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**ORIGINAL
RESEARCH**

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3T MR Imaging of Postoperative Recurrent Middle Ear Cholesteatomas: Value of Periodically Rotated Overlapping Parallel Lines with Enhanced Reconstruction Diffusion-Weighted MR Imaging

BACKGROUND AND PURPOSE: MR diagnostic of postoperative recurrent cholesteatomas is difficult. Our purpose was to compare multishot fast spin-echo periodically rotated overlapping parallel lines with enhanced reconstruction (PROPELLER) diffusion-weighted MR imaging (DWI) with array spatial sensitivity encoding technique (ASSET) single-shot echo-planar DWI and late postgadolinium T1-weighted MR imaging for the detection of postoperative recurrent middle ear cholesteatomas with a 3T imaging unit.

MATERIALS AND METHODS: Thirty-five patients with suggested postoperative recurrent middle ear cholesteatoma underwent 3T MR imaging with PROPELLER DWI, ASSET echo-planar DWI, and late postgadolinium T1-weighted MR imaging. Three radiologists (2 seniors, 1 fellow) analyzed unlabeled images for visualization of recurrence. Interobserver and intraobserver agreement was assessed by using the Cohen κ statistic test. Sensitivity, specificity, and predictive value were assessed for the 3 observers.

RESULTS: Nineteen recurrent cholesteatomas were diagnosed. PROPELLER interobserver agreement was very good (1, 0.89, 0.89) among the 3 observers. Intraobserver agreement between PROPELLER and T1-weighted imaging was very good to moderate (0.88, 0.57, 0.58). PROPELLER DWI provided less interobserver variability than other sequences, and the best sensitivity, specificity, and predictive value.

CONCLUSIONS: On a 3T imaging unit, multishot fast spin-echo PROPELLER DWI allows an easier detection of postoperative recurrent middle ear cholesteatoma than T1-weighted imaging by reducing artifacts and by its better contrast. DWI with PROPELLER is diagnostically robust and accurate.

Diagnosis of postoperative recurrent middle ear cholesteatomas is mainly performed on thin-section high-resolution CT. However, when the middle ear is completely filled, CT is not reliable and MR imaging with late postgadolinium T1-weighting has an additional value.¹⁻³ Several authors showed interest in using diffusion-weighted MR imaging (DWI) for depicting recurrent cholesteatomas on a 1.5T imaging unit. Different methods were described to avoid artifacts on DWI present in this anatomic region.⁴⁻⁹ Multishot fast spin-echo (SE) periodically rotated overlapping parallel lines with enhanced reconstruction (PROPELLER) DWI has already been described in the detection of acute cerebral infarction.¹⁰ Our purpose was to compare it^{11,12} with array spatial sensitivity encoding technique (ASSET) single-shot echo-planar DWI and late postgadolinium T1-weighted MR imaging for detection of recurrent cholesteatomas with a 3T MR imaging scanner.

Materials and Methods

Patients

The local institutional review board approved the study. Thirty-five patients (mean age, 46.4 years; range, 8–89 years; M/F ratio = 19:16)

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were evaluated from October 2006 to March 2008. Each patient had a history of middle ear surgery for cholesteatoma, and the imaging follow-up revealed a soft-tissue mass in the middle ear on thin-section high-resolution CT. Differential diagnosis between cholesteatoma recurrence or postoperative fibrosis was not possible on CT. We performed a 3T MR imaging examination with PROPELLER DWI, ASSET echo-planar DWI, and late postgadolinium T1-weighted MR imaging (at least 45 minutes). On the basis of the imaging diagnosis and after a multidisciplinary decision, 16 patients without suggestive images were not treated. A second- or third-look surgery was performed in 10 patients, and 9 patients were closely followed to monitor the growth and extension of the supposed recurrent cholesteatoma (the recurrence was too small according to the surgical team). At this time, 2 patients were controlled without clinical or imaging change.

MR Imaging Data Acquisition

All patients were examined with a 3T clinical MR imaging unit (Signa HDx; GE Healthcare, Milwaukee, Wis) by using a standard head coil with 8 elements (8 HR Brain; GE Healthcare).

All patients except 2 had protocol on the temporal bone as follows: axial fast SE T2-weighted imaging (TR, 5160 ms; TE, 100 ms; flip angle, 90°; bandwidth, 83.3 kHz; matrix, 384 × 288; FOV, 18 cm; section thickness, 1.5 mm; intersection gap, 0.5 mm; NEX, 4; 20 sections; duration, 5 minutes 6 seconds), axial SE T1-weighted imaging (TR, 475 ms; TE, 14.9 ms; bandwidth, 83.3 kHz; matrix, 320 × 256; FOV, 18 cm; section thickness, 2.5 mm; intersection gap, 0.5 mm; NEX, 4; 13 sections; duration, 3 minutes 1 second), axial ASSET echo-planar DWI (TR, 7000 ms; TE, 75 ms; ASSET factor, 2; bandwidth, 250 kHz; matrix, 192 × 160; FOV, 24 cm; section thickness, 3 mm; intersection gap, 0 mm; NEX, 2; $b=800$; 13 sections; duration, 28

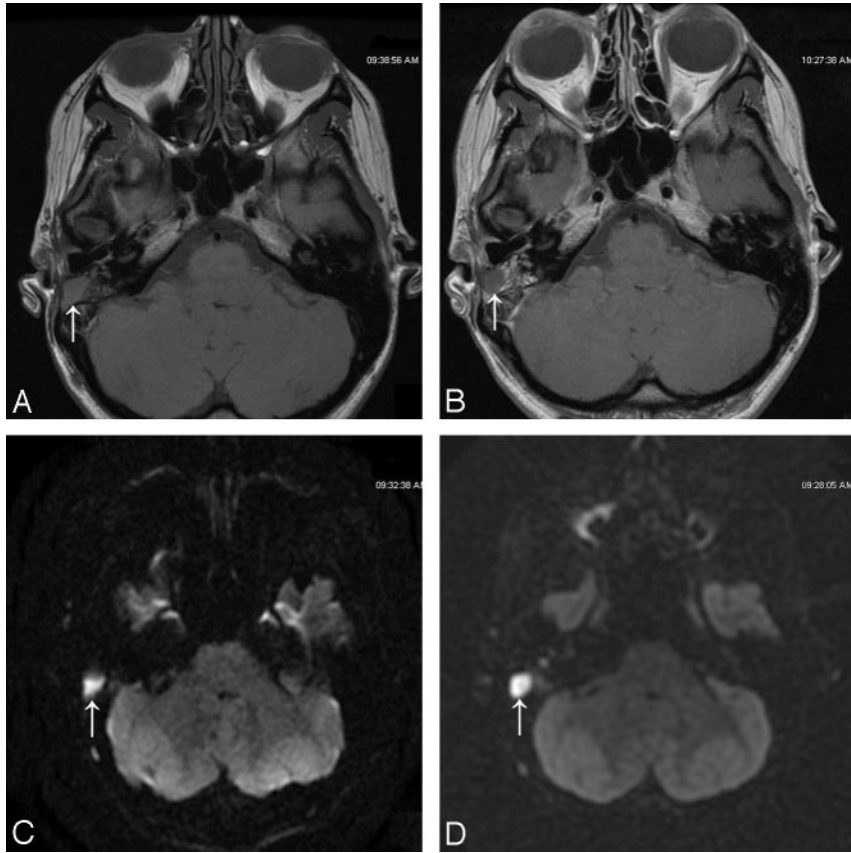


Fig 1. Recurrent cholesteatoma (white arrow). *A*, Unenhanced T1-weighted image with low signal intensity. *B*, Delayed contrast-enhanced T1-weighted image with no change in signal intensity; *C* and *D*, Echo-planar DWI (*C*) and PROPELLER DWI (*D*) show high signal intensity with more artifacts on the echo-planar DWI (*C*).

seconds), and axial PROPELLER DWI (TR, 6000 ms; TE, 123 ms; bandwidth, 83.3 kHz; matrix, 128×128 ; FOV, 24 cm; section thickness, 3 mm; intersection gap, 0 mm; NEX, 2; $b=800$; 13 sections; duration, 4 minutes 30 seconds). The difference in in-plane resolution between the 2 diffusion sequences was selected to limit the time for the PROPELLER sequences: axial SE T1-weighted postgadolinium (0.1 mmol/kg) and late axial SE T1-weighted postgadolinium (at least 45 minutes after contrast injection) with the same parameters as axial SE T1-weighted imaging. One patient was an 8-year-old boy who was not able to stay in the MR imaging unit; he had only PROPELLER DWI. Another patient refused contrast injection.

MR Imaging Analysis

Three radiologists (2 seniors, 1 fellow) working independently analyzed unlabeled ASSET echo-planar DWI and PROPELLER DWI (only $b=800$; apparent decreased coefficient was not used) and SE T1-weighted imaging before and after contrast injection by using a workstation (Advantage Windows, GE Healthcare). Sequences were presented to the readers in a random order but not at different times. Observers assessed images for visualization of cholesteatoma. Recurrent cholesteatoma was diagnosed if the lesion had low signal intensity on unenhanced T1-weighted images, showed no change in signal intensity on delayed contrast-enhanced T1-weighted images, and had high signal intensity on DWIs obtained with a b factor of 800 s/mm^2 (Fig 1). When applicable, the surgical results were classified as recurrence of cholesteatoma or no recurrence of cholesteatoma; if not, the standard was a consensus opinion based on the aggregate of the imaging and clinical data.

Statistical Analyses

For each observer, agreement between ASSET echo-planar DWI, PROPELLER DWI, and T1-weighted sequences was assessed by using the Cohen κ coefficient test. Interobserver agreement for each of the echo-planar DWI, PROPELLER DWI, and T1-weighted sequences was assessed by using the Cohen κ coefficient test. Results of κ tests were referred to the Landis and Koch classification. Sensitivity, specificity, and positive and negative predictive values (PPV, NPV) were evaluated on the basis of a consensus opinion based on the aggregate of the imaging and clinical data. Statistical difference was assessed by the χ^2 test.

Results

Detection of Recurrent Cholesteatoma

Our analysis of CT, MR imaging, clinical examination, and surgical findings (when applicable) concluded that there was no recurrence for 16 patients who were not treated. Nineteen recurrent cholesteatomas were diagnosed.

Interobserver Agreement

The agreement between senior1/senior2, senior1/fellow, and senior2/fellow was as follows respectively: very good (0.82), good (0.68), and good (0.61) for ASSET echo-planar DWI; very good (1), very good (0.89), and very good (0.89) for PROPELLER DWI; and good (0.69), good (0.69), and good (0.63) for T1-weighted imaging.

Sensitivity, specificity, PPV, NPV, and P value for the 3 observers

	Sensitivity (%)			Specificity (%)			PPV (%)			NPV (%)			P Value		
	S1	S2	F	S1	S2	F	S1	S2	F	S1	S2	F	S1	S2	F
EPI	33.3	38.9	44.4	100.0	100.0	87.5	100.0	100.0	80.0	57.1	59.3	58.3	≤0.02	≤.01	≤.05
PROP	100.0	100.0	89.5	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	88.9	≤0.001	≤.001	≤.001
T1	94.1	88.2	88.2	93.7	68.7	81.2	94.1	75.0	83.3	93.7	84.6	86.7	≤0.001	≤.001	≤.001

Note:—EPI indicates ASSET echo-planar DWI; PROP, PROPELLER DWI; T1, T1-weighted imaging; S1, senior1; S2, senior2; F, fellow; PPV, positive predictive value; NPV, negative predictive value.

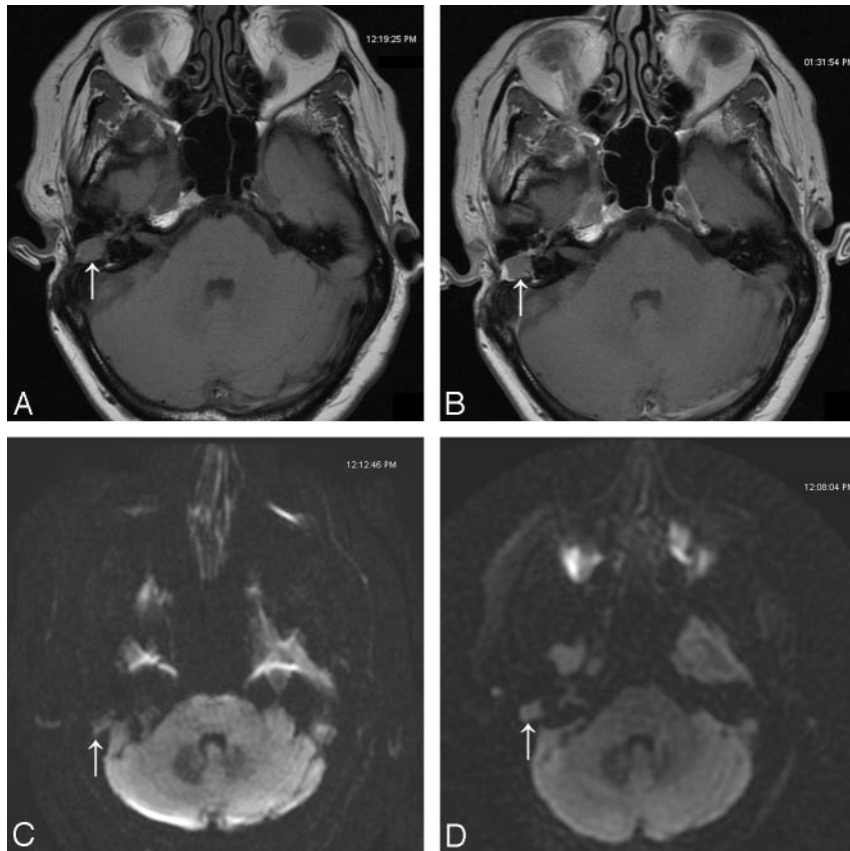


Fig 2. Patient 5 with a wrong diagnosis on delayed contrast-enhanced T1-weighted imaging. No recurrence of cholesteatoma was histologically proved (white arrow). *A*, Unenhanced T1-weighted image shows low signal intensity. *B*, Delayed contrast-enhanced T1-weighted image shows no change in signal intensity. *C* and *D*, Echo-planar DWI (*C*) and PROPELLER DWI (*D*) confirm no recurrence of cholesteatoma. Note the low signal intensity on DWI with more artifacts (*C*).

Intraobserver Agreement

The agreement between ASSET echo-planar DWI/T1-weighted imaging, ASSET echo-planar DWI/PROPELLER DWI, and PROPELLER DWI/T1-weighted imaging was as follows respectively: fair (0.35), fair (0.32), and very good (0.88) for senior1; fair (0.25), fair (0.37), and moderate (0.57) for senior2; and poor (0.18), fair (0.28), and moderate (0.58) for the fellow.

Sensitivity, specificity, PPV, and NPV are displayed in the Table.

PROPELLER provides the most sensitivity, specificity, PPV, and NPV for all the observers with a significant difference. Echo-planar imaging provides better specificity and PPV than T1-weighted imaging. T1-weighted imaging provides better sensitivity and NPV than echo-planar imaging.

Comparison of MR Imaging and Surgery

Nine patients were closely followed to monitor the growth and extension of the cholesteatoma. For 10 patients, a second- or

third-look surgery was performed. Final diagnosis was recurrence for 9 patients (Fig 1) and no recurrence for 1 (Fig 2). For these 10 patients, PROPELLER DWI findings were similar for the 3 radiologists, and axial SE T1-weighted imaging findings were similar for the 2 seniors. PROPELLER DWI was concordant with surgery. For patient 5 (Fig 2), the 3 radiologists agreed that T1-weighted imaging was discordant with surgery, describing a recurrent lesion with low signal intensity on an unenhanced image and no change in signal intensity on a delayed contrast-enhanced image.

Discussion

In this study, we compared PROPELLER multishot fast spin-echo DWI with ASSET echo-planar DWI and found that PROPELLER MR imaging offered improvement in both image quality and detection of recurrent cholesteatoma.

PROPELLER^{11,12} is a multishot fast SE acquisition and is based on a rotating *k*-space acquisition. Rather than going at it line by line, *k*-space is filled with an arrangement of “blades.”

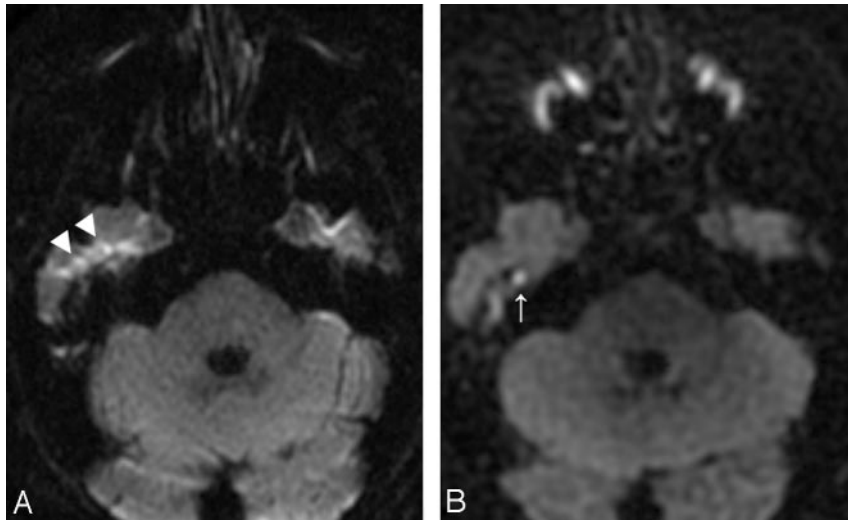


Fig 3. Recurrent cholesteatoma. *A*, Echo-planar DWI shows artifacts (*double arrowhead*) masking the recurrence. *B*, PROPELLER DWI shows small attic recurrent cholesteatoma (*white arrow*).

These blades are rotated in *k*-space at incremental angles. This method results in an oversampling of the center of the *k*-space, providing a more signal-intensity-rich image. The radial trajectory of the blades removes structured motion artifacts, and redundant sampling enables the reduction of bulk patient motion artifacts.

The ability of PROPELLER to reduce motion effectively (on T2-weighted PROPELLER fast spin-echo sequences) and susceptibility (on DWI PROPELLER fast spin-echo sequences) artifacts hinges, in large part, on the amount of data collected during a PROPELLER scanning. The redundant data collected in the center of *k*-space make it possible for PROPELLER to perform several correction steps before final image reconstruction. After the initial signal intensity is obtained, PROPELLER executes fast spin-echo phase correction. Then the program performs 3 additional correction steps: rotation correction, translation correction, and correlation weighting.

Detection of Recurrent Cholesteatoma

The importance of DWI in the detection of recurrent cholesteatoma has been reported in several previous studies with a 1.5T imaging unit.^{4,6-8,13-16} In these studies, sensitivity was evaluated between 77% and 100%; specificity, 91% and 100%; PPV, 93% and 100%; NPV, 75% and 100%. Our values are similar on the 3T imaging unit. Cholesteatoma has high signal intensity on DWIs obtained with b factors of 800 or 1000 s/mm², whereas granulation tissue has low signal intensity. Results of previous studies^{4,16} have proved that visual comparison of DWIs obtained with a b factor of 800 s/mm² without measurement of the apparent diffusion coefficient is sufficient for analysis of the DWI sequence. PROPELLER DWI presented the best agreement of the 3 sequences for the 3 observers (very good for all). It also provided the best sensitivity, specificity, PPV, and NPV for all observers.

On a 3T imaging unit, PROPELLER DWI allows an easier interpretation in 2 main ways: First, diffusion imaging presents a better contrast than T1-weighted imaging and the cholesteatoma hypersignal is easier to detect; second, PROPELLER DWI reduces artifacts. On a 3T MR imaging unit, artifacts

are present much more often than on a 1.5T imaging unit.¹⁷ The ability of DWI to be used consistently to evaluate the temporal bone is hindered by image distortion caused by susceptibility artifacts, chemical-shift artifacts, and ghosts in the phase-encoding direction. This is due to the high bone attenuation of the inner ear and the numerous air-bone interfaces present within the mastoid air cells and the middle ear cavity. With PROPELLER MR imaging, the marked reduction in off-resonance artifacts is primarily caused by the type of sequence (fast SE): Fast SE imaging is less sensitive to changes in the constant magnetic induction field, because of multiple 180° refocusing pulses. Reduction of susceptibility artifacts is particularly important for adequate visualization of the middle ear (Fig 3).

PROPELLER DWI presents a better contrast and reduces artifacts. These points can explain the agreements obtained. Several studies based on morphologic sequences (T1, T2, and T1 with contrast injection) without diffusion imaging¹⁸⁻²⁰ report a sensitivity between 57% and 79% and a specificity between 63% and 71%. These results and the fact that T1-weighted imaging is a more difficult sequence to read explain the intraobserver agreement; only the senior1 (who practices ear, nose, and throat imaging regularly) reported a very good agreement between PROPELLER DWI and T1-weighted imaging.

ASSET echo-planar DWI resulted in a good or very good interobserver agreement and a good specificity and PPV because of the good contrast of diffusion imaging, which helps the detection, but artifacts produced by ASSET echo-planar imaging explain the fair or moderate intraobserver agreement and the worst specificity and NPV due to the number of lesions not seen.

The smallest recurrent cholesteatoma diagnosed measured 3 mm and was surgically proved.

For the 10 patients with a radiosurgical comparison, PROPELLER DWI had a correct diagnosis for the 3 observers, whereas T1-weighted imaging resulted in a misdiagnosis of a recurrence. The specificity of T1-weighted imaging has already been described.³ In these cases, PROPELLER DWI

seems to be more specific, but this hypothesis needs more patients to be validated.

On the other hand, PROPELLER DWI allows only axial sections, which do not provide the best visualization of the tegmen region. Compared with ASSET echo-planar DWI, PROPELLER DWI increases imaging time (56 seconds versus 4 minutes 30 seconds), which can lead motion artifacts.

Conclusions

On a 3T imaging unit, multishot fast SE PROPELLER DWI results in an easier detection of postoperative recurrent middle ear cholesteatoma by reducing artifacts, and it has better contrast than T1-weighted imaging. DWI with PROPELLER is diagnostically robust and accurate with less interobserver variability and provides the highest sensitivity, specificity, PPV, and NPV.

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