissue. Therefore, the recognition of endolymphatic hydrops in the cochlea might be more difficult than in the vestibule.

In the present study, we tried to reduce the scan time by a factor of 3 using 3D-FLAIR-VFL, which resulted in some image degradation. However, a
Fig. 2. A 50-year-old woman with fluctuating sensorineural hearing loss in the right ear. On 3-dimensional fluid-attenuated inversion recovery using conventional turbo-spin-echo (3D-FLAIR-CONV) (a), the size of endolymphatic space in the cochlea (arrow) was scored as 2; on 3D-FLAIR using variable flip-angle technique (VFL) (b), however, it was scored as 0 (arrow). This is probably due to the lower in-plane resolution and more blurring of 3D-FLAIR-VFL compared with 3D-FLAIR-CONV. The probability of endolymphatic hydrops from clinical records in cochlea was scored as 2.

A factor-of-2 reduction, for example, might have been more practical. Further study is needed to determine a practical degree of scan time reduction. The application of further technical developments also might improve the performance of 3D-FLAIR-VFL. For example, a T2-selective inversion recovery scheme may provide a more time-efficient scan, and the introduction of a 32-channel head array coil would improve the signal-to-noise ratio and thereby allow higher parallel imaging factors.

In the present study, we reviewed the images only in the axial orientation. However, 3D-FLAIR-VFL had a higher spatial resolution in the z-direction than did 3D-FLAIR-CONV. The results might have been influenced if we had reviewed coronal or sagittal reformatted images, in addition to the original axial images.

One limitation of this study was the lack of a concrete standard of reference. We arrived at a tentative probability score for endolymphatic hydrops based not only on patient symptoms and history, but also on the results of objective tests such as the electrocochleogram and VEMP. However, it is difficult to evaluate the feasibility of using this score. In some cases, the results of the electrocochleogram and/or VEMP disagreed with clinical symptoms and disease history. The guidelines for Ménière’s disease from the American Academy of Otolaryngology–Head and Neck Surgery (AAO-HNS) Committee of Hearing and Equilibrium define Ménière’s disease mostly in terms of its symptoms, describing the probability of the disease as possible, probable, definite, and certain. Certain Ménière’s disease is defined as definite with histopathologic confirmation; objective diagnosis with histological confirmation is currently virtually impossible. To make the diagnosis of certain Ménière’s disease in the future, MR imaging may be a desirable replacement for histological confirmation.

It would be very interesting if changes in 3D-FLAIR image findings were found to correlate with therapy-induced changes in the symptoms of endolymphatic hydrops. An individual longitudinal study might be useful to confirm the feasibility of this method in detecting and evaluating endolymphatic hydrops in vivo.

To compare the performance of 3D-FLAIR-VFL and 3D-FLAIR-CONV directly, a phantom simulating the actual dimensions of labyrinthine anatomy as well as the Gd-DTPA concentrations of labyrinthine endolymph and perilymph would also be helpful.

Conclusions

3D-FLAIR-VFL can obtain images with a voxel volume comparable to that of 3D-FLAIR-CONV and detect endolymphatic hydrops of the vestibule at a similar rate in a scan time that is nearly a factor of 3 shorter. However, the performance in detecting endolymphatic hydrops of the cochlea was lower with 3D-FLAIR-VFL. Thus, we currently may not be able to replace 3D-FLAIR-CONV with 3D-FLAIR-VFL, at least not with the scanning parameters used in the present study.
References


