Imaging of Endolymphatic Hydrops in 10 Minutes: A New Strategy to Reduce Scan Time to One Third

Shinji NAGANAWA1*, Hisashi KAWAI1, Mitsuru IKEDA2, Michihiko SONE3, and Tsutomu NAKASHIMA3

1Department of Radiology, Nagoya University Graduate School of Medicine
65 Tsurumai-cho, Shouwa-ku, Nagoya 466–8550, Japan

2Department of Radiological and Medical Laboratory Sciences, Nagoya University Graduate School of Medicine

3Department of Otorhinolaryngology, Nagoya University Graduate School of Medicine

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We measured the size of the endolymph using a newly proposed 10-min magnetic resonance (MR) imaging protocol and compared values with those of the previously reported 31- and 17-min protocols in 15 patients. Values for the 3 protocols did not differ significantly in either the cochlea or vestibule. Correlation among the 3 protocols was strong or relatively strong. Evaluation of endolymphatic hydrops is feasible using the newly proposed 10-min protocol.

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

Introduction

The visualization of endolymphatic hydrops was first achieved using a 3-dimensional (3D) fluid attenuated inversion recovery (FLAIR) magnetic resonance (MR) imaging sequence with intratympanic administration of gadolinium-based contrast material (GBCM).1,2 Recently, heavily T2-weighted (hT2W) 3D-FLAIR has been used with the intravenous (IV) administration of a single dose of GBCM (IV-SD-GBCM).3–5 The generation of a HYDROPS-Mi2 image was proposed (HYbrid Of Reversed image Of Positive endolymph signal and native image of positive perilymph Signal-Multiplied by T2) for easier interpretation of images and semi-quantification of endolymphatic size.1,6 Generation of that image using the previously reported MR parameters requires 31 min of scan time (14 min for acquisition of an hT2w 3D-FLAIR or positive perilymph image (PPI),7 14 min for acquisition of a positive endolymph image (PEI),7 and 3 min for acquisition of hT2W MR cisternography (MRC).8–11 To shorten the total scan time, generation of another type of image was proposed—a HYDROPS2-Mi2 image (HYbrid Of Reversed image Of MR cisternography and a positive Perilymph Signal by heavily T2-weighted 3D-FLAIR-Multiplied by T2). This image, generated from PPI (14 min) and MRC (3 min) images, was proposed and tested in comparison with the previous HYDROPS-Mi2 image (acquisition time, 31 min).1,6 Values of the ratio of endolymphatic area ratio measured on the new image (17 min) correlated well with those measured on the previous type (31 min), and interobserver variability was small.6 However, the expectation for further reduction of scan time is increasing as the MR evaluation of endolymphatic hydrops is becoming more popular.

We propose an even shorter version of the HYDROPS2-Mi2 to shorten the total scan time further and dramatically, an image generated from a PPI acquired with a reduced number of excitations (NEX, 7 min) and an MRC (3 min) image. In this study, we compared endolymphatic size between HYDROPS-Mi2 (Image A, 31-min acquisition) and HYDROPS2-Mi2 (Image B, 17-min acquisition; Image C, 10-min acquisition) images in patients with clinically suspected endolymphatic hydrops and tested the feasibility of the newly proposed...
Materials and Methods

Between October and November 2012, 15 patients (4 men, 11 women; aged 25 to 91 years, median 46) underwent MR imaging for the investigation of clinically suspected endolymphatic hydrops. Imaging was begun 4 hours after IV administration of a single dose (0.2 mL/kg or 0.1 mmol/kg body weight) of gadolinium-diethylene-triamine penta-acetic acid-bis methylamide (gadodiamide: Gd-DTPA-BMA; Omniscan, Daiichi-Sankyo Co. Ltd., Tokyo, Japan) on a 3.0-tesla scanner (MAGNETOM® Verio, Siemens, Erlangen, Germany) using a 32-channel array head coil. An experienced otorhinolaryngologist determined the indication for MR imaging based on the presence of ear symptoms, vertigo, average hearing level on pure tone audiometry, results of various ontological tests, and clinical history. The estimated glomerular filtration rate (eGFR) of all patients exceeded 60 mL/min/1.73 m².

According to our hospital’s clinical protocol for the evaluation of endolymphatic hydrops, all patients underwent hT2W MRC for anatomical reference of the total lymph fluid, hT2W 3D-FLAIR with inversion time of 2250 ms (PPI), and hT2W 3D-IR with inversion time of 2050 ms (PEI). Parameters were set as previously reported.6 PPI (14 min), PEI (14 min), and MRC (3 min) images and a PPI with reduced NEX (7 min) were obtained. The PPI with reduced NEX (PPI 7 min) was acquired as a back-up image. Table 1 details the scan parameters. The other 3 images, A, B, and C, were generated as follows: Image A (total scan time, 31 min), (PPI – PEI) × MRC; Image B (total scan time, 17 min), (PPI – 0.04 × MRC) × MRC; and Image C (total scan time, 10 min), (PPI 7 min – 0.04 × MRC) × MRC.

The purpose for multiplication of the MRC is to boost the contrast-to-noise ratio between the endolymph and perilymph while suppressing and stabilizing the background signal of the bone and air.13 We employed a constant value of 0.04 according to a recent study.14 We transferred MR images by CD-ROM to an iMac personal computer (Apple Computer, Inc., Cupertino, CA, USA) with a free DICOM viewer (OsiriX image software, ver. 5.8 32 bit; downloadable at http://www.osirix-viewer.com/index.html), which allowed easy pixel-by-pixel multiplication between the image series in a few seconds.

Pixels with a negative value were estimated as endolymph. In 30 ears, we measured the percentage of the area of endolymphatic space in the total lymphatic space (%EL) for the cochlea and vestibule semi-quantitatively on Images A, B, and C according to the previously reported threshold-based method.6 A neuroradiologist with 25 years of experience in MR imaging evaluated images.

In brief, the observer manually contoured the cochlea and vestibule separately to set up a region of interest (ROI) on the MRC according to the following instructions:6

> “Before starting to contour the cochlea or vestibule on the MRC, set the image window level and width to 400/1000.
> For the cochlear ROI, select the slice on which the cochlear modiolus is visually largest. If the size of the modiolus is comparable on 2 or more slices, choose the slice with the largest height of the modiolus. When contouring the cochlea on the MRC, exclude the modiolus when drawing the ROI.
> “For the vestibular ROI, select the lowest slice in which the lateral semicircular canal ring is visualized more than 240°, and exclude the semicircular canal and ampulla when drawing the ROI for the vestibule on the MRC.”

The ROI of the cochlear slice was defined to select the middle part of the cochlea, and the ROI of the vestibular slice, the middle of the vestibule. These ROIs drawn on the MRC were copied and pasted onto Images A, B, and C. We used the histogram function of OsiriX to measure the number of all pixels within the ROI and the number of pixels with a negative signal intensity value (i.e., endolymph) within the ROI.

The ratio of the area (%) of endolymphatic space in the entire lymphatic space (%EL) was defined as:

\[
\%EL = \frac{\text{the number of negative pixels for the endolymph in the ROI}}{\text{the total number of pixels in the ROI}} \times 100.
\]

We compared the measured %EL values among Images A, B, and C and evaluated the correlation between %EL values in the 2 pairs of processed images by a Pearson’s correlation coefficient (r). A linear regression line was found by implicit function fitting with an orthogonal distance regression iteration algorithm. We evaluated differences between the %EL values in the 2 pairs of processed images using a paired t-test.
### Table 1. Pulse sequence parameters

<table>
<thead>
<tr>
<th>Sequence name</th>
<th>Type</th>
<th>Repetition time (ms)</th>
<th>Echo time (ms)</th>
<th>Inversion time (ms)</th>
<th>Flip angle (degrees)</th>
<th>Section thickness (mm)</th>
<th>Pixel size (mm)</th>
<th>Number of slices</th>
<th>Echo train length</th>
<th>Field of view (mm)</th>
<th>Matrix size</th>
<th>Number of excitations</th>
<th>Scan time (min)</th>
<th>Bandwidth (Hz/pixel)</th>
</tr>
</thead>
<tbody>
<tr>
<td>MR cisternography (MRC)</td>
<td>SPACE with restore pulse</td>
<td>4400</td>
<td>544</td>
<td>NA</td>
<td>90/ initial 180 decrease to constant 120</td>
<td>1</td>
<td>0.5 x 0.5</td>
<td>104</td>
<td>173</td>
<td>150 x 180</td>
<td>322 x 384</td>
<td>1.8</td>
<td>3</td>
<td>434</td>
</tr>
<tr>
<td>Heavily T₂ weighted 3D-FLAIR (PPI)</td>
<td>SPACE with inversion pulse</td>
<td>9000</td>
<td>544</td>
<td>2250</td>
<td>90/ initial 180 decrease to constant 120</td>
<td>1</td>
<td>0.5 x 0.5</td>
<td>104</td>
<td>173</td>
<td>150 x 180</td>
<td>322 x 384</td>
<td>2 or 4</td>
<td>7 or 14</td>
<td>434</td>
</tr>
<tr>
<td>Heavily T₂ weighted 3D-inversion recovery (PEI)</td>
<td>SPACE with inversion pulse</td>
<td>9000</td>
<td>544</td>
<td>2050</td>
<td>90/initial 180 decrease to constant 120</td>
<td>1</td>
<td>0.5 x 0.5</td>
<td>104</td>
<td>173</td>
<td>150 x 180</td>
<td>322 x 384</td>
<td>2</td>
<td>7</td>
<td>434</td>
</tr>
</tbody>
</table>

Generalized autocalibrating partially parallel acquisitions (GRAPPA) x 2 for all sequences
FLAIR, fluid attenuated inversion recovery; PEI, positive endolymph image; PPI, positive perilymph image; SPACE, sampling perfection with application-optimized contrasts using different flip angle evolutions
All sequences utilize frequency selective fat suppression pre-pulse.
Each 3-dimensional (3D) slab is set in an identical axial orientation and has 104 slices.
with Bonferroni corrections for multiple comparisons at a significance level of 5%.

The medical ethics committee of our institution approved this retrospective study, and informed consent was waived.

Results

All patients underwent MR scanning without significant motion. In all patients, Images A, B and C allowed separate visualization of the endo- and perilymph (Fig. 1). The MRC showed the total lymph space anatomy.

Table 2 lists the mean %EL values of the cochlea and vestibule in each image; the values did not differ significantly among Images A, B and C both in cochlea and vestibule.

Figure 2 shows the relationship between the %EL in the 2 pairs of processed cochlear and vestibular

### Table 2. Mean values of the %EL of the cochlea and vestibule in each image

<table>
<thead>
<tr>
<th>Region</th>
<th>Image</th>
<th>mean %EL</th>
<th>Standard Deviation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cochlea</td>
<td>Image A</td>
<td>26.7</td>
<td>22.9</td>
</tr>
<tr>
<td></td>
<td>Image B</td>
<td>24.9</td>
<td>16.9</td>
</tr>
<tr>
<td></td>
<td>Image C</td>
<td>28.1</td>
<td>17.5</td>
</tr>
<tr>
<td>Vestibule</td>
<td>Image A</td>
<td>38.1</td>
<td>31.8</td>
</tr>
<tr>
<td></td>
<td>Image B</td>
<td>37.5</td>
<td>29.1</td>
</tr>
<tr>
<td></td>
<td>Image C</td>
<td>37.3</td>
<td>27.4</td>
</tr>
</tbody>
</table>

No significant difference between Images A, B, and C in both the cochlea and vestibule

%EL = (number of negative pixels for the endolymph in the region of interest [ROI] divided by the total number of pixels in the ROI) × 100
images. A strong or relatively strong linear correlation was observed between them in the cochlear images; the Pearson’s correlation coefficient \( r \) was 0.772 between Images A and B, 0.655 between Image A and C, and 0.901 between Images B and C \((P < 0.001, \text{for all})\). A strong linear correlation was also observed between the vestibular images; the Pearson’s correlation coefficient \( r \) was 0.934 between Images A and B, 0.906 between Images A and C, and 0.980 between Images B and C.
0.001, for all). Except between Images A and B and between Images A and C of the cochlea, the slope of the estimated linear regression line was close to one.

Discussion

A comparison between Images A and B reported previously using different patient groups showed strong linear correlation of the %EL values between the images in both the cochlea and vestibule. The Pearson correlation coefficients between Images A and B by 3 observers ranged from 0.734 to 0.9 in the cochlea and from 0.924 to 0.933 in the vestibule. No significant difference in the %EL values between observers was noted. In the present study, the correlation coefficients between Images A and B, 0.772 in the cochlea and 0.934 in the vestibule, were similar to those reported in the previous study. These similar findings in a different patient cohort add further reliability to the semi-quantitative measurement method by Images A and B.

In the current study, we observed strong or relatively strong linear correlations between Images A and C and between Images B and C in both the cochlea and vestibule. In particular, we observed a strong linear correlation between Images B and C in both the cochlea (r = 0.901) and vestibule (r = 0.980). These results might be expected because the only difference between Images B and C was the number of excitations used for acquisition (i.e., signal-to-noise ratio [SNR]). Thus, Image C can be used instead of Image B. A protocol with fewer excitations is thought to suffer from a lower SNR, but the %EL values correlated well with those obtained by the protocol with longer scan time. This is probably due to compensation in the SNR by multiplication of the MRC. A shorter scan time reduces the chance of image degradation from patient motion. Furthermore, a protocol with shorter scan time can be fit more easily into a busy clinical scanner schedule.

Some data points of Image A showed zero values in either the cochlea or vestibule (Fig. 2). Even in a healthy condition, there is some endolymph in the labyrinth. Image A might be underestimating the %EL values in lower values.

The lack of a standard of reference for values of EL percentage is a limitation of this study, so we cannot determine which values are nearest the real values. However, the results of the present study might be valuable for the conversion of some data from one method to those of another method. Such combination of data obtained by different imaging protocols would promote a larger scale study.

Conclusions

The newly proposed 10-min protocol (HYDROPS2-Mi2; Image C) might be feasible for the measurement of endolymphatic size after IV-SD-GD. This option will promote more widespread use of MR imaging evaluation of endolymphatic hydrops by clinicians.

Acknowledgements

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References