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The Use of Non-EPI DWI MRI Scanning in the Management of Cholesteatoma

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Authors' contributions

This work was carried out in collaboration between both authors. Author WKS designed the study, performed the statistical analysis, wrote the protocol, and wrote the first draft of the manuscript. Author HKS managed the analysis of the study, managed the literature searches and contributed to the final manuscript. Both authors read and approved the final manuscript.

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ABSTRACT

Non-EPI DWI MRI scanning is now an established post-operative investigation in the management of patients treated for cholesteatoma with studies even reporting sensitivity and specificity of up to 100% [1-5]. Following the introduction of endoscopic tympanoplasty, the use of these scans pre-operatively has been adopted to determine the extent and location of cholesteatoma; this operative technique is suitable for cholesteatomas confined to the middle ear and attic without extension beyond the posterior limit of the lateral semi-circular canal. This less invasive technique to remove cholesteatoma has become even more important in the era of Covid-19 where the ability to wear adequate PPE whilst using the microscope and high -speed drills remains challenging. The role of these MRI scans to measure growth rate of cholesteatoma and whether all cholesteatomas require surgical removal should be considered. The technique, benefits and limitations of non-EPI DWI MRI scans in managing our patients pre-and post-operatively is discussed.

Keywords: MRI magnetic resonance imaging; cholesteatoma pre-operative; post-operative.

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1. INTRODUCTION

1.1 The MRI Scanning Technique Utilised in the Investigation of Cholesteatoma

The use of Non-echo planar diffusion weighted imaging magnetic resonance imaging (Non-EPI DWI MRI) to detect the presence of cholesteatoma was first described by de Foer in 2006 and since then the application of this technique to clinical practice has developed [6]. A basic understanding of the MRI sequences is required to enable interpretation of the images. Non-EPI DWI MRI uses a specific MRI sequence and software to map the diffusion of water molecules in tissues and by modifying the original DWI technique used to diagnose vascular strokes, the distortion at air/bone interfaces, for example at the skull base was overcome as well as improving the ability to detect smaller cholesteatomas (from 5 mm to 2 mm) [7-9]. The different strengths and gradients applied to generate DWI are assigned b values.

Cholesteatoma which is keratin in nature has a high protein but lower water content is described as demonstrating “restricted diffusion”. It appears highly hyperintense (bright) at high b values but this is perhaps enhanced by the so called T2 shine through effect.

Apparent diffusion coefficient (ADC) values calculated from b800/b1000 minus b0 (which is actually the T2 sequence) are subsequently low (appearing dark) for cholesteatoma [9].

Initially late post-gadolinium T1 was utilised but studies have shown that non-EPI DWI MRI scanning has greater sensitivity and specificity [6,10].

Cholesteatoma appears hyperintense (bright) on T2, mixed intensity on T1W and it does not enhance with gadolinium. For practical and clinical purposes this means that cholesteatoma appears bright on non-EPI DWI MRI but dark on ADC mapping sequences. It is important however to look at more than just the non-EPI DWI MRI sequence to prevent false positive results such as in the presence of cholesterol granuloma and in other situations discussed later in this article [11].

Three manufacturers have developed their own technique of non-EPI DWI scanning with different names and slightly different image clarity. GEs propellar can only scan in the axial plane but images with different b values can be acquired simultaneously reducing the scanning time [4].

High resolution T2 in other planes aids the localisation of lesions Dr de Foer and the team in Antwerp have suggested the technique described in Fig. 1 to image the temporal bone to detect the presence of cholesteatoma. Bo is in fact T2W, B1000 is non-EPI DWI MRI and ADC is calculated using B1000 minus B0 sequences. Gadolinium is not required routinely but is useful in patients with suspected intracranial complications or abscess formation [12]. A short protocol as used in our radiology department is therefore used most of the time.

2. MATERIALS AND METHODS

2.1 Experience of Non-EPI DWI MRI Scanning

Non-EPI DWI MRI scanning has been used in our department since January 2014, initially in the post-operative follow-up of patients who had had combined approach tympanoplasties (CAT) or mastoid obliteration using hydroxyapatite granules and a peri-cranial flap. 154 ears in 150 patients were identified to require post-operative follow-up MRI scans however 13 were lost to follow-up and three patients did not have the scans for various reasons including one patient refusing to have a scan, one had a pacemaker fitted and another had the scan deferred due to pregnancy. 108 ears in 106 patients had scans with no evidence of restricted diffusion (ie. there was no evidence of cholesteatoma). Restricted diffusion was identified in 28 ears in 26 patients (one patient had a further recurrence of cholesteatoma in the same ear, another had bilateral disease). Of these, cholesteatoma has been confirmed at surgery in 13 ears but 3 had false positive scans with wax, cholesterol granuloma and keratin in the ear canal accounting for the appearance on the MRI scans. In one patient subsequent scanning confirmed resolution of the small area of restricted diffusion. 4 patients are awaiting surgery, 6 are being monitored by further MRI scans (since only small disease (2-3mm) was detected or the patient was unfit or unwilling to undergo further surgery) and 1 was lost to follow-up. One patient clinically with an attic pocket with cholesteatoma had a false negative scan.

A number of cases are presented to highlight the role of MRI scans in the management of patients.

3. RESULTS AND DISCUSSION

3.1 Post-Operative Non-Epi Dwi Mri Scanning

Case 1: Fig. 2 is from a 26 year old male who had bilateral cholesteatomas managed with bilateral combined approach tympanoplasties. Patient had right combined approach tympanoplasty stage 2 in November 2017 and a follow up MRI scan 13 months later found a cholesteatoma in the left ear which was removed at combined approach tympanoplasty stage 1 in August 2019.The scans indicate that the right ear had inflammation or scar tissue only.

Case 2: Fig. 3 is from a 30 year old male had a revision mastoidectomy and obliteration using hydroxyapatite granules and pericranial flap the MRI performed at 36 months post-operatively shows that the cholesteatoma is easily differentiated from the granules.

Recently this MRI technique has also been employed in a number of patients pre-operatively. Some examples demonstrating how this investigation affected the management of our patients are presented.

3.2 To Detect the Presence of an Underlying Cholesteatoma in Chronic Suppurative Otitis Media (COM)

Case 3: Fig. 4 demonstrates the scans from a 24 year old female who presented with a 6 year history of discharge from her right ear. She had an anterosuperior perforation and a conductive hearing loss of 20 to 60 dB HL. The CT scan shows opacity in the mastoid which could be due to fluid or soft tissue although there may evidence of some ossicular erosion. T2W scan is hyperintense, T1W mixed intensity, restricted diffusion is evident in both the axial and coronal non-EPI DWI scans with hypointensity as expected for a cholesteatoma on the ADC. The cholesteatoma at surgery is also shown in the expected location.

- **2mm non EPI DWI sequence B0, B1000, ADC (Apparent diffusion coefficient) map**
- **2mm AXIAL +COR TSE T2W sequence**
- **Unenhanced T1W when high signal is seen on B1000 Non EPI DWI image**
- **2mm AXIAL +COR 45' post Gd T1W if possibly infected cholesteatoma or complications present**
- **AXIAL unenhanced 2mm T1 day after to detect cholesterol granuloma.**

Fig. 1. Shows the regime proposed by de Foer et al to detect the presence of cholesteatoma within the temporal bone.[4]

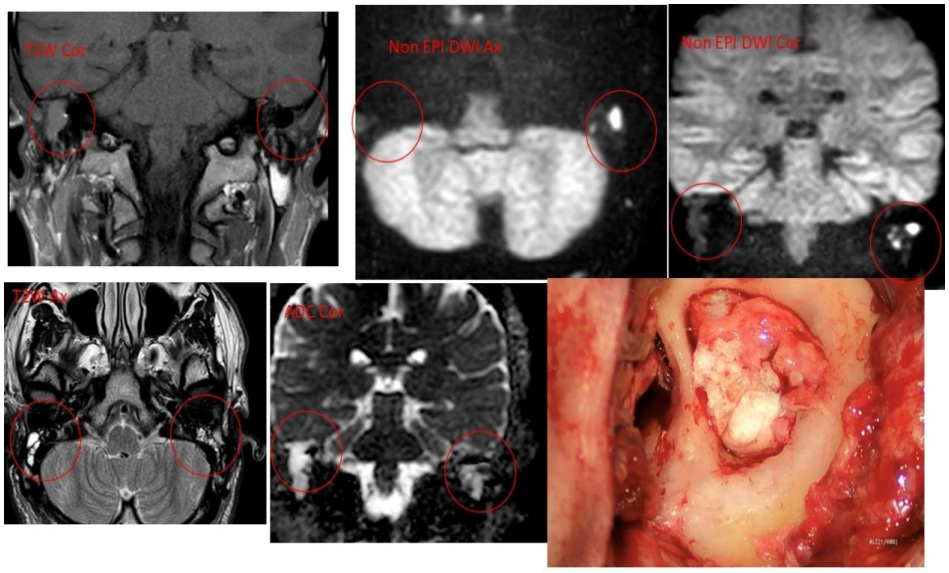

Fig. 2. 26 year old male who had bilateral cholesteatomas managed with bilateral combined approach tympanoplasties

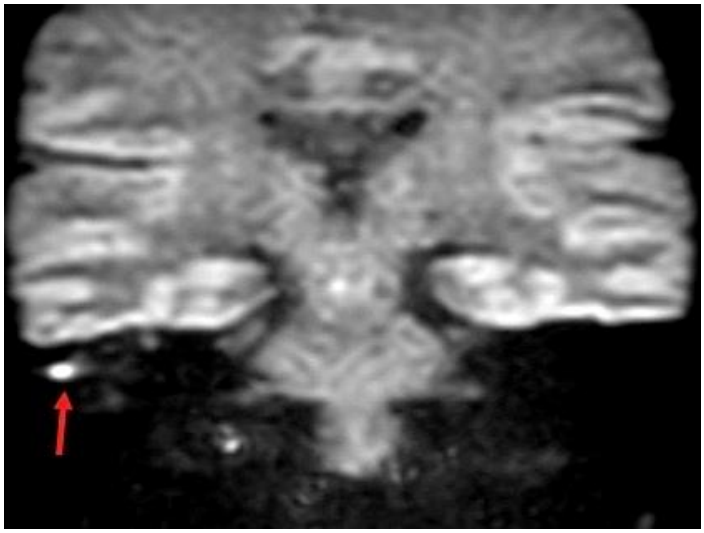

Fig. 3. Hydroxyapatite granules and pericranial flap the MRI performed at 36 months post-operatively

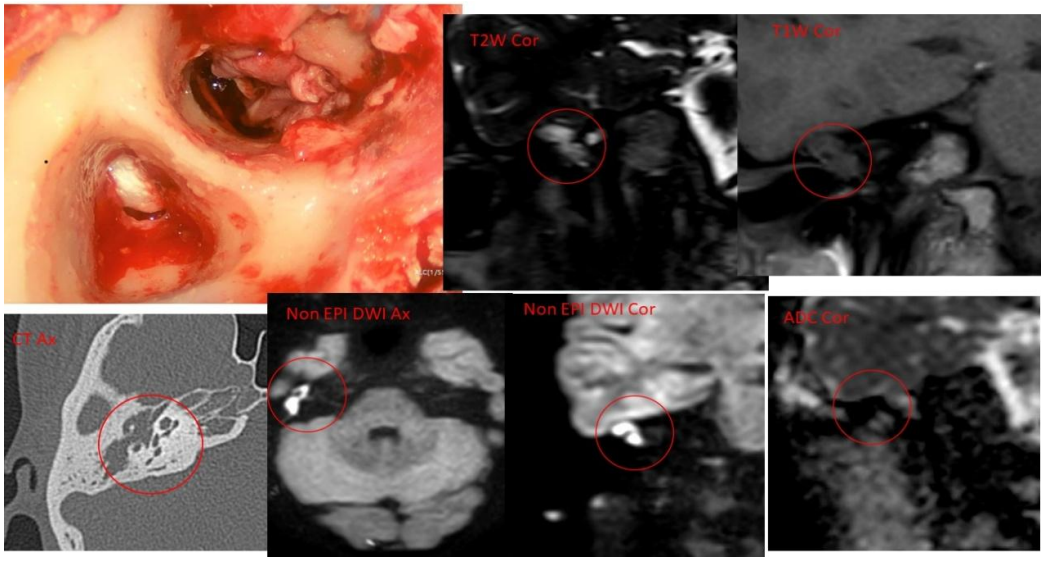

Fig. 4. Scans from a 24 year old female who presented with a 6 year history of discharge from her right ear

Case 4: Fig. 5 demonstrates the presence of an underlying cholesteatoma in a 6 year old girl presenting with hearing loss and a 3 year history of foul smelling discharge which failed to resolve with topical and oral antibiotics. The CT scan showed opacity within the middle ear cleft and mastoid with ossicular erosion. She had a grommet inserted as seen on the CT scan. To determine if this was COM with or without cholesteatoma an MRI scan revealed the typical appearance of cholesteatoma as described in case 1.

3.3 Pre-Operative Non-EPI DWI MRI Scanning To Determine the Extent Of Cholesteatoma and Surgical Approach

Case 5: A 30 year old female had an attic retraction pocket and was scanned pre-operatively to determine the presence and extent of cholesteatoma. In Fig. 6, the CT scan shows opacity in the attic lateral to the ossicles not extending beyond the posterior limit of the lateral

semi-circular canal and the MRI scan shows small area of restricted diffusion. An endoscopic tympanoplasty approach was deemed appropriate. Interestingly a cholesteatoma was found which did not correspond to an opacity on the pre-operative scans.

3.4 Cholesteatoma Found as an Incidental Finding on MRI Scan

Case 6: A 34 year old female had developed a persistent myringitis in the right ear. In Fig. 7 the MRI scan organised to determine if there was an underlying cholesteatoma on the right side indicated there was no cholesteatoma on the right but on the left asymptomatic side the characteristic features of cholesteatoma are seen.

Case 7: A 50 year old male was referred due to hearing loss in his left ear. There was a suspicion of an anterior attic pocket and opacity is seen corresponding to this clinical finding on the CT scan however an additional separate opacity arising in the mastoid tip was identified. Fig. 8 demonstrates this and the MRI scan organized in preparation for an endoscopic tympanoplasty confirmed the presence of the anterior attic cholesteatoma and a presumed congenital cholesteatoma in the mastoid tip. The patient was successfully managed with a canal wall up mastoidectomy with restoration of normal hearing [13].

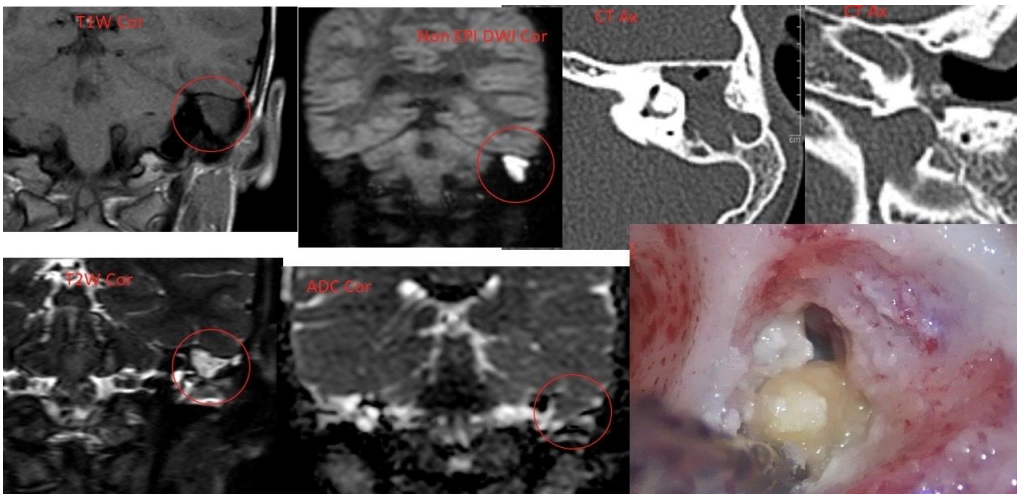

Fig. 5. Presence of an underlying cholesteatoma in a 6 year old girl presenting with hearing loss and a 3 year history of foul smelling discharge

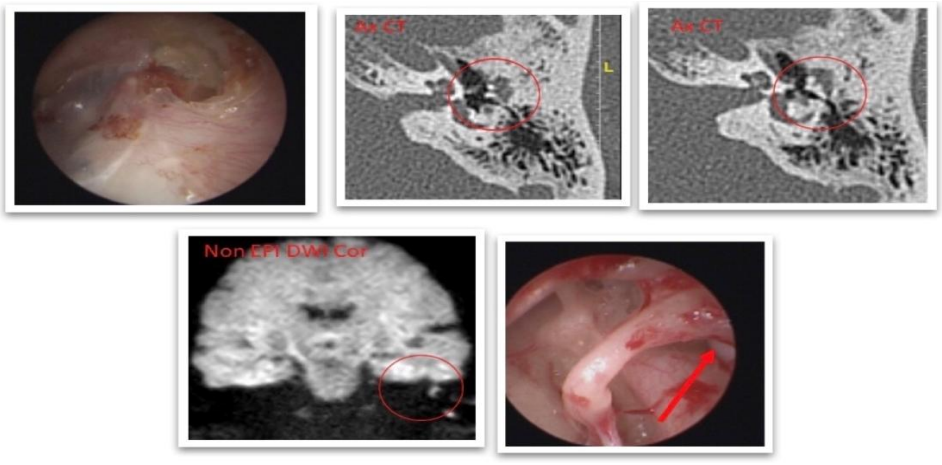

Fig. 6. CT and Non EPI DWI MRI scans with intra-operative endoscopic picture(red arrow) shows opacity in the attic lateral to the ossicles

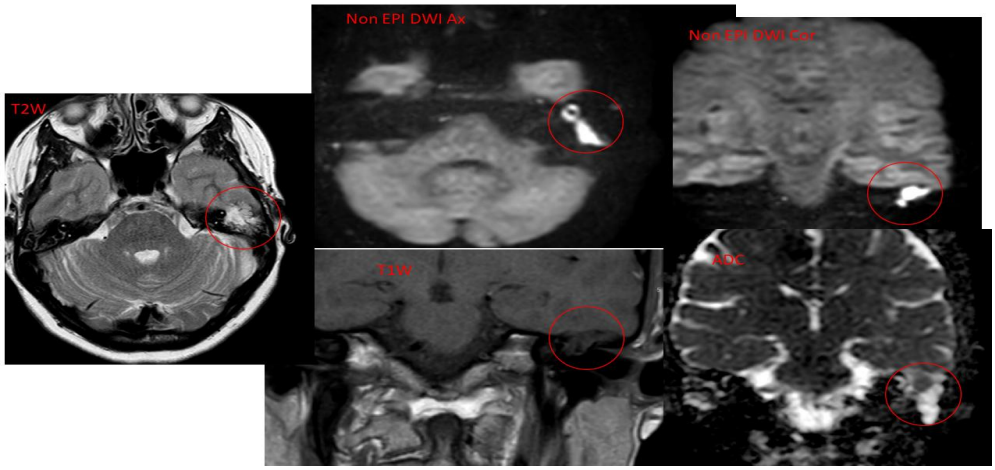

Fig. 7. MRI scan showing incidental left sided asymptomatic cholesteatoma

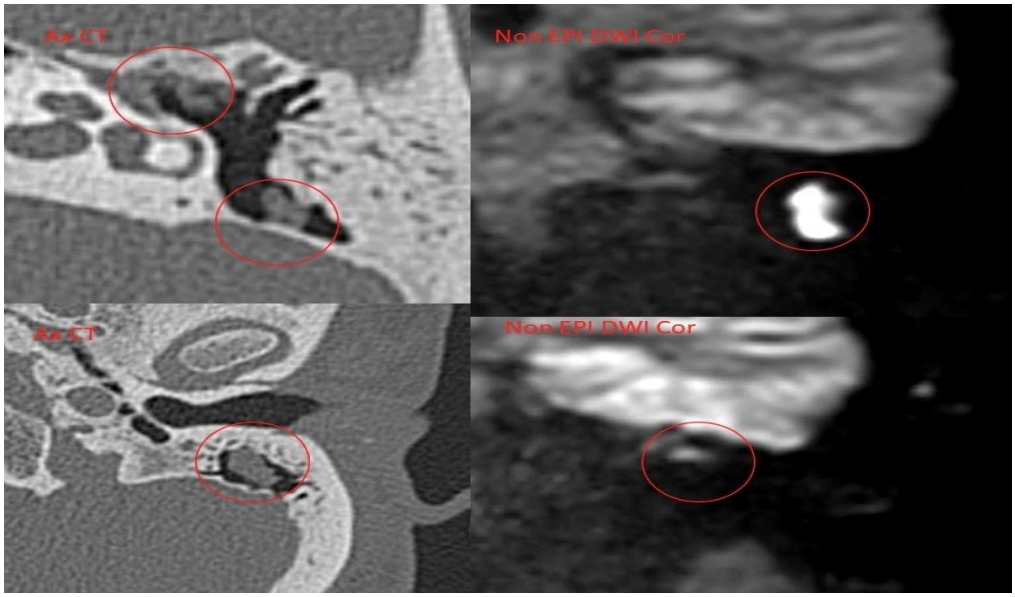

Fig. 8. MRI scan organised in preparation for an endoscopic tympanoplasty

3.5 Case Where MRI Would Have Been Useful but Was Contra-Indicated

Case 8: A 75 year old male had a number of co-morbidities, had a pacemaker and was on epixiban. He had a 3 year history of discharge, deafness and tinnitus in the right ear. There was an impression of fullness in the attic area and myringitis of the tympanic membrane posteriorly. A CT scan showed opacity in the sinus tympani but no abnormality was detected around the malleus head or body/ short process of the incus. Endoscopic surgery confirmed the presence of tenacious glue around the stapes corresponding to the opacity seen on the CT scan in sinus tympani as shown in Fig. 9.

Non-EPI DWI MRI scanning is widely utilised in patients who have had mastoid surgery to detect the presence of residual cholesteatoma or to determine the extent of any recurrent disease. Since January 2016, 154 ears were identified as requiring MRI scans post-operatively. Unfortunately, scans were not performed in 16 patients for a variety of reasons. An area of restricted diffusion was identified in 28 ears in 26 patients post-operatively (but 3 false positive and one resolved but one false negative scan)

indicating 25 potential cholesteatomas in the 138 ears scanned (18% rate of residual and recurrent cholesteatoma). All but 8 of the cholesteatomas appeared in adults with bilateral disease or in children. There has been some discussion in the literature as to whether cholesteatoma is in fact more "aggressive" in children [14,15]. It has certainly been our experience that children and also adults with a bilateral cholesteatomas, have recurrent and more extensive disease, sometimes requiring multiple explorations in an attempt to remove the disease. Although some patients may undergo further surgery to improve their hearing or to repair any residual perforated tympanic membrane, a sizeable proportion of patients no longer require "second" look surgery to exclude the presence of residual cholesteatoma. In addition to the patient not having unnecessary surgery, financial benefits are also recognised in using follow-up MRI scans as exemplified in a Canadian study [16].

CT scans are unable to differentiate cholesteatoma from other soft tissue or fluid [17] and indicators of possible cholesteatoma with erosion of structures is difficult to interpret in the post-surgical ear. MRI scanning is invaluable in this situation as demonstrated in:

Case 1, a patient who had had bilateral cholesteatomas managed with bilateral combined approach tympanoplasties. A follow-up MRI scan confirmed the presence of a large cholesteatoma on the left side with inflammation or scar tissue only being present on the right side. This avoided "unnecessary" surgery in one ear and prevented a potential delay in surgery in the ear with cholesteatoma.

Following revision mastoidectomy and obliteration using hydroxyapatite granules and pericranial flap, patients are scanned at 1 and 5 year post-operatively (with further interval scanning as indicated). The SI units for cholesteatoma are 3 times that of hydroxyapatite granules (HA) (500-600 SI and 1150-1525 SI respectively) and so the cholesteatoma is easily differentiated from the granules as shown in case 2. This MRI technique has been adopted as the follow-up of patients having had a mastoid obliteration using HA granules as well as by others who have use bone pate in primary and secondary mastoid obliterations [10,18].

The role of CT scans in the pre-operative management of patients with cholesteatoma is now established since it provides valuable information on the temporal bone anatomy as well as the presence and effect of disease. Non-EPI DWI is growing in popularity as an adjunct to CT scans in the pre-operative investigations before primary surgery[5]. Although CT scans can identify an opacity within the middle ear cleft, non-EPI DWI can identify the presence and extent of cholesteatoma and differentiate this from non-cholesteatoma pathology such as cholesterol granuloma or scar tissue as seen in case 3. The need to consider the presence of an underlying cholesteatoma in children presenting with hearing loss and recurrent or persistent discharge is well known and case 4 demonstrated how an MRI confirmed a cholesteatoma in 6 year old girl. MRI scanning may be considered the primary investigation modality in a child with a perforated tympanic membrane without obvious cholesteatoma since MRI is safe and does not expose the child to irradiation. Only patients requiring mastoid exploration would require a CT scan although the new cone beam CT scanners enable better images to be obtained faster with a very low dose of irradiation.MRI scans can be useful in patients with similar hearing bilaterally and with bilateral opacities on the CT to determine if there is a preference as to which ear to operate on first based on the extent of disease.

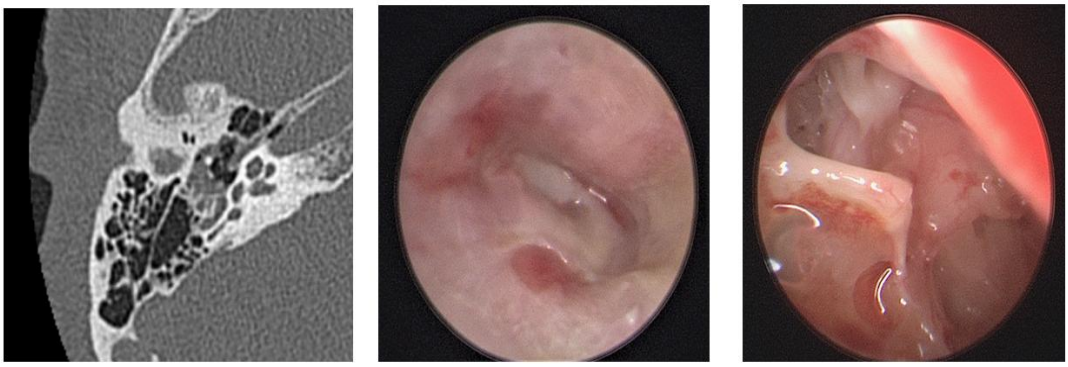

Fig. 9. CT scan in sinus tympani

Following the introduction of endoscopic tympanoplasty, the use of these scans pre-operatively has been adopted to determine the extent and location of cholesteatoma as demonstrated in case 5. This operative technique is suitable for cholesteatomas confined to the middle ear and attic without extension beyond the posterior limit of the lateral semi-circular canal. This less invasive technique to remove cholesteatoma has become even more important in the era of Covid-19 where the ability to wear adequate PPE whilst using the microscope and high speed drills remains challenging and so an endoscopic tympanoplasty technique may be safer for the surgeon and the rest of the theatre team. These scans may also allow a more personalised consent when discussing the relative risks of the procedure dependant on the extent and location of disease and the impact on surrounding structures. It can also improve theatre utilisation.

Cases 6 and 7 are examples where the MRI scans detected asymptomatic cholesteatomas; one was detected on a scan arranged for the opposite ear that had myringitis, and the second patient had a rare case of dual cholesteatomas (a large cholesteatoma in the mastoid tip which was entirely separate from the clinically apparent anterior attic cholesteatoma) [13].

There have been occasions where a non-EPI DWI MRI scan would have been useful but was unable to be done due to the patient having a pacemaker. One example is seen with case 8 where subsequent endoscopic surgery found only tenacious glue around the stapes corresponding to the opacity seen on the CT scan in sinus tympani.

3.6 False Positive MRI Scans

Not all hyperintense lesions seen on non-EPI DWI scans are due to cholesteatoma. Fig. 10 scan shows the characteristic features of cholesteatoma being oval/round appearance in an expected location.

In Fig. 11 the linear pattern of restricted diffusion is due to wax lining the external ear canal. In order to prevent wax causing false positives the ears should be examined prior to an MRI scan and remove wax if present.

Fig. 12 is in a 43 year old male who had a tegmen dehiscence repaired with cartilage and bone wax. The bone wax can produce an area of restricted diffusion. There is a low signal in T2, very low signal on T1 and high on ADC (which is a different pattern of intensities to cholesteatoma). If cholesteatoma is suspected, rescanning perhaps a year later to determine if the area of restricted diffusion increases suggesting disease progression.

To avoid false positives it is necessary to correlate the lesion on the MRI and CT scans [19]. Gadolinium T1 does not enhance with cholesteatoma but will enhance with facial schwanomma and some other lesions.

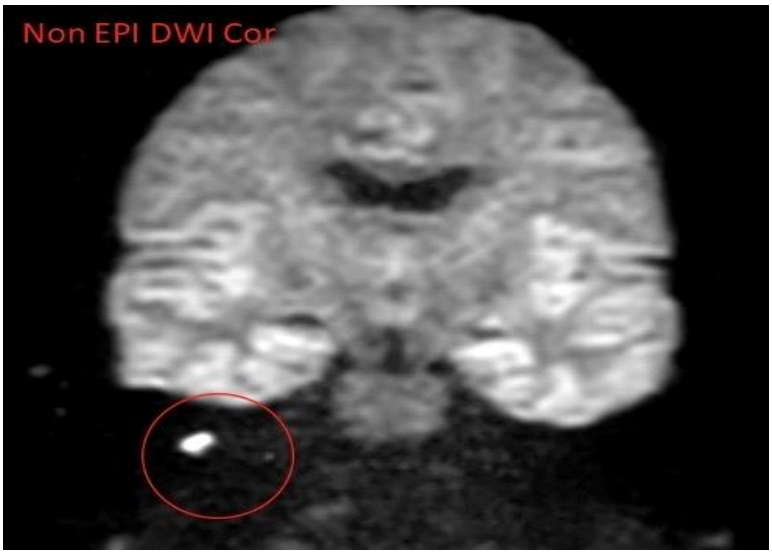

Fig. 10. Scan shows the characteristic features of cholesteatoma

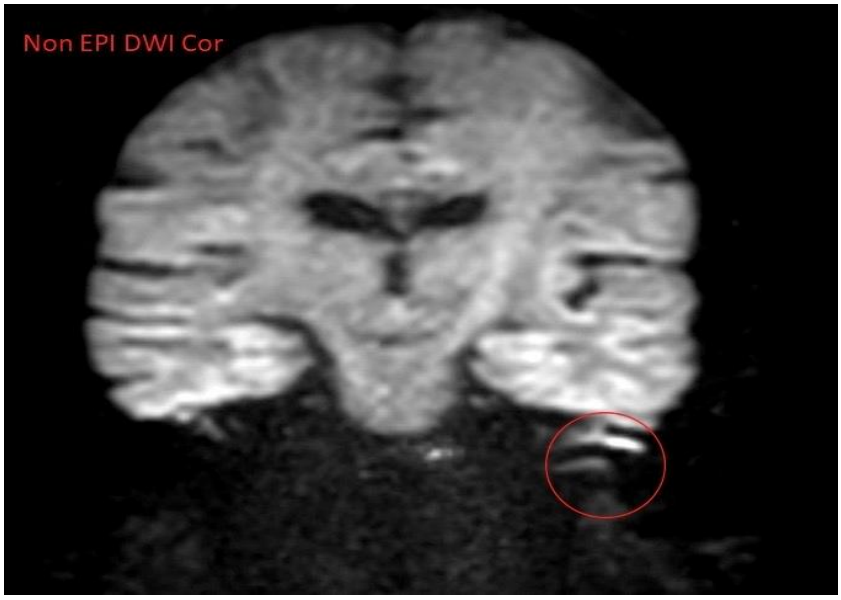

Fig. 11. Linear pattern of restricted diffusion is due to wax lining

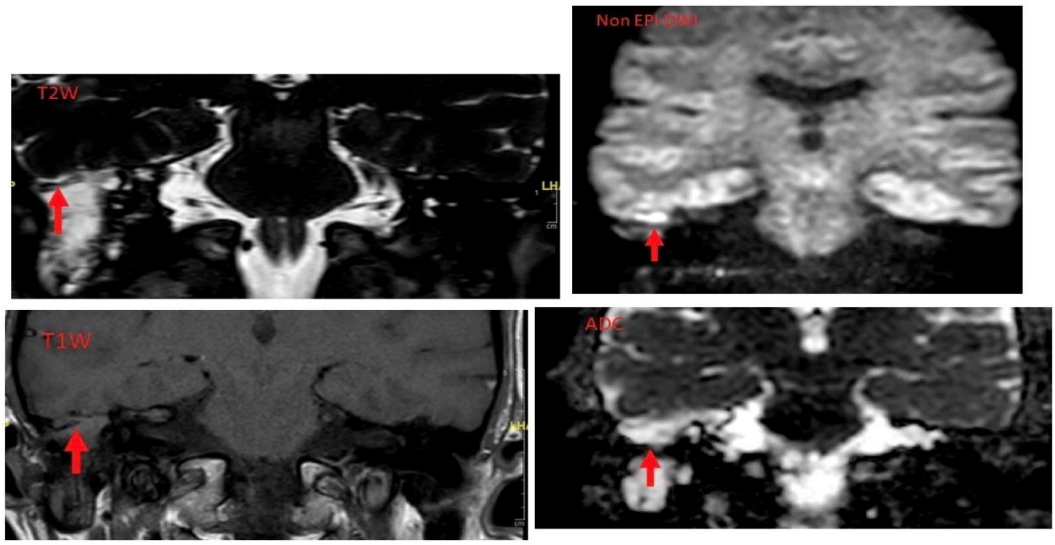

Fig. 12. Tegmen dehiscence repaired with cartilage and bone wax

3.7 False Negative MRI Scans

The other issue is that of false negative scans. These can occur either due to auto-evacuation or a thorough aural toilet being performed prior to the scan. Surgeons should be advised against this and only wax should be removed [8].

If the patient moves too much, poor quality images may be obtained and lesions may be missed [4]. The radiologist should indicate motion has been an issue. Lesions less than 2 mm may be missed. Currently many advise re-scanning at 5-6 years for all but also at 3 years for a child. Additional scans may be required if clinically indicated.

Fig. 13 is an example of a false negative MRI scan, some opacity seen within the middle ear on the CT scan but clinically the cholesteatoma can be seen through a central perforation. This was removed endoscopically and the perforation closed using tragal cartilage and perichondrium

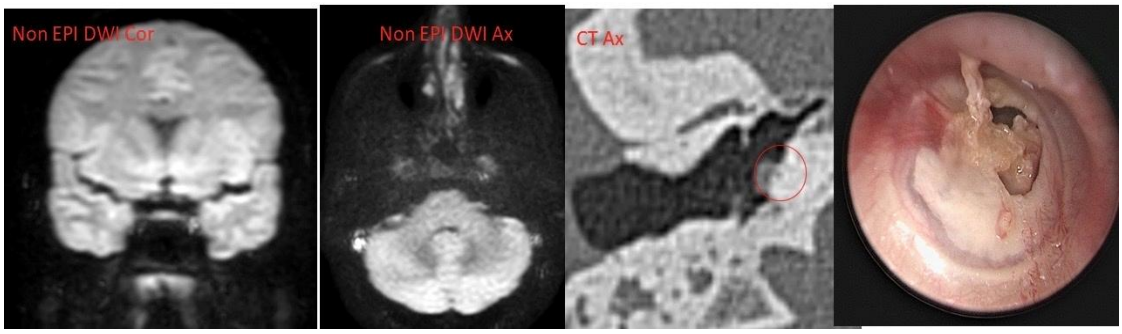

Fig. 13. Example of a false negative MRI scan

The follow-up regime we follow is that used by others including those from Antwerp. Recurrent disease is identified clinically as a further attic retraction etc. MRI can be useful if concerns raised to determine the extent of disease. Residual disease relies upon MRI scanning unless in patients where a second look surgery is indicated if residual disease is apparent clinically or for functional reasons.

One of the issues with MRI scans is the difficulty locating the lesions. This has been partly overcome using T2W sequence images and more recently combining MRI with CT scanning in some departments [20,21]. De Foers team were able to demonstrate the location of two cholesteatomas in a patient using MRI and the latest NewTom 5G cone beam CT scanner [4].

The use of serial non-EPI DWI Scans may also give information on the natural history of cholesteatoma and raises the question that we may be performing unnecessary operations. One study by Wong et al in 2016 [22] in their series of 12 cases in non-operated ears, found one cholesteatoma grew rapidly, 4 grew more slowly and 7 actually regressed with 3 resolving within 17 months. Others have found conflicting effects on the effect of the size of cholesteatoma on growth rate and whether the latter is linear or exponential [23,24]. Further studies are required but a more conservative approach in the future, as seen with the management of acoustic neuromas may be adopted, particularly in the Covid-19 era where surgery is being avoided.

MRI has a role in pre- and post-operative management of cholesteatoma. It is safe with no irradiation and it can identify intracranial complications. It can positively impact on patient management reducing the need of unnecessary second look surgery.

4. CONCLUSION

MRI can detect cholesteatoma as small as 2mm with up to 100% sensitivity and specificity reported in some studies. The ability to detect residual cholesteatoma post-operatively is particularly useful following canal wall up procedures or mastoid obliteration surgery and can reduce unnecessary operations.MRI has an increasing role pre-operatively as total endoscopic ear surgery gains in popularity particularly in the Covid-19 era where the use of PPE is challenging when using the microscope and high-speed drills. The use of different sequences enables the differentiation of cholesteatoma from other pathologies. MRI scans provide an opportunity to review the natural history of cholesteatoma.

CONSENT AND ETHICAL APPROVAL

As per university standard guideline, participant consent and ethical approval have been collected and preserved by the authors.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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