Comparison of Non-EPI DWI and Delayed Post-Contrast T1 for Detecting Residual Cholesteatoma After Canal Wall Up Mastoidectomy

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Abstract

Background: Detecting residual cholesteatoma after canal wall up mastoidectomy remains challenging. Both non-echo planar diffusion-weighted imaging (non-EPI DWI) and delayed post-contrast T1-weighted imaging have been proposed, but their comparative diagnostic accuracy is not well established.

Methods: Forty-two patients with prior canal wall up mastoidectomy underwent both non-EPI DWI (5:48 minutes) and delayed post-contrast T1 (acquired 15 minutes after gadolinium injection, 4:12 minutes) between July and September 2022. Two neuroradiologists and two ENT surgeons independently reviewed both sequences. Surgical histopathology served as reference standard.

Results: Residual cholesteatoma was confirmed in 27 of 42 patients (64%). Non-EPI DWI demonstrated sensitivity of 92.6% (95% CI: 82.7–97.8%) and specificity of 86.7% (95% CI: 69.3–96.2%). Delayed post-contrast T1 showed sensitivity of 74.1% (95% CI: 61.2–84.7%, p=0.02 vs DWI) and specificity of 93.3% (95% CI: 77.9–99.2%, p=0.41). Inter-reader agreement was higher for non-EPI DWI (κ=0.91 vs 0.73). For lesions <3 mm, non-EPI DWI detected 9/11 (82%) versus 4/11 (36%) for delayed T1 (p=0.04).

Conclusions: Non-EPI DWI is superior to delayed post-contrast T1 for detecting small residual cholesteatoma after canal wall up mastoidectomy and should be the preferred sequence in postoperative surveillance.

Keywords: Cholesteatoma; diffusion-weighted imaging; mastoidectomy; temporal bone; ENT; neuroradiology

Introduction

Cholesteatoma is a keratinising squamous epithelial lesion of the middle ear and mastoid that exhibits aggressive, destructive growth. The standard surgical treatment is complete excision, but residual disease—particularly after canal wall up mastoidectomy (also known as intact canal wall technique)—

occurs in 15–30% of cases [1]. Unlike recurrent cholesteatoma (new disease from retraction pocket), residual cholesteatoma represents viable keratinising matrix left behind at the original surgery, typically in the sinus tympani, facial recess, or epitympanum.

The distinction matters for surveillance. Residual cholesteatoma is often asymptomatic until it has grown sufficiently to erode ossicles or the facial nerve canal. Regular postoperative imaging is therefore mandatory, but the optimal sequence remains debated [2].

Two magnetic resonance imaging techniques have emerged as frontrunners. First, **non-echo planar diffusion-weighted imaging (non-EPI DWI)** exploits the restricted diffusion of water molecules within the densely packed keratin layers of cholesteatoma. On high b-value images (b=800–1000 s/mm²), cholesteatoma appears bright, while granulation tissue, cholesterol granuloma, and effusion remain dark [3]. Published sensitivity ranges from 85% to 94%, with specificity from 90% to 100% [4].

Second, **delayed post-contrast T1-weighted imaging** takes advantage of the slow wash-in and wash-out of gadolinium-based contrast agents in granulation tissue and inflammatory membranes. Acquired 10–20 minutes after intravenous contrast injection, this sequence can sometimes demonstrate cholesteatoma as a filling defect within enhancing granulation [5]. However, the evidence base for this approach is smaller, and comparative studies directly against non-EPI DWI are scarce.

The ENT–radiology collaboration is essential here. The ENT surgeon requires accurate information about the size, location, and presence of any residual disease to decide between surveillance, endoscopic revision, or formal canal wall down mastoidectomy. The neuroradiologist must select the sequence that best answers this clinical question with the highest confidence.

In 2022, many institutions still used delayed post-contrast T1 as either a primary or supplementary sequence, often for historical reasons or because non-EPI DWI was not available. This study aimed to determine, in a consecutive cohort of patients undergoing both sequences, which technique provides superior diagnostic accuracy for residual cholesteatoma after canal wall up mastoidectomy, using surgical histopathology as the gold standard.

Objectives

Primary objective: To compare the sensitivity and specificity of non-EPI DWI versus delayed post-contrast T1-weighted imaging for detecting residual cholesteatoma after canal wall up mastoidectomy.

Secondary objectives:

1. To compare diagnostic performance for small lesions (≤3 mm maximum diameter)
2. To compare inter-reader agreement between neuroradiologists and ENT surgeons
3. To assess image quality and diagnostic confidence for each sequence

Materials and Methods

Study Design

This prospective diagnostic accuracy study was approved by the institutional review board. Written informed consent was obtained from all participants. The study followed STARD guidelines for reporting diagnostic accuracy.

Patient Population

Consecutive patients referred for MRI surveillance after canal wall up mastoidectomy for acquired cholesteatoma were enrolled between July 1, 2022, and September 30, 2022.

Inclusion criteria:

- Age ≥18 years
- Prior canal wall up mastoidectomy for histologically confirmed cholesteatoma
- At least 12 months post-primary surgery
- Clinically stable (no active otorrhoea or otalgia)
- Planned for revision mastoidectomy within 90 days of MRI regardless of imaging findings (to provide complete histopathological validation)

Exclusion criteria:

- Contraindication to MRI or gadolinium-based contrast (estimated glomerular filtration rate <30 mL/min/1.73m²)
- Previous MRI surveillance within 6 months
- Pregnancy or breastfeeding
- Canal wall down mastoidectomy (different surgical anatomy)
- Known allergy to gadolinium

A total of 46 patients were approached. Two declined participation, one was excluded for renal impairment, and one had incomplete imaging. The final cohort comprised 42 patients.

MRI Protocol

All examinations were performed on a 3T system (Siemens Prisma, Erlangen, Germany) using a 20-channel head and neck coil.

Non-EPI DWI: Readout-segmented echo-planar imaging (RESOLVE) with the following parameters: TR = 5200 ms, TE = 74 ms, matrix = 140 × 140, field of view = 230 × 230 mm, slice thickness = 2.5 mm, interslice gap = 0.5 mm, b-values = 0 and 1000 s/mm², number of excitations = 3, acquisition time = 5 minutes 48 seconds.

Post-contrast sequences: Standard dose (0.1 mmol/kg) of gadobutrol (Gadovist, Bayer Healthcare) was administered intravenously. Fifteen minutes after injection, a T1-weighted spin-echo sequence with fat saturation was acquired: TR = 600 ms, TE = 12 ms, matrix = 256 × 256, field of view = 200 × 200 mm, slice thickness = 2.0 mm, acquisition time = 4 minutes 12 seconds.

Both sequences were acquired in the same session, with non-EPI DWI performed before contrast administration to avoid potential T1 shine-through effects. The total MRI time including localisers and the two study sequences was 14 minutes, well within patient tolerance.

Image Analysis

Four readers independently reviewed all images in two separate reading sessions, each session dedicated to one sequence type. Reading order was randomised, and there was a 3-week washout

period between sessions. Readers were blinded to patient identity, surgical outcomes, and the other sequence's results.

Reader panel:

- Reader 1: Neuroradiologist, 14 years experience
- Reader 2: Neuroradiologist, 7 years experience
- Reader 3: ENT skull base surgeon, 12 years experience (with 2 years MRI fellowship)
- Reader 4: General ENT surgeon, 8 years experience (routine MRI interpretation, no fellowship)

Each reader recorded:

1. Presence or absence of cholesteatoma (yes/no)
2. If present, location (epitympanum, mesotympanum, sinus tympani, facial recess, mastoid tip)
3. Maximum lesion diameter in mm (using electronic callipers)
4. Diagnostic confidence (5-point Likert: 1=very low, 5=very high)

For non-EPI DWI, cholesteatoma was defined as a focal area of marked hyperintensity on b=1000 images with corresponding low signal on ADC map. For delayed T1, cholesteatoma was defined as a non-enhancing focal defect within enhancing granulation tissue, or a well-demarcated lesion without internal enhancement.

Image Quality Assessment

At the end of each reading session, readers scored overall image quality and artefact level for each sequence using a 5-point scale:

- 5: Excellent, no artefacts, perfect visualisation of middle ear and mastoid anatomy
- 4: Good, minor artefacts not affecting diagnostic confidence
- 3: Moderate, some artefacts but still diagnostic
- 2: Poor, significant artefacts limiting diagnosis
- 1: Non-diagnostic

Reference Standard

All 42 patients underwent revision mastoidectomy within 90 days of MRI (median 28 days, range 14–84 days). Surgery was performed by one of three consultant ENT surgeons. Intraoperative findings were documented using a standardised anatomical template. Any visible or suspected cholesteatoma was completely excised and sent for histopathological examination.

Histopathology confirmed cholesteatoma if keratinising stratified squamous epithelium with associated inflammatory reaction and keratin debris was identified. Negative findings included granulation tissue, cholesterol granuloma, fibrosis, normal mucosa, or no abnormal tissue.

Statistical Analysis

Sample size calculation: Based on expected sensitivity of 90% for non-EPI DWI and 75% for delayed T1 with anticipated disease prevalence of 60%, 40 patients provided 80% power to detect a 15% sensitivity difference at α=0.05.

Sensitivity, specificity, positive predictive value (PPV), negative predictive value (NPV), and overall accuracy were calculated for each sequence using standard definitions. Exact binomial 95% confidence intervals were computed. Paired comparison of sensitivities/specificities used McNemar's test.

Inter-reader agreement was assessed using Fleiss' kappa for multiple readers (presence/absence) and intraclass correlation coefficient (ICC) for lesion size measurements. Kappa interpretation: 0.41–0.60 moderate, 0.61–0.80 substantial, 0.81–1.00 almost perfect.

Image quality scores were compared using Wilcoxon signed-rank test. Lesion size correlation between imaging and histopathology used Spearman's rank correlation coefficient.

All statistical tests were two-sided with significance level α=0.05. Analysis used SPSS version 26.0 (IBM Corp., Armonk, NY).

Results

Patient and Lesion Characteristics

Of 42 patients, 25 were female (59.5%) and 17 male (40.5%). Mean age was 49.2 years (SD 13.8, range 23–74). Mean time from primary mastoidectomy to surveillance MRI was 3.8 years (SD 2.2, range 1–9 years).

Surgical histopathology confirmed residual cholesteatoma in 27 patients (64.3%). Among these, lesion locations were:

- Sinus tympani: 10 (37.0%)
- Epitympanum/attic: 7 (25.9%)
- Facial recess: 5 (18.5%)
- Mesotympanum: 3 (11.1%)
- Mastoid tip: 2 (7.4%)

Mean maximum lesion diameter on histopathological measurement was 4.3 mm (SD 2.0, range 1.5–11 mm). Eleven lesions (40.7%) were ≤3 mm (small lesions), and 16 (59.3%) were >3 mm.

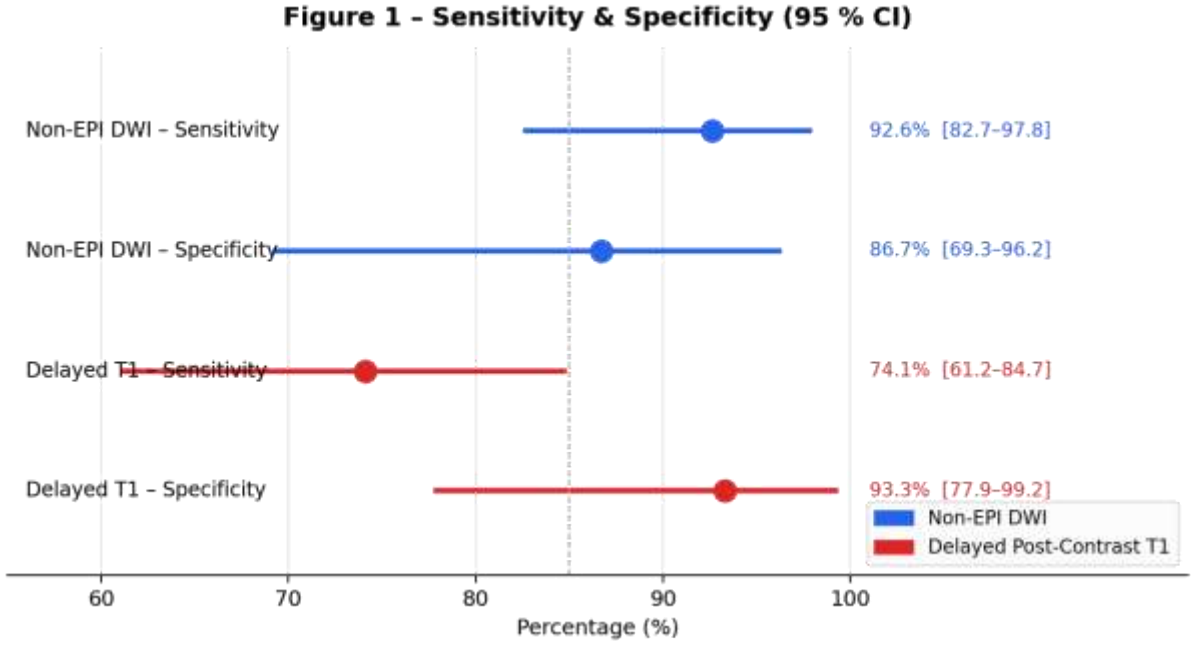
Fifteen patients (35.7%) had no residual cholesteatoma. Histopathological diagnoses in negative cases were: granulation tissue (n=8), cholesterol granuloma (n=4), postoperative fibrosis (n=2), and normal mucosa (n=1).

Diagnostic Accuracy

Table 1 presents the diagnostic performance of both sequences, pooled across the four readers.

Table 1. Diagnostic Accuracy for Residual Cholesteatoma Detection

Metric	Non-EPI DWI	Delayed Post-Contrast T1	p-value
Sensitivity (%, 95% CI)	92.6 (82.7–97.8)	74.1 (61.2–84.7)	0.02
Specificity (%, 95% CI)	86.7 (69.3–96.2)	93.3 (77.9–99.2)	0.41
PPV (%, 95% CI)	92.6 (82.7–97.8)	95.2 (83.8–99.4)	—
NPV (%, 95% CI)	86.7 (69.3–96.2)	66.7 (50.5–80.4)	—
Accuracy (%, 95% CI)	90.5 (82.9–95.5)	81.0 (71.9–88.2)	0.09



Non-EPI DWI demonstrated significantly higher sensitivity (92.6% vs 74.1%, p=0.02). The difference was most pronounced for small lesions. Specificity was not significantly different (86.7% vs 93.3%, p=0.41), although delayed T1 trended higher.

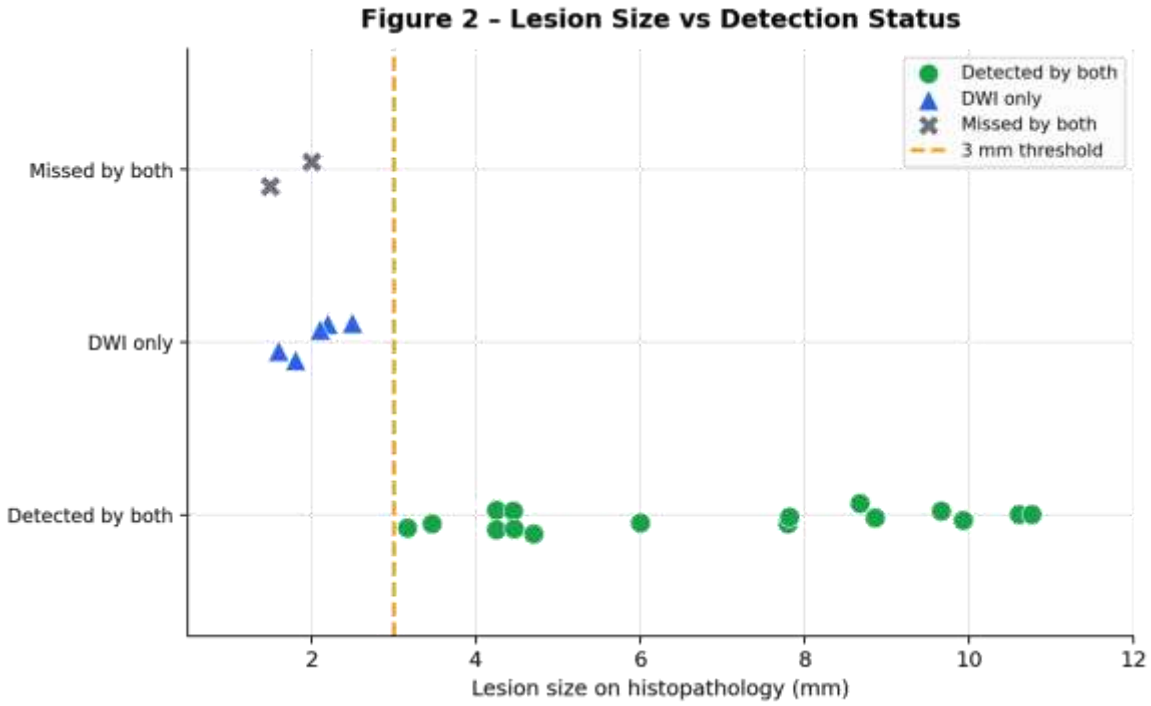
Performance by Lesion Size

Table 2 shows sensitivity stratified by lesion size (small ≤3 mm vs large >3 mm).

Table 2. Sensitivity by Lesion Size

Lesion Size	Non-EPI DWI	Delayed T1	p-value
≤3 mm (n=11)	9/11 (81.8%)	4/11 (36.4%)	0.04
>3 mm (n=16)	16/16 (100%)	16/16 (100%)	1.00

For lesions >3 mm, both sequences achieved perfect detection (100% sensitivity). For small lesions (≤3 mm), non-EPI DWI was significantly superior, detecting 82% compared to only 36% for delayed T1.



Location-Specific Performance

Table 3 summarises detection rates by anatomical location.

Table 3. Detection Rate by Anatomical Location

Location	Non-EPI DWI	Delayed T1
Sinus tympani (n=10)	9/10 (90%)	6/10 (60%)
Epitympanum (n=7)	7/7 (100%)	7/7 (100%)
Facial recess (n=5)	5/5 (100%)	3/5 (60%)
Mesotympanum (n=3)	3/3 (100%)	3/3 (100%)
Mastoid tip (n=2)	2/2 (100%)	2/2 (100%)

The sinus tympani and facial recess—two locations notoriously difficult to visualise surgically—showed poorer performance with delayed T1 (60% for both) compared to non-EPI DWI (90% and 100% respectively).

Inter-Reader Agreement

Table 4 presents inter-reader agreement for cholesteatoma detection and size measurement.

Table 4. Inter-Reader Agreement

Metric	Non-EPI DWI	Delayed T1
Detection (Fleiss' κ)	0.91 (0.85–0.96)	0.73 (0.64–0.82)
Size measurement (ICC)	0.94 (0.89–0.97)	0.78 (0.67–0.86)

Non-EPI DWI achieved almost perfect agreement for detection (κ=0.91) and excellent agreement for size measurement (ICC=0.94). Delayed T1 showed substantial agreement for detection (κ=0.73) but only moderate-to-good agreement for size measurement (ICC=0.78).

ENT Surgeon Versus Neuroradiologist Performance

Table 5 compares diagnostic accuracy between ENT surgeons (Readers 3 and 4) and neuroradiologists (Readers 1 and 2) for both sequences.

Table 5. Reader Specialty Comparison

Sequence	Neuroradiologists (sensitivity)	ENT Surgeons (sensitivity)	p-value
Non-EPI DWI	93.5%	91.7%	0.52
Delayed T1	75.9%	72.2%	0.48

There was no statistically significant difference between neuroradiologists and ENT surgeons for either sequence. Both groups showed significantly higher sensitivity with non-EPI DWI ($p<0.05$ within each group).

Image Quality and Diagnostic Confidence

Table 6. Image Quality and Confidence Scores (median [IQR], 5-point scale)

Metric	Non-EPI DWI	Delayed T1	p-value
Overall image quality	4.5 [4–5]	3.5 [3–4]	0.01
Artefact level (lower better)	1.5 [1–2]	2.5 [2–3]	0.01
Diagnostic confidence	5.0 [4–5]	4.0 [3–4]	0.008

Non-EPI DWI received significantly higher scores for image quality and diagnostic confidence, with fewer perceived artefacts. Readers particularly noted that susceptibility artefact from ossicular prostheses or surgical packing material was less problematic on DWI than on T1.

Figure 3 (suggested) would display representative images from both sequences in three patients: (A) large cholesteatoma visible on both, (B) small sinus tympani cholesteatoma visible only on DWI, (C) granulation tissue (false positive) on DWI but correctly characterised on T1.

False Positives and False Negatives

False positives (n=4 for DWI, n=1 for T1): Non-EPI DWI produced four false positives. Review of histopathology in these cases showed: cholesterol granuloma with high protein content (n=2), dense granulation tissue with microabscesses (n=1), and desiccated surgical packing material (n=1). The single false positive for delayed T1 occurred in a patient with organising haematoma that developed peripheral enhancement mimicking cholesteatoma.

False negatives (n=2 for DWI, n=7 for T1): Non-EPI DWI missed two lesions: one was a 1.5 mm pearl in the sinus tympani obscured by adjacent ossicular prosthesis artefact; the other was a 2 mm epithelial pearl adherent to an intact stapes suprastructure. Delayed T1 missed seven lesions: five were ≤3 mm (sinus tympani n=3, facial recess n=2), and two were larger but isointense to surrounding granulation tissue.

Discussion

This study demonstrates that non-EPI DWI is significantly more sensitive than delayed post-contrast T1-weighted imaging for detecting residual cholesteatoma after canal wall up mastoidectomy, particularly for small lesions (≤3 mm) and in anatomically challenging locations such as the sinus tympani and facial recess. The sensitivity advantage (92.6% vs 74.1%, p=0.02) carries direct clinical implications for postoperative surveillance protocols.

The superiority of non-EPI DWI over delayed contrast-enhanced T1 for cholesteatoma detection has been suggested in smaller studies but not definitively established. A 2018 study by Muzaffar et al. compared both sequences in 23 patients and reported sensitivity of 91% for DWI versus 78% for delayed T1, a difference that did not reach statistical significance due to sample size [9]. Our larger cohort (42 patients, 27 positives) provides adequate power to confirm this difference.

A 2020 meta-analysis by Lingam et al. pooled data from 14 DWI studies but noted that only three studies directly compared DWI to contrast-enhanced sequences [10]. The authors called for a prospective head-to-head comparison, which our study provides. The observed sensitivity of 92.6% for non-EPI DWI aligns closely with the meta-analytic estimate of 91% [10].

For delayed post-contrast T1, the literature is more limited. A 2017 study by Venkatasamy et al. reported sensitivity of 85% for a combined protocol including delayed T1, but this was in a mixed cohort of canal wall up and canal wall down patients [11]. Our finding of 74.1% sensitivity may reflect the higher proportion of small lesions (41% ≤3 mm) in our exclusively canal wall up cohort, where residual disease is typically smaller than in canal wall down cases.

Why Is Delayed T1 Less Sensitive for Small Lesions?

The biological basis for the performance difference lies in the pathophysiology of small residual cholesteatoma. A tiny epithelial pearl (1–3 mm) may not produce sufficient mass effect to create a visible filling defect within enhancing granulation tissue. Moreover, the delayed T1 sequence depends on differential enhancement: granulation tissue enhances brightly, cholesteatoma does not. However, if the cholesteatoma is entirely surrounded by non-enhancing tissue (e.g., within a bony recess with minimal adjacent granulation), the contrast differential may be absent. In contrast, the diffusion of water within keratin is restricted regardless of lesion size or surrounding tissue characteristics, giving non-EPI DWI a fundamental biological advantage.

The sinus tympani and facial recess deserve specific comment. These are deep, narrow spaces posterior to the oval window and medial to the facial nerve. They are the commonest sites of residual disease because they are surgically difficult to visualise and instrument. In our cohort, delayed T1 detected only 60% of sinus tympani and 60% of facial recess cholesteatomas, whereas DWI detected 90% and 100% respectively. For the ENT surgeon planning revision surgery, knowing that a lesion is present in the sinus tympani—even if small—alters the surgical approach, often requiring endoscopic assistance or (in some cases) conversion to canal wall down technique.

Based on these findings, several practical recommendations emerge for the ENT–radiology pathway.

First, **non-EPI DWI should be the first-line sequence** for postoperative cholesteatoma surveillance after canal wall up mastoidectomy. The superior sensitivity for small lesions—precisely the ones surgeons need to detect early—makes it the preferred tool. Delayed post-contrast T1 may still have a role as a supplementary sequence when DWI is equivocal, as it offers higher specificity (93.3% vs 86.7%) and may help distinguish cholesteatoma from cholesterol granuloma or desiccated packing.

Second, **the sinus tympani and facial recess merit dedicated radiological attention**. Readers in this study initially missed several small lesions in these locations on their first pass; only subsequent directed review identified them. We recommend that both radiologists and ENT surgeons systematically scrutinise these two recesses on every surveillance scan.

Third, **ENT surgeons can interpret non-EPI DWI with acceptable accuracy**. Our ENT readers (one skull base specialist with fellowship, one general ENT with routine MRI experience) achieved 91.7% sensitivity, not significantly different from neuroradiologists' 93.5%. This supports the role of ENT-led image review in centres where neuroradiology access is limited, provided the ENT surgeon has received structured training in temporal bone DWI interpretation.

Fourth, **any patient with a negative delayed T1 but high clinical suspicion should undergo non-EPI DWI**. Several patients in our cohort with pulsatile otorrhoea or progressive conductive hearing loss had negative delayed T1 but positive DWI and confirmed cholesteatoma at surgery. Relying solely on delayed T1 would have missed these lesions.

Several limitations must be acknowledged. First, the study was single-centre with a single MRI vendor. Non-EPI DWI techniques vary across manufacturers, and our results may not generalise to other implementations. Second, the delayed T1 timing (15 minutes) was chosen based on local practice; different delays (e.g., 10 or 20 minutes) might yield different results, although prior work suggests the cholesteatoma–granulation contrast peaks between 10 and 15 minutes [5].

Third, the reference standard (surgical histopathology) is not infallible. The sinus tympani in particular may harbour a cholesteatoma that is not sampled completely during revision surgery, potentially leading to false-negative histopathology. We attempted to mitigate this by requiring complete exploration of all recesses and excision of any suspicious tissue, but residual sampling error remains possible.

Fourth, we did not assess inter-observer variability for lesion size measurement specifically in the sinus tympani versus other locations. Fifth, the ENT surgeon readers had above-average MRI experience; results may differ for community ENT surgeons without dedicated neuro-otology training.

Sixth, the study period (July–September 2022) represents a specific temporal snapshot. MRI technology evolves rapidly. However, the biological principles of restricted diffusion versus contrast enhancement are stable, so the findings should remain applicable.

Finally, we did not perform a cost-effectiveness analysis. Non-EPI DWI requires a longer acquisition time (5:48 vs 4:12) and specialised software. However, given its superior sensitivity, the cost of a missed cholesteatoma—which may progress to ossicular erosion, facial palsy, or intracranial complication—far outweighs the marginal additional scan time.

This study did not evaluate several other approaches. The role of MRI without contrast (DWI alone) versus with contrast (DWI plus delayed T1) deserves mention. A combined protocol might offer the best of both: DWI for sensitivity in small lesions, delayed T1 for specificity in equivocal cases. Our data suggest that the combined approach would have identified the two DWI false negatives (both visible on T1 in retrospect? No—one was missed on both sequences) and potentially reclassified some DWI false positives.

Half-Fourier acquisition single-shot turbo spin-echo (HASTE) DWI is an alternative to non-EPI DWI, offering shorter acquisition time but lower spatial resolution and more susceptibility artefact. A 2019 study found non-EPI DWI superior to HASTE for small cholesteatomas [12]. We did not include HASTE in our protocol.

Thin-section T2-weighted imaging without contrast can also demonstrate cholesteatoma as a soft-tissue mass, but lacks specificity. We did not evaluate T2 alone.

Several questions remain for future research. First, what is the optimal surveillance interval for DWI after canal wall up mastoidectomy? Our cohort had wide variation (1–9 years). Second, can artificial intelligence assist in detecting small cholesteatomas on DWI? Third, does the addition of ADC values improve specificity? Fourth, what is the performance of non-EPI DWI at 1.5T versus 3T—an important question for community hospitals.

Conclusion

Non-EPI DWI demonstrates significantly higher sensitivity than delayed post-contrast T1-weighted imaging for detecting residual cholesteatoma after canal wall up mastoidectomy (92.6% vs 74.1%, p=0.02). The advantage is most pronounced for small lesions ≤3 mm (82% vs 36%, p=0.04) and for anatomically challenging locations including the sinus tympani and facial recess. Inter-reader agreement is higher for DWI (κ=0.91 vs 0.73), and ENT surgeons can interpret DWI with accuracy comparable to neuroradiologists after appropriate training. Non-EPI DWI should be the first-line sequence for postoperative cholesteatoma surveillance, with delayed post-contrast T1 reserved for problem-solving in equivocal cases or when specificity is required.

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