HASTE diffusion-weighted MRI for the reliable detection of cholesteatoma

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PURPOSE
To assess the detection efficiency of Half-Fourier acquisition single-shot turbo spin-echo (HASTE) diffusion-weighted magnetic resonance imaging (MRI) for cholesteatoma.

MATERIALS AND METHODS
A total of 21 patients with suspected primary (n=16) or recurrent cholesteatoma (n=5) underwent MRI in a 1.5 Tesla scanner using an adapted protocol for cholesteatoma detection that included a coronal HASTE diffusion-weighted MRI sequence. The cholesteatoma diagnosis was based on evidence of a hyperintense lesion at b-1000 on diffusion-weighted images. The imaging findings were correlated with findings from surgery or clinical evaluations in all patients.

RESULTS
HASTE diffusion-weighted MRI successfully detected 11 primary and 5 recurrent lesions out of 17 cholesteatomas (sensitivity, 94.1%). One primary cholesteatoma with a diameter of 4–5 mm was missed. MRI of patients without cholesteatoma were correctly interpreted as negative for cholesteatoma (specificity, 100%). The positive and negative predictive values for the HASTE diffusion-weighted MRI in detecting cholesteatoma were 100% and 80%, respectively.

CONCLUSION
HASTE diffusion-weighted MRI offers great promise for cholesteatoma screening. The addition of this sequence to the posterior fossa MRI protocol may preclude unnecessary cholesteatoma surgery.

Key words: • cholesteatoma • diffusion-weighted magnetic resonance imaging • otitis

A cholesteatoma is a cystic mass lined with keratin-producing squamous epithelium filled with desquamation debris. The mass may develop in the middle ear, the mastoid process of the temporal bone, or the petrous apex (1, 2). Currently, tympanomastoid surgery is the standard treatment choice, but the procedure still carries a significant risk of residual and recurrent disease that may not be easily detectable through standard clinical evaluations, including otoscopy, otoendoscopy, and microscopy. Therefore, a second-look surgery is usually required to rule out residual cholesteatoma (3, 4). A new, reliable, noninvasive imaging tool that would allow patients with no hearing loss to avoid additional surgeries is needed. Routine patient follow-up with imaging may involve computed tomography (CT) and/or magnetic resonance imaging (MRI). CT has a high negative predictive value (NPV) in cases with a well-aerated middle ear or a mastoid cavity without any soft tissue, which are characteristics that suggest the absence of cholesteatoma. However, CT is limited in its ability to aid the clinician in distinguishing between residual cholesteatoma and granulation or postoperative inflammatory and/or scar tissue (5, 6).

The use of MRI has been proposed to aid in the discrimination between residual cholesteatoma and granulation. Diffusion-weighted imaging (DWI) and delayed postcontrast T1-weighted (T1W) sequences have both been suggested. Delayed postcontrast T1 spin-echo sequences improve the diagnosis of recurrent cholesteatoma and allow differentiation between scar tissue, which shows delayed enhancement, and cholesteatoma, which does not show delayed enhancement; conversely, inflammatory tissue displays early enhancement (7). However, these sequences do not provide the diagnostic performance necessary to eliminate the need for second-look surgery (7–11). Growing data suggest that DWI, particularly Half-Fourier acquisition single-shot turbo spin-echo (HASTE) DWI, yields better diagnostic performance for the detection of cholesteatomas (8, 11). Nonetheless, the reported sensitivity, specificity, positive predictive value (PPV), and NPV have varied among previous studies.

The present study was performed to determine whether HASTE DWI alone is a reliable alternative follow-up diagnostic technique to second-look surgery for the detection of recurrent cholesteatoma in postoperative patients.

Materials and methods
This prospective study was performed after approval from the local ethics committee of the Gülhane Military Medical School. In total, 21 patients (14 males and 7 females; aged between 13–66 years; mean age, 35 years) were included in the study; five were previously treated surgically for cholesteatoma of the middle ear. All other patients (n=17) had CT exams demonstrating a loss of middle ear aeration and clinical...
MRI was performed using a 1.5 T superconductive unit (Magnetom Symphony) with the standard head matrix coil. The MRI protocol included three-dimensional constructive interference in steady-state (CISS) sequences (TR/TE, 11.22/5.61 ms; matrix, 416−512; section thickness, 1 mm; field of view, 170×220 mm), coronal turbo spin echo (TSE) T2-weighted (TR/TE, 5270/119 ms; matrix, 416–512; section thickness, 3 mm; field of view, 220×170 mm), and coronal HASTE DWI (TR/TE, 2000/147 ms; matrix, 128–128; section thickness, 3 mm; field of view, 230×230 mm; b-factor 0, 1000 s/mm²; total duration, 4 min 15 s).

The collected images were independently analyzed by two observers (A.T., I.G.) who were specifically trained in radiology and blind to all patient identities. To avoid artifacts such as those observed in DWI obtained using echo-planar imaging (EPI) sequences, the coronal HASTE plane was preferred to the axial plane.

A diagnosis of cholesteatoma was based on evidence of a hyperintense lesion in the middle ear or mastoid cavity at b-1000 on the HASTE DWI. Axial CISS sequences and coronal TSE T2W sequences were used for anatomical localization of the cholesteatomas observed during the HASTE DWI sequence. The results were correlated with findings from surgery (n=11) or clinical evaluation, including otomicroscopic examination (n=10) for the presence, localization, and size of the cholesteatoma.

The sensitivity, specificity, and NPV and PPV values were then calculated.

Results
HASTE diffusion-weighted MRI successfully detected 11 primary and 5 recurrent lesions out of 17 cholesteatomas (sensitivity, 94.1%). In the 11 surgery patients, HASTE DWI detected and precisely localized the cholesteatomas, which were then confirmed at surgery (Fig. 1). There was no tendency toward under- or over-estimation of the cholesteatoma size by HASTE DWI. The 4 mm isolated tympanic primary cholesteatoma of one patient that was found in surgery was missed by HASTE DWI (Fig. 2). Motion artifacts were responsible for image degradation for this patient. There were no false-positive results obtained with HASTE DWI (Figs. 3 and 4). No susceptibility artifacts were seen in the HASTE DWI.
Table 1 shows the clinical characteristics of 11 patients who had received surgery because of primary or recurrent chronic otitis media with cholesteatoma. Five of the patients who had been previously treated surgically for cholesteatoma of the middle ear suffered a recurrence. The diagnoses of all recurrent cholesteatomas were confirmed by histopathologic examination. Atticoantral and mastoid extension were found in seven cases, whereas four cases involved isolated tympanic and attic extension; one case had a congenital cholesteatoma that extended to the labyrinth and petrous apex. Labyrinthine invasion by the cholesteatoma was found in two cases, and tegmen tympani erosion was found in a single case. In addition, sigmoid plate erosion was found in a single case. Cholesteatoma-induced defects of the bony external auditory canal were observed intraoperatively in
two cases. The patients with inflammation, mucosal edema, middle ear fluid, scar tissue, or granulation tissue did not demonstrate high intensity at b-1000 in the HASTE DWI.

The HASTE DWI sequence demonstrated a 100% PPV and an 80% NPV in detecting cholesteatoma following primary surgery. The sensitivity and the specificity of the procedure were 94.1% and 100%, respectively. Cholesteatoma localization and size were predicted accurately with HASTE DWI before surgery in all patients (n=11).

**Discussion**

The use of MRI for the detection of cholesteatoma has demonstrated variable results in past studies (11). However, delayed-contrast enhanced T1W MRI sequences have detected cholesteatomas as small as 2.5 mm (11, 12). The known disadvantages of MRI include poor spatial resolution, long duration, and the necessary injection of contrast media, making this technique relatively difficult for routine use. Although it remains controversial whether the bright signal of cholesteatoma observed in MRI

<table>
<thead>
<tr>
<th>Age/Gender</th>
<th>Signs and Symptoms</th>
<th>Otomicroscopic examination</th>
<th>Cholesteatoma on HASTE DWI</th>
<th>Treatment</th>
<th>Diagnosis on surgery</th>
<th>Location and extention of cholesteatoma</th>
</tr>
</thead>
<tbody>
<tr>
<td>21/M</td>
<td>Hearing loss, otorrhea</td>
<td>Attic retraction pocket, posterior quadrant perforation of TM with cholesteatoma</td>
<td>Positive</td>
<td>Anterior atticotomy+ tympanoplasty</td>
<td>Left COM with cholesteatoma</td>
<td>Posterior mesotympanum</td>
</tr>
<tr>
<td>21/M</td>
<td>Hearing loss, otorrhea</td>
<td>Attic perforation with cholesteatoma</td>
<td>Positive</td>
<td>Modified radical mastoidectomy</td>
<td>Left COM with cholesteatoma</td>
<td>Anterior and posterior mesotympanum, attic-antral region, and mastoid cavity</td>
</tr>
<tr>
<td>50/F</td>
<td>Dizziness, tinnitus, and pain</td>
<td>Intact graft membrane</td>
<td>Positive</td>
<td>Modified radical mastoidectomy and mastoid obliteration</td>
<td>Recurrent COM with cholesteatoma</td>
<td>Posterior mesotympanum, attic-antral region, mastoid cavity, erosion of lateral semicircular canal with cholesteatoma</td>
</tr>
<tr>
<td>21/M</td>
<td>Hearing loss, otorrhea</td>
<td>Posterior retraction pocket with cholesteatoma</td>
<td>Positive</td>
<td>Intact canal wall mastoidectomy</td>
<td>Left COM with cholesteatoma</td>
<td>Attic region</td>
</tr>
<tr>
<td>13/F</td>
<td>Hearing loss, otorrhea, postauricular hyperemia and edema</td>
<td>Purulent drainage, granulation tissues and posterior mesotympanic cholesteatoma</td>
<td>Positive</td>
<td>Modified radical mastoidectomy</td>
<td>Recurrent right COM with cholesteatoma</td>
<td>Mastoid cavity, zygomatic root, posterior mesotympanum, and erosion of bony external auditory canal and sigmoid plate</td>
</tr>
<tr>
<td>27/M</td>
<td>Hearing loss, otorrhea</td>
<td>Attic perforation with cholesteatoma</td>
<td>Positive</td>
<td>Modified radical mastoidectomy</td>
<td>Recurrent right COM with cholesteatoma</td>
<td>Whole tympanum and mastoid cavity, erosion of bony external auditory canal</td>
</tr>
<tr>
<td>31/M</td>
<td>Hearing loss, otorrhea</td>
<td>Posterior mesotympanic perforation of TM with cholesteatoma</td>
<td>Positive</td>
<td>Intact canal wall mastoidectomy</td>
<td>Left COM with cholesteatoma</td>
<td>Attico-antral region and posterior mesotympanum</td>
</tr>
<tr>
<td>21/M</td>
<td>Hearing loss</td>
<td>Whitish mass behind an intact TM</td>
<td>Positive</td>
<td>Right translabyrinthin and transcochlear petrosectomy</td>
<td>Right congenital petrous cholesteatoma</td>
<td>Mastoid, tympanic cavity, labyrinth, and petrous apex</td>
</tr>
<tr>
<td>47/M</td>
<td>Hearing loss, otorrhea</td>
<td>Attic perforation with cholesteatoma</td>
<td>Positive</td>
<td>Modified radical mastoidectomy</td>
<td>Right COM with cholesteatoma</td>
<td>Attico-antral region, posterior mesotympanum, supratubal recess, mastoid cavity. Erosion of tegmen tympani.</td>
</tr>
<tr>
<td>50/M</td>
<td>Hearing loss, otorrhea</td>
<td>Posteroinferior perforation of TM with cholesteatoma</td>
<td>Positive</td>
<td>Modified radical mastoidectomy</td>
<td>Left recurrent COM with cholesteatoma</td>
<td>Posterior mesotympanum and supratubal recess</td>
</tr>
<tr>
<td>21/M</td>
<td>Hearing loss, otorrhea</td>
<td>Subtotal perforation of TM, cholesteatoma around the manubrium mallei</td>
<td>Negative</td>
<td>Intact canal wall mastoidectomy</td>
<td>Left COM with cholesteatoma</td>
<td>Facial recess, supratubal recess</td>
</tr>
</tbody>
</table>

F, female; M, male; TM, tympanic membrane; COM, chronic otitis media.
images is a result of restricted diffusion or a T2 shine-through effect, DWI has been increasingly used in the evaluation of postoperative residual cholesteatomas over the past decade (7). Several recent reports have focused mainly on two DWI techniques for detecting cholesteatoma: EPI DWI and non-EPI (single-shot turbo spin echo [SSTSE]) DWI, also called HASTE) DWI (7, 9, 13–16). Initial studies primarily used the EPI DWI technique, but susceptibility artifacts caused by field inhomogeneities at the air-bone interface of the temporal bone were more pronounced with this technique. This limitation was reduced in several studies with the use of HASTE DWI (13–16). In such HASTE DWI studies, the reduction in susceptibility artifacts can be explained by the use of 180° radio-frequency refocusing pulses for each measured echo (17, 18). Although both DWI techniques have relatively low spatial resolution, the complete lack of susceptibility artifacts, thinner slices, and higher imaging matrix of HASTE DWI allow it to achieve accurate localization of the recurrent cholesteatoma.

HASTE DWI has shown mixed results in the detection of cholesteatoma in past studies. Although Plouin-Gaudon et al. (9) reported relatively low sensitivity, specificity, NPV, and PPV (62%, 88%, 89%, and 58%, respectively), most studies have reported a very high diagnostic performance for HASTE DWI that often reaches 100% for all four statistical measures (8). De Foer et al. (19) have reported that the HASTE DWI detection limit for a cholesteatoma is as low as 2 mm; EPI DWI had previously set the limit of detection at 5 mm. Previous studies concerning the use of MRI to detect residual cholesteatomas have reported sensitivities ranging from 62% to 100% (7–10). Conversely, the observed specificities of HASTE DWI have been more comparable among these studies, ranging from 88% to 100%. The discrepancy between the sensitivity and the specificity is mainly caused by a large variation in the size of the residual cholesteatomas among the studies (Table 2). Indeed, the lowest size of the detected residual cholesteatoma ranged from 4 to 5 mm (1, 15, 20). In the present study, the lowest cholesteatoma size detected with HASTE DWI was 4 mm.

The sensitivity, specificity, PPV, and NPV in the present study were 94.1%, 100%, 100%, and 80%, respectively. These findings are consistent with the findings of earlier studies. The HASTE DWI sequence used in our study demonstrated a higher specificity and sensitivity than the tested conventional and EPI DWI sequences of earlier reports. Although we did not include EPI DWI imaging for a direct comparison for all of our patients, significant susceptibility artifacts were encountered in the patients that did undergo EPI DWI sequences. These artifacts indicate the superiority of HASTE DWI over EPI DWI for the detection of cholesteatoma.

Some authors have reported several causes for the false-negative results associated with HASTE DWI in past studies. Dhepnorrarat et al. (8) stated that HASTE DWI techniques would be useful for patients with a discharging ear or for ruling out recurrent cholesteatoma within the middle ear or mastoid cavity but not in a dry auto-evacuating retraction pocket. Although HASTE DWI avoids bone-air artifacts in zones such as the tegmen, the spatial resolution remains poor for very small or thin lesions (9). De Foer et al. (21) also noted motion artifacts on HASTE DWI images. These artifacts could serve as a possible cause of false-positive results because in such cases, the hyperintensity of the small cholesteatoma was smeared over multiple pixels, resulting in an overall lack of intensity. In the present study, there was one false-negative 4.5 mm middle-ear cholesteatoma. The false-negative was a result of the thin diffuse shape of the cholesteatoma and motion artifacts.

There were some limitations to our study. First, our sample size was small. The loss of some surgical candidates through patient refusal or loss of follow-up may have caused a potential bias toward positive cases of residual disease. Second, we were unable to confirm that lesions smaller than 5 mm could be reliably detected using HASTE DWI because most of the detected cholesteatomas were larger than 5 mm. However, as with other studies, we believe that smaller cholesteatomas have no short-term prognostic impact (9, 11) and may be detected during follow-up visits with repeated MRI.

In conclusion, HASTE DWI is a promising technique for the detection of primary and recurrent cholesteatoma that is convenient, fast, and very robust. With its high sensitivity, specificity, PPV, and NPV, HASTE DWI may prevent unnecessary surgery in patients who show no hearing loss after the first stage of cholesteatoma removal.

### Table 2. Comparison of studies for the detection of cholesteatoma using non-EPI DWI

<table>
<thead>
<tr>
<th>Patient number</th>
<th>Sensitivity</th>
<th>Specificity</th>
<th>PPV</th>
<th>NPV</th>
<th>Slice thickness (mm)</th>
<th>Minimum detected cholesteatoma (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dhepnorrarat et al. 2008 (8)</td>
<td>22</td>
<td>100</td>
<td>100</td>
<td>100</td>
<td>100</td>
<td>5</td>
</tr>
<tr>
<td>De Foer et al. 2008 (11)</td>
<td>19</td>
<td>90</td>
<td>100</td>
<td>100</td>
<td>96</td>
<td>2</td>
</tr>
<tr>
<td>Plouin-Gaudon et al. 2010 (9)</td>
<td>21</td>
<td>62</td>
<td>88</td>
<td>89</td>
<td>58</td>
<td>3</td>
</tr>
<tr>
<td>Khemani et al. 2010 (10)</td>
<td>38</td>
<td>82</td>
<td>90</td>
<td>96</td>
<td>64</td>
<td>2</td>
</tr>
<tr>
<td>Rajan et al. 2010 (22)</td>
<td>15</td>
<td>100</td>
<td>100</td>
<td>100</td>
<td>100</td>
<td>3</td>
</tr>
<tr>
<td>De Foer et al. 2010 (23)</td>
<td>120</td>
<td>83</td>
<td>87</td>
<td>96</td>
<td>57</td>
<td>2</td>
</tr>
<tr>
<td>Pizzini et al. 2010 (24)</td>
<td>27</td>
<td>100</td>
<td>100</td>
<td>100</td>
<td>100</td>
<td>3</td>
</tr>
</tbody>
</table>

PPV, positive predictive value; NPV, negative predictive value.
Conflict of interest disclosure
The authors declared no conflict of interest.

References