Diagn Interv Radiol 2012; 18:153–158

ORIGINAL ARTICLE

HASTE diffusion-weighted MRI for the reliable detection of cholesteatoma

A. Turan Ilıca, Yusuf Hıdır, Nail Bulakbaşı, Bülent Satar, İnanç Güvenç, Hasan Hüseyin Arslan, Nurcan İmre

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*

From the Departments of Radiology (A.T.I. ✉ *aturca2002@yahoo.com*, N.B., İ.G.), Head and Neck Surgery (Y.H., B.S., H.H.A.), and Anatomy (N.İ.), Gülhane Military Medical School, Ankara, Turkey.

Received 24 January 2011; revision requested 18 February 2011; revision received 23 June 2011; accepted 23 June 2011.

Published online 29 September 2011
DOI 10.4261/1305-3825.DIR.4246-11.3

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

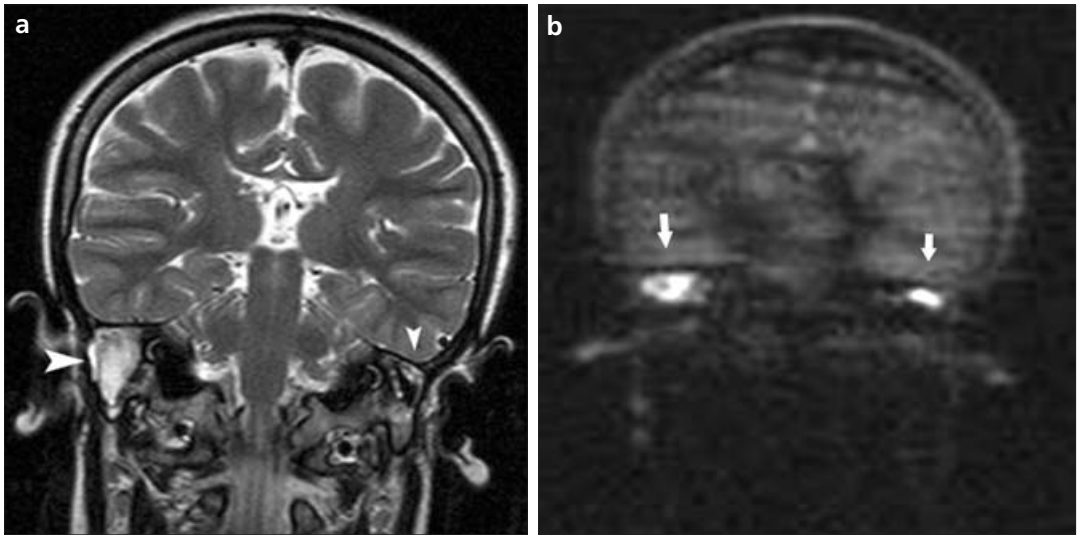


Figure 1. a, b. A coronal TSE T2-weighted MRI showing extensive bilateral atticoantral hyperintense lesions on the right side *(arrowheads)* under the tegmen, suggestive of recurrent cholesteatoma **(a)**. A coronal HASTE DWI (b-1000) of the same patient with bilateral nodular markedly hyperintense lesions (*arrows*) consistent with recurrent cholesteatoma **(b)**.

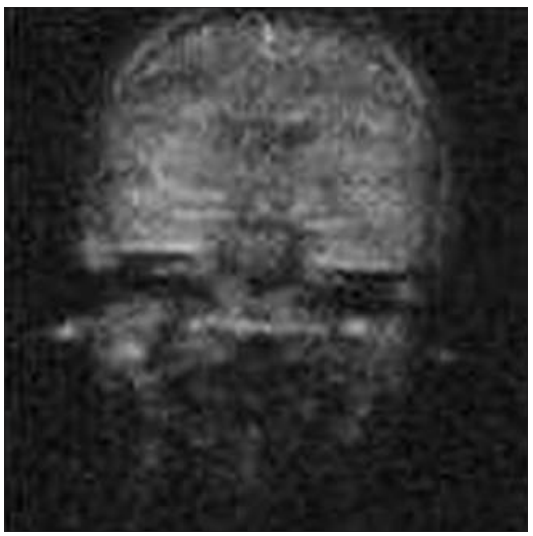


Figure 2. False-negative HASTE DWI. The coronal HASTE DWI (b-1000) does not show a hyperintense lesion suggestive of cholesteatoma. Follow-up surgery revealed a thin, diffuse 4–5 mm cholesteatoma with a facial and supratubal recess. Motion artifacts were responsible for the missed cholesteatoma on the HASTE DWI in this patient.

suspicion of cholesteatoma. From November 2009 to November 2010, 21 patients underwent MRI in a 1.5 Tesla (T) scanner (Magnetom Symphony, Siemens, Erlangen, Germany) with an adapted protocol for cholesteatoma detection that included a coronal HASTE diffusion-weighted sequence. The time between the MRI examination and the initial surgery did not exceed one month, and 11 of 21 patients underwent surgery and had histopathologic samples taken from the cholesteatomatous areas to confirm the diagnosis. There was clinical and otomicroscopic evidence of cholesteatoma in six other patients who could not receive surgery during the study period. Clinical or otomicroscopic evidence of cholesteatoma was not present in the remaining four patients suffering from chronic otitis media without cholesteatoma.

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/mm^2; total duration, 4 min 15 s).

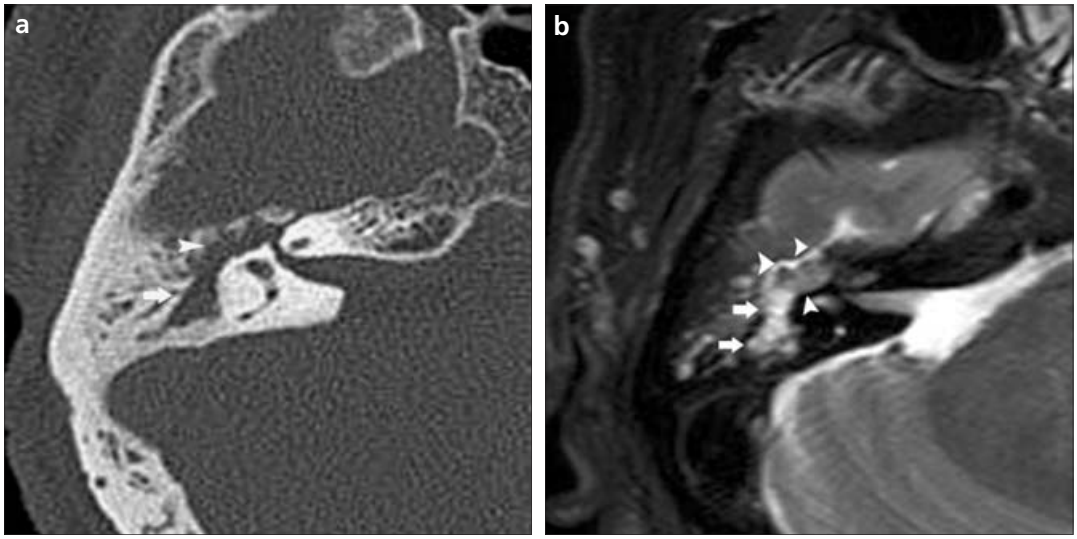
The collected images were independently analyzed by two observers (A.T.İ., İ.G.) who were specifically trained in radiology and blind to all patient identities. To avoid artifacts such as those observed in DWI obtained using echo-planar imaging (EPI) sequences, the coronal HASTE plane was preferred to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



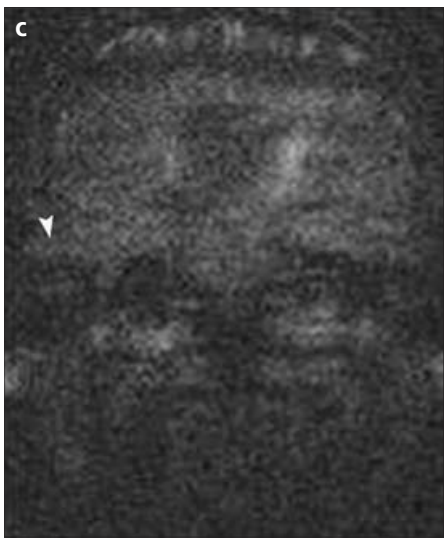


Figure 3. a–c. A true negative HASTE DWI. The axial CT scan shows complete soft tissue opacity in the middle ear and mastoid (*arrow* in the antrum and *arrowhead* in the anterior epitympanum) **(a)**. Axial fat-suppressed T2-weighted MRI shows a high signal in the mastoid antrum, suggesting fluid or granulation tissue (*arrows*), and moderately hyperintense tissue suggestive of a cholesteatoma (*arrowheads*) more anteriorly **(b)**. The coronal HASTE DWI (b-1000) shows no hyperintense lesion indicating the absence of cholesteatoma (*arrowhead*) **(c)**. Dehydrated granulation tissue was verified in follow-up studies.

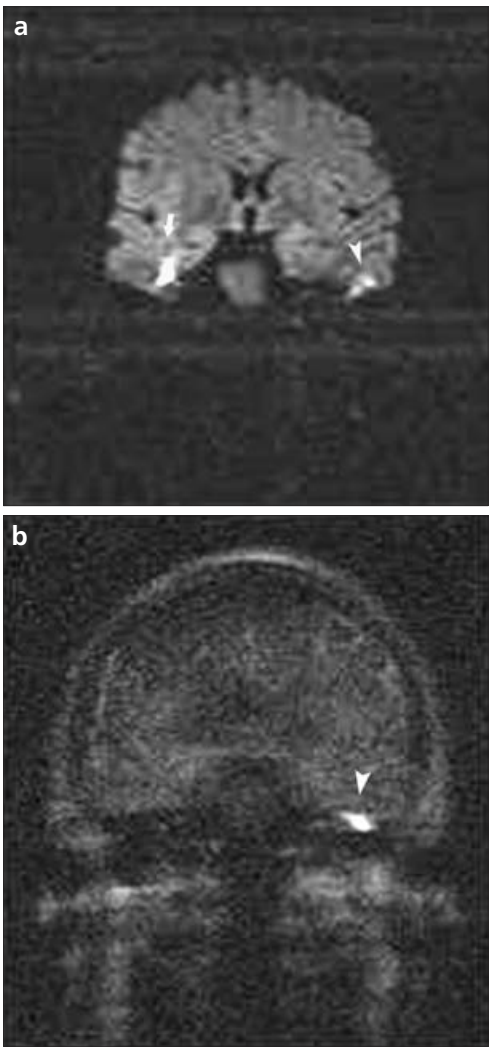


Figure 4. a, b. A coronal EPI DWI with bilateral subtemporal hyperintensities **(a)**. The determination of whether the image represents cholesteatoma or susceptibility artifacts is difficult (*arrow* on right, *arrowhead* on left). A coronal HASTE DWI (b-1000) of the same patient shows only a left nodular markedly hyperintense lesion (*arrowhead*) that is consistent with cholesteatoma **(b)**. The right-sided hyperintensity is a susceptibility artifact.

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

Table 1. Demographic data, signs and symptoms of patients with cholesteatoma that was confirmed histopathologically

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

F, female; M, male; TM, tympanic membrane; COM, chronic otitis media.

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

	Patient number	Sensitivity	Specificity	PPV	NPV	Slice thickness (mm)	Minimum detected cholesteatoma (mm)
Dhepnorrarat et al. 2008 (8)	22	100	100	100	100	5	3
De Foer et al. 2008 (11)	19	90	100	100	96	2	2.5
Plouin–Gaudon et al. 2010 (9)	21	62	88	89	58	3	4
Khemani et al. 2010 (10)	38	82	90	96	64	2	3
Rajan et al. 2010 (22)	15	100	100	100	100	3	3
De Foer et al. 2010 (23)	120	83	87	96	57	2	-
Pizzini et al. 2010 (24)	27	100	100	100	100	3	2

PPV, positive predictive value; NPV, negative predictive value.

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.

Conflict of interest disclosure

The authors declared no conflict of interest.

References

1. Aikele P, Kittner T, Offergeld C, Kaftan H, Hüttenbrink KB, Laniado M. Diffusion-weighted MR imaging of cholesteatoma in pediatric and adult patients who have undergone middle ear surgery. AJR Am J Roentgenol 2003; 181:261–265.
2. Balogh K. The head and neck. In: Rubin E, Farber JL, eds. Pathology. 3rd ed. Philadelphia: Lippincott-Raven, 1998; 1300–1334.
3. Darrouzet V, Duclos JY, Portmann D, Bebear JP. Preference for the closed technique in the management of cholesteatoma of the middle ear in children: a retrospective study of 215 consecutive patients treated over 10 years. Am J Otol 2000; 21:474–481.
4. Vartiainen E. Ten-year results of canal wall down mastoidectomy for acquired cholesteatoma. Auris Nasus Larynx 2000; 27:227–229.
5. Cimsit NC, Cimsit C, Baysal B, Ruhi IC, Ozbilgen S, Aksoy EA. Diffusion-weighted MR imaging in postoperative follow-up: reliability for detection of recurrent cholesteatoma. Eur J Radiol 2010; 74:121–123.
6. Blaney SP, Tierney P, Oyarazabal M, et al. CT scanning in "second look" combined approach tympanoplasty. Rev Laryngol Otol Rhinol (Bord) 2000; 121:79–81.
7. Ayache D, Williams MT, Lejeune D, Corre´ A. Usefulness of delayed postcontrast magnetic resonance imaging in the detection of residual cholesteatoma after canal wall-up tympanoplasty. Laryngoscope 2005; 115:607–610.
8. Dhepnorrarat RC, Wood B, Rajan GP. Postoperative non-echo-planar diffusion-weighted magnetic resonance imaging changes after cholesteatoma surgery: implications for cholesteatoma screening. Otol Neurotol 2009; 30:54–58.
9. Plouin-Gaudon I, Bossard D, Fuchsmann C, Ayari-Khalfallah S, Froehlich P. Diffusion-weighted MR imaging for evaluation of pediatric recurrent cholesteatomas. Int J Pediatr Otorhinolaryngol 2010; 74:22–26.
10. Khemani S, Lingam R, Kalan A, Singh A. The value of non-echo planar (HASTE) diffusion-weighted MR imaging in the detection and localisation of post-operative cholesteatoma. Paper presented at: ESHNR–European Society of Head and Neck Radiology; September 9 2010; Vienna, Austria.
11. De Foer B, Vercruysse JP, Bernaerts A, et al. Detection of postoperative residual cholesteatoma with non-echo-planar diffusion-weighted magnetic resonance imaging. Otol Neurotol 2008; 29:513–517.
12. Williams MT, Ayache D, Alberti C, et al. Detection of postoperative residual cholesteatoma with delayed contrast enhanced MR imaging: initial findings. Eur Radiol 2003; 13:169–174.
13. Fitzek C, Mewes T, Fitzek S, et al. Diffusion-weighted MRI of cholesteatomas in petrous bone. J Magn Reson Imaging 2002; 15:636–641.
14. Vercruysse JP, De Foer B, Pouillon M, et al. The value of diffusion weighted MR imaging in the diagnosis of primary acquired and residual cholesteatoma: a surgical verified study of 100 patients. Eur Radiol 2006; 16:1461–1467.
15. Dubrulle F, Souillard R, Chechin D, et al. Diffusion-weighted MR imaging sequence in the detection of postoperative recurrent cholesteatoma. Radiology 2006; 238:604–610.
16. Stasolla A, Magluilo G, Parrotto D, Luppi G, Marini M. Detection of postoperative relapsing/residual cholesteatomas with diffusion-weighted echo-planar magnetic resonance imaging. Otol Neurotol 2004; 25:879–884.
17. Fisher H, Ladebeck R. Echo-planar imaging image artifacts. In: Schmitt F, Stehling MK, Turner R, eds. Echo-planar imaging: theory, technique and application. New York: Springer-Verlag, 1998; 179–200.
18. De Foer B, Vercruysse JP, Pilet B, et al. Single-shot, turbo spin-echo, diffusion-weighted imaging versus spin-echo-planar, diffusion-weighted imaging in the detection of acquired middle ear cholesteatoma. AJNR Am J Neuroradiol 2006; 27:1480–1482.
19. De Foer B, Vercruysse JP, Pouillon M, Somers T, Casselman JW, Offeciers E. Value of high-resolution computed tomography and magnetic resonance imaging in the detection of residual cholesteatomas in primary bony obliterated mastoids. Am J Otolaryngol 2007; 284:230–234.
20. Venail F, Bonafe A, Poirrier V, Mondain M, Uziel A. Comparison of echo-planar diffusion-weighted imaging and delayed post-contrast T1-weighted MR imaging for the detection of residual cholesteatoma. AJNR Am J Neuroradiol 2008; 29:1363–1368.
21. De Foer B, Vercruysse JP, Bernaerts A, et al. The value of singleshot turbo spin-echo diffusion-weighted MR imaging in the detection of middle ear cholesteatoma. Neuroradiology 2007; 49:841–848.
22. Rajan GP, Ambett R, Wun L, et al. Preliminary outcomes of cholesteatoma screening in children using non-echo-planar diffusion-weighted magnetic resonance imaging. Int J Pediatr Otorhinolaryngol 2010; 74:297–301.
23. De Foer B, Vercruysse JP, Bernaerts A, et al. Middle ear cholesteatoma: non-echo-planar diffusion-weighted MR imaging versus delayed gadolinium-enhanced T1-weighted MR imaging--value in detection. Radiology 2010; 255:866–872.
24. Pizzini FB, Barbieri F, Beltramello A, Alessandrini F, Fiorino F. HASTE diffusion-weighted 3-Tesla magnetic resonance imaging in the diagnosis of primary and relapsing cholesteatoma. Otol Neurotol 2010; 31:596–602.