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Advancements in Cholesteatoma Diagnosis and Management: The Role of Diffusion - Weighted Imaging

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Abstract: ***This article delves into the intricate nature of cholesteatomas, abnormal growths within the ear that can lead to significant damage if not accurately diagnosed and treated. Traditional surgical methods have been the cornerstone of management, aiming to remove these lesions while preserving the ears functional integrity. However, the recurrence of cholesteatoma post - surgery poses a significant challenge, necessitating reliable diagnostic methods for its detection. Recent advancements in imaging technologies, particularly Diffusion - Weighted Imaging DWI, have shown promise in distinguishing cholesteatoma from other ear pathologies, offering a non - invasive alternative to surgical exploration. The paper reviews the technical aspects of DWI, its application in diagnosing cholesteatoma, and how it compares to conventional imaging methods, highlighting its potential to improve patient outcomes by accurately identifying residual or recurrent disease, thus guiding treatment decisions.***

Keywords: ASSET = array spatial sensitivity encoding technique; DWI = diffusion - weighted imaging; EPI = echo - planar imaging; HASTE = half - Fourier acquired single - shot turbo spin - echo; PROPELLER = periodically rotated overlapping parallel lines with enhanced reconstruction; SNR = signal intensity–to - noise ratio; SS TSE = single - shot TSE; TSE = turbo spin - echo

1. Introduction

Cholesteatoma has been defined as a three dimensional epidermal and connective tissue structure, usually in the form of a sac and frequently conforming to the architecture of various spaces of middle ear, attic and mastoid. It has a tendency for progressive and independent growth at the expense of underlying bone and a tendency to recur after removal.1 Acquired cholesteatomas generally occur in the middle ear and mastoid, whereas congenital cholesteatomas or epidermoids can occur in other locations, including the cerebellopontine angle, suprasellar cistern, calvarium, and multiple sites in the temporal bone. Congenital cholesteatomas compose only 2% of middle ear cholesteatomas.2

Several hypotheses exist regarding the genesis of cholesteatoma, but the prevailing consensus among most researchers posits a disruption in the natural course wherein the skin that lines the tympanic membrane migrates outward into the external auditory canal. Retraction pockets, which manifest as inward invaginations of the tympanic membrane into the middle ear cavity, emerge and impede this migration. These pockets predominantly arise from chronic otitis media and dysfunction of the eustachian tube, culminating in negative pressure within the middle ear. Retraction pockets are most frequently observed in the pars flaccida of the membrane, with less frequent occurrences in the pars tensa. Epithelial ingrowth may ensue from this process, with squamous debris potentially becoming ensnared within these retraction pockets within the middle ear.[1 - 3] Furthermore, many researchers also postulate a genetic predisposition to the development of acquired cholesteatoma.2

Surgical excision is the primary treatment for middle ear cholesteatomas. Small cholesteatomas confined to the Prussak space with minimal bone erosion can typically be effectively removed using a transcanal atticotomy approach followed by tympanoplasty. For more extensive disease, patients may undergo either a canal wall up or canal wall down mastoidectomy, often requiring ossiculoplasty to restore the middle ear's ossicular conductive mechanism. Canal wall down mastoidectomy offers greater surgical exposure and is associated with a lower recurrence rate, although it may result in inferior postoperative conductive hearing compared to the canal wall up procedure.4

Traditionally, patients have undergone two - stage operations for cholesteatoma removal, involving a second - look procedure to inspect for residual or recurrent disease typically conducted 6 to 18 months after the initial surgery.5, [6] The majority of cholesteatomas recur within the initial two postoperative years, with approximately 60% recurring within the first year following surgery.7

CT scans have become widely accepted for assessing the extent and localization of cholesteatoma as well as for evaluating associated complications. Preoperative imaging plays a crucial role in highlighting disease in areas not easily visualized during surgery, such as the sinus tympani, and in delineating the spread of disease into the epitympanum (attic) and mastoid antrum. Additionally, CT scans can reveal congenital anatomical variations, such as aberrant courses of the facial nerve.8Notably, granulation tissue and cholesteatoma exhibit similar imaging characteristics on CT scans. Therefore, CT imaging is most valuable when the middle ear and mastoidectomy defect are aerated, but it may lack specificity in the presence of soft tissue.

Post - contrast T1 - weighted MR imaging has been proposed as an effective method for distinguishing granulation tissue from residual cholesteatoma.9 [- 11] Cholesteatomas, being avascular, do not enhance following contrast administration, while granulation tissue, being poorly vascularized, exhibits enhancement on delayed images.

In recent years, there has been growing advocacy for the use of diffusion - weighted imaging (DWI) in evaluating residual or recurrent cholesteatoma post - mastoidectomy. DWI involves a preparatory phase before image acquisition, which enhances MR signal intensity attenuation in response to diffusion and other spin motion.1[2] Although the exact mechanism is not fully understood, cholesteatomas appear hyperintense on DWI images compared to cerebrospinal fluid (CSF) and brain parenchyma, similar to epidermoid cysts which are histologically identical. This may be attributed to a combination of T2 and diffusion effects or predominantly a T2 shine through effect.1[3 - 15] This article aims to discuss the utility of DWI in evaluating cholesteatomas and provide a review of the technical parameters involved.

Technical Considerations

In the realm of applying diffusion - weighted imaging (DWI) to cholesteatoma evaluation, researchers have employed various techniques, ranging from traditional spin - echo echo planar imaging (EPI) - based to turbo spin - echo (TSE) - based methods such as Half - Fourier Acquisition Single - shot Turbo Spin - Echo (HASTE) and BLADE. While these techniques share a common approach to encoding diffusion, they differ in their image acquisition methodology, which significantly impacts sensitivity to factors like bulk or physiologic motion and field inhomogeneities, particularly crucial when imaging near the skull base.

EPI - DWI

Single - shot TSE EPI is the conventional choice for DWI due to its rapid acquisition and relative insensitivity to motion. However, this technique may suffer from image quality degradation due to low resolution, low signal - to - noise ratio (SNR), chemical shift artifacts, susceptibility artifacts, ghosting, and geometric distortion. Distortion and susceptibility artifacts in the temporal bone pose challenges for cholesteatoma evaluation, potentially masking areas of restricted diffusion.1[6, 17]

DWI - HASTE

DWI - HASTE employs a single - shot TSE method for image acquisition. This sequence shares motion insensitivity with EPI, albeit with slightly increased scanning time. Unlike EPI - based techniques, DWI - HASTE does not exhibit image distortion and susceptibility artifacts. However, the longer single TSE echo train may lead to image - quality degradation due to T2 decay during acquisition.1[8] HASTE employs a half - Fourier acquisition to shorten the echo train, reducing the impact of T2 - blurring at the expense of SNR.

DWI - BLADE

Multishot techniques can shorten the echo train and alleviate T2 blurring effects, but they may become sensitive to motion with multiple echo trains contributing to a single diffusion measurement. Utilizing the BLADE sequence, however, reduces sensitivity to bulk motion significantly. The BLADE sequence acquires k - space with radially oriented TSE echo trains (blades) overlapping in the center of k - space. Each blade essentially represents an independent single - shot low - resolution image with reduced motion sensitivity and minimal ghosting.1[7] Reconstruction of the high - resolution image from these low - resolution components retains these advantageous properties. The only drawback to DWI - BLADE is increased scanning time, approximately four times longer than DWI - EPI. Nevertheless, since cholesteatoma evaluation typically requires limited coverage rather than whole - brain coverage, the resulting 4 - to 5 - minute scanning duration fits well into the imaging workflow.

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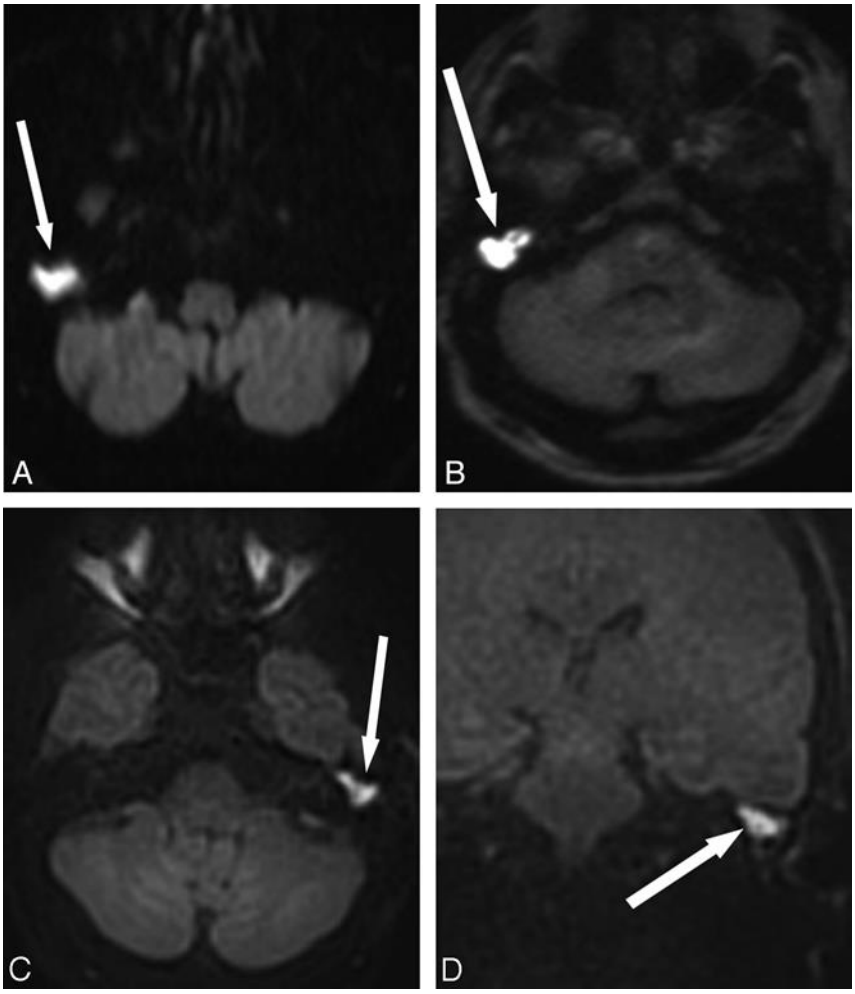

Figure 1: Comparison of different DWI techniques. A, EPI DWI acquired in a patient undergoing evaluation for possible demyelinating disease. Abnormal DWI signal intensity in the right temporal bone (arrow) prompted further evaluation for cholesteatoma. The abnormal DWI signal intensity is clearly visible due to the large size of the lesion, but there are artifacts from the skull base. B, SS TSE (HASTE) DWI sequences obtained in a patient with obscured visual examination due to postoperative changes. Increased diffusion signal intensity is seen in the right middle ear and mastoid defect (arrow), with cholesteatoma confirmed at surgery. C, Multishot TSE DWI (BLADE) image in a patient with otoscopic examination obscured by cartilaginous reconstruction shows increased DWI signal intensity (arrow) in the left epitympanum, with cholesteatoma confirmed at surgery. D, The multishot TSE DWI has the additional advantage of generating images in a coronal plane, which can be especially useful when erosion of the tegmen tympani and/or intracranial extension is suspected. Arrow indicates increased DWI in the left epitympanum. Fig.1B was reproduced with permission from Ear, Nose & Throat Journal (Schwartz KM, Lane JI, Neff BA, et al. Diffusion - weighted imaging for cholesteatoma evaluation.2010; 89: E14 - 19).32

2. Discussion

Patient Selection

Postoperative Ear

Traditionally, patients have undergone a second - look surgery 6 to 18 months post - initial cholesteatoma surgery to assess for residual disease. This necessity arises from limited visibility of the mastoid following canal wall up mastoidectomies or the middle ear due to tympanic membrane reconstruction using cartilage. CT is beneficial if no soft tissue is visible in the middle ear (or petrous apex or mastoid depending on the original disease location). If rounded soft tissue is present, this suggests recurrent disease. However, if amorphous soft tissue or complete middle ear opacification is present, CT lacks specificity and cannot differentiate granulation tissue or scar tissue from recurrent disease.

Kimitsuki et al argued that spin - echo MR should not replace a second - look operation for the evaluation of recurrent cholesteatoma because of incorrect surgical correlation in 30% of their cases.1[9] Vanden Abeele et al also had disappointing results with MR imaging, with a surgical correlation of 50%– 61%.2[0] However, in both studies, no DWI was used, and the post contrast images were not delayed.

More recent studies have reported improved success in the detection of recurrent disease, with only small lesions missed when DWI sequences were used. Lesions of >5 mm have been reliably detected with the EPI - DWI technique, [14, 21 - 27] and even smaller lesions, with non - EPI techniques.[15, 28 - 31] In fact, De Foer et al argued that the SS TSE DWI sequence has high enough sensitivity, specificity, and positive and negative predictive values to replace routine second - stage surgery for the detection of residual cholesteatoma.[28]

MR imaging with DWI sequences has been used at our institution for evaluation of patients with prior cholesteatoma resection with reliable results.3[2] This has been especially useful when the patient's otologic examination is obscured by an opaque tympanic membrane or cartilaginous reconstruction, when CT shows no definite bony erosion, when CT findings are equivocal (Fig 3), and to evaluate complications and extent of disease.

Newly Diagnosed Cholesteatoma

The initial diagnosis of cholesteatoma is typically made through otoscopic examination. However, MR imaging, particularly DWI, may be useful in cases of erosion of the tegmen tympani to ascertain if intracranial extension is present or to assess associated complications such as facial nerve canal dehiscence or semicircular canal fistula. MR imaging can also aid in evaluating a chronically draining ear with inflammation and polypoid disease that obscures physical examination with a nonspecific CT.

3. Review of the Literature

Initial attempts at DWI for cholesteatoma evaluation used EPI - DWI techniques.[14, 16, 21 - 25, 27] The EPI - DWI technique was limited by large section thickness, susceptibility artifacts from the skull base, and low resolution. These EPI images were generally effective for detection of lesions ≥4 or 5 mm, but EPI frequently missed smaller lesions.[14, 21 - 26] This led Vercruysse et al and Venail et al to advocate concurrent use of DWI, considered more specific, and post contrast T1 - weighted images, which were more sensitive.[14, 22]

Non - EPI techniques have more recently been proposed for the reliable detection of smaller cholesteatomas.1[5, 28 - 31] These non - EPI DWI techniques have the advantage of smaller section thickness and better resolution and are less degraded by susceptibility artifacts.

In 1 study, De Foer et al evaluated, with SS TSE DWI, 21 patients strongly suspected of having a middle ear cholesteatoma and found 19 of 21 cholesteatomas.[15]The false - negative cases included a cholesteatoma sac and a cholesteatoma in a child whose images had motion artifacts. The authors did note that lack of anatomic landmarks of the temporal bone on this sequence was a drawback.[15] De Foer et al, in a different study, evaluated 32 consecutive patients with SS TSE DWI sequences 10 –18 months after primary cholesteatoma surgery with canal wall up mastoidectomy and detected 9 of 10 residual cholesteatomas, measuring 2 - 6 mm, missing only one 2 - mm lesion in a motion - degraded study.[28] Dhepnorrarat et al detected and localized cholesteatomas by using SS TSE DWI in all 7 of 22 patients undergoing second - look surgery with recurrent disease, with cholesteatomas ranging from 3 to 9 mm.[29]

Most of the literature has focused on DWI images with 1.5T imaging units. Lehmann et al compared PROPELLER DWI with ASSET single - shot EPI - DWI by using a 3T imaging unit.[33]The 3T PROPELLER technique was associated with better sensitivity, specificity, and positive and negative predictive values for the detection of recurrent cholesteatoma.

4. Conclusions

DWI has demonstrated utility in cholesteatoma evaluation, distinguishing scar tissue, granulation tissue, and inflammatory changes from cholesteatoma, particularly when CT findings are inconclusive. Newer DWI techniques with improved imaging parameters allow for the detection of small lesions, making DWI a valuable tool, especially in cases where visualization is impaired by previous surgeries. DWI may even serve as an alternative to second - look surgery, sparing patients the potential morbidity associated with repeat exploration

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