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Contribution to the Bony Obliteration Tympanoplasty Technique and the Diffusion Weighted MR Imaging to Safety and Success in Cholesteatoma Management

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Every day you may make progress. Every step may be fruitful. Yet there will stretch out before you an ever-lengthening, ever-ascending, ever-improving path. You know you will never get to the end of the journey. But this, so far from discouraging, only adds to the joy and glory of the climb.

Winston Churchill

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The manuscript has mainly been written in UK-English with the exception of some chapters, which contain articles that have been published in American journals. In order to safeguard the authenticity of the published papers, the original format was preserved and not changed from US -English to UK- English.

Chapter 1

Introduction

Chapter 1.1

General Introduction

1. Definition and history of cholesteatoma

A cholesteatoma is defined as a hyperproliferative disease of keratinocytes characterised by mass formation due to accumulation of continuous desquamation of keratin, leading to local invasive destruction of surrounding tissues (1).

The first description of a cholesteatoma was made by a French anatomist JG Duverney in 1683, describing the presence of sheets of tissue in a fistulised mastoid causing hearing loss, a postauricular fistula and foetid discharge from the external meatus (2-3).

Müller was the first to describe in 1838 the term *cholesteatoma* as he became aware of the presence of cholesterin and fat in what he believed to be a tumour (4). Müller also noticed the resemblance between the squamae of cholesteatoma and the cells of the stratum corneum of the skin, but he did not correlate this with a possible epidermal origin of cholesteatoma. The term cholesteatoma, although fundamentally incorrect, persists until today.

2. Epidemiology

The incidence of cholesteatoma is 3 per 100,000 in children and 9.2 per 100,000 in adults, with a male predominance of 1.4/1. Although middle ear cholesteatomas are more present in younger individuals, external auditory canal cholesteatomas present predominantly at a later age (40–70y). There is a higher prevalence among white individuals, and cholesteatoma is rarely detected in the Asian, American Indian and Alaskan Eskimo population (5).

3. Classification of cholesteatoma

Theoretically there are two types of aural cholesteatoma (Figure 1): congenital (A) and acquired cholesteatoma (B).

Congenital cholesteatoma is characterized by the presence of a white pearl of keratinized epithelium behind an intact tympanic membrane (TM) in absence of prior surgery, inflammation, perforation or trauma (6).

The majority of **acquired cholesteatomas** arise when a retraction of the tympanic membrane occurs into the attic and/or posterior mesotympanum, leading to epithelial accumulation and ultimately to an acquired cholesteatoma.



Figure 1. Micro-otoscopy of an acquired pars flaccida cholesteatoma (left) and a congenital cholesteatoma (right).

A. Congenital cholesteatoma

1. Theories of origin and embryology

House published the first case of a primary or congenital cholesteatoma in 1953 (7). Derlacki and Clemis (6) described six cases of congenital cholesteatoma and first established clinical criteria for the diagnosis of congenital cholesteatoma. A congenital cholesteatoma was defined as an epithelial inclusion cyst behind an intact TM in a patient without antecedent history of otitis media. According to the criteria by Levenson et al., a history of prior otitis media no longer excludes the diagnosis of a congenital cholesteatoma (8).

Several theories have been introduced regarding the pathogenesis of a congenital cholesteatoma. In the *ectoderm migration theory* (9), the ectoderm from the primitive ear canal passes through or around the tympanic ring to enter the middle ear space. The *metaplasia theory*-suggests that otitis media or other inflammatory middle ear processes result in squamous metaplasia leading to keratin formation (10). Another theory from Northrop et al., called the *amniotic cell migration theory*, suggested that viable squamous epithelial cells found in amniotic fluid in the middle ear could be a potential source for congenital cholesteatoma (11). The *invagination theory or acquired inclusion theory* by Tos, states that inflammation in the middle ear causes a portion of the tympanic membrane to invaginate, trapping epithelial cells identified in the lateral walls of the embryonic cavity should normally disappear by 33 weeks gestation. If these cell remnants do not involute, a congenital cholesteatoma forms (13).

Although the *epidermoid formation theory* is the most widely accepted for the middle ear cavity, it has not been quoted for the deeper temporal bone structures in which congenital cholesteatoma can occur.

An epidermoid cyst or petrosal cholesteatoma originates at the time of neural tube closure due to entrapment of ectoderm - the later skin - in the head. If the entrapment takes place inside the dura, the lesion is called epidermoid or epidermoid cyst. The most frequent location of an epidermoid cyst is the cerebellopontine angle where it is reported to be the third most frequent mass lesion after the vestibular schwannoma and the meningioma. If the ectoderm gets entrapped outside the dura, but in the petrous bone, it is called a congenital or petrosal cholesteatoma. Histologically, an epidermoid cyst and a congenital cholesteatoma are exactly the same, consisting of entrapped ectoderm or skin. As the skin is gradually exfoliating, the lesion very slowly but gradually starts to grow. Depending on its location, clinical symptoms may arise (14).

2. Incidence and clinical presentation:

Middle ear congenital cholesteatomas represent approximately 2 % of all middle ear cholesteatomas (5). In the paediatric population, the number of congenital cholesteatomas in the overall paediatric cholesteatoma population is higher, reaching 16 % (15).

Congenital cholesteatomas located in the temporal bone are often found in the middle ear cavity, the mastoid, the petrous bone apex, the squama temporalis, within the tympanic membrane and in the external auditory canal. Discussion still exists if a petrous bone apex cholesteatoma does not represent an acquired cholesteatoma finding its way to a pre-existing aerated petrous apex, rather than being a congenital cholesteatoma originating in the petrous bone apex (5, 14).

In the temporal bone, a congenital cholesteatoma is more frequently found in two predilection sites: in the middle ear cavity and near the otic capsule close to the geniculate ganglion.

When situated in the middle ear cavity, it is most frequently found in the anterior superior part, in contact with the malleus head and incus body (5, 14-16). From there on, it can extend towards the antrum and mastoid. It can also be situated in the mesotympanon extending along the long process of the incus, the incudostapedial joint and the crura of the stapes, with subsequent bony erosion (15-16).

Congenital cholesteatoma can be situated in the temporal bone near the otic capsule. In those cases, it is very often found near the geniculate ganglion, from there invading the middle ear and/or the inner ear (14). The middle ear component

can cause conductive hearing loss. Around the geniculate ganglion it can cause progressive facial nerve palsy. When it invades the inner ear, it can cause sensorineural hearing loss. Usually, these patients are young.

B. Acquired cholesteatoma

1. Theories of origin and pathogenesis:

Many recently published review papers have described the existing pathogenic theories on the development of primary acquired cholesteatoma (17-20). The current theories hypothesise that the driving force in the development of acquired cholesteatoma is the outer squamous layer of the TM.

In the *squamous metaplasia theory*, inflammation in the middle ear leads to transformation of the middle ear mucosal lining. Although squamous metaplasia from middle ear mucosa has been observed in animal models, no histological or experimental evidence has been demonstrated that metaplasia results in cholesteatoma. Indeed, all current evidence suggests an ectodermal origin (21).

The *squamous immigration theory* refers to squamous keratinising epithelium migrating along the margin of a TM perforation, thus entering the middle ear cavity. The main dilemma regarding this theory is discrepancy between the incidence of tympanic perforations and the incidence of cholesteatomas. As we obviously know, the great majority of cholesteatomas develops from an intact tympanic membrane (22-23).

In the *basilar hyperplasia theory*, basal keratinocytes are thought to proliferate and penetrate the basement membrane, extending elongated pseudopodia into the subepithelial space. Although inflammation can drive proliferation, there is no supporting evidence for what drives these basal cells to migrate medially rather than laterally. Another requirement for pathogenesis of cholesteatoma in this setting would be the weakening of the supporting structures and inward traction exerted on these basal cells (24).

The *retraction pocket theory*, is the most widely accepted theory today. A dysfunction of the Eustachian tube causes a vacuum of the tympanic cavity, which causes a retraction of the tympanic membrane (25-26). In this theory two different subtypes of cholesteatoma are described depending on the location of origin of the cholesteatoma (Figure 2): the **pars flaccida cholesteatoma** and the **pars tensa cholesteatoma**. Most frequently, these retraction pockets are situated in the *pars flaccida* further expanding into the lateral epitympanic recess, the so-called Prussack's space. Gradually exfoliating, the retraction pocket enlarges, eroding the surrounding bony structures such as the malleus head, the incus body and the



Figure 2 *Left*. The most common type of an acquired cholesteatoma originates in the epitympanum (pars flaccida cholesteatoma). The retraction pocket develops along the long process and body of the incus. As cholesteatoma pocket deepens, it travels along the lateral surface of the body of the incus. As the cholesteatoma further expands, it becomes filled with keratin debris and gradually expands through the aditus ad antrum to involve the mastoid. *Right*: When a retraction occurs in the postero-superior or inferior part of the tympanic membrane this may lead to a pars tensa cholesteatoma, invading the middle ear cavity and displacing the ossicles laterally (Courtesy from Harnsberger in Diagnostic Imaging, Head and Neck, Amyrsis).

lateral epitympanic wall. A defective self-cleaning capacity of the external auditory canal skin enhances the accumulation of keratin leading to the formation of a cholesteatoma. When the cholesteatoma further grows, it will expand and fill up the attic, possibly eroding the tegmen tympani, the bony delineation of the tympanic segment of the facial nerve and the lateral semicircular canal. The cholesteatoma may then invade the middle cranial fossa or the membranous labyrinth. Less frequently, the retraction pocket will originate at the posterosuperior pars tensa of the TM and will expand around the long process of the incus, extending further medially to the stapes. This type of cholesteatoma is often called a sinus cholesteatoma. A pars tensa cholesteatoma usually expands medial to the ossicular chain and upwards and will displace the ossicles laterally. The various theories regarding the etiopathogenesis of acquired cholesteatoma are illustrated in Figure 3.



Existing Theories of Cholesteatoma Pathogenesis

Figure 3. Depiction of the existing theories on the pathogenesis of acquired cholesteatoma (Courtesy from Jackler et al., Laryngoscope 2015).

Recently Jackler et al (27) described a new *mucosal traction theory* where the primary acquired cholesteatoma formation involves the mucosal layer migrating and exerting traction on the tympanic membrane. Trapped pro-inflammatory mucosal elements release cytokines, which stimulate the second phase of growth, further keratinocyte proliferation, and migration. The third stage of cholesteatoma growth occurs when impacted keratin accumulates behind a constrained orifice and exerts an expansile force, further accelerated by associated infection. It should be pointed out that such a biphasic growth pattern (pouch first followed by keratin accumulation) is implicit in all of the earlier cholesteatoma pathogenic theories as well.

4. Imaging of cholesteatoma

A. CT imaging of cholesteatoma

High Resolution or Cone Beam Computed Tomography (HRCT/CBCT) of the temporal bone is still by many surgeons considered to be the imaging modality of choice to evaluate the extension of a suspected acquired middle ear or congenital cholesteatoma, prior to eventual surgery. Indeed, HRCT/CBCT of the temporal bone is able to show the presence of a cholesteatoma in an indirect way: it visualizes the bony destruction caused by the cholesteatoma in great detail, and shows the cholesteatoma usually as the presence of a soft tissue mass in contrast to the adjacent bone or gas. (28-30) However, CT cannot distinguish cholesteatoma from other soft tissue lesions such as inflammatory tissue, scar tissue, cholesterol granuloma, fat and liquid. This fact limits the diagnostic value of CT in the preoperative work-up and postoperative follow-up of cholesteatoma cases. An acquired cholesteatoma most frequently starts as a retraction pocket into Prussack's space. This retraction pocket, seen at micro-otoscopy, is best visualised on a coronal CT as an associated nodular soft tissue lesion in Prussack's space. The bony erosion caused by the pars flaccida cholesteatoma usually starts at the lateral epitympanic recess with erosion of the scutum and the lateral epitympanic wall. It can erode the malleus head, the corpus and short process of the incus and later the long process. These often subtle bony details can best be evaluated by comparison with the contralateral ear. In case of further growth, the cholesteatoma expands into the antrum and further into the mastoid cavity. Bony erosion of the tegmen is best evaluated in the coronal plane. CBCT is to be preferred over CT due to its lower radiation dose, its higher resolution and its ability to perform volume acquisition enabling coronal images with equal resolution to axial images.

The bony delineation of the lateral semicircular canal should always be examined carefully in order to exclude fistulisation. Special attention should be paid to the tympanic or second segment of the facial nerve canal as this is also prone to erosion by a middle ear cholesteatoma. It should be noted that bony erosion can also be seen in cases of non-cholesteatomatous disease. Ossicular chain erosions are rather rare in case of non-cholesteatomatous middle ear disease, but are known to occur and will predominantly erode the incus long process and lenticular process, followed by the stapes head. The malleus and incus body are much less vulnerable to this non-cholesteatomatous kind of erosion, which is believed to be due to release of substances by mononuclear inflammatory cells and osteocytes or osteoclasts.



Figure 4. Pathognomonic image at CBCT of a *pars flaccida cholesteatoma* presenting itself as a soft tissue opacification in Prussack's space with clear erosion of incus body and short process. a Axial CBCT image on the right side at the level of the second segment of the facial nerve. Note the complete opacification of the poorly aerated middle ear. There is almost complete erosion of the incus body and short process (arrowheads). Note the intact appearance of the malleus head (arrow). Compare to the normal left side in Fig. 4b. b Axial CBCT image on the left side at the level of the second segment of the facial nerve (same level as Fig. 4a). Again, there is a poorly aerated middle ear. There is a normal delineation of the malleus head (arrow) and incus body (arrowheads). The incus short process cannot be delineated on this image due to partial volume effect. c Coronal CBCT image on the right side at the level of the cochlea. Note the opacification of the meso- and epitympanon with erosion of the scutum (arrow). The complex of malleus head and incus body-compare to the normal side in Fig. 4d-looks thinned and eroded (arrowheads). d Coronal CBCT image on the left side at the level of the cochlea (same level as Fig. 4c). There is a complete aeration of the middle ear with completely intact delineation of the complex malleus and incus body (arrowheads). Note the intact delineation of the scutum (arrow) and the aerated Prussack's space.



Figure 5. Findings on this CBCT examination are typical for a pars tensa cholesteatoma with ossicular erosion and lateral displacement of the ossicles. a. Axial CBCT image at the level of the oval window. There is complete opacification of the middle ear with an intact delineation of the malleus and incus (arrowhead). Malleus and incus look displaced laterally (compare to the normal side, Fig. 5b). b. Axial CBCT image at the level of the oval window (same level as Fig. 5a). The middle ear is completely aerated with a normal delineation of the ossicular chain (arrowhead). c. Coronal CBCT image at the level of the cochlea. There is complete opacification of the middle ear, antrum and mastoid (arrows). The incus corpus seems to be slightly eroded (small arrowhead) with lateral displacement of the ossicles (compare to the normal situation on the left side in Fig. 5d). d. Coronal CBCT image at the level of the cochlea. There is a normal delineation of the cossicular chain (arrowhead) are completely aerated. There is a normal delineation of the ossicular chain (small arrowhead) and scutum (large arrowhead). Compare to Fig. 5c to evaluate the position of the ossicles.

A **congenital cholesteatoma** can originate in every part of the temporal bone pyramid. In its most frequent middle ear presentation, it can be seen as a small nodular soft tissue density located in the anterosuperior part of the

mesotympanum or in the anterior epitympanum, if diagnosed early on in its development. It is associated with an intact tympanic membrane on otoscopy. However, in a later stage of its development, it can present as a large soft tissue mass extending in the middle ear space, eroding the ossicular chain. When originating in the anterior epitympanum, it is often diagnosed quite late, and can cause invasion into the lateral semicircular canal and damage the facial nerve at the level of the geniculate ganglion.

In the case of petrous bone apex presentation, it usually presents as a sharply delineated punched-out lesion in the bone, associated to a soft tissue mass. The sharp and regular delineation of congenital cholesteatoma in the temporal bone pyramid is its most important characteristic in the differential diagnosis with other lesions such as a metastatic lesion. Depending on its position, it may invade essential parts of the membranous labyrinth, such as the cochlea, the vestibule and semicircular canals as well as the facial canal.

B. MR imaging of cholesteatoma

Cholesteatoma is a cystic lesion consisting in a keratinised, stratified, squamous epithelium matrix filled with desquamation debris (keratin), and surrounded by an inflammatory perimatrix of varying thickness.

On standard T1-weighted MRI sequences, congenital and acquired cholesteatoma have a hypointense signal intensity when compared with the brain's gray matter. A cholesteatoma is a non-vascularised lesion; therefore, it is not enhanced after intravenous gadolinium administration. Theoretically, the enhancement of the surrounding epithelium (matrix) can be seen as a thin, enhanced line (peripheral rim) on T1-weighted images after intravenous administration of gadolinium. However, this is often not distinguishable from the also enhancing inflammation tissue, which often surrounds a cholesteatoma.

On T2-weighted images, cholesteatoma is characterised by an intermediate to high signal intensity, which however is still lower than the intensity of inflammatory tissue or fluid. Its signal intensity is comparable to the signal intensity of the brain's gray matter.

On diffusion-weighted MRI sequences (DW-MRI) (echo-planar as well as non-echo-planar), a cholesteatoma is characterised by a clear hyperintensity on *b*1000 images (31-33).

Inflammatory or fibrous tissue, on the contrary, is characterised by a very high signal intensity on T2-weighted images and a low signal intensity on T1-weighted images, although these are variably and inhomogeneously enhanced after

intravenous administration of gadolinium. It often takes 45 minutes for fibrous tissue to show full enhancement, which necessitates repeated late imaging after gadolinium administration (delayed post-gadolinium T1-weighted imaging). This is quite a logistic burden on the put-through of patients in the imaging department. On *b*1000, inflammatory or fibrous tissue displays a low signal intensity.

A cholesterol granuloma is characterised on MRI by high signal intensities on both T1- and T2-weighted images and a low signal intensity on *b*1000 DW-MRI.

DW-MRI was initially used to diagnose ischemic brain infarction (34). The DW-MRI technique provides information about the diffusion motion of water (protons) and the restriction of this motion within various biologic tissues and pathological entities. In order to visualize the diffusion of water (protons), diffusion-sensitizing gradients must be applied, most often using a fast, single-shot gradient echo sequence (b-values of 0s/mm2 and 1000s/mm2) (34-35). The precise cause of the increased signal intensity of cholesteatoma on DW-MRI is still unclear. Several authors believe that the hyperintensity is caused by a combination of restricted diffusion and the T2 shine-through effect. The cholesteatoma, which is filled with keratin debris, has a moderate to high signal intensity on standard T2-weighted MRI, suggesting that the T2 shine-through effect may contribute to the hyperintensity on diffusion-weighted images.

There are two clinical entities (so-called mimicks) that have the same characteristics as cholesteatoma on DW-MRI: cerumen in the external auditory canal (EAC), and an acute abscess. The first mimic, clearly situated at the level of the EAC, can be avoided by cleaning the EAC before sending the patient for imaging. The second mimic is easily recognized on clinical grounds.

One should also be aware that echo-planar DW-MRI (EP DW-MRI) produces marked hyperintense artefacts, mainly at the level of the tegmen. These artefacts can hide a small residual cholesteatoma. Therefore, in cholesteatoma imaging EP DW-MRI should be abandoned in favour of non-EP DW-MR, which produces much less artefacts, allows thinner slice thickness and has a higher resolution. False positive findings on non-EP DW-MR have been reported in the presence of silastic, bone powder, granulation tissue and protein rich cyts (5).

However, today a marked hyperintensity on *b*1000 DW-MRI can be regarded diagnostic for cholesteatoma.

To avoid false positive findings, correlation of *b*1000 images is done with apparent diffusion coefficients (ADC) maps. The ADC map gives a quantification of the diffusion restriction and is free from any T1 or T2 effects. It provides a true quantitative display of water diffusivity at each voxel. A recent paper demonstrated

that cholesteatoma is the only entitity displaying a true restriction as opposed to non-cholesteatomatous tissue such as granulation tissue, fibrosis and cholesterol granuloma (36). This is reflected in a low signal intensity on ADC maps and a low calculated ADC value. However, ADC quantification can be difficult due to the often small volume of the cholesteatoma so visual inspection on ADC maps looking for the hypointense cholesteatoma will suffice.

The differential diagnosis and imaging characteristics of cholesteatoma on MRI are summarized in Table 1.

	T2-weighted MRI	T1-weighted MRI	Delayed post gadolinium T1 weighted MRI	b1000 DW MRI	ADC map
Cholesteatoma	Moderately intense	Hypointense	Hypointense + rim enhancement (perimatrix)	Hyperintense	Hypointense
Cholesterol granuloma	Strongly hyperintense	Hyperintense	No changes after iv gadolinium	Hypointense	Hyperintense
Inflammation Scar tissue	Strongly hyperintense	Hypointense	Hyperintense on late enhancement	Hypointense	Hyperintense

Table 1. Differential diagnosis and imaging characteristics of cholesteatoma on MRI



Figure 6: Magnetic resonance imaging characteristics of a cholesteatoma

a. Coronal T2-weighted image through the left temporal bone showing a mastoid cavity almost completely filled with a hyperintense nodular lesion.

b. Axial and c. Coronal late (45 minutes) post-gadolinium T1weighted MRI. The cholesteatoma is seen as a hypointense nodular lesion surrounded by a thin layer of enhanced inflammatory and scar tissue.

d. Coronal single-shot turbo spinecho diffusion-weighted sequence (SS TSE DWI: a non-EPI based diffusion weighted image) at the level of the left temporal bone. The cholesteatoma is clearly seen as a hyperintense lesion under the left temporal lobe.

5. Surgery of cholesteatoma

1. Surgical approaches: origin and history

The first description of chronic and suppurative infections of the mastoid was already reported in Ancient Greek manuscripts (Galenus AD 129-217) (37). The first report on mastoid surgery was made in 1671 by Jean Riolan, a French anatomist. It recommended a mastoidectomy unless the surgical procedure would endanger the life of the patient: "If an intolerable and throbbing inflammatory pain fills and obstructs the release of purulent secretion from the head, an incision in the posterior region of the head might be the only solution" (38). Jean-Louis Petit reported multiple cases of mastoid trephinations for acute abscesses in the late 1750 (39-40). A new era for mastoidectomy was inaugurated by Sir William Wilde with his introduction of the eponymous retroauricular incision (41). Schwartze and Eysell, were the first to systematically describe the cortical mastoidectomy in 1873, with a first systematic description of how and under what conditions the procedure should be performed, recommending the use of a chisel and hammer to remove the bone in such a way that the antrum could be properly inspected and efficiently drained (42). In 1890, Zaufal described the first radical mastoidectomy removing the superior and posterior bony ear canal, tympanic membrane, and ossicles in an attempt to eliminate infection, externalize disease, and create a dry ear (43). Ernst Küster and Ernst von Bergmann, both general surgeons, were credited with developing the radical surgery, which was known for some time as Küster-Bergmann surgery. They advocated combining the dissection of several spaces of the attic, antrum, and middle ear, transforming these into a single large cavity, into one surgical procedure (44-46). Bondy popularized the modified radical *mastoidectomy* in which some or all of the middle ear structures were preserved in order to attempt to preserve hearing (47). The introduction of the Zeiss otologic operating microscope in 1953 made more precise dissection possible. Soon thereafter, Wullstein described the first attempts at reconstruction of the tympanic membrane via tympanoplasty (48). The Canal wall up (CWU) mastoidectomy procedure was introduced by Jansen in 1958 (49). This led to tympanoossicular reconstructions with mastoidectomy (the so-called closed cavity mastoidectomy or intact canal wall tympanomastoidectomy or Canal wall up (CWU) mastoidectomy) and to the use of traditional mastoidectomy for the treatment of chronic suppurative and cholesteatomatous otitis. Since then, many variations of the mastoidectomy have been described.

2. Indications and goals of tympanoplasty

The primary goal of the surgical treatment of chronic otitis media with cholesteatoma is the complete eradication of the disease (no residual disease), whereas secondary goals are the prevention of recurrent disease, the improvement of the hygienic status of the ear, and the preservation or improvement of hearing (50). For chronic ear surgery, a CWU mastoidectomy is performed to help eradicate disease and gain access to the antrum, attic and middle ear.

Many variables influence the long-term outcome of surgery. The more extensive the disease and damage at initial presentation, the poorer the outcome. Another important variable influencing the outcome of surgery for chronic otitis media (COM) is the quality of the surgical act, which depends on different factors including the surgeon's personal experience and skills, the adequate choice of the surgical technique and of the material used for the reconstruction.

3. Surgical techniques

3.1. Simple mastoidectomy (Figure 7)

In a simple or cortical mastoidectomy the mastoid cortex and some of the underlying air cells are removed. The dissection may be only superficial or may further proceeded to the mastoid antrum. Most often it is used to remove the mastoid cortex and drain a coalescent mastoiditis with subperiosteal abscess.



Figure 7: Surgical approach of a cortical mastoidectomy (Courtesy by Cremers and Mulder, Kugler publications, Amsterdam 2011)

eec: external ear canal mt: mastoid tip mpl: mastoid plane



3.2. Intact canal wall or Canal wall up mastoidectomy (CWU) (figure 8)

The canal wall up mastoidectomy involves removing the mastoid air cells lateral to the facial nerve and otic capsule bone while preserving the posterior and superior external auditory canal wall. With this technique the epitympanum can be accessed while maintaining the natural barrier between the external auditory canal and mastoid cavity. This approach can be combined with a facial recess approach or posterior tympanotomy for removal of cholesteatoma in the facial recess, a better exposure of the posterior mesotympanum around the oval and round windows, and better visualization of the tympanic segment of the facial nerve. If increased exposure is necessitated, the facial recess can be extended inferiorly or superiorly to gain complete access to the hypotympanum or the epitympanum (49).



Figure 8: Stepwise approach of a posterior tympanotomy (Courtesy by Cremers and Mulder, Kugler publications, Amsterdam 2011)

ct: chorda typmani dfn: descending part of the facial canal rec: facial recess ss: sigmoid sinus pp: pyramidal process rwn: round window niche s: stapes crurae ai: articular groove for the incus cp: cochleariform process pt: posterior tympanotomy

3.3. Modified radical mastoidectomy

Although the classic description of a modified radical mastoidectomy is the atticotomy described by Bondy, most surgeons currently use the term to describe a Canal wall down mastoidectomy with removal of the external auditory canal wall and with tympanic membrane reconstruction. There are both preoperative and intraoperative indications to remove the auditory canal. Preoperative indications for a modified radical mastoidectomy include patients with poor general health

making them an anesthetic risk and patients in whom the long-term follow-up could be problematic. Some surgeons advocate a Canal wall down technique after multiple failed attempts at canal wall intact surgery, in case of an extensive posterior external auditory canal defect, in the presence of a labyrinthine fistula where the surgeon prefers not to dissect the matrix from the fistula and in case of a low-positioned middle fossa dura limiting epitympanic access (50-51).

4. Radical mastoidectomy (Figure 9)

A radical mastoidectomy is performed in patients with insufficient aeration of the middle ear space, irreversible middle ear disease, or unresectable cholesteatoma or tumours. In this procedure the middle ear and mastoid air cells are exteriorized as a single cavity without attempt to reconstruct (52).



Figure 9: Illustration of a radical mastoidectomy (Courtesy by Cremers and

Mulder, Kugler publications, Amsterdam 2011) cav: mastoid cavity dr: digastric ridge epi: epitympanum fn: facial nerve hsc: horizontal semicircular canal mf: middle fossa dural plate sc: stapes crura sm: stapedial muscle ss: sigmoid sinus tm: tympanic membrane tt: tegmen tympani

5. Canal wall up versus Canal wall down mastoidectomy

Two basically different surgical approaches have been and are still advocated in cholesteatoma surgery: CWU and CWD. The CWU technique is defined by the presence of an intact or restored bony canal wall at the end of the operation. The CWD technique is defined by the absence of the bony canal wall at the end of the operation, even when the cavity has been partially obliterated by soft tissue. Both

CWU and CWD techniques have their respective advantages and disadvantages. The advantages of the CWD technique are 1/ no need for staging; 2/ a lower rate of residual cholesteatoma; 3/ a lower rate of recurrent cholesteatoma. The advantages of the CWU technique are: 1/ a better hygienic status of the ear; 2/ a better functional outcome. The disadvantages of the CWD technique are: 1/ the associated higher morbidity, such as the need for regular cleaning, recurrent infections, water intolerance, caloric induced vertigo and the difficulty to wear a hearing aid with an occlusion of the external ear canal if needed; 2/ a worse functional outcome. The disadvantages of the CWU technique are: 1/ the need for staging to detect residual cholesteatoma, potentially later followed by revision surgery; 2/ the need for long-term follow-up to detect recurrent cholesteatoma; 3/ a higher rate of residual disease; 4/ a higher rate of recurrent disease (53).

Approximately half a century of disputes divide the respective defenders of the CWU versus CWD technique. The decision to perform one or the other is often based on the surgeon's personal experience in individualized cholesteatoma cases. However, most surgeons prefer to avoid creating a cavity if possible.

6. Other surgical techniques

Several alternative surgical procedures to the standard mastoidectomy procedures have been described.

Retrograde mastoidectomy (Figure 10). Various reports have been published related to surgical techniques that involve temporary removal of the canal wall for better exposure of the cholesteatoma and its easier elimination, followed by reconstruction of the canal wall using autologous (bone, cartilage) or alloplastic (hydroxyapatite cement, titanium) graft materials (54-61).



Figure 10. Example of a retrograde mastoidectomy with temporal removal of the posterior canal wall (Courtesy by J. Dornhoffer, Otology&Neurotology 2004)

Mastoid obliteration techniques. Mastoid and epitympanic obliteration techniques have been developed for two major indications.

Mastoid obliteration techniques were initially introduced to treat chronically discharging and problematic cavities. Blake (1898) was the first to attempt obliteration of a mastoid cavity, using a blood clot as a medium to induce fibrous growth and thus reduce the cavity size (62). The mastoid obliteration technique was introduced in 1911 by Mosher in order to promote the healing of a mastoidectomy defect using a superiorly based post-auricular soft tissue flap (63). Subsequent to his first description, a variety of surgical techniques have been developed in the 20th and 21st century, using different types of autologous material such as fascia (64-66), fat (67-68), cartilage (69), cortical bone chips (70), bone pâté (71), vascularised musculo-periosteal flaps (63, 72-75) or biocompatible materials such as hydroxyapatite (76), demineralised bone matrix (77), ionomeric cements (78-79), and calcium phosphate ceramics (80-81).

The second, more recent indication for mastoid obliteration is cholesteatoma surgery, with as its specific aim the reduction of the recurrence rate. Mercke was the first to use the mastoid and epitympanic bony obliteration after complete eradication of the pathology in a consecutive series of cholesteatoma cases. He reported a strong decline in the rate of recurrent disease (82-83). Other authors confirmed these results (84 - 85).

6. Lowering residual and recurrent disease

1. Rate of residual cholesteatoma

The primary goal of cholesteatoma surgery is always complete eradication of the pathology. No part of the original cholesteatoma should be left behind. Residual cholesteatoma is defined as a cluster of viable keratinising squamous epithelium cells, left behind at the primary surgery, which has regrown into a cholesteatoma. The problem is inherent in all cholesteatoma surgery, regardless of the applied approach and reconstructive technique. The rate of residual surgical cholesteatoma reported in the literature shows substantial variation, reflecting an important variation in the quality of the surgical act. However, it is found to be consistently higher in the conventional CWU techniques than in the CWD techniques or in the CWU Bony Obliteration Technique (CWU – BOT) (82-97). Moreover, a consistently higher residual rate has been observed in the paediatric population in comparison with the adult population, regardless of the applied surgical approach (84,98-102). Until recently, these observations made exploratory surgical staging after CWU techniques the golden rule. The advent of new MRI sequences, especially the non-echo planar imaging diffusion weighted sequence (non-EP DW MRI), allows for specific characterisation of even small cholesteatoma pearls. On MRI, cholesteatoma can be unambiguously distinguished from other soft tissues such as scar tissue, cholesterol granuloma, granulation tissue and fluid (31-33), thus obviating the necessity for routine exploratory second-look procedures by replacing it with a non-invasive and nonirradiating imaging technique. It should be emphasised that the use of CT for the postoperative follow-up of cholesteatoma cases must be abandoned for two good reasons: 1/ CT cannot discriminate between cholesteatoma and other soft tissues: 2/ repeated CT exposes the patient to unnecessary irradiation.

2. Rate of recurrent cholesteatoma

An important secondary goal of cholesteatoma surgery is the prevention of recurrent disease. Substantially high rates of recurrent cholesteatoma following conventional CWU surgery are reported in the literature, varying from 3% to 25%, with markedly higher rates in the paediatric population (98, 88-102). A comprehensive overview of the published recurrent rates in paediatric and adult series for CWD, conventional CWU and CWU-BOT techniques is given in Table 2. Important variations in the length of the follow-up period should be kept in mind when interpreting these figures. Our own paediatric conventional CWU series showed a recurrent rate of 18% after a mean follow-up of 4.5 years, while the

recurrent rate in our adult series was 5% after a follow-up of 4.5 years (103). These figures convinced us in 1997 that we needed to change our surgical approach to the problem. As a consequence, we developed our personal CWU-BOT approach, which we now apply in approximately 90% of primary cholesteatoma cases.

Table 2	2.	Residual	and	recurrent	cholesteatoma	rate	in	various	types	of	cholesteatoma
surgery	1.										

Author	Ν	Residual cholesteatoma (%)	Recurrent cholesteatoma (%)					
Canal wall up technique								
Glasscock ME 3 rd and Miller GW (1976)(88)	154	12	14	75% (5y)				
Sheehy JL et al (1977)(89)	1024	32	5					
Sanna M et al. (1984)(90)	283	7, 8	13, 4					
Janssen CW (1985)(91)	1904	6,9	3,2					
Mercke U (1987)(92)	56	21,4	25					
Brackmann (1993)(93)	108	14	3					
Kamarkar S et al. (1995)(94)	257	31,2	11,2					
· · · · ·								
Canal	wall up	in paediatric cholesteator	ma					
Sanna M et al. (1987)(99)	151	40	11					
Charachon R et al. (1988)(100)	160	31	20					
Magnan J et al. (1992)(101)	210	26	19,5					
Schilder A et al. (1997)(98)	103	23	18					
Darrouzet V et al. (2000)(102)	190	20,5	8,9					
	Canal	wall down technique						
Cody D&Taylor W (1987)(96)	172	6	8					
Sade J (1987)(95)	65	13	0					
Kos I et al (2004)(97)	259	5,8	0,4					
Kamarkar S et al. (1995)(94)	176	2,38	10					
Obliteratio	on follov	<i>ving</i> Canal wall down <i>tech</i>	hnique					
Ramsey MJ et al (2004) (86)	60	0	0					
Singh V and Atlas M (2007)(104)	51	0	0					
Yung et al. (2007)(105)	102	4.9	0					
Oblitera	tion follo	<i>wing</i> Canal wall up <i>techr</i>	nique					
Mercke U (1987)(82)	57	5.3	0					
Gantz B et al (2005)(84)	130	9.8	1.5					
Lee WS et al (2005) (106)	151	5.4	0					
Vercruysse JP et al.	281	3.5	1.3					
Obliteration fol	lowing (Canal wall up in paediatric	c population					
Gantz B et al (2005)(84)	40	10	0					
Vercruysse JP et al (2008)(107)	52	15.4	1.9					
7. Purpose of the thesis

The purpose of the thesis is to report on the added value of diffusion-weighted MR imaging and the contribution of bony obliteration techniques to safety and success in the clinical management of cholesteatoma.

Before 1997, the surgical philosophy regarding cholesteatoma management at the European Institute of ORL-HNS of the Sint-Augustine Hospital was first to eradicate the pathology using the CWU approach, without bony obliteration of the paratympanic spaces, followed by the reconstruction of the normal anatomy of the bony canal wall with sculpted cortical bone chips and the reconstruction of the middle ear mechanism by means of tympano - ossicular allografts (TOA).

By using this technique we hoped that the biological behaviour of the middle ear's mucosal lining and of the EAC's skin was sufficiently good to allow for long-term biological, physiological and structural stability.

The meticulous and consequent application of this CWU technique yielded good results in many cases, but we were still somewhat disappointed with the long-term outcome, for the following reasons: 1/ the non-negligible rate of recurrent cholesteatoma, observed in 8,4 % in a series of 422 patients (18 % in 103 children, 5 % in 319 adults) (95, 100); 2/ the necessity of staging, leading to an important number of unnecessary operations; 3/ insufficient functional gain (hearing level); 4/ the necessity to change a CWU into a CWD mastoidectomy in cases with extensive, rapidly recurring cholesteatoma (approx. 5%). (95,100). These reasons generated a change in our surgical philosophy concerning cholesteatoma surgery, which led to the adaptation of the surgical technique. In 1997 we decided to find out whether it was possible to combine the advantages and at the same time avoid the disadvantages of both the CWU and CWD techniques, by applying one surgical approach: the Bony Obliteration Technique (BOT), which is by definition a CWU technique. This surgical technique of bony mastoid obliteration is nowadays used in the majority of cholesteatoma cases in our department. Chapter 2 focuses on the surgical principles of the mastoid and epitympanic BOT.

In order to evaluate the value of MR imaging in the preoperative work-up and postoperative follow-up of cholesteatoma, various MRI sequences were evaluated, including the EP-DW sequence, the non-EP DW sequence and the delayed gadolinium-enhanced T1 weighted sequence. *Chapter 3* focuses on the imaging principles of cholesteatoma.

The conventional method to exclude or confirm residual cholesteatoma after CWU surgery is to perform an exploratory second surgical stage 12 to 18 months after

the first stage, exploring all the anatomical sites were residual pathology could be present. In *Chapter 4* the contribution of MR imaging in clinical cholesteatoma management is discussed. The combination of EP DW sequences, T1 and T2 weighted sequences before and after gadolinium administratin, for the diagnostic work-up of primary acquired or congenital cholesteatoma and pre second-look cases is discussed in *Chapter 4.1*. Accurate and reliable imaging follow-up of obliterated mastoids is absolutely necessary to prevent late complications due to residual cholesteatoma buried underneath the obliteration material. Such complications may take many years to appear. This topic is addressed in *Chapter 4.2*.

To find out whether routine exploratory second stage surgery for the detection of residual cholesteatoma could be reliably replaced by MR imaging, we performed a clinical study, preoperatively screening a patient group prior to second look surgery, using non-EP DW and delayed gadolinium enhanced T1 weighted MRI protocols. The imaging findings were then correlated with the intraoperative findings. The results are discussed in *Chapter 4.3.*

In *Chapter 4.4* we retrospectively compared non-EP DW imaging, delayed gadolinium- enhanced T1-weighted magnetic resonance imaging, and the combination of both techniques in the evaluation of patients with cholesteatoma. We concluded in this study that MR imaging for the detection of middle ear cholesteatoma, could be performed by using solely non-EP DW imaging sequences. Use of the non-EP DW imaging sequence combined with a delayed gadolinium-enhanced T1-weighted sequence yielded no significant increases in sensitivity, specificity, negative predictive value, or positive predictive value over the use of the non-EP DW imaging sequence alone.

In *Chapter 5* we evaluate the first surgical results of the bony obliteration technique. The primary goal of cholesteatoma surgery is complete eradication of the disease, but due to higher rates of recurrent and residual disease, children present a greater challenge than adults. In this report, we describe our experience with the BOT in a paediatric series of cholesteatoma cases and in cases with an unstable cavity after CWD surgery for cholesteatoma. The indications and the surgical outcome, including the recurrence rate, the residual rate, the functional results, and the otoscopic and imaging follow-up, are discussed. We considered the outcome of this study to be preliminary in nature, while planning for the long-term 5 year and 10 year postoperative results.

As we allow for the possibility that it takes more than one year for a residual cholesteatoma to develop into a lesion detectable on non-EP DW MRI (>2 mm), we routinely image our post-operative cholesteatoma ears after one and five

years. This is especially important when the bony obliteration technique is used, because it carries the potential risk of burying residual cholesteatoma underneath the obliteration material. It may then take years before the residual pathology becomes clinically evident. Undetected residual cholesteatoma may cause major destruction and complications at a late stage, such as intracranial cholesteatoma and brain abscess. In *Chapter 6.1* we report on the long-term outcome of the BOT in patients presenting with a cholesteatoma or a troublesome CWD cavity, as evaluated by imaging (HRCT and MRI).

Unstable and problematic cavities after CWD mastoidectomy are a major indication for performing bony obliteration of the mastoid and epitympanum. One of the goals of the mastoid and epitympanic obliteration technique is to rebuild an external auditory canal (EAC) with normal dimensions. This results in a better self-cleaning capacity of EAC and leads to a better hygienic status of the ear. *Chapter* **6.2** addresses the long-term clinical outcome of our mastoid and epitympanic obliteration technique with canal wall reconstruction, including the recurrence rate, the residual rate, the functional results, the hygienic status of the ear, the otoscopic evaluation of the tympanic membrane and the long-term safety issues as monitored by non-EP DW MRI.

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Chapter 1.2

Game-changers in chronic otitis media with cholesteatoma

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Chronic otitis with cholesteatoma is still a potentially life-threatening disease when intracranial complications occur (1). Acquired cholesteatoma has a low incidence with only 9 cases per 100,000 per year (2). The impact on the patient's quality of life is high due to lifelong chronic symptoms, often leading to repeated surgical procedures. Two game-changers, a diagnostic imaging tool and a modified surgical technique, have transformed the therapeutic protocol and outcome dramatically.

The driving force in acquired cholesteatoma is skin. A biological dysfunction of the middle ear mucosa generates a tympanic membrane retraction pocket, which gradually invades the middle ear space, causing erosion of the adjacent bony structures (ossicles, canal wall). The progressive loss of the self-cleaning capacity of the skin layer leads to accumulation of keratin, thus creating a cholesteatoma. It then invades the paratympanic space, its growth accelerated by inflammation and infection. Erosion of the bony delineation of the middle cranial fossa, the facial nerve and the cochleovestibular labyrinth can occur, leading to invasion of the middle cranial fossa or the membranous labyrinth. Hearing, equilibrium and facial function can be affected, and meningitis and brain abscess are potentially life-threatening complications (3).

For many years the diagnostic work-up and surgical follow up of cholesteatoma was based on medical history and otoscopy, supported by CT-scan. However, this has completely changed with the introduction of non-echo planar diffusion-weighted MRI sequences for cholesteatoma imaging. The value of these MRI sequences in cholesteatoma diagnosis has been proven and documented extensively during the past decade. In contrast with CT and other MRI sequences, its high sensitivity and specificity allows accurate visualisation of residual cholesteatoma during the surgical follow up (4-8). Routine second look surgery to detect residual disease after primary surgery thus becomes obsolete, and the surgical bony obliteration technique (see below) can now be safely performed (4,6,9).

The primary goal of cholesteatoma surgery is complete removal, preventing damage to the facial nerve and the inner ear as well as intracranial complications. The second goal is preventing recurrent disease. The third goal is to create a dry, self-cleaning, waterproof ear. The fourth goal is hearing improvement. Although often hearing cannot be sufficiently improved by surgery, a hygienically stable ear allows for troublefree hearing aid fitting.

The original surgical technique to eradicate cholesteatoma was to connect the mastoid and the middle ear with the external auditory canal, the "open" or "canal wall down" technique, resulting in a radical cavity. A modified radical cavity is a

variant technique, separating the tympanic cavity from a size-reduced cavity. The major drawbacks of these techniques are often the unstable hygienic situation and the lack of acceptable hearing. Additional fitting of a conventional hearing aid, occluding the ear canal, often induces therapy-resistant chronic otorrhea. Water contact often results in socially invalidating ear discharge and may evoke dizziness.

Since the late sixties an alternative surgical technique was introduced, the "combined approach tympanoplasty". It keeps the bony auditory canal wall intact, and is therefore also called the "closed" or "canal wall up" technique. ⁽¹⁰⁾ The idea was to preserve the gross anatomical structures of the middle ear and external ear canal to get a better wound healing in each preserved compartment of both mucosa and skin, and consequently, to facilitate hearing improvement. The disadvantages of this technique, even in skilled hands, are the relatively high recurrent and residual cholesteatoma rates compared to the "open" technique. Exploratory second look surgery to rule out hidden residual cholesteatoma is necessary in most cases (10, 11).

Recently, the "bony obliteration tympanoplasty" technique was developed and applied as an addition to the "combined approach". Now, the non-echo planar diffusion weighted MRI sequence allows a safe, non-invasive follow up alternative to second look surgery. The obliteration of the mastoid and epitympanum with autologous bone chips and bone paste showed excellent long-term safety and hygienic results. Both the residual and recurrent cholesteatoma rates dropped significantly, resulting in a major reduction of the re-operation rate. Preserving the gross anatomical dimensions of the middle ear provides much better opportunities to restore the hearing, either by ossicular chain reconstruction or if necessary by additional fitting of air conduction hearing aids (6, 9, 12).

This opens a new era for cholesteatoma surgery. The bony obliteration tympanoplasty is a safe and successful technique, resulting in low rates of recurrent and residual pathology as well as an excellent hygienic outcome. It offers optimal opportunities for hearing improvement by ossicular chain reconstruction or hearing aid fitting. The advent of the non-echo planar diffusion weighted MRI sequence provides an excellent tool for non-invasive monitoring of residual pathology. Together they constitute real game-changers in the management of cholesteatoma, offering to the patient a clear improvement in quality of life, and to society a potential improvement of the cost-benefit ratio.

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Chapter 2

Cholesteatoma – surgical principles

Chapter 2.1

Mastoid and epitympanic obliteration. The obliteration technique

Offeciers E, Vercruysse JP, De Foer B, Casselman JW, Somers T. In: Ars B, ed. Chronic Otitis Media. Pathogenesis Oriented Therapeutic Treatment. Amsterdam: Kugler, (2008);299–327

Abstract

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- 2. Goals of tympanoplasty
- 3. Indications and contra-indications for mastoid and epitympanic obliteration
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Abstract

Purpose: The primary goal of the surgical treatment of chronic otitis media with cholesteatoma is the complete eradication of the pathology, while the secondary goals are the prevention of recurrent disease, the improvement of the hygienic status of the ear and the preservation or improvement of hearing. Various techniques have been advocated in order to reach these goals, including Canal wall down (CWD) mastoidectomy with posterior canal wall removal and Canal wall up mastoidectomy (CWU) techniques. In this chapter we describe the rationale, the surgical technique and the results of our version of the Bony Obliteration Technique (BOT), with total bony obliteration of the epitympanic and mastoid cell system. Its application in our department led to a dramatic decrease of the cholesteatoma recurrence rate. As a result, we completely abandoned the application of CWD techniques with its well known disadvantages.

Recent findings: The BOT dramatically lowers the incidence of recurrent disease after primary cholesteatoma surgery and achieves acceptable functional results. It can also be successfully applied to reconstruct unstable and troublesome cavities, caused by CWD surgery for cholesteatoma. Follow-up by imaging techniques, including non echo-planar diffusion weighted MR imaging, provides a safe non-invasive method for the postoperative detection of residual cholesteatoma, and dramatically decreases the number of unneeded second stage procedures.

Summary: The indications, surgical principles, the surgical outcome including the recurrence rate, the residual rate, the functional results, the hygienic status of the ear, and the imaging follow-up are discussed.

Key words: Cholesteatoma, chronic otitis media, mastoid obliteration, bone pâté, mastoidectomy, recurrent, residual

1. Introduction

Mastoid and epitympanic obliteration techniques have been developed for two major indications. Mastoid obliteration techniques were initially introduced to treat chronically discharging and problematic cavities. Blake (1898) was the first to attempt obliteration of a mastoid cavity, using a blood clot as a medium to induce fibrous growth and thus reduce the cavity size (1). The mastoid obliteration

technique was introduced in 1911 by Mosher in order to promote the healing of a mastoidectomy defect using a superiorly based post-auricular flap (2). Subsequent to his first description, a variety of surgical techniques have been developed in the 20th and 21st century, using different types of autologous material such as fascia (3-5), fat (6-7), cartilage (8), cortical bone chips (9), bone pâté (10), vascularised musculo-periosteal flaps (2,11-14) or biocompatible materials as hydroxyapatite (15), demineralised bone matrix (16), ionomeric cements (17-18), and calcium phosphate ceramics (19-20). The second, more recent indication for mastoid obliteration is cholesteatoma surgery, with as its specific aim the reduction of the recurrence rate. Mercke was the first to use the mastoid and epitympanic BOT after complete eradication of the pathology in a consecutive series of cholesteatoma cases. He reported a strong decline in the rate of recurrent disease (21-22).

2. Goals of tympanoplasty

The goals of the surgical treatment of middle ear cholesteatoma are: 1/ the complete eradication of the pathology; 2/ the prevention of recurrent cholesteatoma; 3/ the restoration of the hygienic status of the ear; 4/ the preservation or improvement of the hearing (23). Many variables influence the long-term outcome of surgery. The more extensive the disease and damage at initial presentation, the poorer the outcome. Another important variable influencing the outcome of surgery for COM is the quality of the surgical act, which depends on different factors including the surgeon's personal experience, the adequate choice of the surgical technique and of the material used for reconstruction. Concerning the choice of technique, two basically different surgical philosophies have been and still are advocated to reach these goals: CWU and CWD. The CWU technique is defined by the presence of an intact or restored bony canal wall at the end of the operation. The CWD technique is defined by the absence of the bony canal wall at the end of the operation, even when the cavity has been partially obliterated by soft tissue. Both CWU and CWD techniques used have advantages and disadvantages. The advantages of the CWD technique are 1/ no need for staging; 2/ a lower rate of residual cholesteatoma; 3/ a lower rate of recurrent cholesteatoma. The advantages of the CWU technique are: 1/ a better hygienic status of the ear; 2/ a better functional outcome. The disadvantages of the CWD technique are: 1/ the associated higher morbidity, such as the need for regular cleaning, recurrent infections, water intolerance, caloric induced vertigo and the difficulty to wear a hearing aid if needed; 2/ a worse functional outcome. The disadvantages of the CWU technique are: 1/ the need for staging and potentially ulterior revision surgery; 2/ the need for long-term follow-up to detect recurrent cholesteatoma; 3/ a higher rate of residual disease; 4/ a higher rate of recurrent disease. Before 1997, we used a CWU technique in approximately 95% of our cholesteatoma cases. Our surgical philosophy was: 1/ first eradicate the pathology; 2/ then reconstruct the normal anatomy by means of sculpted cortical bone for rebuilding the canal wall and by means of tympano- ossicular allografts (TOA) for rebuilding the middle ear; 3/ finally hope that the biological behaviour of the middle ear's mucosal lining and of the EAC's skin is normal enough to allow long-term physiological and structural stability (24-25). The meticulous and consequent application of this CWU technique yielded good results in the majority of the cases, but we were still somewhat disappointed, for the following reasons: 1/ the non-negligible rate of recurrent cholesteatoma, observed in 8,4 % in a series of 422 patients (18 % in 103 children, 5 % in 319 adults) (24-25); 2/ the necessity of staging, leading to an important number of unnecessary operations; 3/ insufficient functional gain; 4/ the necessity to change a CWU into a CWD mastoidectomy in cases with extensive, rapidly recurrent pathology (approx. 5%). These reasons generated a change in our surgical philosophy concerning cholesteatoma surgery, which led to the adaptation of the surgical technique. In 1997 we decided to find out whether it was possible to combine the advantages and at the same time avoid the disadvantages of both the CWU and CWD techniques, by applying one surgical approach: the Bony Obliteration Technique (BOT), which is by definition a CWU technique. This surgical technique of bony mastoid obliteration is nowadays used in the majority of cholesteatoma cases in our department.

3. Indications and contra-indications for mastoid and epitympanic obliteration

There are two major indications for bony obliteration of the mastoid and epitympanic space: 1/ primary acquired or recurrent cholesteatoma; 2/ unstable, problematic cavities following CWD surgery. For both indications the surgical principle and technique are the same, the only difference being that in cavities the whole postero-superior bony canal wall needs to be reconstructed, down to the level of the facial canal, by means of one or a few a solid pieces of sculpted cortical bone, while in the cholesteatoma cases the canal wall is at least partially

intact and needs less reconstruction. We apply the BOT in over 90 % of our cholesteatoma cases. We don't obliterate if the mucosa in the mastoid is healthy (as is often the case in congenital cholesteatoma or in pars flaccida cholesteatoma with an intact ossicular chain and limited invasion of the lateral attic space). In all the other cholesteatoma cases we obliterate if we feel certain enough to have eliminated the cholesteatoma completely from the paratympanic space. First we eliminate the disease, soft tissue and unhealthy bone from the paratympanic space (mastoid and epitympanum), using the combined approach technique with posterior tympanotomy and keeping the canal wall intact. The paratympanic space is then isolated from the external auditory canal (EAC) by one or a few solid pieces of sculpted cortical bone at the level of the tympano-attical barrier and the posterior tympanotomy. Subsequently it is completely filled with bone pâté up to the level of the cortex. This seems to prevent new retractions of the tympanic membrane and dramatically lowers the incidence of recurrent cholesteatoma. Perhaps bony obliteration enhances the biological stability of the ear, probably by reducing the size of the middle ear cell system, thus decreasing the total surface of mucosal lining and diminishing its capacity for gas absorption. When in some rare cases tympanic membrane retraction still occurs, further expansion of the retraction pocket is blocked by the solid bony tympano-attical barrier, thus preventing its development beyond the size of the tympanic cavity into a cholesteatoma. As a consequence, the retraction remains self- cleaning. Unstable and problematic cavities after CWD mastoidectomy are the second major indication for obliteration of the mastoid and epitympanum. The decision to perform revision surgery with bony obliteration is usually based on one or more of the following complaints: 1/ persistent or periodic discharge, which is often difficult to control even with regular cleaning and ear drops, 2/ the need for frequent cleaning, 3/ water intolerance, 4/ caloric induced vertigo and 5/ the difficulty to wear a hearing aid if needed. The problems are mainly caused by the loss of the self-cleaning capacity of the ear. The self-cleaning capacity of the migratory skin in the medial part of the EAC has its limitations, and cannot cope with the extended surface area of skin in most cavities. The BOT rebuilds a normally sized EAC, which restores the self-cleaning capacity and solves the hygienic problems. The BOT can also be applied successfully in therapy-resistant COM without cholesteatoma, more specifically when the ear's bone conduction levels offer potential for unaided or aided hearing after reconstruction. However, in therapyresistant COM with severe to profound SNHL, we prefer to use the technique of tympanomastoid exenteration with blind sac closure of the EAC, to eradicate the pathology and solve the hygienic problems. The tympanomastoid space is filled with fat. We use the same technique in deaf ears with COM needing a cochlear implant, as a preparatory stage 3 to 6 months prior to cochlear implantation (26-27). Subtotal petrosectomy with blind sac closure of the EAC accounts for approximately 3 % of our COM cases and is well described and depicted by Fisch (28). Other indications for mastoid obliteration include the treatment of CSF leaks following acoustic schwannoma surgery, using fat as obliteration material, and the repair of mastoidal or attical tegmen defects with encephalocoele, using cortical bone, fascia and bone pâté (29-30). Relative contraindications for primary mastoid obliteration may include suboptimal or uncertain removal of cholesteatoma (e.g. petrosal cholesteatoma), intracranial complications and associated malignancy (27). The major and less common indications and contra-indications for mastoid obliteration are listed in Table 1.

Table 1. Indications for different types of mastoid obliteration.

Mastoid and Epitympanic Obliteration

- Cholesteatoma
- Unstable or problematic Cavities Chronic otorrhea Recurrent infections Excessive recurrent cleaning Water intolerance Caloric Vertigo Hearing device intolerance

Subtotal petrosectomy

- Treatment of chronic otitis media in ears with severe sensorineural hearing loss
- Treatment of chronic otitis media prior to cochlear implantation

Translabyrinthine acoustic neuroma resection

CSF leak

Encephalocoele

4. Surgical principles of mastoid and epitympanic obliteration

4.1 The bony obliteration technique

Our version of the BOT was inspired by the technique and results initially described by Ulf Mercke (21-22). There are two major differences. 1/ We don't temporarily take out the posterior canal wall to facilitate the dissection of the cholesteatoma. Instead we use the classic combined approach technique with posterior tympanotomy for the dissection of the pathology, leaving the canal wall intact. 2/ We use tympano-ossicular allografts for the reconstruction of the tympanic membrane and columella instead of fascia and biomaterials.

A. The BOT in primary or revision surgery for cholesteatoma

Our BOT technique is depicted schematically and illustrated by per-operative photographs (Figure 1 and 2).



Figure 1. A. Peroperative view of a CWU tympanoplasty achieved in a left ear following complete eradication of cholesteatoma. All pathological remnants were removed and the remaining of the mastoid cavity was adequately checked and drilled. Arrows showing the precise location for the positioning of sculpted cortical bone at the posterior tympanotomy (curved arrow) and in the epitympanic space (straight arrow) at the level of the tympano-attical barrier. DP: Dural plate, EAC: External auditory canal, SS: Sigmoid sinus.

B. Placement of the sculpted cortical bone chip at the tympano-attical barrier.

C. Final position of the sculpted cortical bone chip (black asterisk) sealing of the mastoid and epitympanic space from the middle ear cavity. FN: Facial nerve.

D. The epitympanic and mastoid space is progressively and completely filled with bone pâté, up to the level of the cortex of the temporal bone (white asterisk). An arrow points at the cortical bone chip blocking the mastoid and epitympanic space.



Figure 2. Schematic diagram illustrating the surgical steps of mastoid and epitympanic obliteration in CWU–BOT tympanoplasty. Left and right column showing respectively a transverse section and a transmastoid view of the various surgical steps. Step 1 (A and B): CWU combined approach following complete eradication of cholesteatoma. Step 2 (C and D): Sculpted cortical bone chips are placed at the level of the posterior tympanotomy and tympano-attical barrier in continuity with the external auditory canal in order achieve a complete closure of the epitympanic and mastoid space. Step 3 (E and F): The epitympanic and mastoid space is filled with bone pâté up to the level of the cortex of the temporal bone.

All surgery is performed under general hypotensive anaesthesia using facial nerve monitoring. A question mark shaped retro-auricular incision is followed by the elevation of anteriorly based dermal and musculo-periosteal flaps. The retro-auricular and musculo-periosteal incisions must give sufficient exposure of the mastoid cortex and, if necessary, of the temporal squama to allow for the easy harvesting of cortical bone chips and bone pâté. Cortical bone chips are harvested using a flat chisel and put aside. A bone pâté collector (Bess, Berlin-Zehlendorf, Germany) and a cutting burr were used to collect healthy bone pâté from the cortex of the mastoid and if needed from the squama of the temporal bone. Care is taken not to damage the soft tissues and not to harvest diseased bone. The bone pâté is mixed with an antibiotic solution (Rifocine®, rifamycin solution 500mg/10ml) forming a semisolid paste. A cortical mastoidectomy and a wide

posterior tympanotomy using the standard combined approach technique are performed. In contrast to the original Mercke technique (21-22) and to the technique described by Gantz (31), the posterior canal wall is left intact during the whole procedure. The cholesteatoma, diseased soft tissue and mucosal remnants are completely removed. All mastoid and epitympanic cell tracts are cleaned. Unhealthy bone is drilled away. The remnants of the incus are taken out. The canal skin is dissected. The remnants of the drum are dissected from the bony annulus and from the malleus handle, and then cut away, keeping as much healthy canal skin as possible. The malleus is removed after section of the tendon of the tensor tympani muscle. If the chorda tympani is healthy and can be safely dissected from the cholesteatoma, it is often kept intact. The pathology is dissected out of the tympanic cavity. After complete elimination of the pathology, bone chips are sculpted and placed at the level of the tympano-attical barrier and posterior tympanotomy to completely seal off the epitympanum and mastoid from the middle ear cavity. The epitympanic and mastoid space is then progressively and completely filled up with bone pâté, up to the level of the cortex. Subsequently, the tympanic membrane and middle ear are reconstructed (see below).

B. The BOT in cavity reconstruction

The surgical principle is essentially the same as in cholesteatoma cases. A few technical points merit special attention. 1/ It is essential to harvest enough solid cortical bone to allow for complete reconstruction of the postero-superior bony canal wall, down to the level of the facial canal. 2/ Since the mastoid cortex is not (fully) available for harvesting, often the temporal squama must be accessed, by elevating the temporal muscle, without however making extra incisions in the skin. It can be very helpful to make two parallel vertical incisions in the superficial temporal fascia to facilitate the elevation of the muscle during bone harvesting. 3/ It is preferable to use one or as few as possible solid cortical bone fragments to reconstruct the canal wall. There should be no gaps in the reconstruction. 4/ Aim for a normal size of the new EAC. This is important for the skin's healing and its self-cleaning behaviour. 5/ It is of extreme importance to carefully dissect the posterior margin of the cavity's external meatus. Often the skin is folding back posteriorly on itself. This fold must be eliminated by sharp dissection, in order to create a smooth skin surface of the lateral posterior part of the new meatus. If this is neglected or not well executed, a new retraction pocket will develop in the lateral posterior part of the EAC. 6/ All skin and soft tissue remnants must be carefully dissected out from the cavity before obliteration. Unhealthy bone must be drilled

out. 7/ After full reconstruction of a complete bony partition between the tympanic cavity and EAC on the one hand and the paratympanic space on the other hand, the paratympanic space must be completely filled with bone pâté, up to the level of the mastoid cortex. 8/ The new canal wall is covered with a free graft of thin autologous temporal fascia. This can best be done after the reconstruction of the tympanic membrane, just before putting back in place the canal skin. 9/ If necessary, free split thickness skin grafts are used to cover the EAC.

C. The importance of a normal external meatus of the EAC

If the external meatus of the EAC is (too) narrow, we perform, as a preliminary procedure, an M- meatoplasty according to Mirck (32), thus improving the selfcleaning capacity of the skin of the EAC. This minor surgical procedure, which can be done under local anaesthesia, seems to improve the physical conditions in the EAC (lower humidity), facilitates skin healing and normalises skin behaviour after ulterior reconstructive surgery. The Mirck procedure is a very elegant and successful technique, and has become part of our surgical standard armamentarium.

D. Reconstruction of the tympanic membrane and the middle ear

We reconstruct the middle ear by means of tympano-ossicular allografts (33). The allograft consisted of a meatal periosteal cuff in continuity with the tympanic membrane (TM) and malleus handle. The malleus head and neck are removed with a malleus-nipper (Microfrance otology instruments, Medtronic Xomed) at the level of the lateral process of the malleus. The allograft TM is rotated clockwise (left ear) or counter clockwise (right ear) to place the malleus handle in an advantageous position, perpendicularly centred above the oval window. This allows for the most effective columellar energy transduction between the implanted malleus handle and the stapes or stapes footplate. The ossicular reconstruction is executed using a remodelled allograft incus or malleus. If the mucosa in the tympanic cavity was damaged or absent, a thin silastic sheet (0.5-mm thickness) is placed in the tympanic cavity extending from the protympanum to the retrotympanum, to avoid fibrous adhesions and to promote colonisation by healthy middle ear mucosa during postoperative healing. The canal skin is then replaced, partially overlapping the allograft's periosteal cuff. The meatal skin and cuff are covered and kept in place with a multiperforated plastic membrane rolled into a cylinder, inserted through the meatus, and gradually filled with synthetic sponges imbued with an antibiotic and steroid ointment. The retro- auricular wound is closed in three layers. A compressing dressing is applied for 2 days over the retro-

auricular region. The patient is dismissed at the second day after surgery. The external auditory canal packing is left in place during 2 weeks. Epithelial coverage of the allograft tympanic membrane occurs between 3 and 6 weeks after surgery depending on individual variations in healing speed. Antibiotic and steroid drops are continued until complete epithelial coverage of the allograft is achieved. Exposure to water is avoided for 6 months after the surgery. Peri-operative intravenous antibiotics (Cefazoline) are continued for 24 hours. Patients are sent home with amoxicillin-clavulanate or cefuroxim in case of penicillin allergy for 5 days. Tympano-ossicular allografts are harvested and prepared at the tissue bank of the St.-Augustine Hospital, according to the standards of the Belgian law (Belgisch Staatsblad of 13.06.1986) and in compliance with the European directives. Immediately after removal from the cadaver, the grafts are fixed for at least 2 weeks in a solution of 4,5 % buffered formaldehyde. After dissection, tissues are preserved in Cialit (15000 aqueous solution of a sodium salt of an organomercuric compound, Hoechst Pharmaceuticals) for a period of 3 weeks to 2 months. This review does not address the alleged risk of transfer of infectious diseases, such as Creutzfeldt- Jacob disease (CJD) and human immunodeficiency virus (HIV) infections. Transmission of CJD has been reported after implantation of dura mater grafts (34) or corneal grafts (35). However, during its more than 40 years extensive use, it has never been reported after transplantation of tympanoossicular allograft material. In addition, the incidence of CJD is extremely low (1: 1.000.000) and the applied stringent criteria for donor selection exclude donors at risk for CJD. No reports of transmission of HIV by non-vital allograft material have appeared in the literature. Moreover, formaldehyde, used in the preparation of allografts, is known to readily inactivate HIV (36).

E. Surgical staging in the BOT

The primary goal of cholesteatoma surgery is total eradication of the pathology, making sure that no residual pathology is left behind. **Residual cholesteatoma** is defined as keratinizing squamous epithelium left behind during first stage surgery, which has regrown into a visually identifiable cholesteatoma. It should not be confused with **recurrent cholesteatoma**, which is defined as a new cholesteatoma developing from an unsafe, non-self-cleaning retraction pocket in the TM or in the canal wall. When a CWU technique has been used, the conventional method to exclude or confirm residual cholesteatoma is to perform an exploratory second surgical stage 12 to 18 months after the first stage, exploring all the anatomical sites were residual pathology could be present. The decision to stage is made by the surgeon during the first stage. It is based on the extent, the

location and the characteristics of the cholesteatoma, as well as on the age of the patient, given the markedly more elevated level of residual rate in the paediatric population. However, the recent development of new MR imaging protocols, with a high resolution and high sensitivity and specificity for the detection of small cholesteatoma pearls (see further), is changing this decision algorithm. Up to 2006, we relied on surgical staging to detect and eradicate residual cholesteatoma. Since 2006, we select candidacy for staging solely based on imaging with MR. This issue is fully discussed in section 6 of this chapter (longterm safety issues). Although in our BOT the bony reconstruction of the canal wall and of the tympano-attical barrier is always carried out at the first stage, in some cases the obliteration of the mastoid and attic space with bone pâté is postponed until the second stage for safety reasons. This is typically the case in some paediatric cases in which the matrix of the cholesteatoma is very thin, irregular, not well defined and very invasive - hence difficult to dissect it with certainty - and in cases in which part of the matrix, covering a labyrinthine fistula, is knowingly left behind in order not to jeopardise inner ear function.

4.2 Literature review of surgical mastoid and epitympanic obliteration techniques

The BOT surgical technique described in section 4.1 is the standard mastoid and epitympanic obliteration technique developed and used at our department. Since the first description of mastoid obliteration surgery one century ago (2), various surgical techniques have been developed, using a variety of obliteration material. Technological progress, the development of more refined surgical techniques and the availability of new obliteration materials led to progressive improvement of the results. Based on the typical characteristics of the applied technique and material, obliteration techniques can be divided in two distinct subgroups, viz. free graft obliteration (autologous or synthetic) and soft tissue flap obliteration (Table 2). When performing soft tissue flap obliteration, vascularised soft tissue flaps are mobilized and rotated into the empty mastoid cavity. In free graft obliterations, various materials including soft tissues, bone, cartilage or synthetic biomaterials are used to fill the empty mastoid and epitympanic space. The main surgical principle is the intention to decrease the mastoid size and to normalise the size of the EAC.

Autogenous Free Grafts	Biomaterials	Local Flaps
Bone chips	Hydroxyapatite (granules and cement)	Meatally based musculoperiostal flap (Palva Flap)
Bone paté	Demineralized bone matrix	Inferiorly based musculo-periosteal flap
Fat	Ionomeric bone (SerenoCem®)	Mid temporal musculoperisteal flap
Cartilage	Bioactive glass ceramics (Ceravital®)	Superiorly based musculoperiostal flap
Fascia	Biphasic calcium phosphate ceramics	Temporo-parietal fascial flap (TPFF)
		Inferior pedicled composite multi-fractured osteoperiosteal flap

Table 2. Types of obliteration material

A. Obliteration with soft tissue flaps

One of the most influential original techniques in the modern era of mastoid obliteration was reported by Palva (13,37-38) using a meatally based musculoperiosteal flap in addition to cortical bone chips and bone pâté. His technique was a modification of Popper's flap (12). Other authors used other types of soft tissue flaps such as inferiorly and superiorly based pedicled musculoperiosteal flaps and axial flaps (mid temporal pericranial flap and temporo-parietal fascial flap) for mastoid obliteration (39-52). The problem encountered with all these musculo- periosteal flaps was their tendency to atrophy over time, resulting in gradually enlarging cavities. Palva noted a variable resorption rate up to 50% (53-54). Some authors tried to anticipate on this problem by overfilling the cavity at the time of surgery (14), or by combining the flap with additional obliteration material (see table 3).

The combination of musculo-periosteal flaps, free grafts and organic or synthetic obliteration materials is commonly used when obliterating unstable cavities (15, 47-60). A schematic diagram of soft tissue flap techniques and combination of techniques is illustrated in Figures 3 A and 3 B.

B. Obliteration with free grafts

According to Roberson et al. the ideal obliteration material 1/ should stimulate the formation of new bone at the surgical site, 2/ should become incorporated as an inert filler, with no additional stimulation of an inflammatory response 3/ should not have unwanted systemic or local effects, 4/ should be easy to handle and 5/ should be relatively inexpensive (61).

Table 3. Reconstruction and mastoid obliteration following CWD surgery

Obliteration material	Authors (chronologically)
Free temporalis fascia and bone pâté (10)	Perkins RC (1976)
Palva flap and bone chips/pate (38)	Palva I (1979)
Free temporalis fascia and bone pâté (63)	Mills RP (1987)
Palva Flap (39)	Charachon R et al. (1988)
Palva flan and hone nâté (55)	Solomons N and Robinson J (1988)
Temporo-parietal fascial flap (TPEE) (10)	East CA et al. (1990)
Palva flan and hone nôté (15)	Hartwein Land Hormann K (1000)
Palva flap (11) Dalva flap (11)	Soundoro JE et al. (1002)
Palva liap (41)	Saunders JE et al. (1992)
Vascularized muscular flap (Hong Kong Flap) (42)	Van Hasselt CA et al. (1995)
Superiorly based temporalis	Moffat D et al. (1994)
musculoperiosteal flap (43)	
Mid-temporal flap and hydroxy apatite canal	Black B (1995)
prosthesis (44)	
Temporo-parietal fascial flap (TPFF) (45)	Cheney ML et al.(1995)
Inferiorly based parietal flap and hydroxy	Yung M (1996)
apatite granules (46)	
Temporal muscle flap and bone pâté/chips	Nyrop M and Bonding P (1997)
(56)	······································
Free homograft dura/ free temporalis fascia	Estrem SA et al. (1999)
and hydroxy apatite canal	
prosthesis/granules (71)	
Free perichondrium and cartlilage chips (65)	Dornhoffer II (1999)
Free temporalis fascia and hone naté (61)	Roberson IB (2003)
Free periohendrium or Polyo flop/ cartilage	Leatherman BD and Dernhoffer II. (2004)
and dominaralized hone matrix (57)	Leatherman bD and Domnoner JL (2004)
Free temporalis fascia and Biphasic calcium	Bagot D'Arc M et al. (2004)
phosphate granules (20)	
Interiorly based periosteal-perioranial flap	Ramsey MJ et al. (2004)
and bone pâté (48)	
Mid temporal artery flap or inferiorly based	O´sullivan PG, Atlas M (2004)
musculoperiostal flap and hydroxyl apatite	
(49)	
Inferiorly based parietal flap or	Mahendran S and Yung M (2004)
temporoparietal fascial flap or midtemporal	
flap and hydroxy apatite bone cement	
/granules (45)	
Deep temporalis fascial-periosteal flap (59)	Lee DH et al. (2006)
Inferior pedicled composite multi-fractured	Uçar C (2006)
osteoperiosteal flap (60)	
Free temporalis fascia and Serenocem®	Clark MP and Bottrill I (2007)
(19)	
Free temporalis fascia and bone pâté/	Takahashi H et al. (2007)
Apatite ceramics (58)	
Mid-temporal flap, inferiorly based and	Singh V and Atlas M (2007)
superiorly based periosteal flap and bone	
pâté (51)	
Mid-temporal flap and inferiorly based	Yung M and Smith P (2007)
periosteal flap and hydroxyl anatite granules	
cartilage and hone chin/ nâté(52)	
Cartilage and hope pâté (70)	Beutner D and Huttenbrink KB (2007)
Cartilage and Done pate(TO)	Deather D and Flattenblink (2007)



Figure 3. Schematic diagram of the CWD mastoid obliteration techniques. Transverse section showing the use of (A) combination of musculo-periosteal flaps, free grafts (cartilage/fascia) and synthetic obliteration materials (hydroxyapatite granules) and (B) a vascularised musculo-periostal flaps (Palva Flap, Mid-temporal flap or inferiorly/superiorly based musculoperiostal flaps).

Bone pâté fulfils all the requirements. Perkins was the first to demonstrate the value of bone pâté for the reconstruction of cavities (10). An adequate application of healthy cortical bone pâté mimics the natural osteo-induction and osteoneogenesis of bone. Despite encouraging results, several authors abandoned the use of bone pâté for mastoid obliteration. The first reason was the high rate of postoperative infection (16%). The second reason was the high incidence of chronic resorption of bone pâté resulting in local retraction pockets and canal wall defects, leading to long-term failure rates of 52% (44,47).

The BOT procedure applied in our department differs from the above mentioned earlier reports in some very crucial details. The routine administration of intravenous peri-and postoperative antibiotics and the impregnation of the bone pâté with an antibiotic solution lead to a marked reduction in the rate of postoperative infections (less then 5%). This concurs with the reports of several other authors (31,55,61-63).

Moreover, in our BOT technique, the bone pâté is strictly separated from the canal skin over the full length of the EAC by sculpted solid cortical bone, used for the meticulous reconstruction of the canal wall and the tympano-attical barrier. This is an extremely important condition for long-term stability of the new EAC in the reconstruction of unstable cavities. In our experience autogenous solid cortical bone chips are the most ideal material for reconstruction of the external ear canal. They integrate well with the original bone margins, which is a definite advantage over the use of cartilage to reconstruct the canal wall. Moreover, cortical bone is

abundantly available in comparison with cartilage. When performing CWU techniques, the tympano-attical barrier and the posterior tympanotomy are specifically obliterated with solid cortical bone, preventing the long-term development of retraction pockets at these predilection sites for recurrent pathology. A histopathological evaluation concluded that bone chips and bone pâté, used for obliteration, retain their original volume and consistency, whereas subcutaneous tissue and muscle tend to atrophy (64). Other materials used for canal reconstruction and mastoid obliteration includes biomaterials such as fascia(3-5), fat grafts (6-7), cartilage (8) and synthetic materials such as ceramics (demineralised bone matrix, calcium phosphate ceramic granules, hydroxyapatite granules/cement, biphasic ceramic granules) and glass ionomeric cements (15-19) (Table 2). Fat grafts for the obliteration of mastoid cavities have been used by several authors, but were abandoned due to higher rates of infection and resorption (6-7). Montandon et al. used cartilage to block the epitympanum and filled the remainder of the cavity with an abdominal fat graft in CWU mastoidectomy (65). Several authors reported the use of cartilage for mastoid obliteration as well as for TM and canal wall reconstruction (66-68). Cartilage has the advantage to keep its shape and to be more resistant to new retraction pocket formation. It has shown limited spontaneous resorption (66) and is often used in mastoid obliteration combined with cartilage tympanoplasty. The major problem encountered with the use of cartilage is its too limited availability to perform complete mastoid obliteration. Many authors now use cartilage to reconstruct the canal wall in association with obliteration materials such as bone pâté, hydroxyapatite and demineralised bone matrix (57,67-70). Hydroxyapatite is one of the main components of healthy living bone, and is known to have excellent biocompatibility. It is widely used in middle ear surgery, in the form of granules for mastoid obliteration (46,49-50,52,71), as a preformed canal wall prosthesis (72), and as ossicular prostheses (73-74). Hartwein and Hormann originally described the use of hydroxyapatite in mastoid obliteration while reconstructing the posterior canal wall with autologous conchal cartilage (15). Others combined hydroxyapatite granules with musculovascular flaps (46,49-50,52). Surgeons using hydroxyapatite claim minimal resorption of these materials over time, although partial resorption and extrusion of granules have been reported (20,46,75). This occurred less in cases when the material was more cautiously compacted and adequately covered. Mahendran and Yung also attempted the use of hydroxyapatite cement. It resulted in higher rates of postoperative infection in comparison with hydroxyapatite granules. The authors don't recommend its use as obliteration material (50). Hussain has a different experience with the use of hydroxyapatite cement in

mastoid obliteration, reporting satisfactory results without increased infection rate (76). Minatogawa et al. compared the use of biologic with non-biologic materials in mastoid obliteration. They concluded that non-biologic material has a higher extrusion rate and prefer the use of autogenous material (75). An extensive and excellent review of various techniques and materials was published by Black, reporting also his personal experience with mastoid obliteration, canal wall reconstruction and mastoid ablation from 1974 till 1996 (44). To update this excellent review of the literature on mastoid obliteration in unstable cavities and to provide an overview of obliteration in CWU techniques, we conducted a Medline search of English-language literature from 1987 till December 2007, searching for the following MeSH terms: mastoid obliteration, mastoidectomy, mastoid and cholesteatoma An exhaustive updated listing of obliteration techniques and materials is presented in tables 3 and 4.

Table 4. Mastoid and Epitympanic Obliteration following cholesteatoma eradication in CWU

Obliteration Material	Authors (chronologically)
Bone chips and bone pâté (Canal Wall Reconstrution)(21)	Mercke U (1987)
Bone chips and bone pâté (Canal Wall Reconstrution)(22)	Mercke U (1995)
Cartilage chips and fat (65)	Montandon P et al. (1995)
Bone chips and bone pâté (Canal Wall Reconstrution)(31)	Gantz B et al. (2005)
Bone pate and free fascia and fat (62)	Lee WS et al. (2005)
Bone chips and pâté (91)	Vercruysse JP et al. (2008)

5. Results

5.1 Rate of residual cholesteatoma

The primary goal of cholesteatoma surgery is the complete eradication of the pathology. No part of the original cholesteatoma should be left behind. Residual cholesteatoma is defined as a cluster of viable keratinising squamous epithelium, left behind at the primary surgery, which has regrown into a cholesteatoma. The problem is inherent in all cholesteatoma surgery, regardless of the applied surgical approach and reconstructive technique. The rate of residual cholesteatoma reported in the literature shows substantial variation, reflecting an important variation in the quality of the surgical act. However, it is found to be consistently higher in the conventional CWU techniques than in the CWD or in CWU-BOT (21-

22,31,48,59,77-90). Moreover, a consistently higher residual rate has been observed in the paediatric population in comparison with the adult population, regardless of the applied surgical approach (24,31,84-87). Until recently, these observations made exploratory surgical staging after CWU techniques the golden rule. The advent of new MRI sequences, such as late enhanced T1 weighted images and especially the non-echo-planar Imaging diffusion weighted sequence (non-EPI DW MR), allows for specific characterisation of small cholesteatoma pearls. On MRI, cholesteatoma can be unambiguously distinguished from other soft tissues such as scar tissue, cholesterol granuloma, granulation tissue and fluid (see section 6 of this chapter) (106). As a consequence, we now select candidates for staging solely on the basis of the results of the non-EPI DW MR screening, performed at 1 and 5 years after primary surgery. We compared the residual rate of our conventional paediatric cholesteatoma series (24) with the residual rate of our more recent CWU-BOT paediatric series (91). It dropped from 23% to 15.4%. In our adult series it dropped from 7.2% to 3.5% (25). All the residual pearls were detected in the tympanic cavity, while none were detected in the bony obliterated mastoid and attic. In our conventional CWU series the evaluation method was surgical staging. In our CWU-BOT series the residual rate was evaluated, for validation purposes, by a combination of surgical staging and MR imaging. These results are in agreement with the data published by other authors. A comprehensive overview of the published residual rates in paediatric and adults series for CWD, conventional CWU and CWU-BOT techniques is given in Table 5.

Indeed, before obliteration, all soft tissues are carefully taken out, until only healthy bone remains. It is known from clinical experience that skin only reluctantly covers areas of bare bone, but easily covers the same area if it is first lined with a thin layer of fascia. An animal study by Hinohara et al. gives some support to the hypothesis that bony obliteration interferes negatively with the throphic conditions needed to allow residual keratinocytes to develop into a growing cholesteatoma pearl. In an animal study of 11 guinea pigs, the authors report on the histological consequences of bulla obliteration for the development of a residual cholesteatoma pearl. They compared the rate of residual cholesteatoma development after implantation of squamous epithelium into the middle ears of two series of guinea pigs: in the first series the implanted keratinocyte layer was not covered with plaster of Paris (calcium sullate dehydrate), while in the second series the bulla was filled with plaster of Paris, covering the keratinocyte layer.
Table 5. Residual and recurrent cholesteatoma rate in different types of cholesteatoma surgery

Author	Ν	Residual cholesteatoma (%)	Recurrent cholesteatoma (%)			
Canal-wall up technique						
Glasscock ME 3 rd and Miller GW (1976)(77)	154	12	14			
Sheehy JL et al (1977)(78)	1024	32	5			
Sanna M et al. (1984)(79)	283	7, 8	13, 4			
Janssen CW (1985)(80)	1904	6,9	3,2			
Mercke U (1987)(81)	56	21,4	25			
Brackmann (1993)(82)	108	14	3			
Kamarkar S et al. (1995)(83)	257	31,2	11,2			
Canal wall up in pediatric ch	olesteato	oma				
Sanna M et al. (1987)(84)	151	40	11			
Charachon R et al. (1988)(85)	160	31	20			
Magnan J et al. (1992)(86)	210	26	19,5			
Schilder A et al. (1997)(24)	103	23	18			
Darrouzet V et al. (2000)(87)	190	20,5	8,9			
Canal-wall down technique						
Cody D&Taylor W (1987)(89)	172	6	8			
Sade J (1987)(88)	65	13	0			
Kos I et al (2004)(90)	259	5,8	0,4			
Kamarkar S et al. (1995)(83)	176	2,38	10			
Obliteration following Canal wall down technique						
Ramsey MJ et al (2004) (48)	60	0	0			
Singh V and Atlas M (2007)(51)	51	0	0			
Yung et al. (2007)(52)	102	4.9	0			
Obliteration following Canal wall up technique						
Mercke U (1987)(21)	57	5.3	0			
Gantz B et al (2005)(31)	130	9.8	1.5			
Lee WS et al (2005) (62)	151	5.4	0			
Vercruysse JP et al. (2008)	281	3.5	1.3			
Obliteration following Canal wall up in pediatric population						
Gantz B et al (2005)(31)	40	10	0			
Vercruysse JP et al (2008)(91)	52	15.4	1.9			

It is remarkable that to date, we didn't detect residual cholesteatoma within the bony obliterated spaces. This is probably due to the unfavourable local trophic conditions for keratinocyte survival and growth within the bony obliterated space. Post mortem histological evaluation at 2, 4 and 8 weeks after implantation consistently showed cholesteatoma pearl development in the non-covered series, while in the obliterated bulla series only 1 in 6 animals showed a residual pearl (92). However, given the non-negligible rate of residual cholesteatoma after primary surgery, it remains necessary to apply a very strict follow-up to all cases. Non-EPI DW MR provides the clinician with an elegant, fast, relatively low cost and very reliable method. We have no doubt that MRI screening will quickly become the method of choice and will gradually replace exploratory surgical screening. Pre- and postoperative imaging including HRCT and MR imaging of a mastoid and epitympanic bony obliteration technique for cholesteatoma has been illustrated in Figure 4A en 4B.

5.2 Rate of recurrent cholesteatoma

An important secondary goal of cholesteatoma surgery is the prevention of recurrent disease. Substantially high rates of recurrent cholesteatoma following conventional CWU surgery are reported in the literature, varying from 3% to 25%, with markedly higher rates in the paediatric population (24,77-87). A comprehensive overview of the published recurrent rates in paediatric and adults series for CWD, conventional CWU and CWU-BOT techniques is given in Table 5. Important variations in the length of the follow-up period should be kept in mind when interpreting these figures. Our own paediatric conventional CWU series showed a recurrent rate of 18% after a mean follow-up of 4.5 years, while the recurrent rate in our adult series was 5% after a follow-up of 4.5 years (25). These figures convinced us in 1997 that we needed to change our surgical approach to the problem. As a consequence, we developed our personal CWU-BOT approach, which we now apply in approximately 90% of primary cholesteatoma cases. The recurrent rate of the CWU-BOT approach is 1.9% in our paediatric series (106) and 1.3% in our adult series (not yet published data). These results are in agreement with the results of other authors using a similar approach (21-22,31, 43-44,46,51-52,59) (see table 5). The results compare most favourably with the results of the conventional CWU technique in adult and paediatric cholesteatoma (77-87). Moreover, our results are not inferior to the recurrence rate reported by authors using the CWD technique (88-90). However, it is obvious that long-term yearly otoscopic follow-up remains the golden standard to detect recurrent cholesteatoma.



Figure 4A. Pre-operative imaging of a 27 year old man with a recurrent cholesteatoma on the left side after CWU tympanoplasty prior to CWU-BOT surgery.

Axial CT image at the level of the lateral semicircular canal on the left side (Top left). The entire cavity is completely filled with soft tissue (asterisk). On CT it is impossible to differentiate these soft tissues: a recurrent cholesteatoma cannot be excluded nor confirmed. Coronal reformatted CT image at the level of the lateral semicircular canal (Top right). Again, the entire cavity is filled with soft tissues (asterisk) which cannot be differentiated on CT. Recurrent cholesteatoma can - based upon this CT examination – not be excluded nor confirmed. Coronal late (45 minutes) post gadolinium T1-weighted (Below left) showing a large hypo-intense non-enhancing nodular lesion in the cavity (arrow) delineated at its posterior and lateral side by enhancing inflammatory and / or scar tissue: large recurrent cholesteatoma presenting as a characteristic non-enhancing hypo-intense lesion. Non-EPI based diffusion weighted image) at the level of the left temporal bone (Below right). The cholesteatoma is clearly seen as a very hyper-intense lesion under the left temporal lobe. This image is pathognomonic for a cholesteatoma.



Figure 4B. Postoperative imaging (same patient as figure 4A) performed 1 year after CWU-BOT surgery. Axial CT image at the level of the lateral semicircular canal on the left side (Top left). The entire mastoid cavity is homogeneously filled with bone pâté (asterisk) without the presence of soft tissue lesions within the obliterated cavity. Coronal reformation at the level of the lateral semicircular canal on the left ear demonstrating a homogeneously obliterated mastoid (asterisk)(Top right). Note the reconstructed ossicular chain in the aerated middle ear cavity. Coronal T1-weighted MR image of the left ear after intravenous administration of gadolinium showing inhomogeneous enhancement of the obliterated mastoid making reliable interpretation of the images quite difficult (arrows) (Below left).

Non-EPI based diffusion weighted image at the level of the left temporal bone (Below right). No hyperintensity is seen. The correct interpretation of these images is that there is no residual cholesteatoma pearl with a diameter of more than 2mm.

5.3 Anatomical and hygienic outcome

One of the surgical goals of cholesteatoma surgery is to create a dry, self-cleaning and water- resistant ear. The drawbacks of CWD techniques, already mentioned earlier, are the need for regular cleaning, recurrent inflammation and infection, water intolerance, caloric induced vertigo and the difficulty to fit and wear a hearing aid. Even the elimination of all the technical imperfections contributing to unstable cavities, such as too small a meatus, a high facial ridge and a poorly designed cavity does not necessarily result in a stable, dry and self-cleaning cavity, especially in children. The literature reports on intermittent or chronic discharge rates of 10% to 60% (63,93-5). When mastoid obliteration techniques are added to the CWD procedure, reducing the size of the cavity, the rate of postoperative problems following CWD surgery clearly drops. However, in most reports a limited but non-negligible percentage of problems persist. A nonexhaustive overview of the hygienic outcome in terms of discharging ears after CWD with mastoid obliteration is presented in table 6.

Our results with the CWU-BOT approach compare favourably with the hygienic outcome of the CWD approach. In 100% of our paediatric CWU-BOT series a dry self-cleaning ear was obtained. In one patient a dry and self-cleaning perforation occurred. Revision surgery with tympanic membrane closure is planned in order to obtain 100% water-resistant ears in the long-term. If hearing levels are not adequate, a hearing aid is easily fitted and comfortably worn.

5.4 Functional outcome

One of the goals of chronic ear surgery is the improvement or at least the preservation of hearing. The long-term functional outcome depends on the following variables: 1/ the extent and severity of the pathology; 2/ the quality of the surgical act; 3/ the applied technique and the nature of the reconstructive materials; 4/ the quality of the healing process; 5/ the post-operative biological behaviour of the ear (aeration, mucociliary clearance).

There is an inverse relation between the pre-operative extent of the ossicular damage and the post-operative long-term functional gain. It stands to reason that greater ossicular damage often reflects a worse biological behaviour of the ear, hence a lesser chance for the biology to normalise during the post-operative period. Quite often the preconditions for a good middle ear function, such as normal gas exchange and middle ear aeration, are not present. As a consequence, in these cases the functional result will be disappointing to surgeon and patient alike, however well the middle ear is reconstructed. However, the surgeon's skill and experience remain a decisive factor for the functional outcome. It is generally acknowledged that CWU techniques offer a better chance for a good functional outcome than CWD techniques, but the choice of the surgical approach often depends on the severity and extent of the pathology, and accordingly, this choice is often correlated with the biological behaviour of the ear. The same holds true for the quality of the healing process. For many surgeons, the material of choice for ossicular reconstruction remains the autograft ossicle, whenever it is available. Biomaterials offer a good alternative, but care should be taken to either anchor them to the malleus handle when it is available or to shield them from the reconstructed tympanic membrane by a thin layer of cartilage to prevent extrusion. Often, long-term stability remains a problem. Therefore, we continue to use tympano-ossicular allografts for middle ear reconstruction. The malleus handle, as an integral part of the implanted graft, serves as a firm and stable anchor point for columellar reconstruction.

Table 6. Hygienic outcome following mastoid obliteration

Author	Dry ears (%)	Patient population	Outcome
Solomons N and Robinson J (1988)(55)	93,5%	29/31	Intermittent otorrhea
East CA et al. (1989)(40)	75%	9/12	 Incomplete epithelialization
Saunders JE et al. (1992)(41)	93%	26/28	TM perforation
Black B (1995)(44)	89%	48/55	Avascular necrosisInfectionMyringitis
Cheney ML et al (1996)(45)	100%	11/11	None
Yung MW (1996) (46)	97%	35/36	 Incomplete epithelialization
Estrem SA (1999) (71)	75%	23/31	Extrusion hydroxyapatiteGranulation
Dornhoffer JL (1999) (66)	90%	18/20	 Incomplete epithelialization
Roberson JB(2003)(61)	86,2%	54/62	Bone paté resorptionInfection
Leatherman BD and Dornhoffer JL (2004)(57)	82%	9/11	 Granulation (exposure bone matrix)
Bagot D´Arc M et al. (2004)(20)	81%	38/47	InfectionExtrusionResorption
O´sullivan PG and Atlas M (2004)(49)	90%	90/100	Intermittent otorrheaMuscle flap atrophy
Ramsey MJ et al. (2004)(48)	90%	49/60	 Incomplete epithelialization Granulation Meatal stenosis
Mahendran S and Yung MW (2004)(50)	50%	4/8	InfectionFlap necrosisAbscess
Uçar C (2006)(60)	100%	24/24	None
Clark M and Bottrill I (2007)(19)	93,5%	15/16	 Infection (graft exposure)
Takahashi H et al. (2007)(58)	73,5%	75/98	 Infection Extrusion apatite ceramic
Singh V and Atlas M (2007)(51)	94%	48/51	Wound infectionNecrotic flapMeatal stenosis
Yung MW and Smith P (2007)(52)	100%	96/96	• none

This prevents extrusion and adds stability. By slightly rotating the tympanoossicular graft, we can place the malleus handle in a functionally favourable position with respect to the stapes or stapes footplate. This not only improves the quality of the mechanical transduction, but it also enhances the stability of the columellar reconstruction. The stability of the tympanic allograft, which snugly fits the bony annulus of the tympanic frame, allows for routine functional reconstruction during the first stage in most cases. A non-exhaustive listing of hearing results after conventional CWU (23,94-96), CWU-BOT (20,30, 50,60) and CWD surgery (94-98) is given in Table 7.

Canal wall up		Mastoid obliteration		Canal wall down	
Author	AB gap closure	Author	AB gap closure	Author	AB gap closure
Ragheb SM et al. (1987)(96)	52% < 20dB 54% < 20dB (S -)	Charachon R et al. (1988) (39)	56% < 20dB 42% < 20dB (51% S -)	Ragheb SM et al. (1987)(96)	37% < 20dB 19% < 19dB (S-)
Tos M and Lau T (1989)(97)	50% <20 dB	Roberson JB(2003)(61)	59,3% < 20dB (66% S-)	Tos M and Lau T (1989)(97)	35% < 20dB
Shelton C and Sheehy J (1990)(23)	69% < 20dB	Bagot D´arc M et al. (2004)(20)	43% < 20dB	Vartiainen E (2000)(99)	14% < 20 dB
Veldman J (1998)(98)	76% < 30dB	Gantz et al (2005)(31)	50% < 20dB	Berenholz LP et al. (2000)(100)	64% < 20dB
		Lee WS et al. (2005)(62)	66% < 20dB (52% S -)	Veldman J (1998)(98)	55% < 20dB
		Takahashi H et al. (2007)(58)	61,7% < 20dB		
		Yung MW (2007)(52)	50% < 20dB		

Table 7. Functional outcome in different surgical techniques

As stated above, it is difficult to interpret these results in an unambiguous way, because authors often select the surgical approach based on the severity of the damage or the pathology. This seriously biases functional comparison between approaches. However, in general a 50 to 60% chance of improvement of the airbone gap to within 20 dB seems to be the trend for the conventional CWU and CWU-BOT techniques, which somewhat outperform the CWD techniques. We compared the functional outcome of our conventional CWU versus our CWU-BOT technique in cholesteatoma. The conventional CWU series, executed before 1997, was fully consecutive, without selection bias. The more recent CWU-BOT was not

fully consecutive, but presented a considerable bias skewed in favour of the more severe pathology (indeed, approximately 10% of the cases were not included in the series, but were handled with a conventional CWU technique, because the pathology was restricted to the lateral attic, leaving the ossicular chain undamaged or minimally damaged, and because the mastoid mucosa was healthy. Also, during the last decade the percentage of referred revision and multiple revision cases increased, reflecting a relatively higher load of more severe pathology). Notwithstanding this bias, the CWU-BOT series clearly doesn't show a worse functional outcome than the consecutive conventional CWU series (yet unpublished results). We believe this relative improvement with the CWU-BOT technique is due to the better energy transduction by the more advantageous positioning of the implanted malleus handle (see above) on the one hand, and by the improved biological stability of the middle ear in the bony obliterated cases.

5.5 Complications

The literature on mastoid obliteration techniques clearly shows an important learning curve, both in terms of the applied technique and materials and in terms of the individual surgeon. The potential per-operative complications are similar to the conventional CWU and to the CWD techniques, and will not be discussed. The short and long-term post-operative complications are related to the healing process and to the long-term stability and biocompatibility of the obliteration material. Table 8 summarizes the main problems following mastoid obliteration surgery. After CWU-BOT or BOT for cavity reconstruction, the EAC must be completely lined by keratinizing squamous epithelium in order to remain dry, stable and water resistant. During the postoperative healing, the migration of squamous epithelium starts at the margins of the meatal or tympanic membrane skin remnants. This process can be hampered by infection, by areas of bare bone and by ischemia and necrosis of the underlying soft tissue flap. If the EAC doesn't epithelialise completely, it will lead to inflammation and granulation. With time, this will either cause scar tissue formation and secondary stenosis of the EAC, or breakdown of the underlying soft tissue, bone pâté or canal wall and extrusion of the implanted obliteration material. This process can cause intermittent or persistent ear discharge.

Postoperative inflammation or infection can cause perforation of the tympanic membrane graft and extrusion of the columellar reconstruction. Black (42,45) and Roberson (60) used autogenous bone pâté for obliteration, and reported infection rates of respectively 16% and 13,8%.

Postoperative healing related complications	 Obliteration material resorption (partial/total) Canal wall breakdown (lysis/displacement) Flap necrosis Obliteration material exposure Wound infection EAC infection Obliteration material infection (soft tissue flap of free grafts) Incomplete epithelialisation Meatal/EAC stenosis Canal skin epithelial cyst Skin defect EAC
Tympano-ossicular reconstructions related problems	 Myringitis Ossicular prothesis extrusion Tympanic membrane perforations

Table 8. Problems encountered after mastoid obliteration techniques

Gantz reported a reduction in infection rate from 14,3% to 4,5% after the introduction a new protocol, including per- and postoperative intravenous antibiotics and a bacitracin wash-out of the bone pâté (30). Our personal experience corroborates these results. Therefore, in bony mastoid obliteration procedures, we recommend the standard administration of peri-operative antibiotics, continued for 5 days per os, as well as a per- operative wash-out of the bone pâté and the sculpted solid bone chips with an antibiotic solution. The combined creation of a normally sized external meatus and a solid bony ear canal in our experience provides the ideal basis for a stable hygienic condition of the ear.

6. MR imaging and long-term safety issues

The long-term safety of the ear is a primary concern in cholesteatoma surgery. Therefore, surgical staging to detect residual cholesteatoma has been advocated by most authors. However, the recent availability of a new non-EPI DW MRI protocol now offers a safe, non- invasive, selective, sensitive and comparatively cheap alternative to exploratory staged surgery. It reliably detects cholesteatoma pearls down to a size of 2 mm (99-101). Since we allow for the possibility that it takes more than one year for a residual pearl to develop into a detectable lesion, we now routinely image all our cholesteatoma cases at 1 and 5 years post-operatively. MR imaging thus effectively replaces exploratory second stage

surgery in our department since two years. Offsetting the cost of surgical staging to the cost of twice repeated MR imaging, this protocol is not only less burdening to the patient on a physical, practical and emotional level, but it is also much less expensive for both the patient and the public health system. Accurate and reliable imaging follow-up of obliterated mastoids is necessary to prevent late complications due to residual cholesteatoma buried underneath the obliteration material. Such complications may take many years to appear. Because of potential intracranial involvement, they can cause important morbidity and even death. Several authors reported on the respective value of High Resolution Computed Tomography (HRCT) and MR imaging for the detection of residual cholesteatoma in bony obliterated mastoids (102-103). High resolution computed tomography (HRCT) with bone window settings is considered the method of choice for examination of the middle ear structures. It provides excellent contrast between osseous structures, air and soft tissues and it has a high spatial resolution. This allows for the demonstration of subtle osseous details and provides good identification of associated bony erosions and good delineation of the pathology with respect to bony surroundings or air. Although it may take years before they become detectable, small cholesteatoma pearls can be effectively detected in bony obliterated mastoids by HRCT, presenting as punched-out lesions in the bone density (103). However, in a middle ear opacified by soft tissue, HRCT cannot differentiate cholesteatoma from other soft tissues such as scar tissue, cholesterol granuloma, granulation tissue or fluid. Hence HRCT is characterized by a low sensitivity and specificity for cholesteatoma (102). Therefore it is virtually useless for the non-invasive follow-up of cholesteatoma. In contrast, the newly available MRI protocols, such as late, gadolinium enhanced, T1 weighted images (104) and non-EPI diffusion weighted MR (99-103,105), allow for the specific characterization of cholesteatoma. On these MR sequences, cholesteatoma can be unambiguously distinguished from other soft tissue such as scar tissue, cholesterol granuloma, granulation and fluid. Moreover, MR avoids the irradiation of the patient. The non-EPI DW sequence is an important improvement over its predecessor, the now obsolete EPI DW sequence, which had a much lower contrast resolution and was made less reliable by susceptibility artifacts (102,104). On non-EPI DW images a cholesteatoma pearl appears as a hyperintense lesion against a low-intensity background, with good resolution down to a size of 2 mm diameter. Our results indicate that the non-EPI diffusion weighted sequence (non-EPI DWI) also outperforms the late Gadolinium enhanced T1 weighted sequence. The advantages of non-EPI DWI are: 1/ more reliable characterization of the lesion due to a better contrast resolution, resulting in the

highest specificity and selectivity; 2/ no need for contrast (Gadolinium is expensive, and carries a risk for renal fibrosis); 3/ a much shorter examination time, allowing for a much higher patient throughput, which is very important for the logistic organization of medical imaging department. The development of the non-EPI DW sequence as a reliable non-invasive follow-up tool has changed our view on the long-term safety of bony obliteration procedures. Moreover, exploratory second stage surgery has now almost completely been replaced by non-invasive MR imaging follow-up in our department (101).

7. Conclusion

Our experience with the Canal wall up - Bony Obliteration Technique shows that it is the method of choice for the surgical treatment of extensive primary cholesteatoma and recurrent cholesteatoma, and for the surgical reconstruction of unstable cavities. Its meticulous application generated a major reduction in the rate of recurrent pathology. The long-term follow-up documented the absence of residual cholesteatoma pearls in the bony obliterated space, a very low rate of postoperative hygienic problems and an improvement of the functional outcome compared to the conventional CWU and CWD techniques. Exploratory second stage surgery can now be safely replaced by MR imaging, provided the appropriate non-EPI diffusion weighted MR sequence is used.

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Chapter 3

Cholesteatoma – Imaging principles

Chapter 3.1

MRI of cholesteatoma

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Although computed tomography (CT) is still the method of choice for the evaluation of a primary acquired or congenital middle ear cholesteatoma, magnetic resonance imaging (MRI) is gaining growing importance. In acquired or congenital middle ear cholesteatoma, MRI including late postgadolinium T1-weighted and non-echo-planar diffusion-weighted sequences are superior in the discrimination of the cholesteatoma from surrounding inflammation and in the description of possible associated complications. In the postoperative follow-up of cholesteatoma, MRI has been proven to be superior to CT in the detection of residual or recurrent cholesteatoma.

Cholesteatoma should be divided upon its origin into acquired and congenital cholesteatoma (1). Congenital cholesteatoma commonly involves extradural structures predominantly including the middle ear cavity and mastoid but also involving other portions of the petrous bone including the petrous apex and external auditory canal. It originates at the time of closure of the neural tube when ectoderm gets trapped inside the temporal bone. This should be discriminated from another congenital entity originating at this point: the epidermoid cyst or epidermoid tumour, when ectodermal tissue gets entrapped intradurally instead of extradurally in the temporal bone. Essentially, congenital cholesteatoma and epidermoid tumour are congenital lesions and are histologically the same.

Lesions can thus be found in any part of the temporal bone pyramid (2). By definition, congenital cholesteatoma presents itself behind an intact tympanic membrane without any signs of infection. In the middle ear, the majority of lesions arise in the anterior mesotympanum or posterior epitympanum (3).

Acquired cholesteatoma often originates from a posterosuperior retraction pocket of the tympanic membrane (pars flaccida cholesteatoma). A less frequent variant originates at the lower part of the tympanic membrane (pars tensa cholesteatoma) (1,4). Acquired pars flaccida cholesteatoma originates out of retractions of the tympanic membrane, progressively evolving into Prussak's space. Due to its expansion, the cholesteatoma starts eroding surrounding structures such as the bony spur of the scutum and the ossicular chain; mainly the head of the malleus and the long process and body of the incus (1,4). Growing further, the cholesteatoma invades the antrum and mastoid space, eroding additional structures of the middle ear cavity such as the bony cover over the second segment of the facial canal, the tegmen of the middle ear and the bony delineation of the lateral semicircular canal (1,4).

Cholesteatoma is mainly operated on using canal-wall-up (CWU) techniques implying the preservation of the external auditory canal wall and its consequent benefits (5,6). This leads to an increased risk of leaving residual cholesteatoma

behind in comparison with canal-wall-down (CWD) techniques (5–7.) The surgical strategy in CWU]techniques, however, necessitates the need to perform second-stage surgery in order to detect residual cholesteatoma. Usually, these residual cholesteatoma are very small pearls (7).

This should be differentiated from the recurrent cholesteatoma which develops out of a new posterosuperior retraction pocket (7). Recurrent cholesteatoma are often detected during clinical follow-up by micro-otoscopical investigation.

In order to diminish the rate of recurrent cholesteatoma, mastoid and epitympanic obliteration techniques have been advocated. Here, the mastoid and epitympanic cavity are sealed off from the middle ear space by means of sculpted cortical bone chips and subsequently the remainder of the mastoid and epitympanum is obliterated with bone paste. As a result of this primary bony obliteration technique (PBOT), the percentage of recurrence may drop from 36% in adults and 67% in children after a CWU procedure to a few percent in PBOT (8–10).

CT imaging

High-resolution CT of the temporal bone is still the imaging modality of choice to evaluate the extension of a suspected acquired middle ear cholesteatoma, prior to eventual surgery. High-resolution CT of the temporal bone is able to show the sometimes subtle details of a small cholesteatoma (1,4).

The more common pars flaccida choesteatoma starts with a retraction pocket into Prussak's space. This retraction pocket is best evaluated at otoscopy and can be seen on coronal CT scans or reformations. Very often, an associated nodular soft tissue lesion can be found in Prussak's space. Erosion caused by the pars flaccida cholesteatoma usually starts at the lateral epitympanic recessus with erosion of the scutum and the lateral epitympanic wall (Figure. 1).



Figure 1. A 39-year-old woman presenting at otoscopy with a retraction pocket and signs of associated infection and inflammation. CT already demonstrated signs of a cholesteatoma by showing erosion of incus corpus and short process. MRI performed using echoplanar diffusion-weighted and non-echo-planar diffusion-weighted sequences clearly shows the advantages of non-echo-planar diffusion-weighted over echoplanar diffusion-weighted sequences in demonstrating the cholesteatoma.

(A) Axial CT image on the left side, at the level of the tympanic segment of the facial nerve showing a complete erosion of the incus corpus and short process (arrowhead) by an associated soft tissue mass filling up the entire epitympanic cavity. (B) Axial CT image on the right side (same level as [A]) showing a normal ossicular chain. Note the completely normal aspect of the incus corpus and short process (arrowhead) and the well-aerated middle-ear cavity. (C) Axial late post-gadolinium T1-eighted MR image (same level as [A,B]) shows the normal signal void (black or hypo-intense signal) of the normal aerated antrum on the right side (asterisk). On the left side, the cholesteatoma can be seen as an approximately 1 cm large hypo-intense non-enhancing lesion in the epitympanum and antrum (arrowheads). Note the surrounding enhancing inflammation presenting as hyperintense material filling the antrum and mastoid (arrows). (D) Coronal late post-gadolinium T1-weighted MR image at the level of the internal auditory canal. The cholesteatoma is demonstrated as a rather small nodular hypointense non-enhancing lesion in the antrum, almost immediately under the tegmen (arrowheads). Note the

extensive surrounding inflammation presenting as hyperintense enhancing soft tissue (arrows). (E) Coronal echoplanar diffusion-weighted imaging through both temporal bones. On the right side, the characteristic curvilinear artefact is noted at the interface temporal lobe temporal bone (arrow). On the left side, a somewhat nodular hyperintense signal is seen underneath the temporal lobe (arrowhead). Due to the frequent susceptibility artefact, differentiation with a cholesteatoma remains difficult (compare to [F]), (F) Coronal non-echo-planar diffusion-weighted sequence (single shot turbo spin echo diffusion-weighted image) *b*1000 image (same level as [E]). The cholesteatoma is seen as a small hyperintense nodular lesion underneath the left temporal lobe. Note the clear visualisation of the cholesteatoma and the complete absence of any susceptibility artefact. Compared to (E), this image demonstrates the superiority of non-echo-planar diffusion-weighted sequences in the detection of middle ear cholesteatoma. Note that the sequence only demonstrates the cholesteatoma. MRI of cholesteatoma

It can erode the malleus head, the corpus and short process of the incus as well as the long process. These often subtle details can best be seen when comparing both ears on CT scan. In case of further growth, the cholesteatoma grows into the antrum and further into the mastoid cavity. The cholesteatoma can also erode the tegmen which is best evaluated in the coronal plane. Direct coronal images are preferred over coronal reconstruction of a spiral scan as the tegmen can be better delineated on direct coronal images. The bony delineation of the lateral semicircular canal should always be examined carefully in order to exclude fistulisation to the lateral semicircular canal. Special attention should be paid to the tympanic or second segment of the facial nerve canal as this is also prone to erosion by a middle-ear cholesteatoma (1,4).

It should be noted that bony erosion can also be seen in cases of noncholesteatomatous disease. Ossicular chain erosions are rather rare in case of non-cholesteatomatous middle ear disease, but are known to occur and will predominantly erode the incus long process and lenticular process, followed by the stapes head. The malleus and incus body are much less vulnerable to this erosion, which is believed to take place under release of substances by mononuclear inflammatory cells and osteocytes or osteoclasts (11).

Congenital cholesteatoma can originate in every part of the temporal bone pyramid. In cases of the more frequent middle ear presentation, one usually can find a small nodular soft tissue density located in the anterosuperior part of the mesotympanum or in the posterior epitympanum (3). This nodular soft tissue is associated with an intact tympanic membrane without any soft tissues in Prussak's space. However, congenital cholesteatoma in the middle ear can present as an aspecific and sometimes large middle ear soft tissue mass. It can also erode the ossicular chain. Invasion into the membranous labyrinth is most frequent at the level of the lateral semicircular canal (Figure 2).



Figure 2. A 53-year-old woman with severe conductive hearing loss. Otoscopy showed an intact tympanic membrane.

(A) Axial CT image of the right ear at the level of the lateral semicircular canal showing a large soft tissue lesion (arrows) nearly completely filling up the antrum and mastoid. There is subtle erosion of the incus body and short process. The soft tissue mass invades the lateral semicircular canal (arrowheads). (B) Coronal CT reformation at the level of the cochlea showing an intact scutum (arrow). Note the well aerated aspect of Prussak's space and intact aspect of the pars flaccida of the tympanic membrane (arrow). There is no suggestion on CT of an acquired pars flaccida cholesteatoma. (C) Axial late post-gadolinium T1-weighted MR image at the level of the internal auditory canal and vestibule showing the cholesteatoma as a nodular non-enhancing lesion mainly situated in the posterior antrum (arrowheads). There is some associated enhancement in the anterior epitympanic space (arrows). There seems to be no obvious enhancement of the membranous labyrinth. (D) Axial 0.4 mm thick slice out of a 3-D TSE T2-weighted sequence showing the cholesteatoma as an intermediate signal intensity lesion (arrows) invading the lateral semicircular canal (arrowhead). The signal inside the membranous labyrinth on the right side is comparable to the signal on the normal left side. (E) Coronal

SS TSE diffusion-weighted sequence demonstrates a hyperintense lesion in the right middle ear, confirming the diagnosis of a middle ear cholesteatoma. Again, only the cholesteatoma is highlighted by the sequence.

Another frequent location of combined middle ear and temporal bone pyramid congenital cholesteatoma is the region of the geniculate ganglion of the facial nerve (1,3).

In the case of petrous bone apex presentation, it usually presents as a sharply delineated punched-out lesion associated to a soft tissue mass. The sharp and regular delineation of congenital cholesteatoma in the temporal bone pyramid is its most important characteristic in the differential diagnosis with other lesions such as metastasis or glomus tumour. Depending on its position, it may invade essential parts of the membranous labyrinth, such as the cochlea, the vestibule and semicircular canals as well as all the segments of the facial canal (Figure 3) (1,4).

MRI of cholesteatoma

MRI has the capability of multiplanar imaging and has a superior soft tissue differentiation. It was noted in the early 1990s that MRI was able to differentiate cholesteatoma from inflammatory tissue using gadolinium enhanced T1-weighted sequences (12). This is based upon the observation that cholesteatoma is, by definition, an avascular tissue and does not enhance after intravenous (i.v.) gadolinium (Gd) contrary to the enhancing inflammatory tissue. On T2-weighted images, cholesteatoma shows an intermediate hyperintensity, clearly lower than the intensity of accumulated fluid and associated inflammation. The signal intensity of a cholesteatoma looks somewhat similar to that of the grey matter of brain on T2-weighted MRI (Figures 4 and 5).

Recent papers have described aspects of cholesteatoma on diffusion-weighted MRI sequences (13,14). The mechanism of diffusion-weighted-MRI is based on the Brownian motion of water molecules in tissue and, more importantly, on the hindrances/facilitations of the water molecule movements in various types of tissue. In order to make an MRI sequence sensitive to the diffusion of water molecules, the sequence is expanded with a diffusion-sensitizing gradient scheme, usually a very fast, single-shot gradient-echo data collecting sequence (echoplanar).

The amount of diffusion-sensitizing applied is usually indicated by the b-value. In clinical practice, images are generally acquired with a b-value of 1000 s/mm².



Figure 3. A 52-year-old man with a history of long-standing deafness on the left side, presenting with a sudden, severe and persistent facial palsy. Presumed diagnosis on CT and MRI was a congenital cholesteatoma. Surgery confirmed a congenital cholesteatoma. Note the hyperintense aspect of the congenital cholesteatoma on echoplanar diffusion-weighted and the distorted aspect of the lesion and the artefact at the interface between temporal lobe and temporal bone. These imaging findings are very characteristic for echoplanar diffusion-weighted sequences.

(A) Axial CT scan of the temporal bone at the level of the internal auditory canal shows a sharply delineated hypodense lesion situated posterior to the internal auditory canal (arrowheads). The delineation is lost between the lesion and the internal auditory canal. The sharp delineation of the lesion and the absence of a moth-eaten aspect of the adjacent bone makes the diagnosis of a metastatic lesion less probable. (B) Axial T2-weighted MR image of the skull (same level as [A]) shows a nodular intense lesion

posterior to the internal auditory canal (arrowhead). Lesion with aspecific signal intensity on this MRI of the head. (C) Axial post-gadolinium T1-weighted image of the temporal bone (same level as [A,B]) clearly shows the centrally non-enhancing hypo-intense lesion of the left temporal bone (arrowheads). The lesion cannot be delineated from the internal auditory canal suggestive of invasion. Note the thin enhancing matrix around the nonenhancing keratin in the cholesteatoma. There seems to be also some enhancement in the modiolus of the cochlea (arrow), suggestive of invasion. D) Coronal post-gadolinium T1-weighted image with fat saturation. The cholesteatoma can be seen as a nodular hypo-intense lesion (arrowheads), located very medially into the signal void of the temporal bone underneath the left temporal lobe. (E) Coronal echoplanar diffusionweighted *b*1000 images. On this sequence, the lesion can be noted as a rather bi-nodular (instead of oval) hyperintense lesion (arrowheads). Note that the lesion has a distorted aspect (arrowheads) and that there is a curvilinear interface artefact at the border of the temporal lobe and temporal bone on both sides (arrows). Both features are characteristic of an echoplanar diffusion-weighted sequence. However, as the lesion is quite large, echoplanar diffusion-weighted confirms the diagnosis of a congenital cholesteatoma by showing a definite high signal intensity lesion on *b*1000 images.

Diffusion-weighted-MRI is now an established method used routinely for the diagnosis of acute stroke. (15) Extracranial applications of diffusion-weighted MRI are becoming increasingly important (16).

Fitzek and colleagues (13) were one of the first groups to report that cholesteatoma is hyperintense on echoplanar diffusion-weighted MRI, more specifically on *b*1000 images. However, echoplanar diffusion-weighted MRI has the major drawback of a low spatial resolution, a higher slice thickness and a major susceptibility artefact at the interface between air and bone. This clearly limits its value for the diagnosis of middle ear cholesteatoma (Figure 1) (14,17). Very recently, two types of non-echoplanar based diffusion-weighted sequences have been described for the diagnosis of middle ear cholesteatoma (17,18). These turbo spin echo (TSE) or fast spin echo (FSE) based diffusion-weighted sequences have a higher spatial resolution, generate thinner slices and do not suffer at all from susceptibility artefacts. The single-shot TSE diffusion-weighted sequence uses a 180° radiofrequency refocusing pulse for each measured echo, which explains the reduction of the susceptibility artefact (Figure 1) (17).

First reports of results in larger series indicate a much higher sensitivity and specificity for the diagnosis of middle-ear cholesteatoma using these nonechoplanar based diffusion-weighted sequences (19) in which cholesteatoma also appears hyperintense on b1000 images.





Figure 4. A 26-year-old man with ,at otoscopy, a retraction pocket with suspicion of a cholesteatoma. There was also the clinical suspicion of an associated infection. CT scan shows the signs of the cholesteatoma eroding the ossicular chain. MRI makes it possible to differentiate the cholesteatoma from the surrounding inflammation. Final diagnosis was a middle-ear cholesteatoma originating from a retraction pocket expanding into the antrum and mastoid cavity with surrounding inflammation.

(A) Axial CT image of the right temporal bone at the level of the lateral semicircular canal, showing typical features of middle ear cholesteatoma: erosion of the body and long process of the incus (large arrow) by an associated soft tissue density (asterisk), eroding also the lateral epitympanic wall (arrowheads). (B) Axial CT image of the left temporal bone (same level as [A]). Note the intact aspect of the ossicular chain, more specifically of the incus body and short process (arrow) and the normal distance between the ossicular chain and lateral epitympanic wall. (C) Coronal late post-gadolinium T1-weighted MR image at the level of the cochlea clearly showing the non-enhancing cholesteatoma (arrowheads) situated in the antrum with surrounding enhancing inflammation (arrows). (D) Coronal T2-weighted MR image (same level as [C]) showing the cholesteatoma as an intermediate signal intensity lesion in the right epitympanic cavity (arrowheads). (E)

Coronal non-echo-planar diffusion-weighted sequence (same level as [C]) clearly shows the cholesteatoma in the epitympanic cavity, antrum and mastoid as a small rather bilobar hyperintensity. The clear hyperintensity confirms the diagnosis of a congenital cholesteatoma.

MRI of congenital cholesteatoma

In congenital cholesteatoma in a middle ear location, a nodular soft tissue lesion is most frequently found in the anterosuperior part of the mesotympanum or in the posterior epitympanum (Figure 2) (1,3). In other temporal bone locations, CT often shows a sharply delineated, hypodense, punched-out, aspecific, soft tissue lesion, which can be located anywhere in the temporal bone pyramid. In the case of a petrous bone apex lesion, the congenital cholesteatoma can invade the membranous labyrinth and facial nerve canal. Usually, such a lesion demonstrates sharp and regular borders contrary to other more aggressive lesions such as metastasis or glomus tumours (Figure 3) (1,2).

The exact bony delineation of such a lesion can easily be described on CT. MRI is, however, superior in describing the exact location and extension of congenital cholesteatoma in the middle ear or temporal bone pyramid. It is able to demonstrate the relation with other structures of the membranous labyrinth and the facial nerve. Moreover, MRI is able to characterize the lesion with a high degree of confidence (Figures 2 and 3).

If a congenital cholesteatoma is located in the apex of the temporal bone pyramid, differentiating this from an opacified aerated cell in the temporal bone pyramid and a cholesterol granuloma can sometimes be difficult (20). Cholesterol granuloma, however, displays a clear hyperintensity on T1-and T2-weighted images contrary to cholesteatoma which presents as a lesion with a definite lowsignal intensity on T1-weighted images and an intermediate signal on T2weighted images. An opacified and/or infected aerated cell in the apex of the os petrosum pyramid shows a low signal intensity on T1-weighted MR images and a high signal intensity on T2-weighted MR images making the differential diagnosis with a congenital cholesteatoma complex (20). Theoretically, signal intensities on T1-as well as on T2-weighted images may vary in time due to the change in water content of the secretions in the opacified cells (20). In these cases, diffusion-weighted sequences can make the differentiation by showing a high signal intensity lesion on b1000 images in the case of cholesteatoma. One should take into account that the echoplanar diffusion-weighted sequences are very prone to artefacts in the skull base region contrary to the non-echo-planar diffusion-weighted sequences which will clearly show these lesions without artefacts.



Figure 5. A 47-year-old man with, at otoscopy, a large cholesteatoma. CT and MRI demonstrate characteristic features of a large middle ear cholesteatoma, with associated complications.

(A) Axial CT scan at the level of the lateral semicircular canal. Completely eroded antrum and mastoid filled with soft tissues (asterisk). No ossicular chain can be delineated. Note the loss of the bony cover over the lateral semicircular canal (arrowhead). Findings are pathognomonic for a large middle ear cholesteatoma with suspicion of fistulisation to the lateral semicircular canal. (B) Coronal CT reconstruction at the level of the oval window and lateral semicircular canal. There is complete opacification of the middle ear and antrum without any residual ossicular chain (asterisk). The bony delineation over the lateral semicircular canal is lost (arrowhead) suggestive for fistulisation to the lateral semicircular canal. Moreover there is also loss of delineation of the tegmen of the middle ear cavity (arrows) so middle fossa invasion cannot be excluded. (C) Axial late post-gadolinium T1-weighted MR image at the level of the lateral semicircular canal (same level as [A]). There is enhancement at the periphery of the large antral cavity compatible with matrix and perimatrix of the cholesteatoma (arrowheads). The centrally located hypointense soft tissue in the lower part of the large antral cavity is compatible with keratine

(asterisk). Compared to the axial CT image in (A), the keratine is partially evacuated due to suction cleaning by the ENT surgeon via the external auditory canal. There seems to be no clear enhancement of the membranous labyrinth. On the coronal image (not shown) no invasion in the middle cranial fossa could be demonstrated. (D) Coronal T2-weighted image at the level of the vestibule showing the partially evacuated cholesteatoma sac (arrowheads) with centrally the intermediate signal of the keratine (asterisk) in the cholesteatoma sac. Compare the signal intensity of the cholesteatoma to the signal intensity of the adjacent temporal lobe. Note the normal signal intensity of the adjacent temporal lobe, excluding invasion. (E) Coronal non-echo-planar diffusion-weighted image showing a clear hyperintensity under the left temporal lobe. The hyperintensity is caused by the accumulated keratine in the cholesteatoma matrix. Compare to (D). (F) Maximum intensity projection (or MIP reconstruction) of a 3-D TSE T2-weighted sequence. The cholesteatoma can be seen as a large nodular intermediate signal intensity lesion (asterisk). There is partial loss of delineation of the lateral semicircular canal (arrowhead) with a slight signal loss of the lateral semicircular canal compared to the other side. This signal loss is suggestive of possible onset of fibrosis.

Moreover, non-echo-planar diffusion-weighted sequences have the capacity of demonstrating even very small congenital cholesteatoma (19). We consider it important to add a non-echo-planar diffusion-weighted sequence to the standard MRI protocol in cases of MR evaluation of any lytic temporal bone lesion or aspecific middle ear or temporal bone lesion. By doing so, a congenital cholesteatoma will easily be detected without deformation of the region of interest by susceptibility artefacts.

MRI of acquired cholesteatoma

The primary imaging tool for an acquired middle-ear cholesteatoma is high resolution CT of the temporal bone (1,4). However, in selected cases of an acquired cholesteatoma, MRI has a role. When there is an associated surrounding infection, MRI will be able to delineate the cholesteatoma exactly (Figure 4) (4,11,17). If there are suspected complications on CT scan, MRI may act as a diagnostic aid (Figure 5) (17). If a cholesteatoma invades the membranous labyrinth through the lateral semicircular canal, MRI will be able to demonstrate enhancement of the membranous labyrinth on T1-weighted sequences after gadolinium administration. Signal loss on the heavily T2weighted sequences (caused by replacement of the fluid by fibrous tissue) can be noted depending on the stage of the associated labyrinthitis (Figure 5). In the acute phase, enhancement will be noted on T1-weighted images without signal loss on heavily T2-weighted images. In the subacute phase, the enhancement will diminish with subsequent moderate signal loss on heavily T2-weighted sequences. In the chronic phase, no enhancement will be noted with complete signal loss on heavily

T2-weighted sequences due to the fibrosis. In case of suspected tegmen disruption on CT, MRI will nicely demonstrate meningeal enhancement in the middle fossa and eventual changes in signal intensity in the adjacent temporal bone on T2-weighted images.

Cholesteatoma displays a hypo-intense aspect on T1-weighted images surrounded by the cholesteatoma matrix and perimatrix, presenting as an enhancing line (Figure 5). On T2-weighted images, cholesteatoma has an intermediate signal intensity. Usually, even on T2-weighted images, discrimination with surrounding inflammation is possible as inflammation displays a much higher signal intensity (4,17). On echo-planar diffusion-weighted images, acquired cholesteatoma will (as congenital cholesteatoma) display a clear high-signal intensity on *b*1000 images (4,13,14). A recent paper, however, has set the size limit for visualisation of an acquired cholesteatoma at 5 mm due to the above limitations of echo-planar diffusion-weighted MRI, mainly based upon susceptibility artefacts (14). Thus, any cholesteatoma lesion smaller than 5 mm can be missed. giving the possibility of false-negative lesions. Moreover, a cholesteatoma located in the antrum and mastoid underneath the tegmen can easily be hidden in the curvilinear artefact of the interface of bone and air at the tegmen (Figure 1) (17). Echo-planar diffusion-weighted MRI can be used to evaluate an acquired middleear cholesteatoma taking the limitations into account such as size limit, the distortion of the lesion and the susceptibility artefacts. To date, no false positives have been reported using echo-planar diffusion-weighted sequences (14).

However, non-echo-planar based diffusion-weighted sequences have been reported to be superior to echo-planar diffusion-weighted sequences demonstrating acquired middle-ear cholesteatoma (Figure 1) (17,19). These sequences display less artefacts, allow a lower slice thickness and a higher resolution. In a recent study, a specific non-echo-planar based diffusion-weighted sequence (single shot TSE diffusion-weighted) was able to demonstrate acquired middle ear cholesteatoma as small as 2 mm (19). Non-echo-planar diffusionweighted sequences have two major limitations. Motion artefacts can be a cause of false negatives as in these cases the hyperintense signal on b1000 images is smeared out over multiple pixels, thus causing rather iso-intense signals (19). Another possible cause of false negatives is the so-called auto-evacuated cholesteatoma (19). In these cholesteatomas, the content of the retraction pocket is evacuated into the external auditory canal leaving the cholesteatoma matrix behind in its original position in the middle ear and antrum.



Figure 6. A 45-year-old man with a history of cholesteatoma surgery on the right side 14 months ago. Follow-up CT and MR examination were performed. Non-echo-planar diffusion-weighted sequence shows a very small residual cholesteatoma pearl located very posteriorly and laterally in the resection cavity. Apart from this very small residual cholesteatoma, the entire resection cavity and middle ear cavity are filled with scar tissue and granulation tissue.

(A) Axial CT scan at the level of the horizontal semicircular canal shows a complete opacification of the mastoidectomy and middle ear cavity (asterisk). Note some bony remnants in the cavity and a part of the head of the malleus (arrowhead). It is impossible to differentiate these soft tissues on CT as scar tissue, granulation tissue, inflammation and cholesteatoma display the same density on CT. (B) Coronal T2-weighted MR image at the level of the vestibule, superior and lateral semicircular canal. The middle ear and resection cavity are completely filled with homogeneous hyperintense material (arrowheads). Signal intensity is clearly too high to be compatible with cholesteatoma (compare to the signal intensity of the grey matter of the adjacent temporal lobe). (C) Coronal late post-gadolinium T1-weighted MR image (same level as [B]). Note the

complete enhancement of the middle ear and mastoidectomy cavity (arrowheads) excluding any cholesteatoma on this location. (D) Coronal non-echo-planar diffusionweighted image: same level (B,C). No clear hyperintensity can be noted in the resection cavity. The soft tissue in the resection cavity displays a moderate to low intensity (arrowheads). (E) Coronal non-echo-planar diffusion-weighted image posterior in the mastoidectomy cavity. There is a very small nodular hyperintensity visible laterally and posteriorly in the resection cavity (arrowhead). The large nodular moderate intense region caudal to the temporal bone signal void on both sides, is fat in the mastoid tip. (F) Coronal T2-weighted MR image (same level as [E]). There is a very small, moderately intense nodule lateral and posterior in the mastoidectomy cavity (arrowhead). Note the high signal intensity of fat in the mastoid point (asterisk). The rest of the mastoidectomy cavity is filled with high signal intensity material compatible (arrows) with scar tissue and granulation tissue. The very small, moderately intense nodule corresponds to the visualised hyperintensity as seen in (E). Both findings are highly suggestive of a very small residual cholesteatoma pearl. Surgery revealed indeed a very small posteriorly and laterally located 3 mm small residual cholesteatoma pearl.

In these cases, diffusion-weighted sequences (echo-planar as well as non-echoplanar) display no hyperintensity as the keratine in the retraction pocket (responsible for the hyperintense signal on diffusion-weighted sequences) is evacuated. Theoretically, the matrix and perimatrix can be visualized as an enhancing linear structure on T1-weighted post-gadolinium sequences but discrimination is sometimes difficult due to the surrounding inflammation (19).

MRI of postoperative cholesteatoma

The use of Canal wall up tympanoplasty frequently necessitates second-look surgery. In a postoperative setting, MRI is clearly superior to CT in the evaluation of the postoperative ear. Despite CT's reported insufficiency for the detection of postoperative cholesteatoma,(23–25) it is still used world-wide in the postoperative evaluation of middle-ear cholesteatoma. Postoperative monitoring for recurrence will probably become one of the most important indications to perform an MRI for cholesteatoma.

CT, however, is not without merit and, in the well-aerated middle ear and postoperative cavity without any associated soft tissue, a high negative predictive value in excluding postoperative residual or recurrent cholesteatoma is seen (21,22). In nodular-associated soft tissue lesions, CT is able to make the positive diagnosis of a residual or recurrent cholesteatoma (21,22). However, in the vast majority of cases, the postoperative cavity and middle ear are partially or completely filled with soft tissue densities making differentiation on CT impossible.


Figure 7. A 65-year-old woman with extensive prior history of multiple cholesteatoma surgery finally resulting in a complete petrosectomy several years ago. The patient presented with right-sided pain situated in the petrosectomy cavity. This case demonstrates the superiority of non-echo-planar diffusion-weighted sequences in demonstrating post-operative recurrent cholesteatoma. Both cholesteatomas were confirmed on their suspected locations. (A) Axial CT image situated low in the petrosectomy cavity. The petrosectomy cavity is filled at its medial side by partially irregular delineated soft tissues (asterisk). On CT, differentiation of these soft tissues is completely impossible. Note the loss of delineation of the intrapetrosal part of the carotid canal (arrowheads). (B) Axial non-echo-planar diffusion-weighted image at the level of the skull base (right temporomandibular joint is just included in the slice). A nodular hyperintense lesion (arrowhead) can be seen on the right side just laterally to the moderately intense signal of the skull base. This nodular hyperintense lesion is highly suspicious for a small recurrent cholesteatoma. (C) Axial non-echo-planar diffusionweighted image, one slice higher than in (B). A second smaller nodular hyperintense lesion (arrowhead), already suspected in (B), situated laterally to the first lesion is seen. Again, this lesion is also highly suspicious of a second location of a recurrent cholesteatoma. (D) Coronal non-echo-planar diffusion-weighted image at the level of the anterior skull base clearly shows the nodular lesion (arrowhead), located very medially in the skull base. The second very small lesion can already be suspected on this slice (arrow). This second very small lesion was better visualized on an adjacent slice (not shown). (E) Coronal T2-weighted MR image (same level as [D]) shows the cholesteatoma as a nodular moderately intense lesion (arrowhead). The signal intensity of the cholesteatoma looks very similar to that of grey brain tissue in the adjacent temporal lobe. Note the intense signal of the associated scar and granulation tissue (arrows) situated laterally to the recurrent cholesteatoma. (F) Coronal T1-weighted MR image (same level as in [D,E]) shows the cholesteatoma as a nodular non-enhancing lesion (arrowhead). Note the enhancing inflammatory and scar tissue lateral to the cholesteatoma partially filling up the resection cavity (arrows). The second smaller cholesteatoma can also be suspected as a small nodular non-enhancing lesion. Both lesions correspond to the visualized nodular hyperintensities on non-echo-planar diffusion-weighted sequences and are compatible with two recurrent cholesteatomas. (G) Axial T1-weighted MR image (same level as in [A]). The cholesteatoma (large arrowhead) is embedded in enhancing scar tissue (arrows) with centrally nonenhancing cholesteatoma. Note that the cholesteatoma is in very close relationship to the intrapetrosal part of the internal carotid artery (small arrowheads). (H) Axial T1-weighted MR image, one slice higher than (G). The second small cholesteatoma is seen as a small nodular hypo-intense lesion (arrowhead) embedded in enhancing scar and granulation tissue (arrows).

Currently, two types of protocols or techniques are used to demonstrate cholesteatoma, especially in the postoperative setting.

Late post-gadolinium T1-weighted imaging

Williams and colleagues (21,22) were the first to report the use of late postgadolinium T1-weighted sequences for the detection of postoperative residual cholesteatoma. The rationale of this technique is based upon the fact that postoperative scar tissue and granulation tissue enhances slowly. Early scanning after intravenous gadolinium can cause false-positive findings. The main

difference with the early reports on post-gadolinium T1-weighted imaging is that this protocol uses a delay of 45 min after i.v. gadolinium administration. By doing so, the postoperative scar and granulation tissue has the time to enhance, so differentiation with the non-enhancing cholesteatoma can be made. Using this protocol, residual cholesteatomas as small as 3 mm may be detected.

Major limitations, however, are the use of gadolinium which has become controversial due to the appearance of systemic fibrosis in patients with renal insufficiency. Furthermore, this protocol with unenhanced and late postgadolinium T1-weighted enhanced images forms a time-consuming burden on the workflow of a radiology department.

Diffusion-weighted MR imaging

Echo-planar diffusion-weighted sequences were originally developed for the diagnosis of ischaemic brain lesions. This sequence is based upon the demonstration of movement of free water molecules and possible restriction of movement in the case of pathology.

reports have extensively described the echo-planar Several use of diffusionweighted sequences in the diagnosis of middle-ear cholesteatoma (13,14,26,27). Again, differentiation should be made between residual and recurrent cholesteatoma. According to Brackmann, (7) residual cholesteatoma is defined as cholesteatoma left behind at first-stage surgery whereas recurrent cholesteatoma usually starts as a new superoposterior retraction pocket. In our experience, residual cholesteatoma can be located anywhere in the middle ear and resection cavity and is much smaller than the recurrent cholesteatoma. This makes the detection of a residual cholesteatoma much more difficult. In a large series, we retrospectively reviewed the use of echo-planar diffusionweighted sequence in the postoperative middle ear and mastoid cavities in order to evaluate its value to demonstrate these usually small residual cholesteatoma pearls (14). Echo-planar diffusion-weighted imaging has (due to its limitations) a size limit of 5 mm in demonstrating middle-ear cholesteatoma. This makes echo-planar diffusion-weighted sequences useless for the detection of residual cholesteatomas. However, most reported studies using echo-planar diffusionweighted sequences for the evaluation of postoperative cholesteatoma are studies on recurrent cholesteatomas (26,27). All reported postoperative cholesteatomas are recurrent cholesteatomas and are much larger, being easily detectable using echo-planar diffusion-weighted sequences (26).

It has already been reported that non-echo-planar based diffusion-weighted sequence have a higher sensitivity and specificity to detect cholesteatoma (17).

However, until now, only one report mentions the use of non-echo-planar based diffusion-weighted sequences for the evaluation of postoperative cholesteatoma (18). Surprisingly, the reported cholesteatoma are again rather large recurrent cholesteatomas with a minimum size of 5 mm, equalling the detectable size of echo-planar diffusion-weighted sequences (18).

Data from our own most recent results indicate that the non-echo-planar based diffusion-weighted sequences have a very high sensitivity and specificity in evaluating pre-second-look patients (Figure 6) (28). Non-echo-planar diffusion-weighted imaging is able to detect very small residual cholesteatomas and has a high negative predictive and high positive predictive value. These results indicate that non-echo-planar diffusion-weighted sequences can select second look patients thus avoiding unnecessary interventions (28). In our own data, the number of patients undergoing second-look surgery in our institution has dropped from about 65% to less than 10% using this technique.

In the case of a possible recurrent cholesteatoma, MRI is far superior to CT in the evaluation of these patients as CT usually only displays an aspecific soft tissue opacification of the resection cavity (Figure 7). Further studies are currently in progress to evaluate whether one can start the evaluation of postoperative patients by using this non-echo-planar diffusion-weighted sequences alone.

MRI of primary bony obliteration techniques

In primary bony obliteration techniques (PBOTs), a Canal wall up procedure is used in combination with mainly bone and bone paté creating a bone density in the filled cavity. In these cases, a homogeneous aspect of the bony filled cavity should be noted (Figure 8). Any punched-out soft tissue lesion into the obliterated and bony filled cavity is suspicious of a recurrent cholesteatoma (10).

The signal intensities of such a filled cavity on standard MRI sequences are reported to be very inhomogeneous and mixed (10) making the diagnosis of a recurrent cholesteatoma impossible. A recent report on echo-planar diffusion-weighted images demonstrates the limitations of these sequences in the evaluation of the obliterated cavities as well as in the evaluation of an associated middle-ear cavity (10).

Further studies are currently being undertaken to evaluate non-echo-planar based diffusion-weighted sequences in the evaluation of the PBOT as well as the associated (opacified) middle ear.

MRI protocol

Our current MRI protocol consists of the combination of both techniques and is mainly based on late post-gadolinium T1-weighted images and non-echo-planar diffusion-weighted sequences using a 1.5 T superconductive unit (Magnetom Avanto, Siemens Medical Solutions, Erlangen, Germany) with the standard Head Matrix coil. We no longer perform any unenhanced T1-weighted images. All sequences are performed 45 min after i.v. gadolinium administration.

Axial 2-mm thick spin-echo T1-weighted images (TR 400 ms, TE 17 ms, matrix 192 x 256, field of view 150 mm x 200 mm) and coronal 2-mm thick spin-echo T1-weighted images are acquired with the same parameters except for the matrix, which is set at 144 x 256 for the coronal images. Coronal 2-mm thick turbo spin-echo T2-weighted images (TR 3500 ms, TE 92 ms, matrix 192 x 256, field of view 150 mm x 200 mm) and axial 0.4-mm thick 3-D turbo spin-echo T2-weighted images (TR 1500 ms, TE 303 ms, matrix 228 x 448, field of view 107 mm x 210 mm) are also performed. In all patients, a 2-mm thick single-shot turbo spin-echo diffusion weighted sequence is acquired in the coronal plane (TR 2000 ms, TE 115 ms, matrix 134 x 192, field of view 220 mm x 220 mm, b factors 0 and 1000 mm²/s). The coronal plane is preferred over the axial plane due to the fact that in the past, using EP-DW imaging, the coronal plane showed less artefacts. Out of habit, the coronal plane is still preferred.

Conclusions

For the evaluation of acquired and congenital cholesteatoma, MRI clearly has a complementary function to CT due to its superior soft tissue resolution and its ability to discriminate cholesteatoma from surrounding inflammation.

The combination of late post-gadolinium T1-weighted MR sequences and a nonecho-planar diffusion sequence has the highest sensitivity and specificity in the detection of postoperative residual or recurrent cholesteatoma. Therefore, evaluation of the postoperative middle ear should be done on MRI using the combination of both of these sequences.



Figure 8. A 27-year-old man with prior PBOT surgery for cholesteatoma. There is no evidence on CT or MRI for a residual or recurrent cholesteatoma.

(A) Axial CT image at the level of the internal auditory canal and the vestibule. The surgical cavity is completely filled up with a mixture of bone and bone paste (asterisk). Note the complete and homogeneous bone opacification of the cavity with bone. There are no punched-out lesions in the bony opacification. (B) Coronal CT reconstructions at the level of the vestibule. Note, again, the complete opacification of the mastoidectomy cavity with bone (asterisk). There are no punched-out lesions in the bony filled up cavity. Note the well-aerated aspect of the middle ear (arrowhead). (C) Axial late post-gadolinium T1-weighted image (same level as in [A]). Note the hypointense signal of the completely filled up cavity (asterisk).

cholesteatoma. (D) Coronal late post-gadolinium T1-weighted image (same level as in [B]). Note, again, the somewhat inhomogeneous hypo-intense aspect of the filled cavity (arrowheads). It is difficult to exclude any cholesteatoma on this sequence. (E) Coronal T2-weighted MR image (same level as in [B,D]). The signal of the obliterated cavity is homogeneous and very hypo-intense (arrowheads). Compare these to (C,D). Signal intensities on T1-and T2-weighted images are not at all compatible with cholesteatoma. The hypo-intense aspect on T1-weighted sequences and the very hypo-intense aspect on T2-weighted sequences are characteristic of an obliterated cavity. (F) Coronal non-echoplanar diffusion-weighted image shows no hyperintensities at all. Recurrent or residual cholesteatoma can be excluded.

Key points for clinical practice

- Cholesteatoma has an intermediate signal intensity on T2-weighted MR images, a hypo-intense signal with peripheral enhancement on T1-weighted images after i.v. gadolinium and a clear hyperintense signal on *b*1000 diffusion-weighted images.
- Non-echo-planar based diffusion-weighted sequences have the highest sensitivity and specificity for the detection of middle-ear cholesteatoma.
- Non-echo-planar based diffusion-weighted sequences are able to detect middle ear cholesteatoma as small as 2 mm whereas echoplanar diffusion-weighted sequences have a size limit of 5 mm.
- The evaluation of postoperative recurrent cholesteatoma has to be done on MRI using a protocol with late post-gadolinium T1-weighted and non-echo-planar based diffusion-weighted rather than using CT.
- A state-of-the-art MRI protocol for cholesteatoma detection should include a combination of late (45 min) post-gadolinium T1-weighted sequence and a non-echoplanar based diffusion-weighted sequence.

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Chapter 3.2

Magnetic Resonance Imaging of cholesteatoma: an update

Vercruysse JP, De Foer B, Somers T, Casselman JW, Offeciers E. B-ENT (2009): 233-240

Abstract

Magnetic resonance imaging of cholesteatoma: an update.

Objective: To report on the value and limitations of new MRI techniques in pre-and post-operative MRI of cholesteatoma. The current value of magnetic resonance imaging (MRI) in diagnosing congenital, acquired, and post-operative recurrent or residual cholesteatoma is described. Methodology and results: High resolution computed tomography (HRCT) is still considered the imaging modality of choice for detecting acquired or congenital middle ear cholesteatoma. However, MRI may provide additional information on the delineation and extension of cholesteatoma and on potential complications. Detecting post-operative residual or recurrent cholesteatoma with HRCT was shown to be inaccurate due to the technique's low sensitivity and specificity.

Conclusions: Recently, improvements in MRI techniques have led to a more accurate diagnoses of cholesteatoma using delayed contrast enhanced T1-weighted imaging and diffusion-weighted imaging.

Introduction

Confirming a diagnosis of acquired or congenital cholesteatoma through imaging techniques remains a challenge for the head and neck radiologist.

The diagnosis of an acquired cholesteatoma is mostly based on clinical suspicion (otoscopic findings, conductive or mixed hearing loss, and/or otorrhea). High resolution computed tomography (HRCT) is still widely considered to be the primary imaging tool for diagnosing and documenting the extent and potential complications of middle ear cholesteatoma. HRCT provides good information on the presence of associated bony and ossicular erosion as well as on important pre-operative anatomical features, such as the delineation of the tympanic segment of the facial nerve, the tegmen, the position of the sigmoid sinus, and the size of the mastoid cell structure (1)

The additional value of MRI in primary acquired cholesteatoma is due mainly to its capacity to unequivocally confirm the diagnosis of cholesteatoma in cases of clinical doubt; in its capacity to distinguish cholesteatoma from other soft tissues, such as fibrosis, granulation tissue and cholesterol granuloma; and it's potential to document invasion of the labyrinth and of the intracranial space (1-3).

In contrast, many studies have shown that HRCT is inaccurate in detecting postoperative residual and recurrent cholesteatoma (4,5). In completely aerated postoperative cavities absent of any associated soft tissue, HRCT has a high negative predictive value in excluding cholesteatoma. However, HRCT is unable to differentiate cholesteatoma from scar tissue, granulation tissue, or cholesterol granuloma in completely or partially opacified middle ears and post-operative cavities (4,5).

MRI offers the possibility of using different types of sequences — including diffusion weighted sequences and late post-gadolinium T1-weighted images — and different imaging planes (2). In the past few years, MRI, including diffusion-weighted (DW) echo-planar imaging (EPI), has become increasing important in the detection and further characterization of cholesteatoma (6-9). MRI can differentiate granulation tissue from cholesteatomatous tissue, but often fails to clearly detect residual or recurrent cholesteatoma in the ears post-operatively (3,10). Therefore, non-echo-planar DW imaging (DWI) techniques have been tested to see if they could overcome these limitations.

MRI characteristics of cholesteatoma

Cholesteatoma is a cystic lesion formed from keratinized, stratified, squamous epithelium (matrix) filled with desquamation debris (keratin), which commonly involves extradural structures. Predominantly, these structures include the middle ear cavity and mastoid, but also involve other parts of the petrous bone, including the petrous apex and the external auditory canal. Extradural cholesteatoma has traditionally been divided into either congenital or acquired cholesteatoma. Intradurally-located lesions are often found in the cerebellopontine angle or middle cranial fossa, and are known as epidermoid cysts.

On standard T1-weighted MRI sequences, a cholesteatoma, both congenital and acquired ones, have a hypointense signal intensity when compared with the brain's gray matter. A cholesteatoma is a non-vascularised lesion; therefore, it is not enhanced after intra-venous gadolinium administration. Theoretically, the enhancement of the surrounding epithelial (matrix) and granular (perimatrix) layers can be seen as a thin, enhanced line (peripheral rim) on T1-weighted images after intra-venous administration of gadolinium; but this is often not discernible because of associated inflammation, which enhances the image surrounding the lesion. On T2-weighted images, cholesteatoma is characterized by an inter-mediate to high signal intensity, which is definitely lower than the intensity of inflammatory tissue or fluid. Inflammation or fibrous tissue, on the contrary, is characterized by a high signal intensity on T2-weighted images and a low signal intensity on T1-weighted

images, although these are variably and inhomogeneously enhanced after intravenous administration of gadolinium. It often takes 45 minutes for fibrous tissue to show enhancement, which warrants late imaging after gadolinium administration. A cholesterol granuloma on a MRI is characterized by high signal intensities on both T1-and T2-weighted images.

On diffusion-weighted MRI sequences (echo-planar as well as non-echo-planar), a cholesteatoma is characterized by a clear hyperintensity. The DW-MRI was initially used to diagnose ischemic brain infarction (11). The DW-MRI technique provides information about the diffusion motion of water (protons) and the restriction of this motion within various biologic tissues and pathological entities. In order to visualize the diffusion of water (protons), diffusion-sensitizing gradients must be applied, most often using a fast, single-shot gradient echo sequence (b-values of 1000s/mm²) (1,6,9).

The precise cause of the increased signal intensity of cholesteatoma on DW-MRI is still unknown. Several authors believe that the hyper-intensity is caused by a combination of restricted diffusion and the T2 shine-through effect (6,7,9). The cholesteatoma, which is filled with cholesterol-containing keratin debris, has a moderate to high signal intensity on standard T2-weighted MRIs, suggesting that the T2 shine-through effect may contribute to the hyper-intensity on diffusion-weighted images. No false-positive findings were seen in our population. Recently, several authors reported low-intermediate intensities in the presence of silastic, bone powder, and granulation tissue (12-14). However, a marked hyper-intensity on DWI is considered diagnostic for cholesteatoma, but one must be careful not to misinterpret the numerous artefacts on DWIs as cholesteatomas. The differential diagnosis and imaging characteristics of cholesteatoma on MRI are summarized in Table 1, and 3 case illustrations are described in Figures 1, 2, and 3.

	T2-weighted MRI	T1-weighted MRI	T1-weighted MRI with gadolinium	Diffusion weighted MRI
Cholesteatoma	Hyper-intensity	Hyper-intensity	Hypo-intensity Peripheral rim (matrix)	Hyper-intensity
Cholesterol granuloma	Hyper-intensity	Hyper-intensity	Hyper-intensity	Low intermediate
Inflammation/scar tissue	Hyper-intensity	Hypo-intensity	Hyper-intensity	No signal

Table 1. Differential diagnosis and imaging characteristics of cholesteatoma on MRI



Figure 1. A 23-year-old man with a prior history of cholesteatoma surgery on the left side (> 3 years), with a micro-otoscopical suspicion of a recurrent cholesteatoma. Surgery showed the presence of a large recurrent cholesteatoma involving the attic and mastoid; a: Axial HRCT image at the level of the basal turn of the cochlea on the left side. The entire post-operative mastoid cavity is almost completely filled with soft tissue (asterisk). On HRCT, it is impossible to differentiate these soft tissues; a recurrent cholesteatoma is likely, although it can neither be excluded nor confirmed by HRCT; b: Coronal-reformatted CT image at the level of the vestibule. Again, the entire cavity is filled with soft tissue (asterisk) which cannot be differentiated on CT. Based on this CT examination, a recurrent cholesteatoma can neither be excluded nor confirmed; c: Coronal T2-weighted image (at the same level as Figure 1b) through the left temporal bone showing a cavity almost completely filled with a hyper-intense nodular lesion (arrows); d: Coronal late (45 minutes) post-gadolinium T1-weighted MRI (at the same level as Figures 1b and 1c). The cholesteatoma is seen as a large hypo-intense nodular lesion (arrows) surrounded by inflammatory and scar tissue that enhance the image. A large cholesteatoma presenting as a characteristic, non-enhancing, hypo-intense lesion; e: Axial late (45 minutes) postgadolinium T1-weighted MRI at the level of the vestibule. Note the large, hypo-intense, non-enhancing nodular lesion in the cavity (arrows) delineated by peripherally enhanced inflammatory and / or scar tissue; diagnosis of a large cholesteatoma presenting as a characteristic non-enhancing, hypo-intense lesion; f: Coronal single-shot turbo spin-echo diffusion-weighted sequence (SS TSE DWI; a non-EPI-based diffusion-weighted image) at the level of the left temporal bone. The cholesteatoma is clearly seen (arrow) as a very hyper-intense lesion under the left temporal lobe. The presence of hyper-intensity is pathognomonic for a large recurrent cholesteatoma in the mastoid cavity. Note that there is no extension of the cholesteatoma into the middle fossa.



Figure 2. A 52-year-old woman evaluated 18 months after surgery for a primary cholesteatoma on the right side, prior to possible second-look surgery. Based on this investigation, no second look surgery was performed. Clinical micro-otoscopical follow-up 26 months after the primary surgery showed no suspicious signs of residual or recurrent disease. a: Axial HRCT image at the level of the lateral semi-circular canal on the right side. The entire post-operative mastoid cavity is almost completely filled with soft tissue (asterisk). On HRCT, it is impossible to differentiate these soft tissues; a recurrent or residual cholesteatoma can neither be excluded nor confirmed by HRCT; b: Coronal reformatted CT image at the level of the lateral semicircular canal on the right side. Again, the entire cavity is filled with soft tissue (asterisk) which cannot be differentiated on CT. Based on this CT examination, a cholesteatoma can neither be excluded nor confirmed; c: Coronal T2-weighted image (at the same level as Figure 2b) through the right temporal bone showing a mastoid cavity almost completely filled with a high-intensity lesion (asterisk); d: Coronal late (45 minutes) post-gadolinium T1-weighted MRI (at the same level as Figures 2b and 2c). The mastoid cavity is filled with a lesion that is completely enhancing, suggesting the presence of inflammatory and scar tissue (asterisk) without the presence of a recurrent of residual cholesteatoma: e: Axial late (45 minutes) postgadolinium T1-weighted MRI at the level of the lateral semicircular canal. The mastoid cavity is filled with a lesion that is completely enhancing, suggesting the presence of inflammatory and scar tissue (asterisk) without the presence of recurrent of residual cholesteatoma; f: Coronal single-shot turbo spin-echo diffusion-weighted sequence (SS TSE DWI; a non-EPI based diffusion weighted image) at the level of the right temporal bone. No clear nodular hyper-intense lesions can be seen excluding the presence of cholesteatoma (compare with the signal intensity of Figures 1f and 3e).



Figure 3. A 55-year-old woman was referred to our department with a prior history of an endaural tympanoplasty (< 13 months ago) on the right side, presenting with chronic ear discharge and conductive hearing loss. Micro-otoscopy suggested a small residual cholesteatoma behind the tympanic membrane. Surgery revealed a 3-4 mm, small residual cholesteatoma. a: Axial HRCT image at the level of the basal turn of the cochlea on the right side shows a small mesotympanic nodular mass (arrow) behind an intact tympanic membrane. On HRCT, a residual cholesteatoma is probable, but can neither be excluded nor confirmed; b: Coronal reformatted CT image at the level of the right cochlea. Again, in the middle ear cavity, a small nodular mass (arrow) is detected behind an intact tympanic membrane. Based on this CT examination, a residual cholesteatoma, although likely, can neither be excluded nor confirmed; c: Coronal late (45 minutes) postgadolinium T1-weighted MRI (at the same level as Figure 3b). The cholesteatoma is seen as a small hypo-intense nodular lesion (arrow) surrounded by a small layer of enhanced inflammatory and scar tissue; d: Coronal single-shot turbo spin-echo diffusion-weighted sequence (SS TSE DWI; a non-EPI based diffusion weighted image) at the level of the right temporal bone. The cholesteatoma is clearly seen (arrow) as a hyper-intense lesion under the right temporal lobe. The presence of hyper-intensity is pathognomonic for a small residual cholesteatoma.

Detection of primary, recurrent, and residual cholesteatoma

Two types of MRI protocols were recently described for the pre-operative detection and differentiation of middle ear cholesteatoma and post-operative detection of residual and recurrent cholesteatoma. These include the delayed post-gadolinium MRI, (5-16). and the diffusion-weighted imaging techniques, including echo-planar (EP-DWI) (6-9,13,14) and non-echo-planar (non-EP-DWI) sequences (12,17-20).

Delayed post-gadolinium magnetic resonance imaging

With early scanning, slow-enhancing inflammatory and scar tissue can be mistaken for cholesteatoma, causing false positive results. Williams and Ayache described the use of late post-gadolinium T1-weighted sequences in the detection of post-operative residual cholesteatoma (15,16).

They performed a T1-weighted sequence 45 minutes after intravenous gadolinium administration, differentiating non-enhancing and avascular cholesteatoma from slow-enhancing inflammatory and/or scar tissue. Using this protocol, they were able to detect post-operative residual cholesteatoma pearls as small as 3 mm (14,15). However, the administration of intravenous gadolinium is expensive, and has become controversial since the appearance of systemic nephrogenic sclerosis in patients with renal insufficiency (21).

Diffusion-weighted imaging (DWI): echo-planar versus non-echo-planar DWI

The use of EP-DWI in the differentiation of middle ear cholesteatoma from inflammatory changes was originally described by Fitzek et al., (6) who identified middle ear cholesteatoma as hyperintense lesions (white) in the hypo-intense signal void (black) of bone, and air in the temporal bone and middle ear. The major disadvantage of EP-DWI is the presence of important susceptibility artefacts at the air-bone interface at the base of the skull, the variable distortion of the images, and the low spatial resolution. Several reports highlight the value of EP-DWI in the pre-operative evaluation of middle ear cholesteatoma, (9) and in the postoperative follow-up of residual or recurrent cholesteatoma (7-9). EP-DWI seems to be very reliable in detecting primary acquired middle ear and large recurrent cholesteatomas (9) Several reports set the detection threshold of EP-DWI for cholesteatoma at 5 mm (7-9). This 5-mm size limitation is the main reason why EP-DWI cannot be used to detect small residual cholesteatoma pearls before a second look surgery (9). A non-echo-planar based diffusion-weighted sequence (non- EP-DWI) has recently been described for the evaluation of middle ear cholesteatoma (17). This sequence uses a single shot turbo spin echo diffusionweighted sequence (SS TSE DWI) with a 180° radio-frequency refocusing pulse for each measured echo, which reduces the susceptibility for artefacts. Compared with the EP-DWI, this sequence has a higher resolution and thinner slice thickness (2 mm) and can show cholesteatoma as small as 2 mm prior to primary (18,19) and second look surgery (19,20).

A prospective evaluation of this non-EP DWI sequence revealed a high sensitivity for the detection of congenital or acquired middle ear cholesteatoma (18). Of 21 surgically-confirmed cholesteatomas, 19 were diagnosed with non-EP-DW images. One false-negative case was missed due to spontaneous auto-evacuation of a retraction cholesteatoma (absence of keratin responsible for the hyperintensity). Small retraction pockets or evacuated cholesteatoma with an absence of keratin accumulation can be missed on DWI, as previously reported (7,9). Theoretically, apart from this auto-evacuation, a cholesteatoma can also evacuate as a result of suction cleaning of the affected ear by the ENT.

The other false-negative case in a child with a 3-mm congenital cholesteatoma was caused by a degraded image quality caused by motion artifacts. A recent investigation by De Foer et al. (20) indicated that non-EP-DWI sequences have the highest sensitivity for evaluating patients prior to second-look surgery. In our ENT department, non-EP DWI effectively replaces second-stage surgery, thus avoiding unnecessary interventions. The follow-up MRI after primary cholesteatoma surgery is performed routinely after 1 and 5 years. An overview of recent reports, which highlight the value of MRI principals in detecting recurrent and/or residual cholesteatoma, is given in Table 2.

MRI protocol

Our current MRI protocol for the pre-operative evaluation of pri mary acquired and congenital cholesteatoma and for the post-operative follow-up of residual and/or recurrent cholesteatoma consists of a combination of both techniques, and is mostly based on late post-gadolinium T1-weighted images and non-EP DWI sequences using a 1.5 T superconductive unit (Magnetom Avanto, Siemens Medical Solutions, Erlangen, Germany) with the standard Head Matrix coil. We no longer perform any unenhanced T1-weighted images. All sequences are performed 45 minutes after administration of intravenous gadolinium.

Author/Pathology	N	Sensitivity (%)	Specificity (%)	Size limit (mm)	MRI technique
Aikele et al. (7) recurrent cholesteatoma	22	77	100	5	EPI-DWI
Ayache et al. (16) residual cholesteatoma	41	90	100	3	Delayed T1 + gadolinium
Stasolla et al. (8) residual and recurrent	18	86	100	5	EPI-DWI
Vercruysse et al. (9) residual cholesteatoma	45	12.5	100	5	EPI-DWI
Dubrulle et al. (12) recurrent cholesteatoma	24	100	91	5	Non-EPI-DWI
Jeunen et al. (13) residual and recurrent	32	54	90	5	EPI-DWI
Venail et al. (14) residual cholesteatoma	31	60 90	73 55	3 2	EPI-DWI delayed T1 + gadolinium
De Foer et al. (20) residual cholesteatoma	32	90	100	2	Non-EPI-DWI

Table 2. Summary of recent reports on the value of MRI for the detection of cholesteatomas

MRI = magnetic resonance imaging; EPI-DWI = echo-planar-diffusion-weighted imaging.

Axial 2-mm thick spin-echo T1-weighted images (TR 400 ms, TE 17 ms, matrix 192 x 256, field of view 150 mm x 200 mm) and coronal 2-mm thick spin-echo T1-weighted images are acquired with the same parameters, except for the matrix, which is set at 144 x 256 for the coronal images. Coronal 2 mm thick turbo spin-echo T2-weighted images (TR 3500 ms, TE 92 ms, matrix 192 x 256, field of view 150 mm x 200 mm) and axial 0.4 mm thick 3D turbo spin-echo T2-weighted images (TR 1500 ms, TE 303 ms, matrix 228 x 448, field of view 107 mm x 210 mm) are also performed. In all patients, a 2-mm thick single-shot turbo spin-echo diffusion-weighted sequence is acquired in the coronal plane (TR 2000 ms, TE 115 ms, matrix 134 x 192, field of view 220 mm x 220 mm, b factors 0, and 1000 mm²/sec). The coronal plane is preferred over the axial plane because in the past, using EP DWI, the coronal plane showed fewer artefacts. Out of habit, the coronal plane is still preferred. This sequence takes less then 10 minutes and no gadolinium is used.

Surgical implications

The procedure of choice for the surgical treatment of middle ear cholesteatoma in our department is the closed technique, or Canal wall up (CWU) approach, with bony obliteration of the paratympanic space (mastoid and antro-attic cells) (22,23).

This approach dramatically lowers the incidence of recurrent cholesteatoma to a level less than 2%, as observed during long-term otoscopic and imaging follow-up. To prevent late complications with obliteration techniques, follow-up safety measures are necessary to exclude residual cholesteatoma. Traditionally, this implies second-stage surgery after one year. The definite improvement in the resolution and reliability of the non-EP DWI MRI technique encouraged us to use it for both pre-operative evaluations and post-operative follow-ups. In the preoperative stage, the combined use of CT and MRI allows unambiguous confirmation of the diagnosis, the ability to show the extent of the cholesteatoma, evaluate the risk for peri-operative sensory hearing loss related to labyrinthine fistulas, to plan the surgical approach accordingly, and to counsel the patient. During the post-operative stage, the non-EP DWI MRI one and five years after the primary surgical event excludes the presence of residual cholesteatoma in a noninvasive way, thus avoiding unnecessary second-stage surgery in the majority of cases. The high sensitivity and specificity of the non-EP DWI sequence makes it possible to screen for residual cholesteatoma using this technique alone, even in a pediatric population (20).

A reliable interpretation of MRIs requires a high level of training and experience for both the otologic surgeon and radiologist before routinely using it to replace second-look surgery. While offering excellent long-term safety to the patient, this protocol has considerably reduced the number of second-stage procedures. Before the application of this new protocol, we performed routine second-stage surgery in 62% of the cholesteatoma cases. Currently, with the application of this new protocol, we perform routine second-stage surgery in less than 10% of cases. As the overall medical cost of second-stage surgery is easily a factor of 10 times higher than the cost of MRI, the economic implications are obvious. There is also a marked reduction in emotional stress and loss of time for the patient. Another important issue and concern in the imaging follow-up of cholesteatoma patients is the exposure to radiation, implied by the still routinely used repeated CT follow-up. We state that MRI, including non-EP DWI and late post-gadolinium T1-weighted images, should be used rather than CT to evaluate patients before second-look surgery.

Conclusions

HRCT remains the most widely used imaging tool for diagnosing primary cholesteatoma. However, the role of MRI is quickly becoming more important in

both the pre-operative assessment of primary acquired and congenital cholesteatoma, and in the post-operative follow-up screening for residual disease. In our department, MRI has now replaced HRCT as the primary tool for pre-operatively diagnosing and characterizing cholesteatoma and for the post-operative follow-up screening for residual cholesteatoma. The value of HRCT for the pre-operative documentation of the cases remains high, providing the surgeon a surgical road map, which improves surgical planning and safety.

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Chapter 3.3

Diffusion-weighted magnetic resonance imaging of the temporal bone

De Foer B, Vercruysse JP, Spaepen M, Somers T, Pouillon M, Offeciers E, Casselman JW. Neuroradiology. 2010 Sep;52(9):785-807

Abstract

This paper summarizes the value of diffusionweighted magnetic resonance imaging in the evaluation of temporal bone pathology. It highlights the use of different types of diffusion-weighted magnetic resonance imaging in the different types of cholesteatoma, prior to first stage surgery and prior to second look surgery. The value of diffusion-weighted magnetic resonance imaging in the evaluation of pathology of the apex of the petrous bone and the cerebellopontine angle is also discussed.

Introduction

Image evaluation of diseases of the temporal bone has till now mainly been guided by clinical and audiological findings. One can state that conductive hearing loss is mainly evaluated using computed tomography (CT) and that sensorineural hearing loss is mainly examined using magnetic resonance imaging (MRI).

Most pathologies causing conductive hearing loss are situated in the middle ear whereas most causes of sensorineural hearing loss are found in the inner ear or in the central auditory pathways.

However, this somewhat artificial subdivision in image evaluation of pathology of the temporal bone has become more vague for the past few years due to newer technical developments in MRI, such as diffusion-weighted (DW) MRI.

MRI and more specifically DW MRI have gained increasing importance in the evaluation of pathology of the entire temporal bone region.

This review aims to provide an overview of the current status of the published data on DW MRI in the temporal bone region.

A short introduction of this technique is provided followed by the current status in the evaluation of middle ear lesions and cholesteatoma more specifically. The appearance of the most frequent lesions of the petrous bone apex and cerebellopontine angle (CPA) on DW MRI will also be discussed.

Diffusion-weighted magnetic resonance imaging

The mechanism of DW MRI is based on the Brownian motion of water molecules in tissue and, more importantly, on the hindrances/facilitations of water molecule movements in various types of tissue. In order to make an MRI sequence sensitive to the diffusion of water molecules, the sequence is expanded with a diffusionsensitizing gradient scheme, usually a very fast, single-shot gradient-echo data collecting sequence (echo-planar—EP). The amount of diffusion sensitizing applied is usually indicated by the b-value.

In clinical practice, images are generally acquired with a b-value of 0 and 1,000 s/mm^2 (1,2).

However, numerous artefacts can be generated during acquisition of DW MRI, such as eddy current artefacts, susceptibility artefacts, ghosting artefacts, chemical shift, and motion artefacts (3). With the use of higher magnetic fields, these artefacts and image distortions on EP DW imaging are even more pronounced.

Due to the low incidence of movement artefact, the high brain homogeneity and high signal-to-noise ratio research at the onset was mainly focused on the brain.

This resulted in the fact that clinically, DW MR imaging is an established method used routinely for the diagnosis of acute stroke (1,2).

However, over the last few years, several extracranial applications of DW MRI have been developed. Major applications have been described in the diagnosis and treatment follow-up of tumoral lesions in the upper abdomen, pelvis, and head and neck region (1).

In the temporal bone region, the interface between air, bone, and the temporal lobe is particularly prone to susceptibility artefacts (3). For the evaluation of the temporal bone region, several types of non-echo-planar based diffusion-weighted sequences have been described (3–5). These turbo spin-echo (TSE) or fast spin-echo (FSE)based diffusion-weighted have a higher spatial resolution, generate thinner slices (down to 2 mm), and do not suffer at all from susceptibility artefacts (3). The single-shot turbo spin-echo diffusion-weighted sequence uses a 180° radiofrequency refocusing pulse for each measured echo, which explains the reduction of the susceptibility artefact. It permits fast multiplanar imaging in artefact-prone regions, such as the posterior fossa and the inferior frontal and temporal lobes (3).

Cholesteatoma

Congenital versus acquired cholesteatoma

Congenital cholesteatoma

Congenital cholesteatoma is a rare entity originating at the time of closure of the neural tube in which the ectoderm - the later skin - gets entrapped in the skull, extradurally, in the temporal bone (6,7).

When the ectoderm gets entrapped in the skull intradurally, the term epidermoid cyst is used. The term epidermoid tumor is considered a misnomer as this entity is regarded as a congenital anomaly rather than a tumoral entity.

Both congenital cholesteatoma and epidermoid cyst are the same histological entity, comprised of entrapped ectoderm or skin. The lesion starts to expand by the continuous exfoliation and desquamation of the epithelium, giving rise to a slowly expansile lesion with pressure changes on the surrounding tissues. Both lesions contain exfoliated skin or keratin inside.

Congenital cholesteatoma can be found anywhere in the temporal bone pyramid. In the middle ear, it is most frequently found in the anterior superior part of the middle ear. It can extend posterior towards the ossicular chain with possible associated erosion of the ossicular chain (6,7) (Figure 1). By definition, a middle ear congenital cholesteatoma is found behind an intact tympanic membrane without any signs of associated infection (6,7).

Congenital cholesteatoma can also be found in the region of the inner ear and membranous labyrinth in which it has a predilection for the region around the geniculate ganglion (6,7) (Figure 2). Very often, it has a component protruding in the middle ear and a component invading the membranous labyrinth. The component protruding in the middle ear is often causing a conductive hearing loss due to impingement and/or erosion of the ossicular chain. Clinically, the inner ear component is very often causing signs of facial nerve palsy and/or sensorineural hearing loss. Debate still exists whether an isolated petrous bone apex congenital cholesteatoma exists, whether a petrous bone apex cholesteatoma is not always a middle ear cholesteatoma, extending into the petrous bone apex (Figure 3).

Due to their location, surgical treatment of these congenital cholesteatoma is often very difficult. Care should be taken that in case of a component protruding in the middle ear, the inner ear component is resected in toto.

Otherwise, the inner ear part of the congenital cholesteatoma will continue to grow further.

а C Figure 1. A 12-year-old boy presenting with conductive hearing loss and a suspicion of a congenital cholesteatoma at otoscopy.

a Axial CT image at the level of the basal turn of the cochlea. Small nodular soft tissue (small arrowheads) between the handle of the malleus (arrow) and the long process of the incus (large arrowhead). b Coronal reformatted CT image at the level of the cochlea. Small nodular soft tissue (small arrowheads) in the mesotympanum. Note that Prussak's space is free and well aerated and that the scutum is sharp (large arrowhead). c Coronal non-EP DW b1000 image (SS TSE DW sequence or HASTE DW sequence). Small nodular hyperintensity compatible with a small congenital cholesteatoma. Conclusion: Small congenital

cholesteatoma.



Figure 2. A 47-year-old male presenting with a long-standing deafness b on the left side and a sudden onset of facial nerve palsy. a Axial CT scan at the level of the geniculate ganglion, vestibule, and lateral semicircular canal. There is a large lytic lesion centered on the geniculate ganglion (large arrows). The lesion has a component protruding in the anterior epitympanic space with erosion of the malleus head (small arrow). The labyrinthine segment of the facial nerve canal can no longer be delineated suggestive of extension and/or invasion along this segment of the facial nerve. b Axial CT scan at the level of the superior semicircular canal. The lesion is situated anterior and lateral in the temporal bone pyramid (arrows). There is a "C-shaped" extension medially and posteriorly (small arrowheads), crossing the roof of the fundus of the internal auditory canal (large arrowhead). c Coronal reformatted CT image at the level of the cochlea. Large lytic lesion centered on the region of the geniculate ganglion (small arrowheads) with a large component extending in the middle ear epitympanic space (large arrowheads) with erosion of the malleus head (arrow). d Axial 0.4-mm-thick 3D TSE T2-weighted image at the level of the internal auditory canal. The most striking feature is the asymmetrical signal intensity in the internal auditory canal. The signal intensity is much lower in the left internal

auditory canal (small arrowheads). Moreover, the vestibulo-cochlear nerve branches and facial nerve can no longer be discriminated. Compare to the normal signal intensity in the IAC and the visible superior vestibular nerve branch on the right side (large arrowhead). e Axial gadolinium-enhanced 2-mm-thick SE T1-weighted image at the level of the left internal auditory canal. The lesion displays mixed signal intensity with enhancing as well as centrally located non-enhancing parts (small arrowheads). There is also some peripheral enhancement in the internal auditory canal (large arrowhead). f Coronal gadolinium-enhanced 2-mm-thick SE T1-weighted image at the level of the left internal auditory canal. The lesion displays mixed signal intensities with enhancing and centrally located non-enhancing parts (small arrowheads). There is also some enhancement noted at the periphery of the internal auditory canal (large arrowheads). g Coronal 2-mm-thick TSE T2-weighted image at the level of the internal auditory canal (same level as f). The lesion demonstrates a moderate intensity with a "C-shaped" extension towards the roof of the internal auditory canal (small arrowheads). h Coronal non-EP DW b1000 image (SS TSE DW sequence or HASTE DW sequence) (same level as f and g) nicely demonstrating the lesion in the epitympanum (large arrowhead) underneath the temporal lobe, the "C-shaped" extension towards the internal auditory canal (small arrowhead) and the extension into the internal auditory canal (arrow). Conclusion: Congenital cholesteatoma with characteristic location centered on the geniculate ganglion. There is a component protruding into the middle ear which can also be regarded as highly typical for a congenital cholesteatoma. There is medial extension along the course of the facial nerve and probably also via the "C-shaped" extension towards the internal auditory canal. The extension in the internal auditory canal can be seen on the 3D TSE T2-weighted sequence as well as the non-EP DW sequence. The clear hyperintensity on this last sequence confirms the diagnosis of a congenital cholesteatoma.



Figure 3. A 50-year-old female investigated for headache, with a prior history of middle ear surgery on the left side for cholesteatoma. a Axial unenhanced T1-weighted image at the level of the apex of the left petrous bone. There is some residual fat in the apex of the left petrous bone (large arrows). Note the hypointense nodular lesion in the apex of the left petrous bone (small arrows). There is a tail-like extension of the lesion along the posteromedial border of the temporal bone (arrowheads). b Axial post-gadolinium T1weighted image with fat suppression (same level as a). The lesion is not enhancing (small arrows). c Axial EP DW b1000 image. Large nodular hyperintensity in the left petrous bone apex. d Axial 3D CISS image at the level of the petrous bone apex. The lesion has a mixed signal intensity-hypo to moderate intense. Intensity is anyhow lower than CSF (small arrows). Conclusion: Signal intensity on the b1000 image is pathognomonic for a cholesteatoma in the apex of the petrous bone, as cholesteatoma is the only lesion which is displaying a clear hyperintensity on b1000 diffusion-weighted images. Signal intensities on standard sequences are also compatible with petrous bone apex cholesteatoma. Cholesteatoma of the petrous bone apex is probably a secondary cholesteatoma. Most likely, the extension is situated along the posteromedial side of the left temporal bone (Courtesy of Prof. F. Veillon, Strasbourg, France)

Acquired cholesteatoma

The acquired cholesteatoma is originating at a so-called retraction pocket most frequently situated at the upper and posterior part of the tympanic membrane or the pars flaccida.

This retraction pocket gradually starts to fill up Prussak's space, and when it gets sealed off, this retraction pocket is gradually starting to enlarge by the continuous desquamation of the epithelium, the so-called cholesteatoma matrix (8,9).

Growing slowly, this pars flaccida cholesteatoma will start eroding surrounding structures. It will start to erode the scutum — the bony spur of Prussak's space — and the ossicular chain at the level of the malleus head and the body and short process of the incus. The lateral epitympanic wall can also be eroded. By further expanding, the ossicular chain is displaced medially in case of a pars flaccida cholesteatoma (8,9).

When the cholesteatoma expands further, it gradually fills up the attic towards the mastoid and it can erode several structures with possible complications. Extension towards the roof of the middle ear cavity can erode the tegmen with possible invasion into the middle cranial fossa and subsequent complications of meningitis or a temporal lobe abscess (8).

Extension towards the medial wall of the middle ear will erode most frequently the bony layer over the lateral semicircular canal with—in case of invasion—a possible secondary labyrinthitis in a limited number of cases (Figure 4). The tympanic segment of the facial nerve canal can also be eroded with subsequent facial nerve palsy.

A less frequent type of cholesteatoma that can be found is the pars tensa cholesteatoma. These cholesteatomas originate from the mesotympanic part of the tympanic membrane and grow medially and upwards medial to the ossicular chain, displacing the ossicular chain laterally (8,9).

Surgery of a pars flaccida cholesteatoma is most frequently performed using a Canal wall up tympanoplasty (CWU), in which a mastoidectomy is performed, the wall of the external auditory canal is preserved, and disease is eradicated from the middle ear and mastoid. This technique, however, carries the risk of leaving cholesteatomatous tissue behind and makes clinical follow-up difficult as the intact external auditory canal does not allow inspection of the antrum and mastoid (10).

For this reason, about 1 year after first-stage surgery, a second look surgery is performed to evaluate the presence of a "residual" cholesteatoma. This second look surgery is performed in about 60% to 65% of patients with a higher percentage of second look surgery in children, reaching 80% (11). The percentage

of residual cholesteatoma found at second look surgery in adults is about 10% to 15%. In children, the percentage of residual cholesteatoma is higher varying between 23% and 44%, with recurrent cholesteatoma around 20% (11). In order to lower the residual and recurrent rates of cholesteatoma in CWU techniques, primary bony obliteration techniques (PBOT) have been developed. This technique can be used during primary cholesteatoma surgery in order to treat middle ear and mastoid cholesteatoma but can also be assessed in revision cases of recurrent cholesteatoma. When using this technique, the Canal wall up tympanoplasty cavity is subsequently filled up with a mixture of bone and bone pâté in order to diminish the number of recurrence through new retractions of the tympanic membrane (12–14). A functional ossicular chain reconstruction is performed either in the same stage or in a second stage.

The number of residual cholesteatomas (15%) is lower than in the CWU technique with a recurrence rate of about 2% (14,15). Cholesteatoma: diffusion-weighted magnetic resonance imaging

Introduction

Evaluation of an acquired middle ear cholesteatoma was mainly done using CT scan. CT nicely demonstrates the erosion of the lateral epitympanic wall and ossicular chain. Erosion of the lateral semicircular canal can also be evaluated using CT scan (8,9).

To see the direct effect of an associated invasion in the membranous labyrinth, MRI including T2-weighted images and post-gadolinium (Gd) T1-weighted sequences are required. On 3D heavily T2-weighted sequences, the fluid content and signal intensity of the membranous labyrinth can be evaluated. On post-Gd T1-weighted sequences, the enhancement of the membranous labyrinth should be looked after. Most frequently, it is the associated inflammation invading the membranous labyrinth and not the cholesteatoma itself that is causing enhancement (Figure 4).

It was already noted in early reports that differentiation between inflammation and cholesteatoma is possible using Gd-enhanced T1-weighted images as cholesteatoma is by definition "avascular tissue" and does not enhance in contrast to inflammation which clearly enhances (16).



Figure 4. A 28-year-old male presenting with acute onset of vertigo. a Axial CT scan at the level of the lateral semicircular canal. There is a homogeneous opacification of the left middle ear and mastoid (asterisk) without further discrimination of any residual ossicles or bony trabeculation. There is a possible defect in the bony wall of the lateral semicircular canal (arrowhead). b Coronal CT reformation at the level of the intersection of the superior semicircular canal, the lateral semicircular canal, and the vestibule. Soft tissues (asterisk)in the middle ear and mastoid with possible fistulisation towards the lateral semicircular canal (arrowhead). c Axial 0.4-mm-thick 3D TSE T2-weighted image at the level of the lateral semicircular canal. The entire middle ear is filled with a moderate intense nodular lesion (asterisk). Signal intensities in the membranous labyrinth and at the level of the lateral semicircular canal more specifically are normal (arrowhead). d Axial delayed post-gadolinium 2-mm-thick SE T1-weighted image at the level of the lateral semicircular canal. There is a centrally non-enhancing lesion in the middle ear and mastoid (asterisk) compatible with a large middle ear cholesteatoma. At present, there is no enhancement of the membranous labyrinth (arrowheads). e Coronal 2-mm-thick TSE T2-weighted image at the level of the mastoid demonstrating a large hyperintense mass lesion completely filling up the mastoid (asterisk). f Coronal 2-mm non-EP DW MR b1000 image (Multishot (MS) TSE DW sequence or BLADE DW sequence). The lesion demonstrates a clear hyperintensity. g Coronal ADC map (same level as f). The lesion has a hypointense signal on the ADC map (arrowheads). Conclusion: Large middle ear and mastoid cholesteatoma with typical findings on T2 and T1-weighted sequences and on non-EP diffusion-weighted imaging. There is fistulisation to the lateral semicircular canal explaining the complaints of the patient. Actually, no enhancement of the membranous labyrinth or signal loss on heavily T2-weighted sequences is seen. Note the low signal intensity on ADC maps compatible with diffusion restriction

Fitzek was one of the first to demonstrate the hyperintense aspect of cholesteatoma on *b*1000 EP DW images. This hyperintense aspect was completely different from the complete lack of hyperintensity of middle ear inflammatory changes on *b*1000 EP DW images (17). Major drawbacks of the EP DW sequences are, however, the low resolution, the rather thick slices, and the susceptibility artefacts at the interface temporal lobe and temporal bone limiting clearly the capability of this sequence to detect smaller cholesteatomas (18). Recent papers have highlighted the advantages of non-echo-planar-based diffusion-weighted sequences. These sequences are most frequently single shot or multishotbased turbo spin-echo diffusion-weighted sequences. They have a thinner slice thickness, a slightly higher resolution, and a complete lack of artefacts compared to echo-planar diffusion-weighted sequences (3).

Congenital cholesteatoma

The congenital cholesteatoma situated in the middle ear is very difficult to evaluate clinically.

The presence of a congenital middle ear cholesteatoma is often suspected in the presence of a whitish lesion behind an intact tympanic membrane on otoscopic evaluation. Most oftenly, a conductive hearing loss is discovered. Congenital cholesteatomas are most frequently detected during childhood.

CT, however, is able to nicely demonstrate the nodular soft tissue lesion located very often in the middle ear around the ossicular chain. The intact tympanic membrane and the nodular soft tissue mass lesion in a young patient on an atypical location must attract the attention of the radiologist towards the diagnosis of a congenital cholesteatoma.

Due to the fact that congenital middle ear cholesteatomas are very often small lesions, EP DW MRI is unable to detect and characterize congenital middle ear cholesteatoma (18). Non-EP DW MRI, however, is able to detect and characterize the congenital middle ear cholesteatoma due to its thinner slice thickness, higher resolution, and lack of artefacts. It nicely shows the very small nodular hyperintensity on *b*1000 images.

Even a congenital cholesteatoma as small as 2 mm can be detected and characterized on non-EP DW MRI (19) (Figure 1). Moreover, correlation with apparent diffusion coefficient (ADC) maps nicely shows the hypointensity of the congenital cholesteatoma caused by the diffusion restriction in the cholesteatoma.

In case of congenital cholesteatoma situated in the petrous bone near or in the membranous labyrinth, the use of CT and MRI is mandatory. CT is needed to demonstrate the sharply delineated punched-out soft tissue lesion and to show the relation to the geniculate ganglion and the structures of the membranous labyrinth. On DW MRI, the diagnosis is straightforward showing the clear hyperintensity of the lesion on *b*1000 images. On EP DWI, the lesions look rather distorted, while congenital cholesteatoma shows a sharply delineated, nodular hyperintense aspect on non-EP DWI. It is even helpful in the description of the extension by clearly showing the hyperintensity of the congenital cholesteatoma (Figure 2).

Even though the diagnosis can be made on DW MRI images, correlation with standard TSE T2-weighted images, 3D thin slice heavily T2-weighted images, and thin slice post-Gd T1-weighted is complementary in the description of the exact extension and invasion in the different structures of the membranous labyrinth.

Differential diagnosis with other lytic lesions in or around the membranous labyrinth can be made based upon the location and aspect of the lesion, its delineation, and the signal intensity on *b*1000 diffusion weighted images. Congenital cholesteatoma is the only lesion showing a frank hyperintensity on b1000 diffusion-weighted images. Endolymphatic sac tumor and glomus jugulo-tympanicum have a rather specific predilection site. Endolymphatic sac tumor displays mixed signal intensities on standard MRI sequences with enhancement. Glomus jugulo-tympanicum has, apart from its specific predilection site and strong enhancement with salt and pepper appearance on standard sequences, a characteristic MR angiographic appearance. On unenhanced 3D TOF MR angio, the high signal intensity of the small intralesional vessels can be seen. On CT, it shows a very irregular permeative lytic bone pattern. Metastatic lesions to the temporal bone also have a very irregular lytic aspect compared to the sharply delineated and regular lytic aspect of congenital cholesteatoma. Metastatic lesions also enhance.

The facial nerve schwannoma also has a predilection site for the geniculate ganglion, but it follows the course of the facial nerve whereas the congenital schwannoma extends beyond the limits of the facial nerve course. Moreover, the facial nerve schwannoma always enhances. Hemangiomas located in the geniculate ganglion region limit themselves to the region of the geniculate ganglion but also display characteristic calcifications on CT. Moreover, both facial nerve schwannomas and hemangiomas do not display any hyperintense signal on *b*1000 DW MRI.
A non-EP DW MRI sequence should definitely be included in the MR evaluation of a middle ear soft tissue lesion and in the evaluation of a lytic lesion in the temporal bone pyramid.

Acquired middle ear cholesteatoma

Introduction

In the past few years, the role of diffusion weighted MRI in the evaluation of patients with acquired middle ear cholesteatoma has increasingly grown.

In the evaluation of middle ear cholesteatoma, non-EP DW imaging has the advantage over EP DW imaging regarding thinner slices, a higher resolution, and a complete lack of artefacts (3). Non-EP DW imaging is able to detect cholesteatoma as small as 2 mm in size whereas this is limited to 5 mm for EP DW imaging (18,19). In the evaluation of acquired middle ear cholesteatoma, preference should definitely be given to non-EP DW sequences over EP DW sequences.

Acquired middle ear cholesteatoma

In case of a clinical and otoscopical straightforward cholesteatoma, imaging evaluation prior to first stage surgery is done by CT, showing the erosive changes to the lateral epitympanic wall and the ossicular chain (8,20,21). In case of a clinical and/or otoscopical unequivocal diagnosis of a cholesteatoma, detection and diagnosis of a middle ear cholesteatoma can be performed using non-EP DW sequences as a screening tool. In order to localize the cholesteatoma, axial and coronal TSE T2-weighted sequences are added. Gadolinium administration is—in those cases—not required (22).

However, in case of clinical suspicion of associated infection and/or inflammation, the combination of non-EP DW sequences and delayed post-Gd T1-weighted and TSE T2-weighted sequences will be able to differentiate the cholesteatoma from the surrounding infection or inflammation. In case of an associated complication, the combination of standard sequences after gadolinium administration and non-EP DW sequences is recommended (Figure 4).

There are two reasons for false-negative examinations on DW sequences. Evacuation of the keratin from the cholesteatoma sac—by auto-evacuation or

suction cleaning— will cause a false-negative examination as DW sequences detect the keratin inside the cholesteatoma (Figure 5) (17–19).



Figure 5. A 32-year-old woman examined because of right-sided conductive hearing loss. At otoscopy, a cholesteatoma is suspected in a retraction pocket at the pars flaccida on the right side. a Axial CT image at the level of the malleus head, incus body, and short process. Soft tissues can be seen in Prussak's space with erosion of the lateral epitympanic wall (arrow), the malleus head, and incus body (arrowheads). b Coronal CT reformation at the level of the cochlea. There is a nodular soft tissue in Prussak's space (asterisk) with amputation of the scutum (arrowhead). c Axial CT image at the level of the malleus head, incus body, and short process (same level as a). CT examination performed 1 year after the CT examination in a. The soft tissues as seen in a can no longer be seen. The results of the erosion are, however, still visible: erosion of the lateral epitympanic wall (arrow) and the malleus head (arrowhead). This image is pathognomonic of an auto-evacuated cholesteatoma: the cholesteatoma sac has opened and evacuated its content through the external auditory canal. d Coronal reformation at the level of the cochlea (same level as b). CT examination performed 1 year after the CT examination in b. The soft tissues in Prussak's space as seen in b can no longer be seen. The amputation of the scutum can, however, still be seen (arrowhead). Again, this image is typical of an auto-evacuated cholesteatoma sac. e Axial delayed post-gadolinium T1weighted image at the level of the middle ear (same level as a and c, same date of acquisition as c). The tympanic segment of the facial nerve can be seen on both sides (large arrowheads). The cholesteatoma epithelium or matrix can be suspected against the lateral epitympanic wall as a very thin enhancing line (small arrowheads). However, the typical central hypointensity cannot be seen due to the autoevacuation. f Coronal T2weighted image at the level of the cochlea (same level as b and d,same of acquisition as d). No clear hyperintensity can be seen. g Coronal non-EP DW (SS TSE DW sequence or HASTE DW sequence, same level as b, d,and f,same date of acquisition as d and f) *b*1000 image showing no clear hyperintensities. The lack of hyperintensity on diffusion-weighted sequences confirms the diagnosis of an autoevacuated cholesteatoma. Conclusion: Auto-evacuated cholesteatoma confirmed by two consecutive CT scans (a and b versus c and d). In the time between both CT scans, the cholesteatoma sac has evacuated its content through the external auditory canal. The hyperintensity on DWI in case of a cholesteatoma is caused by the retained keratin in the cholesteatoma pocket. In case of auto-evacuation, the keratin gets evacuated and the hyperintensity on DWI is no longer seen. The characteristic findings on standard MRI sequences, a hyperintensity on T2-weighted images, and a hypointensity on T1-weighted images, can also not be found. The cholesteatoma epithelium or matrix is still adherent to the attic but is very difficult to visualize it, most often due to the associated infectious enhancement

Those cholesteatomas are also called "mural" cholesteatomas (9). They form the major subgroup of false-negative DW examinations. Delineation of such an evacuated cholesteatoma is difficult even on standard MR sequences after gadolinium. Theoretically, one should be able to delineate the cholesteatoma matrix or epithelium on post-Gd T1-weighted sequences, but this remains very difficult due to the often surrounding inflammation (Figure 5).

Motion artefacts degraded examinations will also result in a false-negative examination as in these cases the signal intensities of small cholesteatomas on *b*1000 non-EP DW sequences get smeared out over multiple pixels (19). This should be taken into consideration especially in the pediatric population.

False-positive results on DW sequences are rare. There have been reports of false-positive results in cases with acute middle ear infection (17), bone powder (4), silastic sheets (23), granulation tissue (23), and scar tissue (24).

From our own experience, we know that accumulation of cerum in the external auditory canal can give a hyperintense signal on DW sequences. Correlation with standard TSE T2-weighted sequences nicely depicts the cerum in the external auditory canal (Figure 6).

Accumulated sebum in a sebum cyst also gives rise to a hyperintense signal. Careful interpretation of the images will show that the lesion is situated outside the temporal bone (Figure 7).



Figure 6. A 41-year-old male with a large cholesteatoma on the left side. MR imaging performed in a preoperative setting. a Coronal non-EP DW b1000 image (SS TSE DW sequence or HASTE DW sequence). Large nodular hyperintensity on the left side (large arrowheads) compatible with a large middle ear cholesteatoma. There are two linear hyperintensities on the right side (small arrowheads). b Coronal 2-mm-thick TSE T2-weighted image at the level of the internal auditory canal demonstrating the large middle ear cholesteatoma on the left side (large arrowheads). Note that the linear hyperintensities as seen on the diffusion-weighted images are situated against the roof and bottom of the external auditory canal on the right side. Subsequent otoscopy revealed the presence of cerumen in the external auditory canal on the right side. Suction cleaning followed by a repeated coronal non-EP DW sequence showed disappearance of the linear hyperintensity (not shown). Conclusion: Cerumen in the external auditory canal can also present as a hyperintensity on b1000 diffusionweighted images. The linear aspect of the hyperintensity and the location in the external auditory canal are pathognomonic for cerumen.



Figure 7. Follow-up study of a 24-year-old male who previously underwent surgery for a middle ear cholesteatoma. Imaging is performed to exclude residual cholesteatoma. a Coronal non-EP DW b1000 image (SS TSE DW sequence or HASTE DW sequence). No clear hyperintensity can be seen on the right side. Surprisingly, a nodular hyperintensity is seen on the left side. The hyperintensity is located rather low and lateral. Correlation with ADC map (not shown) revealed a clear hypointensity of the lesion. b Coronal 2-mm-thick delayed post-Gd T1-weighted image (same slice position as a). The nodular lesion has a hypointense aspect and is situated outside the temporal bone (small arrow), under the earlobe of the external ear. c Coronal 2-mm-thick TSE T2-weighted image (same slice position as a and b). The nodular lesion can clearly be seen as a moderately intense lesion underneath the earlobe of the external ear (small arrow). Note the clear hyperintensity in the mastoid on both sides (large arrows) being far too intense to be compatible with cholesteatoma. Conclusion: Clinical examination revealed a sebum cyst behind the earlobe of the external ear. Sebum as well as cerumen (see Figure 6) are also exfoliated skin just as cholesteatoma. Hence, they can also present with a hyperintense signal on diffusion-weighted imaging.

Pre-second look evaluation One of the greatest challenges in the past decade has been the question whether MRI could replace second look surgery and if patient selection for second look surgery is possible using MRI.

First and foremost, differentiation should be made between residual and recurrent cholesteatoma (25,26). Residual cholesteatomas are cholesteatomatous pearls left behind at first-stage surgery. It is known that the use of CWU tympanoplasty implies a high number of residual cholesteatomas. They can be found anywhere in the middle ear or mastoid cavity and are usually rather small at the time of detection. Due to this small size and the fact that they can be found anywhere in the middle ear and mastoid cavity, they are difficult to detect (Figure 8).

Recurrent cholesteatoma is cholesteatoma originating again in a retraction pocket at the tympanic membrane or tympanic membrane graft (Figure 9).

Recurrent cholesteatoma takes more time to develop and is usually larger at the time of detection (Figure 10).



Figure 8. A 62-year-old female treated for middle ear cholesteatoma on the left side 15 months before. a Coronal non-EP DW b1000 image (SS TSE DW sequence or HASTE DW sequence). A small nodular hyperintensity (arrowhead) is seen under the medial part of the tegmen. Note the soft tissues lateral to this nodular hyperintensity, isointense with brain tissue (arrows). b ADC map, same level as a. Note the small nodular hypointensity (arrowhead). This small nodular hypointensity corresponds to the nodular hyperintensity in a. c Coronal 2-mm-thick TSE T2-weighted image, same level as a and b. The nodular lesion can be seen as a small nodule with moderate signal intensity (arrowhead) delineated by clear hyperintense material on its lateral and inferior side (arrows). Compared to a and b. d Coronal 2-mm delayed post-gadolinium T1-weighted image, same level as a, b, and c. The lesion can be depicted as a small nodular hypointensity (arrowhead) under the medial part of the tegmen. It is delineated by enhancing material on its lateral and inferior side (arrows). Compare to a, b, and c. e Corresponding coronal CT reformation (same level as a-d). After the Canal wall up tympanoplasty, the middle ear cavity is completely filled up with soft tissue. No further discrimination is possible. The lesion is probably situated medially, when correlated with MR findings(arrowhead). Conclusion: This case demonstrates the strength of the non-EP DW sequence in detecting very small residual cholesteatoma. On CT scan, the cholesteatoma cannot be discriminated from the surrounding postoperative soft tissues which have the same density. The lesion is — without correlation to the non-EP DW sequence — hardly discernable on standard MR sequences. Note that even on the ADC map, this very small cholesteatoma is discernable as a drop in signal intensity, making differentiation with the surrounding postoperative findings possible.



Figure 9. A 22-year-old-male with a history of cholesteatoma on the right side treated with Canal wall up tympanoplasty 3 years before. At otoscopy, a whitish lesion was suspected at the upper limit of the tympanic membrane graft. Upon these clinical and otoscopical findings, MRI — using the non-EP DW protocol — was performed first. CT scanning was performed subsequently, based upon the MR findings. a The coronal non-EP DW b1000 image (SS TSE DW sequence or HASTE DW sequence) clearly shows a small nodular hyperintensity (arrowhead) immediately beneath the right temporal lobe. b On the coronal ADC map (same slice position as a), the lesion can be seen as a small nodular hypointensity (arrowhead) immediately beneath the right temporal lobe. c Coronal 2-mmthick TSE T2weighted image at the level of the cochlea (same level as a and b). The lesion is seen as a small nodule with moderate and high signal intensities (arrowhead). d Axial preoperative CT image, at the level of the vestibule, shows the small nodular soft tissue density (arrowhead) anterior in the post Canal wall up tympanoplasty cavity. e Coronal preoperative reformatted CT image, at the level of the cochlea. A small nodular density is found at the superior insertion of the tympanic membrane graft (arrowhead). Conclusion: Otoscopically, recurrent cholesteatoma at the insertion of the tympanic membrane graft was suspected. Non-EP DW imaging (b1000 images) confirmed the presence of a small recurrent cholesteatoma. Standard TSE T2-weighted sequences revealed the recurrent cholesteatoma situated anterior and superior in the temporal bone. Prior to surgery, an axial volume CT scan with coronal reformations was performed. confirming the location of the recurrent cholesteatoma at the superior insertion of the tympanic membrane graft.



Figure 10. A 25-year-old male with a history of Canal wall up tympanoplasty at the left side for cholesteatoma 5 years before now presents with persistent ear discharge and pain. a Axial CT scan of the left ear presenting some soft tissue density in the external auditory canal (large arrowhead) and a large nodular soft tissue density (arrows) in the cavity created by the Canal wall up tympanoplasty. Some hypodensities are noted in this soft tissue density (small arrowheads) and are probably presenting air. Based on CT, an abscess in the tympanoplasty cavity cannot be excluded. b Coronal non-EP DW b1000 image (SS TSE DW sequence or HASTE DW sequence) (at the level of the external auditory canal) shows a nodular hyperintensity (arrowhead) compatible with a recurrent cholesteatoma. c Coronal non-EP DW b1000 image (SS TSE DW sequence or HASTE DW sequence). Image (see also the position of the brain stem compared to b) located posterior to b. A large peripherally hyperintense nodular structure can be seen in the tympanoplasty cavity (arrowheads). d Axial non-EP DW b1000 image (SS TSE DW sequence or HASTE DW sequence). Both the lesions in the external auditory canal (arrow) and the lesion in the tympanoplasty cavity (arrowheads) which were visible on CT (see image a) have a high signal intensity. Conclusion: Both soft tissue densities on CT display a high signal intensity on the b1000 images. At surgery, cholesteatoma was found against the tympanic membrane as well as in the tympanoplasty cavity. In the tympanoplasty cavity, at surgery, the cholesteatoma demonstrated a centrally located so-called dry cholesteatoma. No abscess could be found.

Early reports on the value of standard MRI sequences replacing second look surgery were very disappointing (27). However, in the last decade, two major types of MR protocols have emerged in the evaluation of cholesteatoma patients prior to second look.

Delayed post-Gd T1-weighted sequences have been reported to be able to detect residual cholesteatoma prior to second look as small as 3 mm. The rationale is based upon the fact that postoperative changes take time to enhance. Therefore, immediate post-Gd T1-weighted imaging can result in a false-positive finding of cholesteatoma. In literature, using this protocol, patients usually get preselected based upon CT findings (28,29).

Echo-planar diffusion-weighted imaging has various reported sensitivities ranging from 12.5% to 86% (18,23,24,30,31). Specificity varies from 73% to 100% (18,23, 24,30,31).

This is explained by the fact that in some studies residual cholesteatomas [18, 23] were evaluated, and in other studies, a mixture of residual and recurrent cholesteatomas was used (24,30,31). EP DW studies have a reported size limit of 5 mm. This is the main reason why EP DW sequences are unable to detect residual cholesteatomas and cannot replace second look surgery (18).

Using EP DW sequences, very high positive predictive values (PPV) were reported (between 80% and 100%), meaning that a positive diagnosis of a cholesteatoma can be made if a hyperintense lesion is detected, provided that artefacts are not misinterpreted as a cholesteatoma (18,23,24,30,31). Negative predictive values (NPV) are reported to be variable (between 40% and 75%). This is explained by the fact that—due to size limits—a lot of false-negative cases are reported.

However, non-EP DW sequences have been reported to be able to replace second look surgery. Using the combination of non-EP DW sequences and delayed post-Gd sequences, a sensitivity of 90% and a specificity of 100% can be achieved (32). One Australian group even screens patients prior to second look using non-EP DW sequences alone (33,34).

Recent literature has indeed demonstrated that non-EP DW sequences alone have the same sensitivity, specificity, PPV, and NPV than the combination of non-EP DW sequences and delayed post-Gd T1-weighted sequences together. Non-EP DW sequences have also a significantly higher sensitivity, specificity, PPV, and NPV than delayed post-Gd T1-weighted sequences (22).

Therefore, evaluation of cholesteatoma patients can be performed prior to second look surgery using non-EP DW sequences alone (22,33,34). In order to be able to

localize suspected lesions on the non-EP DW sequences, an axial and coronal TSE T2-weighted sequence is added (22).

Cholesteatoma patients should definitely be selected for second look surgery using non-EP DW sequences (Figure 8) (22,33,34). CT scanning should no longer be used as the first imaging tool prior to second look surgery. CT scanning prior to second look should only be used in case of a positive MR examination using non-EP DW sequences in an immediate presurgical setting. This will inevitably reduce the number of useless irradiated patients prior to second look surgery.

MRI, including DW sequences, is extremely useful in the evaluation of possible postoperative complications.

Particularly in case of an associated tegmen defect, one cannot differentiate soft tissues in the middle ear. MRI and DW sequences in particular have the possibility to differentiate associated soft tissue lesions. Meningoceles and meningoencefaloceles can easily be detected on MRI (Figure 11).

Following a PBOT, imaging becomes even more important as there is still the risk of burying a residual cholesteatoma in the bony obliterated cavity. The rate of residual and recurrent cholesteatoma has been reported to be much lower than in the CWU technique.

EP DWI seems to be useless in the evaluation of these patients as these lesions are very small (35). However, again, non-EP DW sequences are reported to have the highest sensitivity and specificity (36). Recurrences are situated in most cases superficial to the obliterated mastoid or at the interface between the obliterated mastoid and the middle ear cavity (Figure 12).

In these cases, CT is complementary to MRI—using non-EP DW sequences— in showing the corresponding CT soft tissues densities to the MR reported hyper-intensities (Figure 12).

Petrous apex lesions

DW MRI is also very helpful in the differentiation of various lesions in the petrous bone apex (37,38) (Table 1).



Figure 11. A 25-year-old female with a history of cholesteatoma surgery on the left side. The clinical examination was unremarkable. a Coronal 2-mm-thick TSE T2-weighted MR image at the level of the mastoid. On the left side, there seems to be protrusion of a part of the temporal lobe through a defect in the tegmen (small arrowheads) into the mastoid. On the right side, an oval structure with intermediate signal intensity is seen beneath the tegmen (large arrowheads). b Coronal 2-mm-thick delayed post-gadolinium SE T1weighted MR image (same level as a). On the left side, the protruding temporal lobe can be seen as a lesion which is isointense to brain (small arrowheads) and which is surrounded by enhancing inflammatory tissue with a slightly higher signal intensity (long arrows). On the right side, there is an oval hypointensity underneath the tegmen (large arrowhead), surrounded by enhancing inflammatory tissue with a clear hyperintensity (short arrows). c Coronal non-EP DW b1000 image (SS TSE DW sequence or HASTE DW sequence). The lesion on the right side demonstrates a clear high signal intensity on the non-EP DW b1000 image (large arrowhead). The herniated temporal lobe is not hyperintense. The intensity on the left side is comparable to the intensity of the rest of the left temporal lobe. Conclusion: On the left side, standard MR sequences are highly suspicious of a herniated left temporal lobe. On the right side, by surprise, an attical cholesteatoma was found. Both findings were confirmed by surgery.

	T1 W1	T2 W1	<i>b</i> 1000 DW	ADC map
Asymmetric apex air	Signal void	Signal void	No signal	No signal
Asymmetric apex fat	Very high	Moderately high	Low	High
Opacified/infected	Low	High	Low	High
apex		ů.		J.
Cholesterol granuloma	High	High	Moderately high	High
Cholesteastoma	Low	High	High	Low
Petrous apex cephalocele	Low	High	Low	High

Table 1. Signal intensity on various sequences of the most frequent lesions and pseudolesions of the apex of the petrous bone.



Figure 12. An 18-year-old male operated for a cholesteatoma on the right side using the primary bony obliteration technique (PBOT) or technique of Mercke. In this technique, the cavity created by the Canal wall up (CWU) technique is filled up with a mixture of bone and bone pâté. The obliteration of the resection cavity results in a much lower incidence of cholesteatoma recurrence compared to the classical CWU technique. a Axial CT scan at the level of the oval window and vestibule. The CWU tympanoplasty cavity is filled up using material with both soft tissue and bone density (asterisk). There are some soft tissues left at its anterior and lateral border (arrowheads). b Coronal reformatted CT image at the level of the oval window and internal auditory canal. The CWU tympanoplasty cavity is filled up using a mixture of bone and bone pâté (asterisk). Note that there are some soft tissues left in the hypotympanum (small arrowheads) and lateral and caudal to the cavity (large arrowheads). c Axial delayed postgadolinium T1-weighted image at the level of the vestibule and internal auditory canal (same level as a). The signal intensities of the PBOT are mixed and inhomogeneous (arrows). Due to the mixed character of these signal intensities, it is impossible to detect the characteristic signal intensities of a residual cholesteatoma. No conclusions can be drawn from this sequence. d Coronal TSE T2-weighted image at the level of the vestibule and internal auditory canal (same level as b). The signal intensities of the PBOT are mixed and inhomogeneous (arrows). There are several small regions of very low signal intensity probably due to signal void of small parts of bone. Note a nodular zone of intermediate signal intensity (arrowhead). e Coronal non-EP DW b1000 image (SS TSE DW sequence or HASTE DW sequence) (same level as b and d). There are two small regions of clear hyperintensity (small and large arrowheads). Correlation with b and d shows that there is residual cholesteatoma in the hypotympanum and lateral to the obliterated cavity (see also the nodular zone of intermediate intensity on d). Conclusion: Diffusion-weighted MRI reveals two nodules of residual cholesteatoma situated in the hypotympanum and lateral to the obliterated cavity. Diagnosis can only be reliably made based upon the non-EP DW images. Correlation with CT makes it possible to localize the lesions. It is striking that in case of PBOT, the residual or relapsing cholesteatoma is usually found at the periphery of the obliteration but never in the center of the obliteration.

Asymmetry in aeration of the petrous bone apex is one of the most common pseudo-tumorous lesions of the petrous bone apex (Figure 13).

If one apex is aerated, it displays a signal void on standard MR sequences as well as on diffusion-weighted sequences. The contralateral non-aerated apex contains fat with a high intensity on T1-weighted sequences and a moderate intensity on T2-weighted sequences. It lacks, however, a clear high intensity on b1000 DW MRI. Some hyperintensity can, however, be noted due to T2 shine through. The intensity on T2-weighted sequences is much lower that the intensity of cholesterol granuloma (see below) (37,38).

An aerated petrous bone apex can get fluid filled and infected, displaying a low intensity on T1-weighted sequences with possible peripheral enhancement. On T2-weighted sequences, signal intensity is high. On *b*1000 DW MRI, there is no high signal intensity making the differential diagnosis with a petrous bone apex cholesteatoma possible (Figure 14).

In the chronic phase, a mucocele of the petrous apex can develop areas of higher signal intensity on T1-weighted images and low signal intensity on T2-weighed images with an expansile appearance of the lesion on MRI and CT. Again, this lesion displays no hyperintensity on the *b*1000 diffusion-weighted sequence (37,38).

A petrous bone apex cholesterol granuloma is the most common primary lesion of the petrous apex accounting for about 60% of all lesions in that region. They can occur bilateral. A history of serous or chronic otitis media has been identified as a major risk factor for the development of a cholesterol granuloma. They contain a brownish liquid with cholesterol crystals. Repetitive cycles of hemorrhage and granulomatous reaction initiated by an obstruction of the ventilation outlet of the apex are believed to be the cause (37,38).

The entity of a petrous bone apex cholesterol granuloma presents as an expansile lesion with a clear high signal intensity on T1-weighted as well as on T2-weighted images (Figure 15). This lesion does not display a high signal intensity on diffusion-weighted sequences. A slight hyperintensity can, however, be seen due to a T2 shine through effect. However, signal intensity on an ADC map remains high in contrast to the drop of signal intensity in case of a cholesteatoma. The contralateral petrous apex is usually pneumatized (37,38).



Figure 13. A 16-year-old female with a history surgery for left-sided middle ear cholesteatoma. A primary bony obliteration technique was performed. a Right-sided axial CT scan at the level of the tympanic segment of the facial nerve. There is a clear aeration of the apex of the right petrous bone (arrowheads). b Left-sided axial CT scan at the level of the tympanic segment of the facial nerve (same level as a). There is a non-aerated apex of the left petrous bone (arrowheads). Note the PBOT technique in the left mastoid in which the entire mastoid is filled with a mixture of bone and bone paté, obliterating the entire mastoid and epitympanum (asterisks). c Coronal CT reformation at the level of the cochlea. There is a clear aeration of the apex of the right petrous bone (arrowheads). d Coronal CT reformation on the left side (same level as c). Note the lack of aeration (arrowheads) and the obliterated aspect of the epitympanum (asterisk). e Coronal 2-mm TSE T2-weighted image (same level as c and d). Asymmetry at the level of the apex of petrous bone. The hypointensity on the right side is explained by the presence of air in the aerated apex (small arrows). The hyperintensity on the left side is explained by the presence of fat containing bone marrow in the apex of the left petrous bone apex (large arrows). f Coronal post-gadolinium SE T1-weighted image (same level as c, d, and e). Note again the hypointensity-caused by air-in the apex of the right petrous bone (small arrows). The leftsided hyperintensity is explained by the presence of fat (large arrows). g Coronal non-EP DW image (SS TSE DW sequence or HASTE DW sequence) (same level as c-f). The asymmetry is also visible on this b1000 image in which the air-filled apex of the right petrous bone displays a marked hypointensity (small arrows) and the left fat filled apex of the petrous bone has an intermediate to low signal intensity (large arrows). Conclusion: Clear asymmetry in the apex of the petrous bone explained by the air in the apex of the petrous bone on the right side and the fatty bone marrow on the left side. CT is straightforward in diagnosing this asymmetry but signal intensities on MRI can be confusing, especially when correlation with CT is not available. This asymmetry is one of the major causes of a "pseudotumoral" lesion of the petrous bone apex on MRI. In the MRI differential diagnosis, one should include cholesterol granuloma, but this entity displays a definite higher signal intensity on T2-weighted images. Petrous apex cholesteatoma is excluded due to the lack of hyperintensity on b1000 DW images and due to the hyperintense aspect of the lesion on T1-weighted images.



Figure 14. A 39-year-old female presenting with mixed hearing loss on the right side. a Axial CT scan of the right temporal bone at the level of the vestibule, maleus head, and incus body. A well aerated middle ear and mastoid can be noted. There is aeration of the petrous bone medially to the otic capsule (large arrowhead). Note the homogeneous ossification of the petrous apex (small arrowheads). b Axial CT scan of the left temporal bone at the level of the superior semicircular canal. Note the homogeneous nodular density in the apex of the petrous bone (asterisk). There is a small triangular air density posterior to it (small arrowhead). This small air density is suggestive of a near total opacified aerated petrous apex with fluid and/or inflammation. c Axial 4-mm-thick TSE T2weighted image through the posterior fossa at the level of the internal auditory canal. There is a nodular hyperintense lesion in the apex of the left petrous bone (arrow). Note that the lesion has a slightly higher intensity than CSF. d Axial 2-mm-thick postgadolinium SE T1-weighted image at the level of the internal auditory canal. The lesion situated in the apex of the left petrous bone (small arrows) shows a central hypointensity with a linear peripheral enhancement. Note the homogeneous hypointense petrous bone apex on the right side (large arrows). e Coronal 2-mm-thick postgadolinium SE T1-weighted image at the level of the cochlea. The lesion has a central hypointensity (asterisk). Note the peripheral enhancement (arrowheads). f Coronal 2-mm non-EP DW MR b1000 image (Singe Shot (SS) TSE DW sequence or HASTE DW sequence) (same level as e). The lesion can be suspected on this b1000 images but displays a complete lack of hyperintensity (arrowheads). Conclusion: The most likely diagnosis on CT scan is an opacified apex cell of the left petrous bone. Standard MR sequences exclude the diagnosis of a petrous apex cholesterol granuloma as the lesions display no hyperintensity on T1-weighted images. A petrous bone apex cholesteatoma is excluded on the b1000 diffusion-weighted images and can be recognized by the complete lack of hyperintensity. The final diagnosis is an opacified and inflammed petrous apex. Eventually, this lesion might evolve into a petrous apex mucocele.



Figure 15. A 32-year-old male presenting with headache. a Axial CT image (bone window) through the skull base at the level of the clivus. A sharply delineated lytic lesion is seen in the skull base and clivus on the left side (arrowheads). b Axial CT image (bone window) through the skull base at the level of the petrous apex demonstrating a large sharply delineated lytic lesion (arrowheads). c Axial 3-mm-thick TSE T2-weighted MR image through the posterior fossa. The lesion has a homogeneous hyperintense appearance (arrowheads). d Axial 3mmthick SE T1-weighted MR image through the posterior fossa. The lesion displays a homogeneous hyperintense signal (arrowheads). e Axial 3-mm-thick EP DW MR image through the posterior fossa. The lesion remains hypointense (arrowheads). f Axial ADC map. Note the hyperintense aspect of the lesion on the ADC map. The lesion has no diffusion restriction. g Axial post-gadolinium 3-mm-thick SE T1-weighted MR image. The lesion is not enhancing. Conclusion: Large, sharply delineated lesion in the apex of the left petrous bone, with spontaneous hyperintensity on T2-and T1-weighted images, without any hyperintensity on b1000 diffusion-weighted images or diffusion restriction on ADC map, compatible with a large cholesterol granuloma of the petrous apex (Courtesy of T. Stadnik, T. Buisseret UZ Brussel, Jette, Belgium).

Petrous bone apex cholesterol granuloma should be differentiated from the petrous bone apex cholesteatoma. This is again an expansile lesion with signal intensities comparable to the signal intensities of middle ear cholesteatoma: low signal intensity on T1-weighted sequences and a high signal intensity on T2-weighted sequences. To differentiate such a lesion from an opacified petrous bone apex or a petrous bone apex mucocele, diffusion-weighted MRI is very helpful and will display a clear hyperintensity on *b*1000 images with a drop in signal intensity on ADC map (Figure 3).

Discussion still exists if a petrous bone apex cholesteatoma is a congenital cholesteatoma or an acquired cholesteatoma extending from the middle ear to the petrous bone apex (39). There is a tendency towards the hypothesis that a petrous bone apex cholesteatoma is always an extension of a middle ear cholesteatoma into the petrous bone apex.

Petrous apex cephaloceles may be confused with "cystic"-like appearing lesions of the petrous apex such as the opacified petrous bone apex or the cholesteatoma. They result from herniation of the posterolateral dural wall of Meckel's cave into the anterolateral aspect of the petrous bone. It is frequently associated to a hydrops of Meckel's cave and to an empty sella. Signal intensities on standard sequences are those of cerebrospinal fluid (CSF) and the lesion shows a sharply delineated scalloping of the anterior and lateral aspect of the temporal bone (37,38,40). Apart from the fact that the lesion is eccentric to the petrous bone apex, signal intensities on various sequences of the most frequent lesions and pseudolesions of the petrous apex is given in Table 1.

CPA lesions

The scala of CPA lesions is large and diverse and is beyond the scope of this paper. The top three of space occupying lesions in the cerebello-pontine angle are vestibule-cochlear schwannoma, meningeoma, and epidermoid cyst (41,42).

The biggest group consists of vestibulo-cochlear schwannomas and meningeomas, accounting for about 90% of all tumorous lesions of the CPA. Both lesions display an isointensity to brain on unenhanced T1-weighted images, have a slight hyperintensity on T2-weighted images, and demonstrate a clear enhancement on postgadolinium T1-weighted images. Vestibulo-cochlear schwannomas are always situated in the course of the vestibulo-cochlear nerve with often a component inside the internal auditory canal (IAC) and a component

protruding in the CPA. The CPA component has sharp angles with the posteromedial surface of the temporal bone and can rarely display a dural tail (41,42).

The meningeoma is usually eccentric to the IAC, but it may cover the IAC and even extend into the IAC. It has obtuse angles with the posteromedial surface of the temporal bone and displays a dural tail caused by either tumorous infiltration either caused by inflammatory changes (41,42).

The epidermoid inclusion cyst is the third most common lesion of the CPA, accounting for about 5% of all mass lesions in the CPA. It can have a supratentorial extension with components into the middle cranial fossa, Meckel's cave, the suprasellar region, and the quadrigeminal plate cistern. It is considered a congenital lesion rather than a tumoral lesion originating at the time of closure of the neural tube. It is a slowly growing mass due to continuous desquamation of the lining epithelium. Symptoms are usually caused due to compression of cranial nerves, the brain stem, and/or the cerebellum (42).

The epidermoid inclusion cyst has as a CSF-like appearance on standard MRI sequences, looking isointense on T1-weighted images and hyperintense on T2-weighted images. On these sequences, differentiation with an arachnoid cyst is very difficult. Arachnoid cysts are frequent in the CPA and can have a compressive effect on the 7th and 8th cranial nerve or on the 9th, 10th, and 11th cranial nerve depending on its location. Arachnoid cysts also have a CSF-like appearance.

On heavily T2-weighted sequences and fluid-attenuated inversion recovery (FLAIR) sequences, arachnoid cysts still have CSF appearance whereas epidermoid inclusion cysts have a mixed hyper–hypointense appearance on these heavily T2-weighted sequences and an inhomogeneous hyperintense appearance on FLAIR sequences. The appearance on heavily T2-weighted sequences and FLAIR sequences is caused by the fact that an epidermoid cyst is constituted of lamellated desquamated keratin. Diffusionweighted imaging clearly shows a hyperintense signal intensity in case of an epidermoid inclusion cyst as epidermoid inclusion cysts are histologically exactly the same as acquired or congenital cholesteatoma (Figure 16). Arachnoid cysts do not display hyperintensity on diffusion-weighted images (42,43) (Figure 17).

Non-EP diffusion-weighted sequences are to be preferred over EP diffusionweighted sequences because of their lack of susceptibility artefacts.

Diffusion-weighted sequences are also crucial in the postoperative follow-up as it allows confirmation of the presence of a possible residual tumor (42) (Figure 18).

In the evaluation of a CPA lesion, a diffusion-weighted sequence should always be included. It narrows differential diagnosis in lesions in which standard MR sequences are not equivocal (Figure 19).



Figure 16. A 72-year-old male presenting with headache. a Sagittal 3mm-thick SE T1weighted image. A slightly inhomogeneous mass lesion is seen in the prepontine cistern (small arrowheads) with compression on the brain stem (large arrowheads). The linear flow void situated just anterior to the brainstem is the compressed basilar artery. b Axial 3mm-thick FLAIR image through the posterior fossa. The mass lesion demonstrates an inhomogeneous appearance (small arrowheads). Compare with the homogeneous hypointense appearance of the CSF in the fourth ventricle (large arrowhead). c Axial 3mm-thick TSE T2-weighted image through the posterior fossa. The mass lesion has a homogeneous high signal intensity (small arrowheads) and compresses the brainstem and basilar artery (large arrowheads). d Axial 4-mm EP DW *b*1000 image showing the hyperintense signal intensity of the mass lesion (arrowheads). Conclusion: Epidermoid cyst in the prepontine cistern. Differential diagnosis with an arachnoid cyst cannot be made based on the findings on the T2-and T1-weighted sequences. On FLAIR images,

epidermoid cysts typically have an inhomogeneous appearance with an intensity higher than that of CSF. The diagnosis is confirmed on diffusion-weighted images on which the epidermoid cyst has a high signal intensity on b1000 images. Note the distorted aspect of the epidermoid cyst on this EP DW sequence.



Figure 17. A 55-year-old male investigated for sensorineural hearing loss on the left side. a Axial 4-mm-thick TSE T2-weighted MR image through the posterior fossa. In the posterior part of the right CPA, a nodular homogeneous hyperintense lesion is found (asterisk). The intensity is homogeneous and the lesion is sharply delineated. b Axial 1mm-thick 3D TSE T2-weighted MR image through the posterior fossa. The lesion is situated in the posterior and lateral aspect of the right CPA, showing a homogeneous hyperintensity (asterisk). There is anterior displacement of the right vestibulo-cochlear and facial nerve (arrowheads). c Axial 4-mm-thick EP DW b1000 image. The lesion has a low signal intensity (arrowheads). d Axial 2-mm-thick SE T1-weighted image after gadolinium administration. There seems to be no enhancement of the homogeneous hypointense lesion (asterisk) in the right CPA. e Coronal 2-mm-thick SE T1-weighted image with fat saturation after gadolinium administration. There is a clear asymmetry with visualization of an oval homogeneous hypointense lesion in the right CPA (asterisk). There is no enhancement. Conclusion: The lesion has CSF-like intensities and has no high signal intensity on diffusion-weighted images. Based on these findings, diagnosis of a right-sided arachnoid cyst can be made (compare to Figure 16).



Figure 18. A 38-year-old female with a history of surgery for a large CPA epidermoid with supratentorial extension. Imaging performed in the follow-up status of the patient. a Axial post-gadolinium 3D GRE T1-weighted image. There is a large hypointense region in the left temporal region probably a region of tissue loss as a postoperative sequel (asterisk). There is another rounded hypointense region deep in the left temporal lobe (arrowhead). b Axial 2-mm-thick MPR of a 0.4mm 3D TSE T2-weighted sequence. Large hyperintense region in the left temporal region, probably a region of tissue loss as a postoperative sequel (asterisk). There is another rounded hyperintense region deep in the left temporal lobe (arrowhead). b Axial 2-mm-thick MPR of a 0.4mm 3D TSE T2-weighted sequence. Large hyperintense region in the left temporal region, probably a region of tissue loss as a postoperative sequel (asterisk). There is another rounded hyperintense region deep in the left temporal lobe (arrowhead). c Axial 3-mm-thick non-EP DW sequence. The large area in the left temporal fossa is indeed a postoperative sequel with an area of tissue loss (asterisk). However, the small nodule deep in the left temporal lobe is a remnant of the epidermoid cyst (arrowhead). Conclusion: Large region of postoperative tissue loss in the left temporal lobe. Diffusion-weighted imaging is, however, the only technique that is able to demonstrate or exclude a residual epidermoid cyst.



Figure 19. A 43-year-old male presenting with headache. a Axial contrast enhanced CT scan through the posterior fossa. There is a large hypodense lesion (large arrowheads) in the prepontine cistern, encasing the basilar artery (arrow). Note the irregular bony delineation of the clivus (small arrowheads). b Sagittal SE T1-weighted. There is a large hypointense lesion in the preportine cistern, compressing the brain stem (large arrowheads). Note the relation to the clivus. The latter is partially hyperintense due to the fat and partially hypointense due to invasion by the lesion (small arrowheads). c Axial TSE T2-weighted image through the posterior fossa (same level as a). Large hyperintense mass lesion in the preportine cistern with compression of the brainstem and cerebellum (large arrowheads), encasing the basilar artery (arrow). Note again the relationship with the clivus (small arrowheads). d Axial gadolinium-enhanced SE T1-weighted image through the posterior fossa (same level as and c). The lesion does not enhance. e Axial non-EP DW b1000 image (SS TSE DW sequence or HASTE DW sequence). The lesion is isointense with the cerebellum. There is no clear hyperintensity. Conclusion: The large mass lesion displays signal intensities on standard MR sequences which might be compatible with an epidermoid cyst. However, the lack of clear hyperintensity on b1000 diffusion-weighted images and the relation to the clivus disfavour the diagnosis of an epidermoid cyst.

At surgery, pathology revealed a chordoma. The clue to the diagnosis is indeed given by the relation of the lesion to the clivus.

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Chapter 4

Contribution of diffusion weighted MR imaging in clinical cholesteatoma management

Chapter 4.1

The value of diffusion-weighted MR imaging in the diagnosis of primary acquired and residual cholesteatoma: a surgical verified study of 100 patients

Vercruysse JP, De Foer B, Pouillon M, Somers T, Casselman J, Offeciers E. Eur Radiol (2006) 16: 1461-1467

Abstract

Our goal was to determine the value of echo-planar diffusion-weighted MR imaging in detecting the presence of primary acquired and residual cholesteatoma. One hundred patients were evaluated by preoperative magnetic resonance (MR) imaging with diffusion-weighted MR imaging. The patient population consisted of a first group of 55 patients evaluated in order to detect the presence of a primary acquired cholesteatoma. In the second group, 45 patients were evaluated for the pre sence of a residual cholesteatoma 8–18 months after cholesteatoma surgery, prior to second-look surgery. Surgical findings were compared with preoperative findings on diffusion-weighted imaging (DWI). The sensitivity, specificity, positive and negative predictive values of both groups was assessed. In the group of primary surgery patients, hyperintense signal compatible with cholesteatoma was found in 89% of cases with a sensitivity, specificity, positive and negative predictive value for DWI of 81, 100, 100 and 40%, respectively. In the group of second-look surgery patients, only one of seven surgically verified residual cases was correctly diagnosed using DWI, with a sensitivity, specificity, positive and negative predictive values of 12.5, 100, 100 and 72%, respectively. These results confirm the value of DWI in detecting primary cholesteatoma, but show the poor capability of DWI in detecting small residual cholesteatoma.

Introduction

The detection of a primary or residual cholesteatoma with the use of imaging techniques remains challenging. The diagnosis of a primary cholesteatoma is mainly based on clinical suspicion (otoscopic findings, conductive or mixed hearing loss and otorrhea). Imaging can provide additional information concerning extension and ossicular and bony erosion on high-resolution computed tomography (CT). Magnetic resonance (MR) imaging is useful in selected cases for further characterisation of soft tissues and description of possible complications.

The detection of residual cholesteatoma after cholesteatoma surgery with the use of CT and MR imaging techniques has been shown to be inaccurate, due to poor sensitivity of high-resolution CT (1–3) and MR (4–6) imaging. Recent reports, however, suggested the improvement in the MR imaging technique in diagnosing cholesteatoma with the use of delayed contrast-enhanced T1-weighted imaging (7,8) and echo-planar diffusion-weighted MR imaging (9–14).

The purpose of this study was to evaluate the value of echo-planar diffusionweighted MR imaging (DWI) using 3 mm thick slices in detecting primary or residual cholesteatoma in a large serie of surgically verified cases.

Materials and methods

Between the 5th March 2001 and the 14th March 2005, MR imaging with DWI was performed on 100 patients suspected to have a middle ear cholesteatoma. Two separate groups were formed based upon the type of performed surgery.

In the first group, 55 patients were referred for MR imaging for a clinically suspected acquired cholesteatoma. In the second group, 45 patients were referred for MR imaging before a planned second stage surgery within 8–18 months after primary cholesteatoma surgery. The primary and second stage cholesteatoma surgery was performed by two experienced surgeons. Our series consisted of 77 male and 33 female patients with an average age of 28.4 years (median: 23.9 years, range: 5.5–66.5 years). Thirty-one patients of the reported cases were children (\leq 16 years). All patients underwent MR imaging at an average of 15 days (median: 11 days, range: 1–57 days) prior to second look surgery.

MR imaging

MR imaging was performed with a superconductive 1.5 Tesla machine (Echospeed Horizon, GE Milwaukee, USA), using a circularly polarised head coil. The examination was centred—for all sequences but the 3D FSE T2weighted images and the diffusion-weighted images—(B0 and b1000) on the affected ear in a small field of view (14 cm) with a saturation band on the contralateral ear.

Coronal FSE T1-weighted images (TR/TE, 475/14; slice thickness 3 mm, spacing 0; matrix, 256×224; 2 NEX; field of view 140×140 mm) and T2-weighted images, (TR/TE, 3,000/102; slice thickness 3 mm, spacing 0; matrix, 256×224; 5 NEX field of view 140×140 cm) axial 3D FSE T2-weighted images (TR/TE,4,000/180:slice thickness 0.8 mm; matrix, 256×256; 2 NEX) and coronal diffusion-weighted images (TR/TE,10,000/88 ms; slice thickness 3 mm; matrix 128×128; b value, 0 and 1,000 s/ mm; scan time, 40 s) were performed before injection of gadolinium. Parallel imaging techniques were not used, because they were not available on our MR.

After injection of gadolinium in a dosage of 0.1 mmol/kg body weight coronal and axial T1-weighted images were obtained.

Radiological interpretation

All DWI images were analysed in consensus by two radiologists with long-standing experience in head and neck radiology. The identity of patients, clinical data and operative results were blinded for the observers. Standard MR sequences were evaluated looking for a moderate hyperintense lesion on T2-weighted images, the characteristic peripheral enhancing cholesteatoma matrix and the central non-enhancing cholesteatoma on T1-weighted images. Cholesteatoma was diagnosed on DWI as a marked hyperintense signal in comparison with brain tissue (*b*1000). All cases were classified as positive or negative, according to the above-described signal characteristics. The sensitivity, specificity and positive and negative predictive values were assessed.

Results

In the first group of presumed primary acquired cholesteatoma (n=55), we found cholesteatoma in 89% (n=49). Apparent diffusion coefficient (ADC) values could be evaluated in 20 out of 49 cholesteatomas. Mean ADC values for cholesteatomas and grey matter were 0.844 and 0.837 (10^{-3} mm²/s), respectively (Table 1).

A correct diagnosis was made in 84% (n=46) with 40 patients diagnosed as true positives and six patients as true negatives. In nine patients, DWI failed in diagnosing surgically verified cholesteatoma (i.e. false negatives). The size of the primary acquired cholesteatomas ranged from 5 to 21 mm. An additional evaluation of standard MR sequences revealed the detection of two supplementary cholesteatomas in this group of false negatives by identifying a characteristic region of non-enhancing cholesteatoma on gadolinium-enhanced T1-weighted images surrounding by enhancing cholesteatoma matrix. The surgical findings of false negatives cases revealed atelectatic retraction cholesteatoma or partially evacuated cholesteatoma with limited keratin accumulation. No false positives were seen in this group. The sensitivity, specificity, positive and negative predictive values were 81, 100, 100 and 40%, respectively. In the second group of patients during second look surgery (n=45), residual cholesteatoma was found in 17% (n=7). In this group, ADC values could not be calculated due the small volume of the lesions (Table 2). A correct diagnosis using DWI was made only in one patient with a residual pearl with a shortest diameter of 6 mm. All other residual pearls detected during the second stage surgery were ≤4 mm.

Cholesteatoma dimension (mm)	თ	13	10	0	ω	14	ω	ω	O	15	12	NA	17	16	5	16	D	NA	ი	Retraction	CIDIESIERIUIIA	α	AA	Partially evacuated	CIUESEALUIIA	Retraction cholesteatoma	21	ω	15	NA
Enhancement T1 + gadolinium	Peripheral	Complete	Peripheral	Peripheral	Peripheral	Peripheral	Peripheral	Complete	Peripheral	Partial		Peripheral	Complete	Partial		Absent	Peripheral	Peripheral	Peripheral	Complete										
ADC in cholesteatoma (10 ⁻³ mm ² /s)	×	×	×	×	0.817	0.832	1.07	×	0.703	0.664	×	NA	0.763	×	×	1.07	×	NA	×	×		1.107	AA	×	;	×	0.74	×	×	NA
ADC in grey matter (10 ⁻³ mm ² /s)	×	×	×	×	0.947	0.82	0.827	×	0.775	0.83	×	NA	0.859	×	×	0.855	×	NA	×	×		0.8/3	NA	×	;	×	0.978	×	×	NA
°IWD	+	+	+	+	+	+	+	+	+	+	+	ı	+	+		+	+		+	ı		+				ı	ı	+	+	1
Surgical results ^a	+	+	+	+	+	+	+	+	+	+	+	1	+	+	+	+	+	1	+	ı		+	ı	+		+	+	+	+	I
Age (years)	47	63	14	14	22	64	43	55	58	48	49	ი	33	71	9	48	54	37	41	12	1	4/	57	50	·	21	46	9	49	57
Gender	E	f	f	f	f	E	E	Ŧ	E	E	E	E	÷	E	E	E	E	E	E	E		E	E	E		E	f	f	E	f
Patients	-	7	ო	4	5	9	7	ω	ი	10	11	12	13	14	15	16	17	18	19	20	2		22	23		24	25	26	27	28

Table 1. detailed description of the first study group (n=55) [*m* male, *f* female, *NA* not opplicable (absence of cholesteatoma), *X* data not available]

13	13	11	Partially evacuated cholesteatoma	Partially evacuated cholesteatoma	13	10	18	17	NA	ი	19	15	12	15	NA	13	ω	13	Q	10	18	O	14	Partially evacuated	cholesteatoma	5	ω	
Peripheral	Peripheral	Peripheral	Partial	Absent	Peripheral	Peripheral	Peripheral	Peripheral	Complete	Peripheral	Peripheral	Peripheral	Peripheral	Peripheral	Complete	Peripheral	Partial	Peripheral	Peripheral	Peripheral	Peripheral	Peripheral	Peripheral	Partial		Peripheral	Peripheral	
×	1.09	0.992	×	×	×	0.783	0.723	×	NA	×	0.703	0.939	0.89	0.686	NA	×	×	×	×	×	0.688	0.809	×	×		×	0.811	
×	0.849	0.686	×	×	×	0.935	0.907	×	NA	×	0.714	0.989	0.717	0.7	NA	×	×	×	×	×	0.858	0.835	×	×		×	0.782	
+	+	+	ı	ı	+	+	+	+	,	+	+	+	+	+		+	+	+	ı	+	+	+	+			,	+	eatoma tion
+	+	+	+	+	+	+	+	+	ı	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+		+	+	of cholest∉ VI evaluat
8	39	32	45	12	13	51	48	17	26	6	37	27	37	36	53	4	24	ω	16	43	51	60	40	16		11	49	sence (-) o itive (-) DV
E	E	E	÷	f	E	Ŧ	E	Ŧ	E	E	E	E	E	f	E	E	E	f	E	f	f	f	E	E		E	f	e (+) or ab: (+) or nega
29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53		54	55	^a Presence ^b Positive

	Cholesteatoma		NA	S	NA	NA	NA	NA	NA	NA	4	2	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	0	NA	ю	NA	AA
	Enhancement T1 +	Partial	Complete	Peripheral	Complete	Complete	Partial	Complete	Complete	Partial	Peripheral	Partial	Complete	Complete	Peripheral	Partial	Complete	Complete	Complete	Complete	Absent	Complete	Complete	Partial	Complete	Partial	Complete	Partial	Complete	Partial	Complete	Complete
	ADC in cholesteatoma	(c) IIII (c) MN	NA	NM	NA	NA	NA	NA	NA	NA	NM	NM	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NM	NA	NM	NA	NA
	ADC in grey matter	NM NN	NA	NM	NA	NA	NA	NA	NA	NA	NM	NM	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NM	NA	NM	NA	NA
	۵IWD					1	1					,						,	,		,								,			
	Surgical results ^a			+						1	+	+	1		,	,	,		ı	,		,	,	,	ı		,	+		+		
	Age (veare)	(years) 6	62	18	7	26	39	47	10	24	45	17	66	10	46	50	59	43	8	7	8	17	50	13	34	52	53	5	21	11	21	11
5	gender	E	ΞE	÷		Е		E	E	-	E	E	E	E	-	E	E	÷	E	E	E	E	E	-	÷	E	E	E	E	E	Е	E
5	Patients	~	0	e	4	5	9	7	ω	თ	10	,	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31

Table 2. Detailed description of the second study group (n=45) [*m* male, *f* female, *NA* not opplicable (absence of cholesteatoma), *NM* ADC not measureable]
AN	AN	2	AN	AN	AN	ΝA	AN	2	ΝA	AN	AN	AN	AN	
mnlete	mplete	rtial	rtial	mplete	rtial	rtial	rtial	ripheral	rtial	mplete	mplete	rtial	mplete	
Ö	C O	Par	Par	Col	Par	Par	Par	Per	Par	Col	Col	Par	Co	
٩N	NA	ΣZ	AN	AN	AN	AN	AN	∑Z	AN	AN	AN	AN	AN	
AN	NA	MΝ	AN	ΝA	ΝA	ΝA	ΝA	ΣN	ΝA	ΝA	ΝA	ΝA	AN	
								+					1	atoma
		+						+						of choleste
10	45	ω	35	13	8	28	40	51	34	13	24	9	41	sence (-) o
Ę	: 도				ц		ц	L		۲	F	ц		(+) or abs
32 n	33 n	34 f	35 f	36 f	37 n	38 f	39 n	40 n	41 f	42 n	43 n	44 n	45 f	^a Presence

^b Positive (+) or negative (-) DWI evaluation

No false positives as well were seen in the second group. The sensitivity, specificity, positive and negative predictive values were 12.5, 100, 100 and 84%, respectively.

Discussion

The detection of primary or residual cholesteatoma with the use of imaging techniques remains challenging for the head and neck radiologist. The primary examination tool for the evaluation of a suspected primary acquired cholesteatoma is still high-resolution CT, as it provides good information on cholesteatoma delineation and extension, delineation of the tympanic segment of the facial nerve, bony erosion and anatomical features such as the delineation of the tegmen and bony labyrinth. MR imaging offers the possibility of using different types of sequences—including diffusion-weighted sequences and post gadolinium T1-weighted images—and different imaging planes. However, after primary surgery, eventual soft tissue extension in the middle ear and mastoidectomy cavity cannot be differentiated by using high-resolution CT (1-3).

MR imaging has been shown to be able to differentiate granulation tissue from cholesteatomatous tissue (15).

Cholesteatoma (congenital, acquired or residual) has been reported to have, in comparison with brain tissue, moderately hyperintense signal intensity on T2weighted images and an isointense signal intensity on T1-weighted images without or with moderate peripheral enhancement after i.v. gadolinium administration (16,17). Several reports have shown that standard MR imaging sequences are not able to detect residual cholesteatoma prior to second stage surgery (4-6). Spinecho diffusion-weighted MR imaging has primarily been used for the diagnosis of ischemic brain infarction (18), but has recently been described as an additional diagnostic tool in detecting congenital, acquired and residual cholesteatoma (9-14). Congenital, acquired and residual cholesteatoma appear to have a high signal on diffusion-weighted images. The combination of restricted water diffusion and a T2 shine-through effect is thought to be responsible for high signal intensity on DWI (9,10). In our study, calculated ADC values revealed that there was no clear diffusion restriction (Table 1). This supports the hypothesis that a T2 shinethrough effect is predominantly responsible for the hyperintensity on DWI. A known additional problem using spin-echo DWI imaging are the artefacts caused by susceptibility disturbances at air-bone interfaces at the skull base. Artefacts appear rim-shaped and are situated preferentially at the position of the tegmen.

Furthermore hyperintense signals on spin-echo DWI have a somewhat distorted shape (10). The use of parallel imaging is able to reduce these artefacts (19).



Figure 1. a. A 60-year-old male suspected of having a primary acquired middle ear cholesteatoma. Coronal echo-planar DWI shows a clear hyperintens lesion in the left mastoid region under the tegmen (arrow). b. Same atient as in a. Corresponding coronal T1-weighted image after gadolinium administration shows a non-enhancing cholesteatoma with peripheral enhancing cholesteatoma matrix (arrow). Surgery revealed the presence of a large mastoid cholesteatoma corresponding with MR findings on echo-panar DWI and contrast-enhanced T1-weighted MR images.

In our study, a high sensitivity of 81.6% (40/49) and specificity of 100% was obtained when detecting primary acquired cholesteatoma (Figure 1a,b). These results were very similar to previous results reported by Fitzek et al. (10), supporting the additional value of DWI in detecting presumed primary cholesteatomas. Analysis of our surgical results revealed in the false negative cases (n=9), the presence of an atelectatic retraction cholesteatoma and/or partially evacuated cholesteatoma, with limited keratin accumulation, which was similar to the results reported by Fitzek et al. (10).

Additional evaluation of standard MR sequences revealed the detection of two supplementary cholesteatomas in the group of false negatives by visualisation of a nonenhancement on gadolinium enhanced T1-weighted images of the cholesteatoma matrix (Figure 2a,b). This suggests that the combination of standard MR imaging sequences and diffusion-weighted sequences appears to have a higher sensitivity in detecting middle ear cholesteatoma (13).

In the second group of patients, only one of seven residual cholesteatoma pearls was correctly diagnosed using DWI, with a diameter of 6 mm (Figure 3a,b). All other residual pearls detected during the second stage surgery were ≤ 4 mm.



Figure 2. a. A 10-year-old boy suspected of having a primary acquired cholesteatoma. Previous MR imaging shows a large curvilinear artefact under the tegmen and middle fossa on both sides on echo-planar DWI. A clear hyperintensity, suggestive for a cholesteatoma was not seen on echo-planar DWI. b. Same patient as in a. Note the hypointense non-enhancing nodular lesion in the retrotympanum on axial contrast-enhanced T1-weighted images suggestive of a cholesteatoma (arrow). Surgery revealed the presence of a cholesteatoma in the retrotympanum with a diameter of 5 mm.



Figure 3. a. A 51-year-old male planned for second look surgery. MR imaging prior to second-look surgery shows a nodular hyperintense lesion under the tegmen on echoplanar DWI imaging (arrow). b. Same patient as in a. Axial contrast-enhanced T1weighted MR image shows a peripheral enhancing nodular lesion, suggestive of cholesteatoma. Surgery revealed the presence of a residual cholesteatoma with a diameter of 6 mm

In recent literature, Aikele et al. (9) reported a sensitivity of 77% (10/13) in detecting residual or recurrent cholesteatoma using the combination of standard MR imaging sequences and DWI missing three small residual cholesteatoma pearls (<5 mm).

Specificity, positive and negative predictive values of 100%, 100% and 75% were reported (9). Another recent report by Stasolla et al. (14) reported a sensitivity of 86% (6/7) detecting recurrent cholesteatoma using echo-planar DWI. In their series only one small cholesteatoma of 2 mm was missed, while the size of the other cholesteatomas varied from 4 to 14 mm. Specificity, positive and negative predictive values of 100%, 100% and 92% were reported (14). In both studies, included patients were clinically suspected of having residual of recurrent

cholesteatoma. In comparison, our findings differ significantly from these studies. In order to exactly evaluate the capability of DWI to detect residual cholesteatoma, we planned 45 consecutive patients for second stage surgery 8–18 months after primary surgery. In this group no recurrent cholesteatoma was suspected. The reason for the higher sensitivity in those two previously reported studies is probably caused by larger size of the recurrent cholesteatoma in these clinically suspected patients. On the basis of these results, we think that the major limitations for detecting cholesteatoma on diffusion-weighted sequences is definitely the size of the lesion (4–5mm), combined with the low spatial resolution, the relative thick slices and the air-bone artefacts.

Conclusion

On the base of our results, we conclude that DWI has an important role in the evaluation of primary acquired middle ear cholesteatoma. Its sensitivity can be augmented when associated with standard MR imaging sequences. Our results do not confirm the high sensitivity of DWI of previous reports detecting residual cholesteatoma due to the fact that in our study we did not select patients on a clinical basis. We think that at the present time DWI has a limited role in the detection of residual cholesteatoma after primary surgery due to the small size of residual cholesteatoma, the air-bone artefact of DWI at the tegmen, the low resolution and relative thick slices of DWI. With current MR imaging techniques (standard MR imaging sequences and spin-echo echo-planar DWI sequences) second look cannot be replaced by MR imaging. The development of newer non-echo-planar diffusion-weighted sequences with a higher resolution and less susceptibility artefacts in combination with late post contrast T1 images remains to be evaluated in detecting residual cholesteatoma.

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Chapter 4.2

Value of high-resolution computed tomography and magnetic resonance imaging in the detection of residual cholesteatomas in primary bony obliterated mastoids

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Abstract

Purpose: The objective of this study was to assess the value of high-resolution computed tomography (HRCT) and that of magnetic resonance imaging (MRI), including postcontrast T_1 -weighted images and echo-planar diffusion-weighted (EP-DW) images, in the detection of residual cholesteatomas after primary bony obliteration of the mastoid.

Patients and methods: Twenty-three patients underwent a second-look surgery 8 to 18 months after they underwent a primary bony obliteration technique. All patients were evaluated by HRCT and MRI before their second-look surgery. A retrospective analysis was performed.

Results: A residual cholesteatoma was found in 2 of the 23 patients; both cases of cholesteatoma had a diameter less than 4 mm. In these 2 patients, residual cholesteatoma was found in the middle ear cavity and not in the obliterated mastoid. In all cases, HRCT showed a homogeneous obliteration of the mastoid cavity. On MRI, only one cholesteatoma pearl was detected using contrast-enhanced T_1 -weighted imaging. Findings from the EP-DW imaging were negative for all cases.

Conclusion: This study demonstrates that HRCT is still the imaging technique of choice for the evaluation of bony obliterated mastoids. It shows the low sensitivity and specificity of HRCT for the characterization of an associated opacified middle ear and those of contrast-enhanced T_1 -weighted imaging and EP-DW imaging for the detection of small residual cholesteatomas after primary bony obliteration.

Introduction

The surgical goals in the treatment of primary cholesteatomas include full eradication of the pathology, prevention of recurrences, controlling the hygienic status of the affected ear, and restoration of hearing (1). Several authors reported on the additional value of mastoid bony obliteration for diminishing recurrences (2,3,4,5,6). Although primary bony obliteration provides excellent results with low recurrence rates, it also carries with it the risk of obliterating and obscuring residual cholesteatomas. Follow-up by means of imaging is mandatory to prevent late complications after possible obliteration of residual cholesteatomas. The aim

of this study was to assess the value of high-resolution computed tomography (HRCT) and that of magnetic resonance imaging (MRI), including contrastenhanced T_1 -weighted images and echo-planar diffusion-weighted (EP-DW) images, in detecting residual cholesteatomas in the middle ear and bony obliterated mastoids.

Material and methods

Between December 11, 2002, and March 17, 2004, 23 patients underwent a primary bony obliteration technique for their cholesteatoma. In all patients, during the first-stage surgery, the cholesteatoma was removed by an intact canal wall technique followed by primary bony obliteration of the mastoid and epitympanic space using bone pâté mixed with fibrin glue. During this surgery, reconstruction of the tympano-ossicular system was performed either by allograft (7) and (8) or by fascia. Our series consisted of 23 consecutive patients (12 male patients and 11 female patients) with an average age of 31.6 years (median, 35.7 years; range, 8.7–61.2 years). All patients underwent an HRCT and an MRI with an average of 20 days (median, 15 days; range, 1–57 days) before their second-look surgery. Between January 7, 2004, and May 31, 2005, all patients underwent a second-look procedure with an average of 13.2 months (median, 12.9 months; range, 8.1–18 months) after their first-stage surgery. In all cases, a transcanal approach with a Roosen incision was performed to evaluate the middle ear space.

Imaging technique

All CT scans were performed on a 16-row multislice CT scanner (LightSpeed, GE, Milwaukee, WI) using an axial volume scan (140 kV; 250 mA; 1-second rotation; 5.62 pitch; high-resolution bone algorithm) with coronal reformations. Axial slices were acquired in 1.25-mm thickness and were reformatted to 0.625 mm, centered on the left and right ears, with an interval of 0.2 mm. Magnetic resonance imaging was performed with a superconductive 1.5-T system (EchoSpeed Horizon, GE) using a circularly polarized head coil. The examination was centered—for all sequences but the 3-dimensional fast spin-echo (FSE) T_2 -weighted images and the DW images—on the affected ear using a small field of view (FOV; 140 mm) with a saturation band on the contralateral ear. Coronal FSE T_1 -weighted imaging (repetition time [TR]/echo time [TE], 475/14 ms; slice thickness, 3 mm; spacing, 0; matrix, 256 × 224; number of excitations [NEX], 2; FOV, 140 × 140 mm), T_2 -weighted imaging (TR/TE, 3000/102 ms; slice thickness, 3 mm; spacing, 0; matrix,

256 × 224; NEX, 5; FOV, 140 × 140 cm), axial 3-dimensional FSE T_2 -weighted imaging (TR/TE, 4000/180 ms; slice thickness, 0.8 mm; matrix, 256 × 256; NEX, 2; FOV, 100 × 100 mm), and spin-echo-planar DW imaging (TR/TE, 10 000/minimum ms; slice thickness, 3 mm; matrix, 128 × 128; *b* values, 0 and 1000 s/mm; FOV, 220 mm) were performed before the injection of gadolinium. Apparent diffusion coefficient maps were not calculated because of the expected small volume of the lesions. After the injection of gadolinium (0.1 mmol/kg), coronal and axial T_1 weighted images, initially the coronal series and secondly the axial series, were obtained, hence serving as an early delayed-phase sequence.

Radiologic interpretation

Two radiologists with long-standing experience in head and neck imaging evaluated in consensus all CT and MR images. They were blinded as to the identity of patients, clinical data, and operative results. A consensus agreement was made for the evaluation of residual cholesteatomas, which were marked either as positive (ie, residual cholesteatoma present) or as negative (ie, residual cholesteatoma absent). The interpretation on HRCT was based on the presence of soft tissue within the middle ear and/or bony obliterated mastoids and punched-out lesions in the obliterated mastoid. On MRI, interpretation relied on the signal intensity of the soft tissue extension on non-enhanced T_1 -weighted images and T_2 -weighted images. Evaluation of the enhancement after the intravenous injection of gadolinium checked for non-enhancing cholesteatomas and/or peripheral enhancing cholesteatoma matrices. Echo-planar DW imaging was performed to look for characteristic hyperintense cholesteatoma pearls.

Results

The study results are summarized in Table 1.

Surgical results

A residual cholesteatoma was found in 2 of the 23 patients (9%) during their second-look surgery. The cholesteatoma pearls were both found in the retrotympanum. One of the residual pearls measured 2 mm in diameter; the other, 4 mm. The preoperative clinical case findings are also outlined in table 1.

EP-DW imaging			ı	1	1	ı	ı	ı	1	ı	1	ı	1	ı	1	ı	ı	ı	ı	ı	ı	ı	ı	1	·
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2	Middle ear					1	1	1		1		+		ı		1	I	ı	I	I	I	ı	I		-
E O	Mastoid	1		1	1	ı	ı	ı	1	ı	1	ı	1		1	ı									,
HR	Middle ear	STD	A	STD	STD	A	STD (NA)	A	STD	STD	STD	STD	A	STD	STD (NA)	STD	A	A	A	STD (NA)	A	STD	A	A	-
Surgical results		1		1		1	1	1		1		1		+		1		1				1			aerated.
	Tympanic membrane	Perforation	Intact	Intact	Intact	Intact	retraction	Intact	Retraction/Granulation	Intact	Intact	Intact	Intact	Intact/Granulation	Intact/Granulation	Intact	Intact	Perforation	Intact	Intact	Intact	Intact	Intact	Intact/Granulation	nsity; A, aerated; NA, not
	Ear discharge) 1		1	1	1	1	1	+	1	1	1	1	+	+	1		1				1		+	oft tissue der
Time between primary Surgery and second- look		12.9	14	13.8	10.8	8.1	12.3	12.6	12.9	13.6	18	12.4	13.6	12.2	17.6	13.4	17.4	12.4	11.6	15.6	13.2	12.1	11.8	14.5	left; R, right; STD, s
Side				_	_		с		_		£	с	_	_	£		£	с	£	£	£	с	£	с	indicates
Patient		.	2	ო	4	5	9	7	œ	6	10	11	12	13	14	15	16	17	18	19	20	21	22	23	L

For clinical findings, + indicates presence of otorrhea; -, dry. For surgical results, + indicates presence of cholesteatoma; -, absence of cholesteatoma. For MRI, - indicates negative; +, positive; MS, mixed signal intensity.

Table 1. Study results

High-resolution computed tomography scan evaluation

An aerated middle ear was found in 43.5% of the patients (10/23; figure 1 A and B). A soft tissue obliterated middle ear was seen in 56.5% of the patients (13/23), with a complete opacification of the middle ear cavity in 13% (3/23). In the bony obliterated mastoids, no soft tissue defect or punched-out lesion was detected (Figure 1 and Figure 2).



Figure 1. (A) Axial HRCT image of the left ear at the level of the round window and the basal turn of the cochlea. Note the aerated middle ear cavity (arrows) and the bony obliterated mastoid (arrowheads). (B) Coronal reformation of the left ear at the level of the round window demonstrating the reconstructed ossicular chain in the aerated middle ear (arrows). Note the homogeneously obliterated mastoid (arrowheads).







Figure 2. Findings for a 10-year-old boy who underwent primary bony obliteration technique of the right ear and a small residual cholesteatoma in the retrotympanum. (A) The left panel shows an axial HRCT image of the right ear at the level of the horizontal semicircular canal. The mastoidectomy cavity is filled with bone chips and pasta (asterisk). No punched-out soft tissue lesion was found. The right panel shows an axial HRCT image of the right ear at the level of the round window and the basal turn of the cochlea. Note a specific soft tissue lesion in the retrotympanum (arrow). Because of the rounded aspect of the lesion, a residual cholesteatoma was suspected. (B) Coronal reformatted HRCT image of the right ear at the level of the vestibulum and the lateral semicircular canal. The mastoidectomy cavity and epitympanum are filled with bone chips and pasta (asterisk). The rounded soft tissue mass in the retrotympanum is again suggestive of a residual cholesteatoma (arrow). (C) Coronal MR images centered on the right ear at the level of the vestibulum and the lateral semicircular canal. The left panel is a T_2 -weighted image showing a rounded, mainly hyperintense, lesion in the hypotympanum (small arrow). The middle panel is a T_1 -weighted image showing that the lesion in the hypotympanum is hypointense (small arrow). The right panel is a T_1 -weighted image taken after intravenous administration of gadolinium showing that the lesion in the hypotympanum displays only a peripheral enhancement (small arrow). Note the filling of the mastoidectomy cavity with mixed signal intensities as a result of the primary bony obliteration technique on all sequences (large arrows). Discrimination of enhancement in the filled cavity was difficult. On DW images (not shown), no clear hyperintense signal was found.



Figure 3. Findings for a 10-year-old boy who underwent primary bony obliteration technique of the right ear and a small residual cholesteatoma in the retrotympanum. (A) Coronal T_2 -weighted image of the left ear at the level of the vestibulum and the lateral semicircular canal showing the mixed and inhomogeneous signal intensities of the bony obliterated mastoid (arrows). (B) Coronal T_1 -weighted MR image of the left ear after intravenous administration of gadolinium showing inhomogeneous enhancement of the obliterated mastoid (arrows). Recognition of an eventual characteristic central non-enhancing cholesteatoma was impossible. (C) Axial postgadolinium T_1 -weighted MR image at the level of the vestibulum again showing inhomogeneous enhancement of the obliterated mastoid, making the diagnosis of an eventual residual cholesteatoma impossible.

Magnetic resonance imaging evaluation

Only 1 of the 2 surgically detected residual cholesteatomas was clearly detected on contrast-enhanced T_1 -weighted images as a posterior hypotympanal nonenhancing hypointensity (Figure 2C). None of the residual cholesteatomas was seen on EP-DW imaging. No false-positive finding was seen in this series.

Discussion

A complete eradication of the pathology, together with prevention of recurrent cholesteatomas, is the main surgical goal in the treatment of primary cholesteatomas. Other important goals in cholesteatoma surgery are controlling the hygienic status of the ear and preserving or improving hearing status (1). The best way to obtain these surgical goals is to try to restore normal anatomy and physiology after total eradication of the pathology and its etiologic factors. In our department. use-among other techniques—an intact canal we wall tympanoplasty with additional bony mastoid obliteration in one surgical procedure to eradicate the pathology and prevent recurrences. Obliteration of the attic and mastoid by means of bone pâté prevents new retractions of the tympanic membrane and, therefore, recurrent cholesteatomas. With this technique, we adapt the middle ear to the defective physiology in combination with preservation of normal external ear canal. Several authors described the advantages of bony obliteration of the mastoid and achieved excellent results with a low recurrence ratio (2,3,4,5,6).

The use of this technique implies the risk of obliterating residual cholesteatomas. Therefore, accurate imaging follow-up of obliterated mastoids is necessary to prevent late complications after possible obliteration of residual cholesteatomas. High-resolution computed tomography has been shown to be very effective in detecting small pearls in obliterated mastoids, presenting as punched-out lesions in the bone density of these obliterated mastoids. However, in the case of an associated opacified middle ear, HRCT is not able to differentiate these soft tissue masses after primary surgery and is characterized by low sensitivity and specificity (9,10,11,12). In our study, we found no punched-out soft tissue lesion inside the obliterated mastoid cavities. However, in 61% of the patients, we found an associated opacified middle ear, hiding at surgery a small cholesteatoma in 2 cases. High-resolution computed tomography was unable to further characterize this soft tissue opacification and to detect these cholesteatomas.

Magnetic resonance imaging may provide additional information and lead to a more accurate diagnosis (13) and (14). Apart from an excellent soft tissue contrast, MRI offers the possibility of using various pulse sequences, including EP-DW imaging, and the administration of intravenous contrast material. Recently, several reports described the value of delayed contrast-enhanced T_1 -weighted images, which make the differentiation between an enhancing scar tissue and a non-enhancing cholesteatoma possible (15) and (16). The value of EP-DW imaging in the detection of primary and residual cholesteatomas has been previously reported by several authors (17,18,19). Congenital, acquired, and residual cholesteatomas have a high signal intensity on EP-DW imaging. The T_2 shine-through effect is probably responsible for this hyperintensity on EP-DW imaging (17). The major limitations for detecting cholesteatomas on standard MRI sequences and DWI are the size of the lesion (5 mm) and the susceptibility artifacts at the air-bone interface of the temporal lobe and the temporal bone (20). In our study, on standard MRI sequences, we found mixed and confusing signal intensities in the obliterated mastoids as a result of the presence of a bone pâté, thus making the diagnosis of cholesteatoma in the obliterated mastoid impossible (figure 3A-C). Therefore, we mainly relied on HRCT for the evaluation of the obliterated cavity. In our study, the size of the residual cholesteatoma also seemed to be a limiting factor (ie, 2 and 4 mm) for MRI. Only one cholesteatoma in the middle ear could be recognized as a characteristic non-enhancing hypointense lesion on a postcontrast T_1 -weighted image (figure 2C). Furthermore, none of the cholesteatomas was visualized on DWI sequences, probably again because of the small size of the residual cholesteatomas, the low resolution, the relatively thick slices, and the important air-bone interface artifact of the echo-planar DWI sequences. The development of new non-EP-DW sequences seems to be very promising in overcoming this size limitation and in reducing this air-bone interface artifact (20). On the basis of these results, we conclude that HRCT is still recommended as the initial screening procedure to be applied when using the bony obliteration technique. In the absence of punched-out soft tissue lesions in the obliterated cavity or in the absence of soft tissue extension in the middle ear, follow-up HRCT can be performed.

The presence of any associated soft tissue lesion in the middle ear can then eventually further be characterized with the use of delayed contrast-enhanced T_1 -weighted imaging with DWI, taking into account that small residual pearls (<5 mm) still cannot be detected. Therefore, staging after primary bony obliteration in cholesteatoma remains to be necessary.

The value of new non–EP-DW imaging techniques in association with delayed postcontrast T_1 sequences seems to promising but remains to be studied in the evaluation of primary bony obliterated mastoids.

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Chapter 4.3

Detection of postoperative residual cholesteatoma with non-echo-planar diffusion-weighted magnetic resonance imaging

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Abstract

Objective: The aim of this study was to analyze the role of non-echo-planar imaging (non-EPI)-based diffusion-weighted (DW) magnetic resonance imaging (MRI) for the detection of residual cholesteatoma after canal wall-up mastoidectomy before eventual second-look surgery.

Study Design: Prospective and blinded study.Setting: Tertiary referral center. Patients: The study group included the surgical, clinical, and imaging follow-up of 32 consecutive patients after primary cholesteatoma surgery.

Interventions: All patients were investigated with MRI, including late postgadolinium T1-weighted sequence and non-EPI-DW sequence, 10 to 18 months after first-stage cholesteatoma surgery by experienced surgeons using a canal wall-up mastoidectomy. The non-EPI-DW images were evaluated for the presence of a high-signal intensity lesion consistent with residual cholesteatoma. Imaging findings were correlated with findings from second-stage surgery in 19 patients, clinical follow-up examination in 11 patients, and, in 2 patients, clinical and MRI follow-up examination.

Results: Non-EPI-DW sequences depicted 9 of 10 residual cholesteatomas. The only lesion missed was a 2-mm cholesteatoma in an examination degraded by motion artifacts in a child. All other diagnosed cholesteatomas measured between 2 and 6 mm. Sensitivity, specificity, positive predictive value, and negative predictive value were 90, 100, 100, and 96%, respectively.

Conclusion: Except for motion artifact-degraded examinations, non-EPI-DW MRI is able to detect even very small residual cholesteatoma after first-stage surgery by showing a high-signal intensity lesion. It has the capability of selecting patients for second-look surgery, avoiding unnecessary second-look surgery.

Surgical treatment of an acquired middle ear cholesteatoma can be performed by a canal wall-up (CWU) procedure, but this carries the risk of leaving residual cholesteatoma behind (1-4).The detection of residual cholesteatoma after CWU techniques with the use of computed tomography has been shown to be inaccurate (5-7). Recent reports, however, suggested an improvement in magnetic resonance imaging (MRI) technique in diagnosing cholesteatoma using delayed contrast-enhanced T1-weighted imaging (8-9) and echo-planar diffusion-weighted (EPI-DW) sequences (10-13). However, EPI-DW imaging still has a size limit of 5 mm in visualizing postoperative middle ear cholesteatoma due to its low resolution, thicker slices, and susceptibility artifacts (10,12,13). Therefore, EPI-DW sequences seem to be useless for the detection of the usually quite small residual cholesteatoma (13),

Very recently, the use of non-EPI-based DW sequences has been described for the detection of middle ear cholesteatoma (14) and postoperative recurrent cholesteatoma (15). These turbo spin-echo (TSE) DW sequences have a higher imaging matrix, thinner slice thickness, and -more importantly- a complete lack of susceptibility artifacts. The purpose of this study was to evaluate the sensitivity and specificity of a single-shot (SS) TSE DW sequence in detecting residual cholesteatoma after first-stage cholesteatoma surgery.

Patients and methods

Patients

Between July 2005 and April 2007, we investigated 32 consecutive patients (22 men and 10 women; age range, 7-71 yr; mean age, 39.4 yr) in a blinded and prospective study. Institutional review board approval and informed consent were not required. All patients had undergone first-stage cholesteatoma surgery between 10 and 18 months earlier and were clinically followed by micro-otoscopy and audiometry. All patients had computed tomographic (CT) and MRI evaluation regardless of their previous first-stage surgical findings. Both readers were blinded to the clinical information of the patient, first-stage surgical findings, and CT findings. The decision to perform second-look surgery was made by the ear, nose, and throat surgeon and was based upon the findings during first-stage surgery. The decision not to stage reflected the surgeon's evaluation of having completely removed cholesteatoma at the first stage in patients with easily dissected less extensive disease. In 19 patients, a second stage was performed either as a planned stage to check for residual disease in the patients with more extensive cholesteatoma or as a functional second stage in patients with remaining conductive hearing loss. All patients were regularly observed for a clinical followup, including micro-otoscopy and audiometry. The remaining 13 patients, with limited cholesteatoma extension during first-stage surgery and reassuring clinical and otoscopic findings, were observed for clinical follow-up examination, including micro-otoscopy and audiometry. Two of these clinically negative patients received further MRI follow-up examinations, including late postgadolinium T1-weighted and

SS TSE DW imaging. Surgical findings, including exact location of the residual cholesteatoma, were obtained from surgical reports.

Imaging Technique

Computed tomographic scanning was performed on a 16-row multislice CT scan (Lightspeed, GE, Milwaukee, WI, USA) using an axial volume scan (140 kV, 250 mA, 1-s rotation, 5.62 pitch, high-resolution bone algorithm) with coronal reconstruction. Axial slices were acquired with a thickness of 0.625 mm, centered in a 9.6-cm field of view on the right and left ear, with a reconstruction interval of 0.2 mm. Magnetic resonance imaging was performed on a 1.5-T superconductive unit (Magnetom Avanto; Siemens Medical Solutions, Erlangen, Germany) using the standard Head Matrix coil. Axial 2-mm-thick spin-echo T1-weighted images (repetition time [TR], 400 ms; time to echo [TE], 17 ms; matrix, 192 × 256; field of view, 150 × 200 mm), and coronal 2-mm-thick spin-echo T1-weighted images were acquired with the same parameters except for the matrix, which was set at 144 × 256 for the coronal images. Coronal 2-mm-thick TSE T2-weighted images (TR, 3,500 ms; TE, 92 ms; matrix, 192 × 256; field of view, 150 × 200 mm) and axial 0.4-mm-thick 3-dimensional TSE T2-weighted images (TR, 1,500 ms; TE, 303 ms; matrix, 228 × 448; field of view, 107 × 210 mm) were also performed. In all patients, a 2-mm-thick SS TSE DW sequence was acquired in the coronal plane (TR, 2,000 ms; TE, 115 ms; matrix, 134 × 192; field of view, 220 × 220 mm; b factors, 0 and 1,000 mm²/s). The coronal plane was preferred more than the axial plane because in the past, using EPI-DWI, the coronal plane showed less artifacts.

All sequences were acquired 45 minutes after intravenous contrast injection of 0.1 mmol/kg of body weight of gadoterate meglumine (Dotarem; Guerbet, Roissy, France) or gadopentetate dimeglumine (Magnevist; Schering, Berlin, Germany).

Image Interpretation

Images were evaluated prospectively in consensus by 2 experienced head and neck radiologists blinded to the results of first-stage surgery and clinical and CT data of the patient. The SS TSE DW sequences were evaluated first. Turbo spinecho T2 and late postgadolinium T1-weighted sequences were evaluated afterward for correlation with the SS TSE DW sequences. Single-shot TSE DW images were considered positive for cholesteatoma if a nodular hyperintense lesion was observed. On the TSE T2 images, a cholesteatoma was diagnosed in case of a nodular moderately intense lesion, with a corresponding non-enhancing or rim-enhancing lesion on the late postgadolinium T1-weighted images. An aerated middle ear and postoperative cavity were diagnosed if the homogeneous signal loss of the temporal bone-caused by air and bone-can be observed on late postgadolinium T1-weighted and on T2-weighted MR images. In case of postoperative and/or inflammatory changes, a lack of hyperintensity on SS TSE DW images, a complete enhancement on late postgadolinium T1-weighted sequences, and a clear hyperintense signal on T2-weighted images were observed. All examinations were classified as either positive or negative for cholesteatoma. The greatest diameter of the cholesteatoma was measured.

Statistical Evaluation

The sensitivity, specificity, and negative and positive predictive values were calculated.

Results

Of the 19 patients who underwent surgery, 18 were proven to have the correct diagnosis on the basis of the SS TSE DW sequence alone. There were true-positive findings for cholesteatoma in 9 patients. The cholesteatoma size varied between 2 and 6 mm (Table 1). Of these 9 true-positive patients, 6 showed a surrounding surrounding signal void on standard MRI sequences corresponding to a well-aerated postoperative cavity (Figure 1B). In the remaining 3 true-positive patients, the cholesteatoma was embedded in postoperative and/or inflammatory changes (Figure 2, B and C). On computed tomography, only the residual cholesteatoma in an aerated middle ear and postoperative cavity can be visualized (Figure 1A)), whereas the residual cholesteatoma embedded in an opacified middle ear and postoperative cavity could not be discerned (Figure 2A).

True-negative findings were recorded in 9 patients. In all these patients, the mastoidectomy cavity was completely or partially filled with postoperative and/or inflammatory changes. On computed tomography, it was impossible to exclude any residual cholesteatoma (Figure 3A).

In 1 motion-artifact-degraded examination, a 2-mm small cholesteatoma pearl was missed on all sequences, resulting in 1 false-negative case (Case 10). There were no false-positive cases. Thirteen patients had limited cholesteatoma extension during first-stage surgery, allowing for easy, total eradication of the disease. In these patients, no second-stage surgery was performed, and the clinical follow-up and audiometry were reassuring. Micro-otoscopy showed an intact postoperative

tympanic membrane or graft without a retraction pocket. In this subgroup, no nodular hyperintensities were found on SS TSE DW images.

			Aeration	Aeration	Surgical	SS TSE	Size,
No.	Side	Age,Yr	ME	POC	findings	DW1	mm
1	L	37.5	+	-	Positive	Positive	2
2	R	48.2	+	+/-	Negative	Negative	-
3	L	37.2	+	+/-	Negative	Negative	-
4	R	34.5	+	-	Negative	Negative	-
5	R	6.7	+	-	Negative	Negative	-
6	L	23.8	-	-	Negative	Negative	-
7	L	55.2	-	-	Negative	Negative	-
8	R	43.1	-	-	Negative	Negative	-
9	R	41.9	+/-	-	Positive	Positive	4
10	L	5.7	-	-	Positive	Negative	2
11	L	39.2	+	+	Positive	Positive	2.5
12	L	69.9	+	-	Negative	Negative	-
13	R	47.2	+	+/-	Negative	Negative	-
14	L	23.2	+	+	Positive	Positive	4
15	R	50.9	+	+	Positive	Positive	3
16	R	43.5	+	+	Positive	Positive	4
17	L	17.5	+	+	Positive	Positive	6
18	R	35.0	+	+	Positive	Positive	3
19	R	45.7	+	-	Positive	Positive	4

Table 1. Summarized findings of the 19 patients who underwent second-look surgery.

Thirteen patients followed by otoscopic and imaging are not outlined in this table (see text for further details).

- indicates no data available; aeration ME (+), aerated middle ear cavity; aeration ME (-), opacified/non-aerated middle ear cavity; aeration ME (+/-), partial aeration of the middle ear cavity; aeration POC (+), aerated postoperative cavity; aeration POC (-), opacified/non-aerated postoperative cavity; aeration POC (+/-), partial aeration of the postoperative cavity; L, left; R, right; SS TSE DW1, single-shot turbo spin-echo diffusion-weighted magnetic resonance imaging; SS TSE DW1 (+), presence of a clear hyperintensity; SS TSE DW1 (-), absence of a clear hyperintensity.

In 4 of these patients, extensive postoperative scarring was observed on computed tomography with complete or partial opacification of the middle ear and postoperative cavity. In 9 patients, a signal void was noted on T1- and T2-weighted images corresponding with an aerated and disease-free middle ear and postoperative cavity.All of these patients were interpreted as showing negative findings for cholesteatoma. The period of clinical follow-up ranged from 11.2 to 40.3 months, with a mean of 25.2 months.Two patients received further MRI follow-up, including SS TSE DW, and late postgadolinium T1-weighted and T2-weighted sequences showing no hyperintensity on SS TSE DW. Sensitivity and

specificity of SS TSE DWI were 90 and 100%, respectively. Positive and negative predictive values were 100 and 96%, respectively.



Figure 1. A 35-year-old man evaluated 13 months after cholesteatoma surgery before second-look surgery. Second-look surgery demonstrated a 3 mm small residual cholesteatoma (case 18). *A*, Axial CT scan demonstrates the small soft tissue nodule at the anterior epitympanic space consistent with the small residual cholesteastoma (*arrow*). *B*, Coronal SS TSE DW sequence showing the cholesteatoma as a very small nodular hyperintense lesion (*arrow*) in the signal void of the right temporal bone under the right temporal lobe. The diagnosis of the cholesteatoma in an aerated middle ear and cavity can be equally performed by the SS TSE DW sequence as by the CT scan.



Figure 2. A 42-year-old man evaluated 17 months after first-stage cholesteatoma surgery before second-look surgery. Second-look surgery demonstrated a 4-mm small anterior epitympanic residual choleteatoma in a postoperative cavity filled with scar tissue (case 9). *A*, Axial CT scan. A status after CWU mastoidectomy is found with a partial opacification of the middle ear and postoperative cavity. It is impossible to locate the cholesteatoma on these images. When correlated with MRI, a nodular soft tissue lesion in the anterior epitympanic space can be suspected (*arrow*). *B*, Coronal SS TSE DW sequence showing a small nodular hyperintyense lesion (*arrow*) under the tegmen in the signal void of the right temporal bone, consistent with the small residual cholesteatoma. *C*, Coronal late postgadolinium SE T1-weighted image (same4 slice position as *B*). The cholesteatoma is observed as a small nodular non-enhancing lesion (*arrow*).



Figure 3. A 35-year-old man evaluated 12 months after first-stage cholesteatoma surgery before second-look surgery. Second-look surgery demonstrated postoperative and inflammatory changes without any evidence of residual cholesteratoma (case 4). *A*, axial CT scan. A status after CWU mastoidectomy is noted. Complete opacification of the postoperative cavity can be found (*arrows*). No differentiation of these soft tissues can be made. *B*, Coronal SS TSE DW sequence. No clear nodular hyperintense lesions can be observerd excluding resicual cholesteatoma (compared with the signal intensity of the residual cholesteatoma in figures 1B and 2B). Note the moderately intense signal of the inflammatory and postoperative changes in the cavity (*arrows*). *C*, Coronal late postgadolinium T1-weighted image. Enhancement of the inflammatory and postoperative changes in the cavity can be noted (*arrows*).

Discussion

In our hospital, we perform the CWU technique for the treatment of middle ear cholesteatoma. This technique carries the risk of residual cholesteatoma behind, thus often requiring second-look surgery. Distinction should be made between residual and recurrent cholesteatoma. Residual cholesteatoma is defined as keratinizing epithelium left behind at the first stage that has regrown into a cholesteatoma pearl. Recurrent cholesteatoma is defined as newly developed cholesteatoma arising from a retraction pocket in the tympanic graft (16). The decision to perform second-stage surgery was based upon the surgical findings during first stage. The percentage of residual cholesteatoma in this current study is slightly higher than the number in the previously reported data from our ear, nose, and throat department (17-18) but substantially lower than the number of residual or recurrent cholesteatoma in literature, almost invariably reaching 50% (9,10,15). Computed tomographic scanning has been reported to be insufficient in detecting the presence of residual cholesteatoma after first-stage surgery (5-7). Several recent reports have highlighted mainly 2 MRI techniques in detecting primary, recurrent, and residual cholesteatoma (Table 2). The technique of late postgadolinium T1-weighted sequences is able to detect residual cholesteatomas as small as 3 mm (8,9). Other articles have highlighted the use and limitations of EPI-DW sequences for the demonstration of acquired middle ear cholesteatoma (11,13), residual (13), and recurrent (10,12) cholesteatoma. Very recently, 2 articles have described non-EPI-DW sequences for imaging cholesteatoma (14,15). Dubrulle et al. (15) used a multishot TSE DW sequence in the detection of postoperative recurrent cholesteatoma. Despite the fact that this sequence has a lack of artifacts, a higher resolution, and a thinner slice thickness, the size limit for the detection of recurrent cholesteatoma in this study was analyzed at 5 mm, equaling the size limit for EPI-DW (10,12). In a technical report, we demonstrated the advantages of a SS TSE DW sequence over EPI DW: complete lack of susceptibility artifacts, thinner slices, and a higher imaging matrix (14). In a recent study, we succeeded in demonstrating middle ear cholesteatoma as small as 2 mm in non-operated ears using this SS TSE DW sequence (19). In the 9 truepositive cases of the operated subgroup, SS TSE DW images correctly depicted residual cholesteatoma as a nodular hyperintense dot, with a size varying between 2 and 6 mm (Table 1). Correlation of these images to standard sequences made it possible to make the differentiation between a completely aerated middle ear/postoperative cavity and an opacified middle ear/postoperative cavity (Figure 2).

uthors	Cholesteatoma type	MR technique	c	Size limit, mm	Sensitivity, %	Specificity, %	PPV, %	NPV%
itzek et al. (11)]	Primary acquired	EP1-DW1	15	ł	ł	ł	ł	ł
ikele et al. (10)	Recurrent	EP1-DW1	22	2	77	100	100	75
yache et al. (9)	Residual	Late post-Gd T1-W1	41	ო	06	100	100	92
tasolla et al. (12)	Residual/recurrent	EP1-DW1	18	2	86	100	100	92
ercruysse et al. 13)	Primary acquired	EP1-DW1	55	2	81	100	100	40
ercruysse et al. (13)	Residual	EP1-DW1	45	2	12.5	100	100	72
ubrulle et al. (15)	Recurrent	Non- EP1-DW1	24	5	100	91	93	100
e Foer et al. (19)	Primary acquired	Non- EP1-DW1	5	2	ł	1	ł	1

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Table 2. Sypnosis of the major published references on magnetic resonance of choleteatoma.

- indicates no data available; EP1-DW1, echo-planar diffusion-weighted imaging; late post-Gd T1-W1 postgadolinium enhanced T1-weighted imaging; non-Ep1-DW1; non-echo-planar diffusion weighted imaging; NPV, negative predictive value; PPV, positive predictive value.

In aerated middle ears and postoperative cavities, SS TSE DW imaging equals computed tomography in detecting small residual cholesteatomas (Figure 1). We conclude that the SS TSE DW sequence is far superior to EPI-DW sequences in detecting small residual postoperative cholesteatoma (Table 1). In 9 cases, SS TSE DW images showed no hyperintensity leading to a true negative diagnosis, confirmed by second-stage surgery. It is clear that SS TSE DW allowed us to exclude cholesteatoma in these cases. In 1 case, motion artifacts caused falsenegative findings. In our previous study on SS TSE DW, we already mentioned motion artifacts as a possible cause of false-negative findings because in these cases, the hyperintensity of the small cholesteatoma is smeared out over multiple pixels, causing a lack of intensity (19). This is the reason why the small residual cholesteatoma was missed on the motion artifact-degraded examination in 1 child. Our findings resulted in a sensitivity of 90% and a specificity of 100%. The positive predictive value was 100%, with a negative predictive value of 96%. If we do not take into account the examinations degraded by motion artifacts, the sensitivity even reaches 100%. This opens the possibility of screening for residual cholesteatoma by using the SS TSE DW sequence alone. We conclude that the SS TSE DW sequence is far superior to EPI-DW for the detection of residual middle ear cholesteatoma. Its high sensitivity, specificity, and positive and negative predictive value makes it possible to replace routine second-stage surgery for detection of residual cholesteatoma, thus avoiding unnecessary interventions.

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Middle Ear Cholesteatoma: non-echo-planar diffusion weighted MR imaging versus delayed gadolinium-enhanced T1 weighted MR imaging

De Foer B, Vercruysse JP, Bernaerts A, Meersschaert J, Kenis C, Pouillon M, De Beuckeleer L, Michiels J, Bogaerts K, Deckers F, Somers T, Hermans R, Offeciers E, Casselman J. Radiology 2010;255:866-872

Abstract

Purpose: To retrospectively compare non–echo-planar (non-EP) diffusionweighted (DW) imaging, delayed gadolinium-enhanced T1-weighted magnetic resonance (MR) imaging, and the combination of both techniques in the evaluation of patients with cholesteatoma.

Materials and Methods: This institutional review board–approved study, for which the need to obtain informed consent was waived, included 57 patients clinically suspected of having a middle ear cholesteatoma without a history of surgery and 63 patients imaged before "second-look" surgery. Four blinded radiologists evaluated three sets of MR images: a set of delayed gadolinium-enhanced T1weighted images, a set of non-EP DW images, and a set of both kinds of images. Overall sensitivity, specificity, negative predictive value (NPV), and positive predictive value (PPV), as well as intra- and interobserver agreement, were assessed and compared among methods. To correct for the correlation between different readings, a generalized estimating equations logistic regression model was fitted. Results were compared with surgical results, which were regarded as the standard of reference.

Results: Sensitivity, specificity, NPV, and PPV were significantly different between the three methods (P < .005). Sensitivity and specificity, respectively, were 56.7% and 67.6% with the delayed gadolinium-enhanced T1-weighted images and 82.6% and 87.2% with the non-EP DW images. Sensitivity for the combination of both kinds of images was 84.2%, while specificity was 88.2%. The overall PPV was 88.0% for delayed gadolinium-enhanced T1-weighted images, 96.0% for non-EP DW images, and 96.3% for the combination of both kinds of images. The overall NPV was 27.0% for delayed gadolinium-enhanced T1-weighted images, 56.5% for non-EP DW images, and 59.6% for the combination of both kinds of images.

Conclusion: MR imaging for detection of middle ear cholesteatoma can be performed by using non-EP DW imaging sequences alone. Use of the non-EP DW imaging sequence combined with a delayed gadolinium-enhanced T1-weighted sequence yielded no significant increases in sensitivity, specificity, NPV, or PPV over the use of the non-EP DW imaging sequence alone.

In the past, computed tomography (CT) was considered the imaging technique of choice for the evaluation of middle ear cholesteatoma. Magnetic resonance (MR) imaging has gained increasing importance in the evaluation of the complicated middle ear cholesteatoma (1), in the postoperative follow-up of patients who have

undergone middle ear surgery for cholesteatoma to detect residual cholesteatoma before "second-look" surgery (2-10), and in the evaluation of recurrent cholesteatoma (3,9-11).

Various MR imaging protocols have been proposed that are mainly based on the use of delayed gadolinium-enhanced T1-weighted sequences (2,4) diffusion-weighted (DW) imaging sequences (3,8,9,10), or a combination of both techniques (1,5-7,11). As regards DW imaging, distinction should be made between echoplanar (EP) DW imaging sequences [3,5,7,9,10] and non-EP DW imaging sequences (1,6,8,11). Non-EP DW imaging sequences have a thinner section thickness and a higher imaging matrix and are less prone to susceptibility artifacts than EP DW imaging sequences (6,8,12). The purpose of this study was to retrospectively compare non-EP DW imaging, delayed gadolinium-enhanced T1-weighted MR imaging, and the combination of both techniques in the evaluation of cholesteatoma.

Materials and Methods

Patients

This retrospective study was approved by the institutional review board of Sint-Augustinus Hospital, with a waiver of informed consent. We evaluated 120 patients with cholesteatoma (44 female patients [mean age, 35.8 years; range, 10–75 years] and 76 male patients [mean age, 35.4 years; range, 4–75 years]). The overall mean age was 35.7 years, with a range of 4–75 years. Data in patients before first-stage surgery and before second-look surgery were collected between July 1, 2005, and July 1, 2008. No MR imaging examination was degraded by motion artifacts, so no examination was excluded from the study. No significant difference in age distribution between sexes was present (P = .955). Patients undergoing first-stage surgery were similar in demographic variables, signs, symptoms, and disease status to patients undergoing second-look surgery.

Fifty-seven patients who were clinically suspected of having a middle ear cholesteatoma were included. They underwent an MR imaging study before first-stage surgery, which was performed within 2 weeks after imaging. The decision to perform first-stage surgery was made by the surgeon on the basis of clinical, otoscopic, audiologic, and CT findings.

Sixty-three patients who had undergone previous surgery for cholesteatoma (Canal wall up tympanoplasty) were also included. They underwent an MR imaging study before second-look surgery that was designed to help search for

residual cholesteatoma (21 patients) or recurrent cholesteatoma (42 patients). The decision to perform second-look surgery was made by the surgeon on the basis of findings at clinical follow-up and the findings at first-stage surgery. Surgery was performed within 2 months after imaging.

Imaging Technique

MR imaging was performed by using a 1.5-T superconducting unit (Magnetom Avanto; Siemens, Erlangen, Germany) with the standard head matrix coil and two 7-cm surface ring coils. To increase the signal-to-noise ratio, the 7-cm surface ring coils, which were receive only, were used together with the head matrix coil for all sequences except the whole-brain T2-weighted turbo spin-echo (SE) sequence. Axial 2-mm-thick SE T1-weighted images were obtained with the following parameters: repetition time msec/echo time msec, 400/17; matrix, 192 × 256; field of view, 150 × 200 mm; 12 sections; two acquisitions; acquisition time, 3 minutes 50 seconds. Coronal 2-mm-thick SE T1-weighted images were acquired with the same parameters except the matrix, which was set at 144 × 256.

Coronal 2-mm thick turbo SE T2-weighted images (3500/92; matrix, 192×256 ; field of view, 150×200 ; turbo factor, 13; 12 sections; two acquisitions; acquisition time, 2 minutes 41 seconds) and axial 0.4-mm-thick three-dimensional turbo SE T2-weighted images (1500/303; matrix, 228×448 ; field of view, 107×210 mm; turbo factor, 37; 48 sections; one acquisition; acquisition time, 6 minutes 19 seconds) were also obtained. In all patients, a 2-mm-thick single-shot turbo SE DW sequence was performed in the coronal plane (2000/115; matrix, 134×192 ; field of view, 220×220 mm; *b* factors, 0 and 1000 sec/mm²; 20 sections; six signals acquired; imaging time, 2 minutes 14 seconds).

All sequences were performed 45 minutes after intravenous injection of 0.1 mol gadoterate meglumine (Dotarem; Guerbet, Roissy, France) or gadopentetate dimeglumine (Magnevist; Schering, Berlin, Germany) per kilogram of body weight. MR imaging was performed by the same group of four technicians, each of whom had at least 8 years of experience in MR imaging.

Image Evaluation

Three data sets were retrospectively evaluated. In the first data set, delayed gadolinium-enhanced T1-weighted standard MR images—that is, axial and coronal delayed gadolinium-enhanced SE T1-weighted images, coronal turbo SE T2-weighted images, and three-dimensional turbo SE T2-weighted images—were evaluated alone. In the second data set, non-EP DW imaging, the single-shot turbo SE DW images were evaluated alone. Apparent diffusion coefficient maps

were not calculated. In a third data set, the combined data set, images obtained with all sequences were evaluated together. All images were made anonymous and put in a random order.

All data sets were analyzed twice by four radiologists, with an interval of at least 2 weeks between readings. Two radiologists had long-standing experience in head and neck radiology (observers 1 [A.B.] and 2 [R.H.], with 7 and 18 years of experience, respectively). The other two radiologists (observers 3 [J. Meersschaert, a resident in radiology] and 4 [M.P.]) had little or no experience in MR imaging of the head and neck or the middle ear. All radiologists were blinded to patient identity, clinical and surgical findings, and CT data.

Cholesteatoma was diagnosed if a marked hyperintensity in comparison with brain tissue was noted on DW images obtained with a *b* factor of 1000 sec/mm². Images obtained with standard MR imaging sequences were evaluated for a moderately hyperintense lesion on T2-weighted images and the characteristic peripheral enhancing cholesteatoma matrix and a central non-enhancing area on delayed gadolinium-enhanced T1-weighted images. All sets of images were classified as "definitely yes," "probably yes," "probably no," or "definitely no." Surgical findings were considered the standard of reference.

Cholesteatoma surgery was performed by one of two experienced surgeons (T.S. and E.O.). The surgeons had more than 20 (T.S.) and 30 (E.O.) years of experience in cholesteatoma surgery at a tertiary referral center. Surgical results were classified as indicating cholesteatoma, residual cholesteatoma, recurrent cholesteatoma, or no cholesteatoma. Histologic evaluation was not performed.

Statistical Analysis

The results of the original classification into four classes were dichotomized into "no" and "yes" for the purpose of analysis by combining the "definite" and "probable" categories. For only the intraobserver agreement for the different methods, the four categories were also analyzed. Interobserver agreement for each method was estimated by using the κ coefficient of agreement. Intraobserver agreement for each combination of reader and method was calculated by means of (weighted) κ values. κ Values were interpreted as suggested by Landis and Koch [13].

The diagnostic accuracy of each of the three methods was described by sensitivity, specificity, positive predictive value (PPV), and negative predictive value (NPV).

To correct for the correlation between the different readings, a generalized estimating equation logistic regression model that assumed an independent

working correlation matrix was fitted. An interaction term between observer and method was tested. In the case of no interaction, the average diagnostic measure over observers for each method was calculated. A global test for differences between methods was performed, and post-hoc pairwise testing between the methods was corrected for multiple testing by using the Bonferroni-Holm method. A significance level of .05 was used, and a corresponding 95% confidence interval (CI) was always calculated. With the sample size of our study, reasonable 95% CI widths could be obtained.

For analysis of the interobserver agreement and diagnostic accuracy, the first reading of each observer was used. All analyses were performed with software (SAS, version 9.2; SAS Institute, Cary, NC).

Results

At surgery, 95 (79.2%) cholesteatomas were found in a total of 120 patients. Fifty (88%) cholesteatomas were found in the 57 patients in the first-stage group; 15 (30%) were regarded as small and/or empty retraction pockets. Forty-five (71%) cholesteatomas were found in the 63 patients in the second-look group; 11 (24%) were considered residual cholesteatomas and 34 (76%) were considered recurrent cholesteatomas.

The overall κ coefficient of interobserver agreement showed substantial agreement for the non-EP DW images ($\kappa = 0.788$) and the combined images ($\kappa = 0.781$). The κ coefficient for the delayed gadolinium-enhanced T1-weighted images showed fair agreement ($\kappa = 0.363$) (Table 1).

Table 1. Overall κ coefficient of interobserver agreement

Method	к Coefficient
Delayed gadolinium-enhanced T1-weighted sequence	0.363 (0.347, 0.379)
Non-EP DW imaging sequence	0.788 (0.775, 0.802)
Combined sequences	0.781 (0.768, 0.7945)

Note.—Data in parentheses are 95% CIs.

Intraobserver reliability, measured with a weighted κ coefficient of agreement, showed almost perfect agreement for both the non-EP DW images and the combined images for the four observers (with κ values ranging from 0.814 to 0.982). For the delayed gadolinium-enhanced T1-weighted images, observers 1 and 3 showed almost perfect agreement (κ = 0.894 and 0.826, respectively), and

observers 2 and 4 showed moderate agreement (κ = 0.549 and 0.518, respectively) (Table 2).

Table 2. Intraobserver reliability according to method: weighted $\boldsymbol{\kappa}$ coefficients of agreement

Observer	Delayed Gadolinium- enhanced T1-weighted imaging	Non-EP DW imaging	Combined method
1	0.894 (0.844, 0.943)	0.982 (0.962, 1.000)	0.976 (0.953, 0.999)
2	0.549 (0.446, 0.651)	0.875 (0.815, 0.936)	0.814 (0.730, 0.897)
3	0.826 (0.758, 0.894)	0.979 (0.946, 1.000)).926 (0.882, 0.970)
4	0.518 (0.399, 0.637)	0.885 (0.828, 0.942)	0.856 (0.785, 0.927)

Note.—Data in parentheses are 95% CIs.

A significant interaction between method and observer was found for sensitivity (P = .049) but not for specificty (P = .30). For ease of interpretation, the interaction for sensitivity was also dropped.

Overall sensitivity for the delayed gadolinium-enhanced T1-weighted images was 56.7% (95% CI: 49.2%, 63.8%), with a specificity of 67.6% (95% CI: 53.0%, 79.4%). Overall sensitivity for the non-EP DW images was 82.6% (95% CI: 74.8%, 88.3%), with a specificity of 87.2% (95% CI: 69.0%, 95.4%). Overall sensitivity for the combined data set was 84.2% (95% CI: 76.7%, 89.6%), with a specificity of 88.2% (95% CI: 70.7%, 95.8%) (table 3). Detailed sensitivity and specificity values per method and observer can be found in (Table 1).

Table 3. Overall Sensitivity and Specificity according to Method

Method	Sensitivity (%)*	Specificity (%)
Delayed gadolinium-enhanced sequence	56.7 (49.2, 63.8)	67.6 (53.0, 79.4)
Non-EP DW imaging sequence	82.6 (74.8, 88.3)	87.2 (69.0, 95.4)
Combined sequences	84.2 (76.7, 89.6)	88.2 (70.7, 95.8)

Note.—Data in parentheses are 95% CIs.

^{*}A significant interaction between observer and method was found (P = .049).

No statistically significant difference in sensitivity or specificity could be shown between the non-EP DW images and the combined images (P = .157 and P = .705, respectively), whereas there were statistically significant differences in sensitivity and specificity between the delayed gadolinium-enhanced T1-weighted images and the combined images (P < .001 and P = .004, respectively). There

was also a significant difference in sensitivity and specificity between the delayed gadolinium-enhanced T1-weighted images and the non-EP DW images (P < .001 and P = .006, respectively).

A significant interaction between method and observer was found for NPV (P = .002) but not for PPV (P = .36). For ease of interpretation, overall NPVs were still calculated.

The overall PPV for the delayed gadolinium-enhanced T1-weighted images was 88.0%, that for the non-EP DW images was 96.0%, and that for the combined images was 96.3%. The NPV for the delayed gadolinium-enhanced T1-weighted images was 27.0%, that for the non-EP DW images was 56.5%, and that for the combined images was 59.6% (Table 4). Detailed PPV and NPV values according to method and observer can be found in Table 2.

Table 4. Overall PPV and NPV according to method

Method	PPV (%)	NPV (%)*
Delayed gadolinium-enhanced T1-	88.0 (79.1, 93.4)	27.0 (18.0, 38.4)
weighted sequence		
Non-EP DW imaging sequence	96.0 (89.7, 98.5)	56.5 (41.3, 70.5)
Combined sequences	96.3 (90.4, 98.6)	59.6 (44.0, 73.4)

Note.—Data in parentheses are 95% CIs.

^{*}A significant interaction between observer and method was found (P = .002).

No statistically significant difference in PPV could be shown between the non-EP DW images and the combined images (P = .62), whereas there was a significant difference in PPV between the delayed gadolinium-enhanced T1-weighted images and the combined images (P = .003). There was also a significant difference in PPV between the delayed gadolinium-enhanced T1-weighted images and the non-EP DW images (P = .004). For each observer, a significant difference in NPV between methods was seen (P < .0026 for all observers). For all observers, no significant difference could be shown between the non-EP DW images and the combined images, but a significant difference was found between the delayed gadolinium-enhanced T1-weighted images and between the delayed gadolinium-enhanced T1-weighted images and the non-EP DW images.

Discussion

Our results demonstrate that the highest diagnostic accuracies were achieved with the non-EP DW imaging sequence, as well as with the combined protocol.

The delayed gadolinium-enhanced T1-weighted images, however, had a significantly lower sensitivity, specificity, PPV, and NPV compared with the non-EP DW images alone and the combined images.

Comparable results were obtained by the non-experienced and experienced readers, especially for the non-EP DW images and the images obtained with the combined protocol. These results suggest that even non-experienced readers are able to correctly diagnose the presence of a cholesteatoma by using the non-EP DW imaging sequence.

In the literature, the highest sensitivity, specificity, PPV, and NPV in the diagnosis of residual cholesteatoma have been reported for delayed gadolinium-enhanced T1-weighted sequences (2,4), as well as for the combination of delayed gadolinium-enhanced T1-weighted sequences and non-EP DW imaging sequences (6,8).

The lower diagnostic accuracy for delayed gadolinium-enhanced T1-weighted images can probably be explained by the fact that our patient population included patients being imaged before first-stage and second-look surgery, without selection on the basis of CT findings. This resulted in a mixture of completely aerated, partially aerated and/or opacified, and completely opacified middle ears, mastoids, mastoidectomy cavities, and resection cavities (Figure 1). This gave rise to various signal intensities, making it difficult to recognize the characteristic signal intensities of cholesteatomas. The strength of the non-EP DW imaging sequence is that only cholesteatoma shows high signal intensity on images obtained with a *b* factor of 1000 sec/mm² (1) (Figure 2).

higher spatial resolution, and a complete lack of susceptibility artifacts at the interface between the temporal lobe and temporal bone (12).

In an electronic letter, Williams (14) states that delayed gadolinium-enhanced T1weighted imaging remains more sensitive for small lesions than DW imaging and that both techniques are needed for the detection of cholesteatoma. The fact that in our study no significant difference in sensitivity, specificity, PPV, and NPV between non-EP DW imaging and the combined protocol could be found opens the possibility of performing MR imaging in patients with cholesteatoma by using the non-EPI sequence alone, avoiding the need for intravenous contrast agent administration.



Figure 1. Coronal MR images of attic cholesteatoma in the left middle ear with surrounding inflammation in a 42-year-old man. All observers graded the non-EP DW imaging data set and the combined data set as "definitely yes" and the delayed gadolinium-enhanced T1-weighted data set as "probably yes." (a) Turbo SE T2-weighted image (3500/92; section thickness, 2 mm) shows a moderately intense nodular lesion (arrow) underneath the left temporal lobe in the left temporal bone. Note the surrounding soft tissues with high signal intensity in the mastoid and middle ear (arrowheads). (b) Delayed gadolinium-enhanced SE T1-weighted image (400/17; section thickness, 2 mm) shows the non-enhancing cholesteatoma (arrow) surrounded by enhancing inflammation in the middle ear and mastoid (arrowheads). (c) Single-shot turbo SE DW image obtained with a *b* factor of 1000 sec/mm² (section thickness, 2 mm) shows the cholesteatoma as a small hyperintense lesion in the signal void of the left temporal bone (arrow).



Figure 2a. Coronal MR images of a small residual cholesteatoma in the right mastoid, under the tegmen and against the medial wall, in a 44-year-old woman. All observers graded the non-EP DW imaging data set, as well as the combined data set, as "definitely yes." However, on the delayed gadolinium-enhanced T1-weighted data set alone, scores varied from "definitely yes" to "probably yes" and "definitely no." The size of the cholesteatoma was estimated to be 3 mm in its longest diameter. (a) Turbo SE T2-weighted image (3500/92; section thickness, 2 mm) shows a very small nodular area of hyperintensity under the tegmen in the mastoid (arrow). (b) Delayed gadolinium-enhanced SE T1-weighted image (450/17; section thickness, 2 mm) shows the cholesteatoma as a very small hypointense lesion surrounded by a small rim of enhancement underneath the right temporal lobe (arrow). (c) Single-shot turbo SE DW image obtained with a *b* factor of 1000 sec/mm² (section thickness, 2 mm) shows the cholesteatoma as a small hyperintense lesion in the signal void of the right temporal bone (arrow).

Recent publications demonstrated that non-EP DW imaging sequences have higher sensitivity and specificity in the detection of residual middle ear cholesteatoma (6,8) than do EP DW imaging sequences [8]. This is explained by the fact that non-EP DW imaging sequences have thinner section thicknesses,

The relatively low NPV in our study can be explained by the mixture of patients undergoing first-stage surgery with those undergoing second-look surgery and by the presence of a relatively high number of small and/or empty retraction pockets in the first-stage group. These findings are in line with those in the literature (1,5), in which small and/or empty retraction pockets are responsible for false-negative findings at diffusion-weighted imaging in patients before first-stage surgery.

On the basis of these results, our imaging protocol for cholesteatomas has been changed. Delayed gadolinium-enhanced T1-weighted sequences are no longer used. To better localize suspected lesions identified at non-EP DW imaging, an axial and coronal turbo SE T2-weighted sequence is added. This results in a substantial shortening of imaging time. This will also result in an important cost saving for the health care system and a higher patient throughput for MR imaging.

No subgroup analyses between the first-stage and second-look surgery groups were performed in our study because the respective sample sizes were too small to allow us to draw valid inferences. No formal power analysis was performed before the study was started. For the patient population at hand, however, the sample size is quite large compared with that in other studies (1-4,6-9,11).

A probable bias of our study might be the high number of cholesteatomas detected at surgery. In the first-stage surgery subgroup, this can be explained by the fact that patients were included on the basis of clinical suspicion. In the second-look surgery subgroup, this can be explained by the fact that in our institution, patients with negative MR imaging findings before second-look surgery do not undergo surgery. As we considered surgical results as the standard of reference, we included only patients undergoing surgery, resulting in a relatively high number of cholesteatomas at second-look surgery. In this retrospective study, this high positive number is less relevant, as the goal of the study was not to evaluate the detection rate of cholesteatoma before second-look surgery but to compare different MR imaging techniques in patients with cholesteatoma.

Another cause of probable bias could be the delay between MR imaging and surgery, which was longer in the second-look surgery subgroup. This also seems less relevant, as cholesteatomas grow very slowly.

In conclusion, MR imaging in patients suspected of having middle ear cholesteatoma can be performed by using only a non-EP DW imaging sequence, avoiding the need for further contrast agent administration. Also, non-EP DW imaging sequences have significantly higher sensitivity, specificity, PPV, and NPV than delayed gadolinium-enhanced T1-weighted sequences, and results are less dependent on the observer's experience.

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Chapter 5

Contribution of bony obliteration techniques in clinical cholesteatoma management: short term results

Chapter 5.1

Mastoid and epitympanic bony obliteration in pediatric cholesteatoma.

Vercruysse JP, De Foer B, Somers T, Casselman J, Offeciers E. Otology & Neurotology (2008) 29: 953-960

Abstract

Objective: The primary goal of cholesteatoma surgery is complete eradication of the disease. To lower the recurrence rate in the pediatric population in Canal wall up techniques and to avoid the disadvantages of Canal wall down techniques, the bony obliteration technique with epitympanic and mastoid obliteration has been developed. The objective of this study was to evaluate the long-term surgical outcome and recurrence rate of this technique in children.

Study Design: Retrospective case review.

Setting: Tertiary referral center.

Patients: Fifty-two children (<16 yr) were operated on in 90.4% (n = 47) for a primary or recurrent cholesteatoma and in 9.6% (n = 5) for an unstable cavity.

Intervention: In all cases, we closed the tympanoattical barrier and the posterior tympanotomy with sculpted cortical bone and then completed obliteration of the epitympanum and mastoid with bone pâté. A reconstruction of the middle ear was performed by means of an allograft tympanic membrane including the malleus handle and a sculpted allograft malleus or incus for columellar reconstruction.

Main Outcome Measures: Recurrent rate; residual rate; functional outcome; hygienic status of the ear; long-term safety issues.

Results: The mean follow-up time was 49.5 months (range, 12-101.3 mo). Recurrent cholesteatoma occurred in 1.9% (n = 1). Residual cholesteatoma was detected in 15.4% (n = 8) of the cases. Postoperative hearing results revealed a median gain on pure-tone averages of 14.3 dB and a median postoperative airbone gap of 25.6 dB.

Conclusion: The mastoid and epitympanic BOT is an effective technique to lower the recurrence rate of cholesteatoma in the pediatric population. Follow-up by magnetic resonance imaging provides a safe, non-invasive method for postoperative detection of residual cholesteatoma.

The primary goal of the surgical treatment of chronic otitis media with cholesteatoma is the complete eradication of the disease (no residual disease), whereas secondary goals are the prevention of recurrent disease, the improvement of the hygienic status of the ear, and the preservation or improvement of hearing (1). Due to higher rates of recurrent and residual disease, children present a greater challenge than adults (2-6). Various techniques have been advocated in order to reach these goals. The Canal wall down (CWD) mastoidectomy provides lower recurrence rates, but it often requires regular cavity

cleaning and is associated with recurrent infection, water intolerance, caloricinduced vertigo, and the diminished ability to wear a hearing aid (7,8). The Canal wall up (CWU) technique preserves the normal bony anatomy, avoids the disadvantages associated with cavities, and has shown better hearing results, but it has a significantly higher recurrence rate. Retraction pocket formation in CWU ears can lead to recurrent cholesteatoma. The bony obliteration technique (BOT) consists of the meticulous bony reconstruction of the canal wall and of sealing off the middle ear by means of sculpted cortical bone chips and then by a complete obliteration of the drilled out epitympanum and mastoid with bone pâté. This seems to dramatically lower the incidence of recurrent disease. In this report, we describe our experience with the BOT in a pediatric series of cholesteatoma cases and in cases with an unstable cavity after CWD surgery for cholesteatoma. The indications, the surgical outcome including the recurrence rate, the residual rate, the functional results, and the otoscopic and imaging follow-up, are discussed. Our results should be considered preliminary until the complete 5-and 10-year followup results become available.

Material and methods

We retrospectively evaluated a series of 52 consecutive children younger than 16 years. All children underwent a CWU-BOT operation at the University ENT Department of the Antwerp St-Augustine Hospital between September 1997 and June 2006. Forty-seven children presented with a primary acquired (n = 16) or recurrent (n = 31) cholesteatoma and five children with a problematic or draining cavity. All surgery was performed by the two senior authors (E. O. and T. S.). The following outcome measures were analyzed: recurrent rate, residual rate, functional outcome, hygienic status of the ear, and long-term safety issues. For this purpose, a database was created, including age at surgery, sex, side, history of surgery, surgical findings, otoscopic follow-up, and audiological testing results with preoperative and postoperative air conduction (AC), bone conduction (BC), air-bone gaps (ABGs), and pure-tone averages (PTAs). Audiological assessment was conducted every 3 months in the first postoperative year and once yearly in the following postoperative years in a soundtreated room using a Madsen Electronics OB 822 and Interacoustics AC33 Clinical Audiometer, calibrated according to ISO standards. No response to air-conducted sound was coded as 120 dB, and no response to bone-conducted sound was coded as 80 dB. Missing values were coded as such. The postoperative anatomical status of the external

auditory canal (EAC) and tympanic membrane (TM) was evaluated by yearly otoscopic control, thus controlling for the presence of retraction pockets, canal wall breakdown, or recurrent cholesteatoma. The presence of residual cholesteatoma was visually evaluated during planned or functional second stage surgery or by the combination of high-resolution computed tomography (HRCT) and magnetic resonance imaging (MRI). Recurrent cholesteatoma is defined as a new cholesteatoma developing from an unsafe, non-self-cleaning retraction pocket. Residual cholesteatoma is defined as keratinizing squamous epithelium left behind during first-stage surgery, which has regrown into a visually identifiable cholesteatoma. Second-look surgery using a retroauricular (n = 23) or transmeatal approach (n = 19) was executed after 12 months. The decision to stage was taken by the surgeon during the first-stage surgery based on the extent and characteristics of the cholesteatoma and on the surgical complexity of the anatomy. Although the bony reconstruction of the canal wall and of the tympanoattical barrier was always performed at the first stage, in 23 cases, the obliteration of the mastoid and attic space with bone pâté was postponed until the second stage for safety reasons, taking into account the possibility of residual disease. During second-look surgery, subsequent bony obliteration and, if needed, functional correction were performed. When we considered the odds for residual disease negligible, no second-stage surgery was performed. However, all patients were regularly followed up by yearly micro-otoscopy and by HRCT and MRI including non-echo-planar diffusion-weighted imaging (non-EPI DWI) sequence at 1 and 5 years after surgery. Adequate long-term imaging follow-up of obliterated mastoids is compulsory to prevent late complications due to residual cholesteatoma. Counts, percentages, histograms, and box plots were used to describe nominal data. Statistical analysis was performed using a t test, and significance was defined as p < 0.05.

Surgical Technique

The BOT was applied in two subgroups of the study population. The first group comprised cases with either primary cholesteatoma or recurrent cholesteatoma after previous CWU surgery. The second group comprised cases with an unstable cavity. In both groups, the same surgical principal was applied. Surgery was performed under general hypotensive anesthesia using facial nerve monitoring. A classic retroauricular incision was followed by the elevation of anteriorly based dermal and musculoperiosteal flaps. Cortical bone chips were harvested using a flat chisel and put aside. A bone pâté collector (Bess, Berlin-Zehlendorf, Germany) and a cutting burr were used to collect healthy bone pâté from the cortex of the

mastoid and if needed from the squama of the temporal bone. Care was taken not to damage the soft tissues and not to harvest diseased bone. The bone pâté was mixed with an antibiotic solution (rifamycin solution, 500 mg/10 ml) forming a semisolid paste. A cortical mastoidectomy and a wide posterior tympanotomy using the CWU technique were performed. In contrast to the original Mercke technique (9) and the technique described by Gantz et al. (10)), the posterior canal wall was left intact during the whole procedure. Our aim was to preserve maximum vitality of the remaining bony canal wall, thus speeding up the healing process. cholesteatoma. diseased soft tissue. ossicular remnants The (eroded incus/malleus), and unhealthy bone were completely removed, and all cell tracts were cleaned.

If the malleus handle was favorably positioned for columellar reconstruction to the head of the stapes or to the footplate, the head of the malleus was removed using a malleus nipper. Bone chips were sculpted and placed at the tympanoattical barrier and posterior tympanotomy to completely seal off the epitympanum and mastoid from the middle ear cavity. Lesions of the scutum and the bony canal wall were carefully reconstructed with sculpted solid cortical bone. In case of a radical cavity, the epithelial lining and all pathological remnants were first removed, and the remaining mastoid cavity was adequately checked and drilled to remove mucosal remnants. Harvested cortical bone was sculpted to form a new bony canal wall in continuity with the complete closure of the tympanoattical barrier. The paratympanic space was thus completely isolated from the middle ear cavity by a solid bony partition. It was then progressively and completely filled up with bone pâté, up to the level of the cortex. An M-meatoplasty according to Mirck (11)) was often performed to optimize the size of the external meatus, thus stimulating the self-cleaning capacity of the outer ear canal. The middle ear reconstruction was performed using a tympano-ossicular allograft (TOA) (12). The allograft consisted of a meatal periosteal cuff in continuity with the TM and malleus handle. The malleus head was removed with a malleus nipper at the level of the lateral process of the malleus. The allograft TM (with malleus handle) was rotated clockwise (left ear) or counterclockwise (right ear) to place the malleus handle in an advantageous position, perpendicularly centered above the oval window. This allows for the most effective columellar energy transduction between the implanted malleus handle and the stapes or stapes footplate. The ossicular reconstruction was executed using a remodeled allograft incus or malleus. If needed, a thin silastic sheet (0.5 mm) was placed extending from the protympanum to the retrotympanum, to avoid fibrous adhesions and to promote the regrowth of healthy middle ear mucosa during postoperative healing. Perioperative intravenous

antibiotics (cefazoline) were continued for 24 hours. Patients were sent home with amoxicillin-clavulanate or cefuroxim in case of penicillin allergy for 5 days. TOA are harvested and prepared at the tissue bank of the St-Augustine Hospital, according to the standards of the Belgian law (Belgisch Staatsblad 13.6.86). Immediately after removal from the cadaver, the grafts are fixed for at least 2 weeks in a solution of 4.5% buffered formaldehyde. After dissection, tissues are preserved in Cialit (15,000 aqueous solution of a sodium salt of an organomercuric compound) for a period of 3 weeks to 2 months. This study does not address the alleged risk of transfer of infectious diseases, such as Creutzfeldt-Jacob disease (CJD) and human immunodeficiency virus (HIV) infections. Transmission of CJD has been reported after implantation of dura mater (13)] or corneal grafts (14). It has, however, never been reported after transplantation of tissues other than brain, cadaveric dura matter, or corneal grafts. In addition, the incidence of CJD is extremely low (1: 1,000,000), and the applied stringent criteria for donor selection exclude donors at risk for CJD. No reports of transmission of HIV by non-vital allograft material have appeared in the literature. Formaldehyde, used in the preservation of allografts, is known to inactivate HIV readily (15).

Results

Fifty-two children underwent the BOT. Thirty-four (65%) were males and 18 (35%) were females. One child had a cleft palate. The mean age was 11.6 years (range, 5-15 yr). Thirty-six patients (69.2%) had a history of ear surgery. The mean postoperative follow-up period was 49.6 months (range, 12-101.3 mo; Table 1). Twenty-one (40.4%) of the children had a follow-up period of 5 years. Three patients were followed for more than 8 years. At latest follow-up, a safe, dry, and trouble-free graft was present in 46 children (88.5%). One patient developed a perforation after an acute otitis media during the sixth postoperative year. In five patients, otoscopic follow-up revealed the presence of a self-cleaning mesotympanic retraction pocket, one of which progressively evolved toward a recurrent cholesteatoma in the third year of otoscopic follow-up (Figures 1 and 2). In this case, revision surgery revealed the presence of a mesotympanic atelectatic TM, partial resorption of the tympanoattical barrier with extension of the retraction into the attic, and presence of cholesteatoma (Figure 3). Reclosure of the epitympanum by means of bone chips and pâté, in combination with cartilage tympanoplasty, was performed. During subsequent follow-up, no new recurrence developed.

Table 1. General patients characteristics (n = 52)



Figure 1. Histogram showing population follow-up data (n): Aspect of the tympanic membrane (TM); normal, retraction, perforation TM, or cholesteatoma. An asterisk shows the occurrence of a recurrent cholesteatoma after 3 years of follow-up (see text for further details).



Figure 2. Histogram showing population follow-up data (% of total population): Aspect of the tympanic membrane (TM): normal TM, retraction TM, perforation TM, or cholesteatoma. An asterisk shows the occurrence of a recurrent cholesteatoma (see text for further details).



Figure 3. Postoperative imaging performed after primary bony obliteration. A, Coronal reformation HRCT image of a patient showing the presence of an atelectatic tympanic membrane with an attical soft tissue lesion causing a partial destruction of the attico-tympanal barrier, suggestive for the presence of a recurrent cholesteatoma (arrows) of the right ear. B, Coronal reformation HRCT images of a patient with normal postoperative bony obliteration with an homogeneous obliteration (asterisk) and middle ear aeration (arrow). C, Coronal non-echo-planar diffusion weighted image (same patient as Fig A) showing a nodular hyperintense lesion on the right side (arrow), characteristics for the presence of a recurrent cholesteatoma. D, Coronal non-echo-planar diffusion weighted image (same patient as Fig D) showing no clear nodular hyperintensity.

In three other patients, the self-cleaning retraction was surgically corrected using cartilage reinforcement during planned functional surgery. The fifth retraction pocket remained self-cleaning and stable during follow-up. The percentage of ears that remained without recurrent disease was 98.1% (n = 51). In 52% (n = 27) of all cases, a preliminary (n = 6), first-stage (n = 20) or second-stage (n = 1) M-meatoplasty has been performed to widen the external meatus, thus enhancing

the self-cleaning capacity of the outer ear canal. Second staging by means of second look tympanotomy (n = 42) or imaging follow-up (HRCT and non-EPI DWI; n = 31) revealed in eight cases the presence of a residual cholesteatoma pearl, each of which was present in the tympanic cavity (15.4%). No residual cholesteatoma within the bony obliteration was detected to date.

One case of the studied population needed readmission for wound infection, which was treated with intravenous antibiotics. This case was one of the first cases in our series and did not receive preoperative and postoperative antibiotics. Following this event, antibiotics became the rule. No other complications (facial nerve, SNHL, bone resorption, or canal wall breakdown) occurred in this studied population. A list of complications is summarized in Table 2.

Table 2. Postoperative complications after using the BOT (see text for further details)

Postoperative wound infection	1
Perforation	1
Mesotympanic self-cleaning retraction	4 (5)
Residual cholesteatoma	8
Recurrent cholesteatoma	1

A reconstruction of the ossicular chain was attempted during primary surgery in all patients. One of the reconstructive advantages of TOAs is that they allow a stable positioning of the TM. The fibrous annulus is anchored in the patient's bony annulus, and the periosteal cuff of the graft is securely glued in place in the bony EAC. The implanted malleus handle forms an integral part of the graft and allows for stable anchoring of the remodeled allograft ossicle as a columellar reconstruction to stapes or stapes footplate. If a residual cholesteatoma pearl is detected at second stage or by follow-up MRI, the columella can be removed with the pearl and a new ossicular reconstruction can be made.

At primary surgery, the stapes superstructure was absent in 61.5% (n = 32) due to destruction by primary or recurrent cholesteatoma. A fixed footplate was found in 5.7% of the patients (n = 3). The median preoperative PTA-AC was 51.67 dB with a median preoperative PTA-ABG of 43.32 dB. Postoperative hearing results were assessed after 1 year and revealed a median gain on PTA of 15 dB and median postoperative ABG of 25.6 dB.

The postoperative ABG closure after ossicular reconstruction is presented in Figure 4 and Table 3. No statistically significant difference was found between preoperative and postoperative bone conduction (p < 0.05; t test).



Figure 4. Pre-and postoperative hearing levels in 52 children for whom full audiometric data were available 1 year postoperatively. Box and Whisker plots showing pre-and postoperative hearing thresholds (PTA). Preop BC, preoperative bone conduction threshold; Preop AC, preoperative air conduction threshold; Postop AC; postoperative air conduction threshold; Postop AC; postoperative bone conduction threshold; Gain AC, difference between Preop AC and Postop AC. Whiskers, minimum values; Large rectangles, 25th-75th percentile; Small horizontal black bars, median values; Dots, outlying value.

Table 3. Detailed summary of the postoperative hearing levels of 52 children for whom full audiometric data were available 1 year postoperatively

	Percentage ABG closures (n = 52)
0-10 dB	13.4% (n = 7)
11-20 dB	30.8% (n = 16)
21-30 dB	25% (n = 13)
>31 dB	30.8% (n = 16)

The hearing results (PTA) are expressed in percentages of ABG closures.

In 44% (n = 23/52) of the patients, a functional correction was attempted during second-look surgery, using a remodeled malleus (n = 18) or incus allograft (n = 5).

In several children, a conductive hearing loss persisted because of the lack of middle ear aeration or because of a fixed footplate (n = 3).

Discussion

The goals of the surgical treatment of middle ear cholesteatoma are the complete eradication of the disease, the prevention of recurrent cholesteatoma, the restoration of the hygienic status of the ear, and the preservation or improvement of the hearing (1). Two basically different techniques have been advocated to reach these goals: CWU and CWD techniques. The advantages of the CWD technique are as follows: no need for staging, a lower rate of residual cholesteatoma, and a lower rate of recurrent cholesteatoma. On the other hand, the advantages of the CWU technique are as follows: a better hygienic status of the ear and a better functional outcome (2-5). The disadvantages of the CWD technique are associated higher morbidity, such as the need for regular cleaning, recurrent infections, water intolerance, caloric-induced vertigo, and the difficulty to wear a hearing aid if needed; and a worse functional outcome. The disadvantages of the CWU technique are the need for second and potentially further staging, the need for long-term follow-up to detect recurrent cholesteatoma, higher rates of residual disease, and higher rates of recurrent disease (1-8).

In 1997, we decided to find out whether it is possible to combine the advantages and, at the same time, avoid the disadvantages of both the CWU and CWD techniques: the mastoid and epitympanic bony obliteration. As a comparison basis for our study, we used our previously published results of the conventional CWU with TOA reconstruction (16) and the results of the CWU and CWD techniques available in the literature.

Many materials have been used to obliterate the mastoid cavity (17) ncluding autologous material as fascia, fat, vascularized musculoperiosteal flaps, cortical bone chips, cartilage and bone pâté', and other biocompatible materials such as hydroxyapatite granules/cement (18-19) and demineralized bone matrix [20]. Preservation and/or reconstruction of a normal anatomy of the EAC and TM are possible in most patients. The presence of a solid bony barrier and obliteration of the mastoid with bone pâté close off the epitympanum and mastoid from the middle ear cavity and seem to lower the incidence of new retractions of the TM.

Rate of Recurrent and Residual Cholesteatoma

In our study, the recurrence rate was 1.9% after a mean follow-up of 49.6 months (range, 12-101.3 mo). This compares very favorably to the outcome of our previously published series of the CWU technique in a pediatric population, which showed a recurrence rate of 18% after a mean follow-up of 54 months (range, 12-191 mo) (16). It seems safe to infer that bony obliteration enhances the biological stability of the ear, probably by reducing the size of the middle ear cell system, thus decreasing the total surface of mucosal lining and diminishing its capacity for gas absorption and/or inflammation. Our results confirm the lower recurrence rates of the BOT in a pediatric population reported by Gantz et al. (10). Other reports on complete bony obliteration showed similar results in an adult and childhood cholesteatoma population (9,10,17-23). The results also compare favorably to the outcome of other papers reporting on the results of the conventional CWU technique in pediatric cholesteatoma (3-5).

Moreover, our results are not inferior to the recurrence rate reported by authors using the CWD technique (3,6-8).

It must be emphasized that our results must be considered preliminary until the full 5-and 10-year follow-up results of the presented series have become available. Therefore, it is obvious that long-term, yearly otoscopic follow-up remains the criterion standard in cholesteatoma surgery. The residual rate in our study was 15.4%, as evaluated by the combination of staging and postoperative imaging. It is lower in comparison with the results of our previously published conventional CWU study on pediatric cholesteatoma, which showed a residual rate of 27% (16). To date, no residual cholesteatoma has been detected within the obliterated paratympanic spaces. However, given the non-negligible rate of residual disease, it remains compulsory to apply a very strict follow-up. In all our cases nowadays, a non-EPI DWI control is executed or planned at 5 years after surgery (Long-Term Safety Issues).

Functional Outcome

The functional outcome at 1 year of this series seems somewhat poorer or similar than those reported by some others in CWU surgery (1,3,5,7,16) but comparable to those reported by Gantz et al. (10) after pediatric bony mastoid obliteration. Despite the fact that these children experienced poor hearing with a median preoperative PTA-AC of 51.67 dB and median preoperative PTA-ABG of 43.3 dB, postoperative measurements revealed a marked improvement with acceptable hearing results with a median postoperative PTA-ABG of 25.6 dB, a median

postoperative PTA-AC of 32.5 dB, and PTA-ABG closure 20 dB or less in 30.9% (Table 3).

The improvement is probably due to the fact that we now position the malleus handle of the TOA in a more advantageous position, as compared to the conventional position of the monobloc TOA. In the latter case, a fullmonobloc TOA, consisting in a TM, malleus, incus, and the anterior stapedial crus with half a footplate, is used for the reconstruction of the middle ear. In our actual series, we used a columellar reconstruction between the malleus handle and the stapes head or footplate. However, by a slight rotation of the graft, the malleus handle is placed in a more favorable position, perpendicular to the center of the oval window. This allows for the most effective energy transduction. Although a columellar reconstruction seems to achieve better functional results, the conventional drawbacks are its long-term instability and its tendency toward extrusion. The use of TOAs for columellar reconstruction offers a distinct advantage. The malleus handle is firmly incorporated in the allograft TM and, as such, forms a stable anchor point for the columella, while at the same time, it protects against columellar extrusion. The functional outcome of our series compares poorly to the results of non-cholesteatoma chronic otitis surgery. This is due to the high percentage of cases in which the stapes superstructure was absent (61.5%), to the fixed footplate in 3 cases, and to the fact that, in cholesteatoma ears, an essential precondition for functional success, that is, normal middle ear aeration, is often lacking.

Hygienic Status of the Ear

At latest follow-up, a safe, dry, and trouble-free graft was observed in 46 children (88.5%). All patients are still followed up by yearly otoscopic control. With the exception of the perforated case, all ears are dry, self-cleaning, and water-resistant to date. The combined presence of a normal-sized external meatus, achieved in 52% of the cases by means of an M-meatoplasty, of a normal-sized ear canal protected by a solid bony wall, and of a TM well placed in its normal position seems to provide the ideal basis for a stable hygienic condition of the ear.

Long-Term Safety Issues

The long-term safety of the ear is a primary concern in cholesteatoma surgery, especially in children. Therefore, surgical staging to detect residual cholesteatoma has been advocated by most authors (1-5,9,10). Adequate imaging follow-up of obliterated mastoids is necessary to prevent late complications when residual cholesteatoma remains buried in the bony obliterated mastoid. HRCT has been

shown to be very effective in excluding and detecting small pearls in obliterated mastoids, presenting as punched-out lesions in the dens bone (24,25). However, in the case of associated opacified lesions, further characterization of the lesion by MRI will be necessary. Until recently, small residual pearls (<5 mm) could not be detected using DWI (24,26).

The recent availability of the non-EPI DWI MRI sequence offers a safe, noninvasive, selective, sensitive, and comparatively cheap alternative to exploratory staged surgery. It allows for the detection of cholesteatoma pearls down to a size of 2 mm (27-29). Because we allow for the possibility that it takes more than 1 year for a residual pearl to develop into a detectable lesion, we now routinely image all our cholesteatoma cases at 1 and 5 years postoperatively. MRI thus effectively replaces second-stage surgery in our department for 2 years. Offsetting the cost of surgical staging to the cost of twicerepeated MRI, this protocol is not only less burdening to the patient on a practical and emotional level but also compares most favorably on the budgetary level for both the patient and the public health system. Our analysis showed that the full HRCT and MRI protocol, repeated twice, is six times cheaper than exploratory surgery within the Belgian context. We recently completed the validation process of the non-EPI DWI MRI sequence [29]. Therefore, we now use only this sequence in the follow-up screening for residual cholesteatoma. For screening purposes, we deem the use of HRCT and the use of the MRI sequence 45 minutes after injection with gadolinium no longer necessary. The advantages are evident. 1) The non-EPI DWI sequence by itself takes less than 5 minutes to execute. On the logistic level, this optimizes patient put-through in the radiology department.

2) The cost of the expensive gadolinium is avoided.

3) The examination becomes much less burdening for the patient on the emotional level. In conclusion, the financial and emotional cost of follow-up screening for residual disease of cholesteatoma becomes negligible in comparison with the cost of exploratory surgery in cases without residual disease.

Conclusion

Our results indicate that the BOT, performed in children with primary/recurrent cholesteatoma or unstable cavities reconstruction of cavities, is a very useful technique to deal with the higher rates of residual and recurrent cholesteatoma in the pediatric population. The results show that the incidence of recurrent cholesteatoma has dramatically declined. Acceptable functional results have been

achieved. The problem of residual cholesteatoma can be safely dealt with by staging and/or postoperative imaging, using a combination of CT and new MRI techniques including non-EPI DWI MRI. We are using this surgical technique in the majority of cholesteatoma cases.

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Chapter 6

Contribution of bony obliteration techniques in clinical cholesteatoma management: long-term results
Chapter 6.1

Long-term follow-up after bony mastoid and epitympanic obliteration: radiological findings

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Abstract

Objective: The Canal wall up bony obliteration technique lowers the incidence of recurrent cholesteatoma, but carries the potential risk of obliterating residual cholesteatoma. The objective of this study was to report long-term follow-up radiological findings after performing a Canal wall up bony obliteration technique procedure, in order to detect residual and/or recurrent cholesteatoma.

Patients: Fifty-one patients presenting with a cholesteatoma or a troublesome cavity were operated upon using the Canal wall up bony obliteration technique, and were evaluated by follow-up imaging a mean of 76.4 months post-operatively (range, 53.8–113.6 months).

Intervention: All patients were evaluated with high resolution computed tomography and magnetic resonance imaging (including delayed contrast, T1-weighted imaging and non-echo-planar, diffusion-weighted imaging).

Results: Imaging revealed the presence of one residual, one recurrent and one congenital petrosal apex cholesteatoma. On high resolution computed tomography, completely obliterated mastoid filled with bone was observed in 74.5 per cent (38/51) of patients, and an aerated middle-ear cavity in 64.7 per cent (33/51). High resolution computed tomography clearly detected any associated soft tissue present in the middle-ear cavity (18/51) and in the obliterated mastoids (13/51), but could not characterise this tissue. Non-echo-planar, diffusion-weighted magnetic resonance imaging clearly identified all three cholesteatomas, and differentiated them from other associated soft tissues. No cholesteatoma was found within the obliterated mastoids.

Conclusion: Long-term follow-up indicated that the Canal wall up bony obliteration technique is a safe method with which to treat primary and recurrent cholesteatoma and to reconstruct unstable cavities. Soft tissue was found quite often in the middle ear and obliterated mastoids. High resolution computed tomography identified its presence but could not further characterise it. However, non-echo-planar, diffusion-weighted magnetic resonance imaging succeeded in differentiating soft tissues, enabling detection of residual or recurrent cholesteatoma after a Canal wall up bony obliteration technique procedure.

Introduction

The goals of cholesteatoma surgery are the complete eradication of pathology, the prevention of recurrent disease, the restoration of the hygiene status of the ear, and the preservation of hearing loss or improvement of hearing (1).

Our preferred surgical procedure for the treatment of middle-ear cholesteatoma has been the closed technique, or Canal wall up approach, with bony obliteration of the mastoid and epitympanic cells, the so-called Canal wall up bony obliteration technique (2). This technique dramatically lowers the incidence of recurrent disease after primary cholesteatoma surgery, and achieves excellent ear hygiene and acceptable functional results (2-5). It can also be successfully applied to reconstruct unstable and troublesome cavities caused by Canal wall down surgery for cholesteatoma (2,3,6).

When performing bony obliteration, the main concern is the risk of burying residual cholesteatoma beneath the obliteration material. Follow-up of obliterated mastoids using accurate and reliable imaging is mandatory to prevent late complications, which may take many years to appear.

Several authors have reported on the value of high resolution computed tomography (CT) and magnetic resonance imaging (MRI) for the detection of residual cholesteatoma in mastoids which have undergone bony obliteration.[2-8] High resolution CT is characterised by a low sensitivity and specificity for cholesteatoma, and cannot differentiate cholesteatoma from other soft tissues. Recently, non-echo-planar, diffusion-weighted MRI sequences have proven their value in detecting acquired, congenital and residual cholesteatoma down to a size of 2 mm (9-11).

The aim of this study was to report on the long-term imaging follow-up of bony mastoid and epitympanic obliteration, including CT and MRI modalities.

Materials and methods

We retrospectively evaluated a series of 51 patients who had undergone eradication of cholesteatoma using the bony obliteration technique at the St Augustine Hospital, Antwerp, between 21 September 1998 and 9 December 2002. All surgery had been performed by the senior author (EO).

The indication for bony obliteration of the mastoid and epitympanic space had been the presence of a primary acquired or recurrent cholesteatoma (42 patients) or an unstable, problematic cavity following earlier Canal wall down surgery (nine patients). For both indications, the surgical principles and technique were the same, the only difference being that in the problematic cavity patients the whole posterosuperior bony canal wall required reconstruction down to the level of the facial canal by means of one or a few solid pieces of sculpted cortical bone, while in the cholesteatoma patients the canal wall was at least partially intact and needed less reconstruction. Subsequently, the mastoid and epitympanic space was filled with bone pâté up to the level of the cortex (2,3).

All patients underwent high resolution CT and MRI, including non-echo-planar, diffusion-weighted MRI, a mean period of 76.4 months (median, 76.4 months; range, 53.8–113.6 months) after Canal wall up bony obliteration technique surgery, in order to detect residual or recurrent cholesteatoma. The imaging protocol for follow-up of cholesteatomas consisted of high resolution CT and MRI scanning, the latter including delayed contrast, T1-weighted imaging and non-echo-planar, diffusion-weighted sequences.

Imaging interpretation

All high resolution CT and MRI sequences were retrospectively evaluated by experienced head and neck radiologists (JC and BDF). Evaluators were blinded to all clinical data, including the surgical report and outcome, patient identity, and any 'second look' surgical findings.

The radiologists scored the imaging scans for the presence of cholesteatoma, categorising each case as either positive (i.e. residual cholesteatoma present) or negative (i.e. residual cholesteatoma absent). Interpretation of high resolution CT scans was based on the presence of soft tissue within the middle ear and/or bony obliterated mastoids and 'punched-out' lesions in the obliterated mastoid. On conventional MRI sequences, interpretation relied on the signal intensity of the soft tissues on T2-weighted images and late gadolinium-enhanced, T1-weighted images. On T2-weighted images, cholesteatoma presented as a nodular, moderately intense lesion. On late post-gadolinium, T1-weighted images, the lesion was non-enhancing but often showed an enhancing rim which corresponded to the perimatrix. On non-echo-planar, diffusion-weighted MRI sequences, cholesteatoma showed as a characteristically hyperintense lesion. All scans were scored as either positive or negative for cholesteatoma.

Imaging techniques

Magnetic resonance imaging was performed using a 1.5 T superconductive unit (Magnetom Avanto; Siemens Medical Solutions, Erlangen, Germany) using the standard head matrix coil. Axial, 2 mm thick, spin-echo, T1-weighted images and

coronal, 2 mm thick, spin-echo, T1-weighted images were acquired with the same parameters. Coronal, 2 mm thick, turbo spin-echo, T2-weighted images and axial, 0.4 mm thick, three dimensional, turbo spin-echo, T2-weighted images were also obtained.

In all patients, a 2 mm thick, non-echo-planar, diffusion-weighted sequence (single-shot, turbo spin-echo, diffusion-weighted sequence) was acquired in the coronal plane (b factors 0 and 1000 mm²/sec). All sequences were acquired 45 minutes after intravenous contrast injection with either gadoterate meglumine (0.1 mmol/kg body weight; Dotarem, Guerbet, Roissy, France) or gadopentetate dimeglumine (Magnevist, Shering, Berlin, Germany). Computed tomography was performed using a 16-row, multislice CT scanner (Lightspeed; General Electric, Milwaukee, Wisconsin, USA) with coronal reformations. Axial slices were acquired with a thickness of 0.625 mm.

Results

Our series comprised 51 patients (28 males and 23 females; 17 were children aged 16 years or less) with an average age of 30.5 years (median, 28.4 years; range, 6.9–68.5 years). Three cholesteatomas were detected: one recurrent, one residual and one petrosal apex. Patients' most recent clinical follow-up images had been taken between 53.8 and 113.6 months (mean, 76.4 months) after their primary Canal wall up bony obliteration technique procedure. Clinical and imaging data were available for all 51 patients.

Patient one

One patient (a 17-year-old man) had a partial breakdown of the canal wall, which resulted in a recurrent cholesteatoma. This was visualised on both high resolution CT and MRI (Figure 1). The recurrent cholesteatoma was clearly seen at the posterosuperior margin of the external auditory canal, with extension into the bony obliterated mastoid. The canal wall had broken down, with subsequent bone pâté resorption. This recurrent, external auditory canal cholesteatoma was treated 56.8 months after the primary bony obliteration technique surgery. During the revision surgery, the cholesteatoma was completely removed and the external auditory canal defect was closed using solid sculpted cortical bone and bone pâté. During subsequent follow-up, no new recurrence was detected.



Figure 1. A 17-year-old man with a prior history of Canal wall up bony obliteration technique surgery for cholesteatoma on the left side, and with suspected recurrent external auditory canal cholesteatoma on micro-otoscopy. Surgery revealed recurrent cholesteatoma with canal wall breakdown and partial bone pâté resorption. (a) Axial, high resolution computed tomography (CT) image at the level of the basal turn of the left cochlea. The external auditory canal wall is interrupted by a presumed recurrent cholesteatoma with marked bone pâté resorption (arrowheads). The remainder of the post-operative mastoid cavity is filled with bone pâté. (b) Coronal, reformatted CT image at the level of the lateral semicircular canal, showing canal wall breakdown and soft tissue enhancement in the bone-obliterated cavity (arrows). The remainder of the post-operative mastoid cavity is filled with bone pâté (asterisk). (c) Axial, late (45 minutes) postgadolinium, T1-weighted magnetic resonance imaging (MRI) scan. A recurrent cholesteatoma is seen as a large defect in the external auditory canal surrounded by enhancing inflammatory and scar tissue (arrowheads). (d) Coronal, non-echo-planar, diffusion-weighted MRI scan at the level of the left temporal bone. The cholesteatoma is clearly seen (arrow) as a very hyperintense, horseshoe shaped lesion under the left temporal lobe. The keratin content has partially evacuated downward into the external auditory canal. Such a hyperintensity seen on non-echo-planar, diffusion-weighted scanning is pathognomonic for cholesteatoma.

Patient two

In a second patient (a 30-year-old man), micro-otoscopy showed a small mass positioned on top of the intact tympanic graft, suspected to be a cholesteatoma pearl (Figure 2).



Figure 2. A 30-year-old man with a prior history of Canal wall up bony obliteration technique surgery for cholesteatoma on the right side, with micro-otoscopic suspicion of a residual cholesteatoma lateral and superior to the tympanic graft in the external auditory canal. Surgery revealed a residual cholesteatoma with canal wall breakdown and partial bone pâté resorption. (a) Axial, high resolution computed tomography (CT) image at the level of the right vestibule. A nodular lesion (black arrow) is seen eroding the surrounding bone-obliterated mastoid cavity (black asterisk). The tympanic cavity is well aerated. (b) Coronal, reformatted CT image at the level of the lateral semicircular canal. A clear, nodular lesion (white arrow) is seen lateral and superior to the tympanic graft. The remainder of the post-operative mastoid cavity is filled bone pâté (black asterisk). (c) Axial, late (45 minutes) post-gadolinium, T1-weighted magnetic resonance imaging (MRI) sequence. Note the confusing and often mixed signal intensities in the obliterated cavity (white arrows). Based on this sequence, a residual cholesteatoma cannot be confirmed or excluded. (d) Coronal, non-echo-planar, diffusion-weighted MRI sequence at the level of the left temporal bone. The cholesteatoma is clearly seen (white arrow) as a very hyperintense lesion under the left temporal lobe. The presence of such a hyperintensity on non-echo-planar, diffusion-weighted scanning is pathognomonic for cholesteatoma.

On high resolution CT, a small tissue opacification was seen just lateral to the superior margin of the tympanic graft, partially protruding into the external auditory canal and extending into the obliterated mastoid, supporting a diagnosis of residual cholesteatoma pearl (Figures 2a and 2b). This diagnosis was confirmed on non-echo-planar, diffusion-weighted MRI sequences (Figure 2d). However, on the late gadolinium-enhanced, T1-weighted MRI sequences the lesion could not be differentiated from the surrounding bony obliterated mastoids content. At reintervention, the cholesteatoma pearl measured 5–6 mm and was located at the superior margin of the external auditory canal, lateral to the tympanic membrane, with extension into the bony obliterated mastoids. It had presumably arisen from a fragment of the original cholesteatoma which had been covered by a piece of sculpted bone graft during canal wall reconstruction. During revision surgery, the residual cholesteatoma was completely removed, and the external auditory canal defect was closed using solid sculpted cortical bone and bone pâté.

Patient three

In a third patient (a 69-year-old woman), non-echo-planar, diffusion-weighted MRI showed a characteristic hyperintense lesion set against a low intensity background, located in the apex of the temporal bone at the posterior margin of the internal carotid artery (see (Figure 3). On standard MRI sequences, the lesion had the typical features of a cholesteatoma, namely a characteristic high signal intensity on T2-weighted scans and a hypointense signal with peripheral enhancement on late gadolinium-enhanced, T1-weighted scans. Retrospective evaluation of a high resolution CT scan taken prior to the primary bony obliteration in January 2001 revealed a (hitherto overlooked) small lesion in the petrosal apex. There was no clear connection between the original, acquired cholesteatoma, which had been successfully removed in 2001, and this more recently visualised, congenital cholesteatoma. Because the latter lesion had not grown since January 2001, no additional surgical treatment was planned. The patient has since been further monitored by non-echo-planar, diffusion-weighted MRI.

Imaging interpretation

High-resolution computed tomography

An aerated middle ear was found in 64.7 per cent of patients (33/51). A soft tissue obliterated middle ear was seen in 35.3 per cent of patients (18/51). Middle-ear cavity opacification was complete in 17.6 per cent (9/51) and partial in 17.6 per

cent (9/51). In the bony obliterated mastoids, non-specific soft tissue opacification was visualised in 25.5 per cent (13/51), while 74.5 per cent (38/51) were homogeneously filled with bone. The soft tissue opacification in the middle-ear cavity and within the bony obliterated mastoids could not be further characterised using high resolution CT.



Figure 3. A 69-year-old woman with a prior history of Canal wall up bony obliteration technique surgery for a left-sided cholesteatoma, with a normal micro-otoscopic investigation. (a) Axial, high resolution computed tomography (CT) image at the level of the left internal auditory canal. A non-specific, nodular lesion (white arrow) is seen in the petrosal apex. Note the homogeneously obliterated mastoid cavity (black asterisk). Based upon this image, a petrosal cholesteatoma cannot be confirmed or excluded. (b) Coronal, reformatted CT image at the level of the lateral semicircular canal. Again, a non-specific, nodular lesion (black arrow) is seen in the petrosal apex. Note the homogeneously obliterated mastoid cavity (black arrow) is seen in the petrosal apex. Note the homogeneously obliterated magnetic resonance imaging (MRI) sequence. Note the large, hypointense, non-enhancing, nodular lesion (white arrows), enabling diagnosis of a large petrosal cholesteatoma. (d) Coronal, non-echo-planar, diffusion-weighted image at the level of the left temporal bone. The cholesteatoma is clearly seen (white arrow) as a very hyperintense lesion. The presence of a hyperintensity on non-echo-planar, diffusion-weighted images is pathognomonic for cholesteatoma.

Magnetic resonance imaging

Non-echo-planar, diffusion-weighted MRI was performed on all patients, and detected three cholesteatomas, one of which was a clinically unsuspected petrosal (congenital) cholesteatoma. In all the other patients, no marked hyperintensity was visualised on the non-echo-planar, diffusion-weighted MRI sequences. Magnetic resonance imaging evaluation of bony obliterated mastoids relied mainly on the non-echo-planar, diffusion-weighted sequences. Indeed, on standard MRI sequences (including late gadolinium-enhanced, T1-weighted images) we found mixed and confusing signal intensities in the obliterated mastoids, probably due to the mixed presence of bone pâté and scar tissue; this made cholesteatoma diagnosis in obliterated mastoids impossible on standard MRI sequences. No false positive findings were seen on the non-echo-planar, diffusion-weighted MRI images in this series.

Discussion

The main goals of cholesteatoma surgery include total eradication of pathology and prevention of recurrent cholesteatoma (1). The Canal wall up bony obliteration technique, when correctly executed, is effective in lowering the recurrence rate of cholesteatoma (2-6).

However, the problem of residual cholesteatoma is inherent in all cholesteatoma surgery, regardless of the surgical approach and reconstructive technique applied. Therefore, the long-term safety of the ear is of primary concern in cholesteatoma surgery. This is especially the case when bony obliteration techniques are used, because they carry the potential risk of burying residual cholesteatoma beneath the obliteration material. It may then take years before the residual pathology becomes clinically evident, and major destruction and complications may ensue.

To avoid these problems, most authors advocate surgical staging after Canal wall up surgery, in order to detect residual cholesteatoma (1). The major drawback of this approach is the need for a second operation.

Over the last decade, attempts have been made to replace second stage surgery with imaging follow-up. Until recently, high resolution CT was the imaging technique of choice for post-operative follow-up evaluation of mastoids undergoing bony obliteration (7,8). High resolution CT using bone window settings is considered the method of choice for examination of the middle-ear structures. It provides excellent contrast between osseous structures, air and soft tissues, and it has a high spatial resolution. This enables visualisation of subtle osseous details,

and allows good identification of associated bony erosions and good delineation of the pathology with respect to bony surroundings and air. Although it may take years, small cholesteatoma pearls may eventually become detectable in boneobliterated mastoids by high resolution CT, appearing as punched-out lesions in the bone density (8). However, high resolution CT cannot differentiate cholesteatoma from other soft tissues such as scar tissue, cholesterol granuloma, granulation tissue or fluid. Therefore, high resolution CT has a low sensitivity and specificity for cholesteatoma.

In our study, high resolution CT revealed soft tissue lesions within obliterated mastoids in 25.5 per cent (13/51) of patients. Theoretically, such lesions could represent either residual cholesteatoma or scar tissue replacement after partial bone resorption, or incomplete bony obliteration of the mastoid cavity. In addition, high resolution CT revealed that 35 per cent of all our patients' middle-ear cavities were partially or completely opacified, due to lack of aeration and/or the presence of fibrous and/or inflammatory tissue. Further CT characterisation of these soft tissues in the middle-ear cavity and obliterated mastoid was impossible. Therefore, we conclude that high resolution CT is virtually useless for the non-invasive follow-up of cholesteatoma.

In contrast, two newly available MRI protocols - late gadolinium-enhanced, T1weighted sequences and non-echo-planar, diffusion-weighted sequences - enable specific characterisation of residual and recurrent cholesteatomas (9-12). Using these MRI protocols, cholesteatoma can be unambiguously distinguished from other soft tissue such as scar tissue, cholesterol granuloma, granulation and fluid. The non-echo-planar, diffusion-weighted MRI sequence is an important improvement over the echo-planar, diffusion-weighted sequence, as the latter has a much lower contrast resolution and is made less reliable by susceptibility artefacts, thicker slices and a lower imaging matrix (7,10,11,13,14). Non-echoplanar, diffusion-weighted MRI has three advantages over late gadoliniumenhanced, T1-weighted sequences, namely: more reliable lesion characterisation (due to better contrast resolution) resulting in a high specificity and selectivity; no need for contrast; and a shorter examination time. However, a disadvantage of non-echo-planar, diffusion-weighted MRI, compared with late gadoliniumenhanced, T1-weighted sequences, is its lower spatial resolution, which makes cholesteatoma localisation more difficult.

The current study also confirmed our previously reported findings, namely the difficulty of detecting and evaluating residual cholesteatoma within obliterated mastoids using standard MRI techniques (including late gadolinium-enhanced, T1-weighted scans), due to the frequent presence of mixed and confusing signal

intensities (7). Following a Canal wall up bony obliteration technique procedure, the presence of a hyperintense lesion on non-echo-planar, diffusion-weighted MRI indicates the need for additional imaging (namely high resolution CT and late post-gadolinium, T1-weighted images) in order to determine the exact location and extension of any residual or recurrent cholesteatoma. If the hyperintense lesion is situated in the tympanic cavity, standard MRI sequences (including T2-weighted and late post-gadolinium, T1-weighted sequences) can provide additional information on the localisation of the lesion and its differentiation from any associated soft tissue in the middle-ear cavity. If the hyperintense lesion is situated in the obliterated mastoid, we advise high resolution CT scanning to exactly localise the soft tissue lesion, in order to facilitate surgical planning.

In Canal wall up bony obliteration technique cases, the confusing and often mixed signal intensities seen on standard T2-weighted and late post-gadolinium, T1-weighted MRI images have led us to the working hypothesis that it is better to use non-echo-planar, diffusion-weighted MRI sequences for initial residual cholesteatoma screening. We allow for the possibility that it takes more than one year for a residual cholesteatoma to develop into a detectable lesion; therefore, we routinely image our post-operative cholesteatoma ears after one and five years.

Remarkably, we did not detect residual cholesteatoma within bone-obliterated spaces, even over long-term follow-up; this is in concordance with other authors' findings (7-9). This is probably due to the unfavourable local trophic conditions for keratinocyte survival and growth within the bone-obliterated space. Indeed, before obliteration we carefully removed all soft tissues until only healthy bone remained. It is known from clinical experience that skin only reluctantly covers an area of bare bone, but easily covers the same area if it is first lined with a thin layer of fascia. An animal study by Hinohara *et al.* gives some support to the hypothesis that bony obliteration interferes with the trophic conditions needed to allow residual keratinocytes to develop into a growing cholesteatoma pearl (15). However, given that the rate of residual cholesteatoma following primary surgery is not negligible, strict follow-up of cases remains necessary.

- The Canal wall up bony obliteration technique lowers the incidence of recurrent cholesteatoma, but carries the potential risk of masking residual cholesteatoma
- The aim of this study was to report long-term follow-up imaging findings after Canal wall up bony obliteration technique surgery, in order to detect residual and/or recurrent cholesteatoma
- Long-term follow-up indicated that the Canal wall up bony obliteration

technique was a safe method of treating primary and recurrent cholesteatoma and reconstructing unstable cavities

 Magnetic resonance imaging, including delayed contrast and non-echoplanar, diffusion-weighted sequences, enabled detection of recurrent and residual cholesteatoma

Since operated ears quite often have residual soft tissue at the level of the middle ear and bony obliterated mastoids, which high resolution CT fails to characterise, we evaluate obliterated mastoids using non-echo-planar, diffusion-weighted MRI sequences. Such imaging has totally replaced exploratory second stage surgery in our department.

Conclusion

Long-term clinical and radiological follow-up after Canal wall up bony obliteration technique procedures for cholesteatoma shows that this is a safe surgical treatment for primary and recurrent cholesteatoma, and for reconstruction of unstable cavities. Its meticulous application in our department greatly reduced the incidence of recurrent pathology.

After Canal wall up bony obliteration technique procedures, long-term imaging follow-up frequently shows associated soft tissue in the obliterated mastoid and middle-ear cavity. This soft tissue can be easily differentiated using non-echo-planar, diffusion-weighted MRI. Exploratory second stage surgery can now be safely replaced by MRI scanning, provided the non-echo-planar, diffusion-weighted MRI sequence is used.

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Chapter 6.2

Long-term results of troublesome CWD cavity reconstruction by mastoid and epitympanic bony obliteration (CWR-BOT) in adults

Vercruysse JP., Van Dinther J, De Foer B, Casselman J, Somers T, Zarowski A, Cremers C, Offeciers E. Otology Neurotology 2016;37:698-703

Abstract

Objective: To present the long-term surgical outcome of the bony mastoid and epitympanic obliteration technique with canal wall reconstruction (CWR-BOT) in adults with an unstable cavity after previous canal wall-down surgery for extensive cholesteatoma.

Study Design: Retrospective study.

Interventions: Therapeutic.

Setting: Tertiary referral center.

Patients: Fifty consecutive adult patients undergoing a CWR-BOT between 1998 and 2009.

Main Outcome Measure(s): (A) Recurrence and residual rates of cholesteatoma, (B) postoperative hygienic status of the ear, including postoperative aspect of the tympanic membrane and external ear canal integrity (EAC), (C) functional outcome, and (D) long-term safety issues.

Results: (A) The percentage of ears remaining safe without recurrent or residual disease after CWR-BOT was 96% after a mean follow-up time of 101.8 months. Recurrent cholesteatoma occurred in 2% (n = 1) and a residual cholesteatoma was detected in 2% (n = 1) of the patients.(B) A safe dry, and trouble-free graft and selfcleaning EAC was achieved in 94%. (C) The postoperative hearing results showed a gain of 1.7 dB on pure-tone average air-conduction. (D) Non-echoplanar diffusion-weighted imaging (non-EP DW magnetic resonance imaging) documented the residual (n = 1) and recurrent cholesteatoma (n = 1). The 1-and 5-year imaging follow-up revealed no other recurrent or residual disease.

Conclusion: The CWR-BOT is a safe and very effective option for treatment of problematic unstable canal wall-down mastoid cavities, resulting in dry trouble-free ears.

The primary goal of surgical treatment of chronic otitis media with cholesteatoma is the complete eradication of the disease, whereas secondary goals are the prevention of recurrent disease, the improvement of the hygienic status of the ear, and the preservation or improvement of hearing (1). Many variables influence the long-term outcome of surgery. The more extensive the disease and damage at initial presentation, the poorer the outcome. Another important variable influencing the outcome of surgery for chronic otitis media is the quality of the surgical act, which depends on different factors including the surgeon's personal experience, the adequate choice of the surgical technique and of the material used for the reconstruction. The Canal wall down (CWD) mastoidectomy yields lower recurrence rates, but often requires regular cavity cleaning and is associated with recurrent otorrhea because of inflammation/infection, water intolerance, caloricinduced vertigo, and the diminished ability to comfortably wear a hearing aid. The problem of recurrent inflammation and infection is mainly caused by the loss of the self-cleaning capacity of the ear, which leads to accumulation of epithelial debris and thus necessitates regular cleaning of the mastoid cavity (2,3). One of the goals of the mastoid and epitympanic bliteration technique is to rebuild an external auditory canal (EAC) with normal dimensions. This results in a better self-cleaning capacity of EAC and leads to a better hygienic status of the ear (4–7). This article addresses the long-term outcome of our mastoid and epitympanic obliteration technique with canal wall reconstruction, including the recurrence rate, the residual rate, the functional results, the hygienic status of the ear, and the otoscopic evaluation of the tympanic membrane and the long-term safety issues using nonecho-planar diffusion-weighted magnetic resonance imaging (non-EP DW MRI) (8-12).

Methods

Fifty consecutive patients (> 16 yr) were surgically treated by means of the CWR-BOT after presenting with a troublesome cavity, and were retrospectively evaluated. All surgery was performed at the European Institute for ORL-HNS at the Antwerp St-Augustine Hospital between September 1998 and March 2009. The surgery was performed by the senior author (E.O.). The indication for bony obliteration was the presence of an unstable, problematic cavity after earlier Canal wall down surgery, leading to complaints of chronic or recurrent otorrhea because of inflammation/infection, the bothersome need for regular cleaning of the cavity, vestibular intolerance, hearing aid intolerance, and in some patients recurrent cholesteatoma.

Methodology

The following outcome measures were analyzed: cumulative recurrence rate, residual rate, hygienic status, hearing results, and long-term safety issues of the operated ear. The parameters of Bony Obliteration Tympanoplasty database included in the study: age at surgery, sex, side, surgical history, surgical findings, reconstruction method and material, otoscopic, radiological and audiometric follow-up details. During the clinical follow-up, the postoperative anatomical status

of the EAC and tympanic membrane was evaluated by yearly micro-otoscopic control, checking for retraction pockets, canal wall breakdown, bare bone exposure, external meatal stenosis, or recurrent cholesteatoma. We defined recurrent cholesteatoma as a new cholesteatoma, developing from an unsafe, non-self-cleaning retraction pocket in the tympanic graft or through the reconstructed bony canal wall, as identified by micro-otoscopy. We defined residual cholesteatoma as keratinizing squamous epithelium left behind during the CWR-BOT surgery, which has regrown

into a cholesteatoma, identified by direct vision during a planned transmeatal second-stage procedure or by non-EP DW MRI follow-up.

The audiological database included the preoperative and postoperative air conduction, bone conduction, and pure-tone averages. The audiological assessment was conducted every 3 months during the first postoperative year and once yearly in the following postoperative years, in a sound-treated room.

Surgical Technique

The surgery was performed under general hypotensive anesthesia using facial nerve monitoring. A question mark-shaped retro-auricular incision was made, sufficiently wide to facilitate cortical bone and bone pâté harvesting, followed by the elevation of a musculoperiosteal flap. Since in radical cavities the mastoid cortex is not (fully) available for bone harvesting, often the temporal squama must be accessed. Cortical bone chips are harvested using a flat broad chisel and put aside. It is essential to harvest enough solid cortical bone. Preferably one or as few solid fragments that allow complete reconstruction of the posterosuperior bony canal wall to have less risk of gaps in the reconstruction. A bone pâté collector and a cutting burr were used to collect healthy bone pâté. The bone pâté was mixed with an antibiotic solution (rifamycin solution) forming a semisolid paste. During the subsequent dissection of the radical cavity, the epithelial lining and all pathological soft tissue, cholesteatoma, diseased ossicular remnants, and unhealthy bone were removed and the remaining bony walls of the mastoid and attic space were adequately checked and drilled clean (Figure 1, A and E).

It is of extreme importance to carefully dissect the posterior margin of the cavity's external meatus. The skin is often sharply folding back posteriorly toward the cavity. This fold must be eliminated by sharp dissection, to create a smooth skin surface of the lateral posterior part of the new meatus. If this is neglected or not

well executed, a new retraction pocket can develop in the lateral posterior part of the EAC.

To create a new, normally sized EAC, a complete bony partition between the tympanic cavity and EAC on the one hand and the paratympanic space on the other hand was then built up by means of the cortical bone chips, from the cortical level down to the facial nerve canal (Figure 1, B and F). Bony irregularities on the EAC side can be smoothened out with a diamond burr, and minor gaps can be filled up with hydroxyapatite bone cement (OtoMimix). The paratympanic space was then completely filled with bone pâté, up to the level of the mastoid cortex (Figure 1, C and G). The new canal wall was covered with a vascularized autologous deep emporoparietal fascial flap (13), or lacking that, a free graft of autologous temporal fascia.



Figure 1. Surgical principle of the CWR-BOT with intact stapes superstructure. A, E, All the epithelial lining of the radical cavity and all athological soft tissue, cholesteatoma, diseased ossicular remnants, and unhealthy bone were removed. B, E, A new, normally sized external auditory canal is built up by means of the cortical bone chips, from the cortical level own to the facial nerve canal. C, F, Paratympanic space obliteration with bone pâté. D, G, Counter clockwise tympano-ossicular graft rotation with malleus handle above oval window.

When the external meatus of the EAC was too narrow, an M-meatoplasty according to Mirck (14) or an antero-superior oblique extended meatocanalplasty according to Offeciers (15) was performed to optimize the size of the external meatus. The middle ear reconstruction was performed using a tympanoossicular allograft. The malleus head was removed with a malleus nipper at the level of the lateral process of the malleus. The allograft TM (with malleus handle) was rotated clockwise (left ear) or counterclockwise (right ear) to place the malleus handle in

an advantageous position, perpendicularly centered above the oval window (Figure 1, D and H). This allows for the most effective columellar energy transduction between the implanted malleus handle and the stapes or stapes footplate. The ossicular reconstruction was done by placing a remodeled allograft incus or malleus between the malleus handle and the stapes head or footplate. Peroperative intravenous antibiotics (cefazoline) were continued for 24 hours.

Surgical Staging and Imaging Follow-up

Before the non-EP DW MRI sequence became available, patients were often surgically staged for safety reasons. Secondlook surgery was performed in 64% of the patients (n = 32), after a mean time delay of 13.7 months, using a transmeatal or retroauricular approach. The decision to perform a second stage or not was taken by the surgeon during the first-stage surgery. Functional revision surgery was considered an elective procedure, not a planned, compulsory second-stage procedure. However, all patients were regularly followed up by yearly micro-otoscopy. Before 2006, we mainly relied on high-resolution computed tomography (HRCT) and echo-planar diffusionweighted images (EP DW MRI) for the follow-up of obliterated mastoids. Since the availability of an MRI protocol including the non-EP DW MRI sequence, all patients were followed using this protocol, 1 and 5 years after primary surgery.

Results

Fifty adult patients were surgically treated by CWR-BOT. Thirty-four (68%) were men and 16 (32%) were women. The left–right ear ratio was 24/26. The average age was 44.71 years (range, 16.3–68.1yr). All patients had before the CWR-BOT at least one to nine surgical procedures with (mean of 2.5 surgical procedures). The mean postoperative follow-up period was 100.3 months (range, 29.36–165.96mo). Seventeen patients (34%) had a follow-up of 10 years or more. Six patients were followed for more than 12 years (Table 1).

Forty-nine of the 50 ears (98%) remained without recurrent disease and 49 ears (98%) were free of residual disease. The standard long-term recurrent and residual rate in this series of CWR-BOT are respectively 2% and 2%.

Table 1. Patient demographics

Mean age (yr)	44.71 yr (range, 16.3-68.1 yr)
Sex (M/F)	34/16
Side (R/L)	24/26
Average previous surgical acts	2.5 (range, 1-9)
Average postoperative follow-up (mo)	101.86 (range, 29-166 mo)
Follow-up > 10 yr	17 (34%)
Follow-up > 12 yr	6 (12%)

Table 2. Surgical indications (n = 50)

Recurrent infections	50	
Excessive recurrent cleaning	32	
Vestibular/caloric intolerance	2	
Hearing device intolerance	20	
Cholesteatoma (residual/recurrent)	4	

Primary Surgery

The indications for CWR-BOT are outlined in Table 2.

During primary surgery, a reconstruction of the ossicular chain was done in 88% (n = 44). The stapes superstructure was absent in 68% (n = 34) because of previous destruction by a primary or recurrent cholesteatoma. All ossicular reconstructions were performed using remodeled incus (n = 27) or malleus allografts (n = 17). In three patients the reconstruction of the ossicular chain was postponed to the planned second-look stage (n = 2) because of the presence of extensive, invasive cholesteatoma. In three patients it was not performed because of stapes fixation (n = 2) or sensorineural hearing loss (SNHL; n = 1). This last patient was urgently operated on because of a progressive facial paralysis and profound SNHL on the affected side, ear because of an extensive cavity infection. The CWR-BOT was successfully performed, resulting in a dry trouble-free ear and recovery of the facial nerve function. The SNHL remained unchanged. In this CWR-BOT series no major complications (facial nerve palsy or paresis, SNHL) occurred.

Second Stage and Residual Disease

The decision to perform a planned second-look stage was made by the surgeon during the primary surgery in 64% (n = 32). In the later patients, since 2006, imaging follow-up using the non-EP DW MRI protocol was performed at 1 and 5 years after the first stage. This revealed the presence of one residual cholesteatoma after primary CWR-BOT surgery. The residual cholesteatoma was located in the epitympanum eroding the reconstructed tympano-attical barrier resulting in a lysis of the bony obliterated epitympanic space. A meticulous

removal of the residual cholesteatoma was subsequently performed, followed by reobliteration of the epitympanic cavity with bone pate and cortical bone. At latest MRI follow-up no other residual or recurrent cholesteatoma was detected in the middle ear cavity or within the bony obliteration. Functional revision was performed in 38% (n = 19) as an elective second-stage transmeatal or retroauricular procedure (n = 19).

During these procedures, minor TM defects and EAC irregularities were surgically corrected, including a self-cleaning retraction pocket in the TM (n = 3), a TM reperforation (n = 2), a minor canal wall depression (n = 9), bare bone exposure (n = 4), and external meatal narrowing (n = 1).

The self-cleaning retraction pockets and perforations were corrected with cartilage reinforcement. Minor canal wall depression in the EAC, which possibly could result in a later canal wall lysis and/or breakdown, was corrected during this elective second-stage surgery by means of sculpted cortical bone ships and bone pâté. Bare bone exposure in the reconstructed canal wall was covered with split skin dermal grafts. The meatal stenosis was corrected using a meatocanalplasty.

Retraction/Recurrent Disease

In four patients, the otoscopic follow-up revealed the presence of a self-cleaning mesotympanic retraction of the TM. One patient progressively became a recurrent cholesteatoma in the 9th year of otoscopic follow-up. In this patient, revision surgery revealed partial resorption and lysis of the medial superior reconstructed canal wall and of the tympanoattical barrier with extension of the cholesteatoma into the attic. Reclosure of the epitympanum and reconstruction of the canal wall by means of bone chips and bone pâté, in combination with cartilage tympanoplasty, was performed. During subsequent follow-ups, no new recurrence developed.

Hearing Results

The median preoperative pure-tone average air-conduction was 61.7 dBHL with a preoperative PTA-ABG of 36.7dBHL. Postoperative hearing results were assessed after 1 year and on the latest evaluation date (average follow-up: 100.3 mo) and revealed respectively a postoperative pure-tone average air-conduction of 55 dBHL and 60 dBHL. No statistically significant difference was found between preoperative and postoperative bone conduction (p > 0.05; t test). A primary ossicular reconstruction was performed in 88% (n = 44) of all patients during the primary CWR-BOT. In six patients a functional correction was postopened because of extensive cholesteatoma in three patients and abandoned in three patients

because of the presence of a fixed footplate (n = 2) and a severe SNHL (n = 1). In 59.3% (n = 19) of the patients undergoing an elective second stage (n = 32), a functional correction was attempted using a remodeled malleus or incus allograft for chain reconstruction. In several patients, a conductive hearing loss persisted because of the lack of middle ear aeration or a fixed footplate. In many of the patients in the series there was a quite important sensorineural component of the hearing loss pre-existing to the primary CWR-BOT. Seventeen patients (34%) were fitted with a conventional hearing aid (n = 14) or bone-anchored hearing aid (n = 3), because of unsatisfactory hearing levels at the affected side.

Long-term and Safety Results

A safe dry, trouble-free graft, and self-cleaning EAC was achieved in 94% (n = 47) at the latest micro-otoscopic evaluation. Three patients developed a tympanic reperforation, which needed no further surgery. All perforations observed during otoscopic follow-up were dry perforations of which two were very small dry perforations. Myringitis of the tympanic graft was temporarily present in two patients. A minor lateralization of the graft was observed in six patients. One patient required occasional ear canal cleaning. At the latest micro-otoscopic follow-up, four patients had a minor external auditory canal wall depression, not accumulating keratin, thus not necessitating a further treatment. Imaging follow-up by non-EP DW MRI performed after a follow-up of 5 years or even longer in some patients after the primary surgery (since the availability of the non-EP DW MRI sequence) was available in 76% (n = 38). Before 2006 HRCT and/or EP DW was performed in 14% (n = 7). In the remaining five patients, the MRI control was deemed redundant because of an earlier executed planned second-look control without pathological findings. In summary, in this early series of 50 CWR-BOT, the long-term combined safety control by means of planned second-look surgery and late non-EP DW MRI showed one of residual cholesteatoma (2%) and one recurrent cholesteatoma (2%). Because our current imaging protocol for cholesteatoma surgery follow-up has been strictly validated (8-12), we no longer apply routine planned second-look surgery.

Discussion

Unstable and problematic cavities after CWD mastoidectomy are a major indication for performing an obliteration of the mastoid and epitympanum. The decision to perform revision surgery with bony obliteration is usually based on one or more of the following complaints; persistent or periodic discharge that is difficult to control with regular cleaning and eardrops, the need for frequent microotoscopic cleaning, water intolerance, caloric induced vertigo, and the difficulty to wear a hearing aid (2,3). The problems are mainly caused by the loss of the selfcleaning capacity of the ear. The selfcleaning capacity of the migratory skin in the medial part of the EAC has its limitations, and cannot cope with the extended surface area of skin in most cavities. When performing CWR-BOT we aim to rebuild a normally sized EAC, which restores the EAC anatomy and its selfcleaning capacity, thus solving the hygienic problems. The CWR-BOT can also be applied successfully in therapy-resistant COM without cholesteatoma, more specifically when the ear's bone conduction levels offer potential for unaided or aided hearing after reconstruction. Since the first description of mastoid obliteration surgery more than one century ago (16), various surgical techniques have been developed, using a variety of obliteration material and can be divided into two distinct subgroups: free graft obliteration (autologous or synthetic) and soft tissue flap obliteration (17). When performing soft tissue flap obliteration, vascularized soft tissue flaps are mobilized and rotated into the empty mastoid cavity (18,19). In free graft obliterations, various materials including soft tissues (20), bone (21), cartilage (22), or synthetic biomaterials (23–25) are used to fill the empty mastoid and epitympanic space. The main surgical principle is the intention to decrease the mastoid size and to normalize the size of the EAC. The ideal obliteration material should stimulate the formation of new bone at the surgical site, become incorporated as an inert filler without additional stimulation of an inflammatory response, should not have unwanted systemic or local effects, should be easy to handle, and should be relatively inexpensive. Bone pâté fulfills all the requirements (21). Perkins (26) first demonstrated the value of bone pâté for the reconstruction of cavities. An adequate application of healthy cortical bone pâté mimics the natural osteoinduction and osteoneogenesis of bone. Several authors abandoned the use of bone pâté for mastoid obliteration because of the high rate of postoperative infection (16%) and the high incidence of chronic resorption of bone pâté resulting in local retraction pockets and canal wall defects, leading to long-term failure rates of 52% (17,21,27). The CWR-BOT procedure applied in our department differs from the above-mentioned earlier reports in two very crucial aspects. The administration of intravenous per-and postoperative antibiotics and the impregnation of the bone pâté with an antibiotic solution lead to a marked reduction in the rate of postoperative infections, as was also previously reported (28)]. Moreover, in our CWR-BOT technique, the bone pâté is strictly separated from the canal skin over the full length of the EAC by sculpted solid

cortical bone, used for the meticulous reconstruction of the canal wall and the tympano-attical barrier. This is an extremely important condition for long-term stability of the new EAC in the reconstruction of unstable cavities. In our experience autogenous solid cortical bone chips are the most ideal material for reconstruction of the external ear canal. They integrate well with the original bone margins, which is a definite advantage over the use of cartilage to reconstruct the canal wall. Moreover, cortical bone is abundantly available in comparison with cartilage. A histopathological evaluation concluded that bone chips and bone pâté, used for obliteration, retain their original volume and consistency, whereas subcutaneous tissue and muscle tend to atrophy (29). During the postoperative healing, the migration of squamous epithelium starts at the margins of the meatal or tympanic membrane skin remnants. This process can be hampered by infection, by areas of bare bone and by ischemia and necrosis of the underlying soft tissue flap. If the EAC does not epithelialize completely, it will lead to inflammation and granulation. With time, this will either cause scar tissue formation and secondary stenosis of the EAC, or breakdown of the underlying soft tissue, the reconstructed canal wall bone, and the underlying bone paté. This process can cause intermittent or persistent ear discharge. Postoperative inflammation or infection can cause perforation of the tympanic membrane graft and extrusion of the columellar reconstruction. The combined creation of a normally sized external meatus and a solid bony ear canal provides the ideal basis for a stable hygienic condition of the ear, as reported in this study.

Hearing Results

One of the goals of chronic ear surgery is the improvement or at least the preservation of the preoperative hearing level. The long-term functional outcome depends on the following variables: the extent and severity of the pathology; the quality of the surgical act; the applied technique and the nature of the reconstructive materials; the quality of the healing process; the postoperative biological behavior of the ear. There is an inverse relation between the preoperative extent of the ossicular damage and the postoperative long-term functional gain. It stands to reason that greater ossicular damage and a higher number of previous surgical interventions often reflect a worse biological behavior of the ear, which makes it less probable for the biology to normalize during the postoperative period. The preconditions for a good middle ear function, such as normal gas exchange and middle ear aeration as well as the presence of normal mucosa with efficient mucociliary clearance, are often not present. As a consequence, in these patients the functional result will be disappointing to

surgeon and patient alike, however well the middle ear is reconstructed. As a result of these preconditions, it is not surprising that a number of patients reported in this study have a persistent air-bone gap despite adequate ossicular chain reconstruction. Although the average long-term improvement (101.8 mo after previous surgery) in hearing was small in many patients, also some patients experienced a major improvement. When the postoperative hearing was unsatisfactory after primary surgery on the affected side a conventional hearing aid was fitted.

The decision making for using the CWR-BOT or an alternative surgical technique, such as a subtotal petrosectomy, is mainly based on the preoperative hearing level. If the preoperative hearing of the patient is a severe or profound hearing loss, we prefer the technique of tympanomastoid exenteration with blind sac closure of the EAC over the CWR-BOT technique, to eradicate the pathology and solve the hygienic problems (30). A subtotal petrosectomy with blind sac closure of the EAC accounts for approximately 3% of our COM patients. In the absence of residual disease as documented by non-EP DW MRI after primary surgery, a bone anchored hearing aid, an active middle ear implant, or a cochlear implantation can be safely performed. In case a non-surgical hearing revalidation is needed in the presence of an open external ear canal, a conventional air conduction hearing aid remains the first option. If the air-bonegap exceeds 35dB,a passive semiimplantable Bone Anchored Hearing Device (BAHD) (Baha by Cochlear or Ponto by Oticon) and a semi-implantable active bone conduction device like the Bonebridge (Medel) might be expected to outperform the conventional air conduction hearing aid option. If the sensorineural component in such a mixed hearing loss is in between 40 and 60 dB, the bodyworn variant of the BAHD might be taken into consideration as a good option. So when a subtotal petrosectomy with blind sac closure has been performed the options for hearing revalidation are mainly determined by the present sensorineural hearing level. The Vibrant Soundbridge option (Medel) should only be applied if the sensorineural component is 20 dB or even better. If the sensorineural component exceeds 60 to 70 dB cochlear implantation is the only option (31). After performing a subtotal petrosectomy in patients of a profound conductive hearing loss (air bone gap >30-35dB), a bone-anchored hearing aid (BAHA) can be implanted or a middle ear implantable hearing aid if bone conduction levels are worse than 40 dB but better than 70 dB (31). The subtotal petrosectomy technique is also used in deaf ears or profound SNHL with COM needing a cochlear implant, as a preparatory stage 3 to 6 months before cochlear implantation.

Long-term Safety Issues

Adequate imaging follow-up of obliterated mastoids is necessary to prevent late complications caused by residual cholesteatoma left behind in the bony obliterated mastoid. Previous studies published in the literature advocated the combination HRCT and diffusionweighted MR imaging in the follow-up of cholesteatoma after mastoid obliteration (32). The application of non-EP DW MRI monitoring has become a standard evaluation protocol in our department at 1 and 5 years postoperatively. In case of doubt we repeat the examination after 1 year (8–12). Clinical monitoring by micro-otoscopy and audiometry remains mandatory to exclude recurrent disease. Therefore, we advise yearly otoscopy for at least 10 years, and 3-yearly micro-otoscopic and audiometric follow-up later on.

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Chapter 7

Discussion Samenvatting/ Summary / Résumé Curriculum Vitae List of publications List of abbreviations

In *Chapter 1.1* we described the surgical principles and diagnostic imaging principles of cholesteatoma, which historically contributed to safety and clinical success in clinical cholesteatoma management. Before 1997, we applied the conventional CWU technique in approximately 95% of our cholesteatoma cases. In approximately 5% we applied the modified radical CWD technique, usually because of fast and aggressive recurrent cholesteatoma after primary CWU surgery. The majority of the CWU cases had exploratory second-look surgery to check for residual cholesteatoma. Our follow-up studies at the time showed recurrence and residual rates comparable to the literature. However, we were still not happy with the results, especially regarding the recurrence rates in children, which we thought to be too high to be acceptable. Therefore, in 1997 we decided to change our surgical strategy. Inspired by the work of Ulf Mercke, who was the first to report on a consecutive series of cholesteatoma cases treated by means of his bony obliteration technique (1), we developed our own adapted bony obliteration tympanoplasty technique.

In *Chapter 1.2* we have summarized in a Commentary (submitted for publication into a journal of general medicine) the great value and so the great progress that has been made by having nowadays available the non-echo planar Diffusion Weigthed MR Imaging sequence to detect and diagnose Cholesteatoma and so its value at present for the diagnosis and the management of chronic otitis with cholesteatoma is emphasized. By applying the new bony obliteration tympanoplasty technique combined with this new non-echo planar Diffusion Weigthed MR Imaging sequence this has changed dramatically the surgical outcomes of ear surgery for cholesteatoma. By naming these two contributions Game Changers in the management and treatment of chronic otitis with cholesteatoma this describes in a concise way their great value.

In *Chapter 2.1* we report on the adapted bony obliteration technique (BOT), as it was first published by Offeciers et al. (2). This includes the description of the technique when used to reconstruct unstable CWD cavities: the CR-BOT (Cavity Reconstruction-BOT). Since its application in our department the BOT technique led to a dramatic decrease of the cholesteatoma recurrence rate. However, the primary goal of cholesteatoma surgery is the complete eradication of the pathology: no residual cholesteatoma should be left behind after primary surgery. Since at the time of the start of the BOT project the existing imaging techniques were not reliable enough to monitor for residual disease in a non-invasive way, we initially staged the surgery. At primary surgery the pathology was cleaned out, the

tympano-ossicular barrier and posterior tympanotomy were closed by means of sculpted cortical bone and the middle ear was reconstructed, but the obliteration of the paratympanic space (mastoid and attic) with bone pâté was deferred to the second-look, performed one year after primary surgery to screen for residual cholesteatoma. In parallel our radiologists started the search for better imaging techniques, which would obviate the need for staging. Residual cholesteatoma is a problem inherent in all cholesteatoma surgery, regardless of the applied surgical approach and reconstructive technique. The rate of residual cholesteatoma reported in the literature shows substantial variation, reflecting an important variation in the quality of the surgical act. Therefore obliteration techniques in cholesteatoma management can only be safely used when either staging is done or when reliable imaging techniques are available. Accurate and reliable imaging follow-up of obliterated mastoids is necessary to prevent late complications due to residual cholesteatoma buried underneath the obliteration material. Such complications may take many years to appear. Because of potential labyrinthine and intracranial involvement, they can cause important morbidity and even death. The detection of residual cholesteatoma after primary surgery by CT (6-8) and conventional MR imaging techniques (9-11) has been shown to be inaccurate, due to poor sensitivity. New MRI sequences such as delayed contrast enhanced T1weighted imaging and non-EP diffusion-weighted imaging provide a more accurate diagnoses of cholesteatoma (3-5).

Chapter 3.1, 3.2 and 3.3. report on the imaging techniques we use for cholesteatoma (3-5). The advent of new MRI sequences allows for specific characterization of small cholesteatoma pearls. On MRI, cholesteatoma can be unambiguously distinguished from other soft tissues such as scar tissue, cholesterol granuloma, granulation tissue and fluid. **Chapter 3.3** (5) summarizes the value of diffusion-weighted magnetic resonance imaging in the evaluation of temporal bone pathology. It highlights the use of different types of diffusion-weighted magnetic resonance imaging in the different types of cholesteatoma, prior to first stage surgery and prior to second-look surgery. The value of diffusion-weighted magnetic resonance imaging in the evaluation of pathology of the apex of the petrous bone and the cerebellopontine angle is also discussed.

Chapter 4 describes the various steps we made in researching and validating the contribution of diffusion-weighted imaging to the clinical management of cholesteatoma. **Chapter 4.1** reports on our first imaging study patients. One hundred patients (n = 100) were preoperatively evaluated by echo-planar diffusion-
weighted MR imaging (EP DWI) (12). The patient population consisted of 2 groups. A first group of patients (n = 55) was preoperatively evaluated to confirm the otoscopically observed presence of a primary acquired cholesteatoma. The second group patients (n = 45) was evaluated 8- 18 months after primary cholesteatoma surgery, but prior to second-look surgery to screen for residual cholesteatoma. The surgical findings were compared with the preoperative EP DWI findings. In the group of primary surgery patients, a hyperintense signal compatible with cholesteatoma was found in 89% (n = 49) of cases with a sensitivity, specificity, positive and negative predictive value for EP DWI of 81, 100, 100 and 40%, respectively. In the group of exploratory second-look surgery patients, only one of seven surgically found residual cholesteatoma pearls was correctly diagnosed using EP DWI, with a sensitivity, specificity, positive and negative predictive values of 12.5, 100, 100 and 72% respectively. Based on these results, we concluded in 2006 that EP DWI has a place in the preoperative evaluation of primary acquired cholesteatoma. Its sensitivity can be augmented when associated with standard MR imaging sequences. However, our results did not confirm the high sensitivity of EP DWI for detecting residual cholesteatoma, published in other reports (13-14). This disparity may have been caused by a selection bias in the other papers, which tended to select the patients on clinical grounds using often a combination of small residual and large recurrent cholesteatoma. This may have led to the selection of larger residual pearls. In contrast, in our study we did not select patients on a clinical basis. Our only selection criterion was "primary CWU cholesteatoma surgery 12-18 months ago". We concluded that EP DWI has but a limited capacity to detect residual cholesteatoma pearls after primary surgery at a sufficiently early stage in their development (before they present a potential danger to the patient's wellbeing). The reasons for this are the low resolution and relative thick slices of EP DWI, its quite important air-bone artefact at the level of the mastoid and attic tegmen, which may hide a residual cholesteatoma pearl, and the need to visualise the residual cholesteatoma pearls when they still have a small volume. We finally concluded in 2006 that standard MR imaging sequences and spin-echo echoplanar DWI sequences cannot successfully replace exploratory second-look surgery.

In our second imaging study (*Chapter 4.2*) we assessed the value of HRCT and MRI, including post-contrast T₁- weighted images and EP-DWI, for the detection of residual cholesteatoma after primary bony obliteration of the mastoid (15). The patients in this study (n = 23) had a second-look operation 8 to 18 months after

primary surgery for cholesteatoma using the CWU-BOT technique. All the patients were evaluated by HRCT and MRI before having their second-look operation. During second-look surgery two residual cholesteatoma pearls were found in the tympanic cavity. The preoperative HRCT showed a homogeneous bony obliteration of the mastoid cavity, without the punched-out images typical for residual cholesteatoma. In 56,5% (13/23) of the cases it showed a degree of opacification of the tympanic cavity. Two residual pearls, with a respective diameter of 2 mm and 4 mm, were hidden in the opacification, and could not be distinguished from the surrounding soft tissue on HRCT. The EP-DWI findings were negative for all cases. The contrast-enhanced T₁- weighted MRI detected only one cholesteatoma pearl (4mm diameter). This study suggested at the time (2007) that HRCT was still the imaging technique of choice for the evaluation or residual cholesteatoma in bony obliterated mastoids. It confirmed the low sensitivity and specificity of HRCT for the characterization of a residual cholesteatoma pearl in a middle ear partially or totally filled with scar tissue. It also confirmed the low sensitivity and specificity of contrast-enhanced T1- weighted MRI and EP-DWI for the detection of small residual cholesteatoma pearls after primary BOT surgery.

In chapter 4.3 we investigated the value of non-EP DW imaging in combination with delayed post-gadolinium T1-weighted sequences as a safe, non- invasive, selective, sensitive and comparatively cheap alternative to exploratory secondlook surgery (16). Non-EP DW MRI in combination with delayed post-gadolinium T1-weighted sequences was used to screen for residual cholesteatoma after Canal wall up mastoidectomy, prior to planned second-look surgery in a consecutive series of patients (n = 32). The non-EP-DWI sequence in combination with delayed post-gadolinium T1-weighted sequences identified 9 out of 10 residual cholesteatoma pearls found during surgery. The only lesion missed was a 2-mm cholesteatoma pearl in an examination degraded by motion artifacts in a child. The other diagnosed residual pearls measured between 2 and 6 mm. Sensitivity, specificity, positive predictive value, and negative predictive value were 90, 100, 100, and 96%, respectively. We concluded that, except for motion artifactdegraded examinations, non-EP DW MRI in combination with delayed postgadolinium T1-weighted sequences could detect even very small residual cholesteatoma pearls. Used as a screening tool to identify patients who need a second surgical stage, it obviates unnecessary, routinely executed second-look surgery.

The 2010 Radiology paper (17) figuring in *Chapter 4.4* reports on the advantages of the non-EP DWI sequences over delayed gadolinium- enhanced T1-weighted MRI . Non-EP DWI sequences have a thinner section thickness and a higher imaging matrix and are less prone to susceptibility artifacts than EP DWI sequences (14). We retrospectively compared non-EP DWI, delayed gadolinium-enhanced T1-weighted MRI, and the combination of both sequences for the evaluation of patients with cholesteatoma. We concluded that combining both the non-EP DW imaging sequence and the delayed gadolinium-enhanced T1-weighted sequence yields no significant increase in sensitivity, specificity, negative predictive value, or positive predictive value over the use of the non-EP DW imaging sequence alone. The Non-EP DWI sequence suffices.

Chapter 5 reports on our first clinical results of mastoid and epitympanic obliteration in a paediatric cholesteatoma population (n = 52) (18). The study group comprised children presenting with primary cholesteatoma, children with recurrent cholesteatoma after previous CWU surgery and children with an unstable CWD cavity. Due to higher rates of recurrent and residual disease, children present a greater challenge than adults. The ears were evaluated after a mean follow-up of 49.5 months (range 12-101 months). The screening for residual cholesteatoma was done by exploratory second-look surgery in the early cases and a combination of non-EP DW MRI and HRCT in the more recent cases. We found a residual cholesteatoma in 15.4% (8/52). The follow-up for recurrent cholesteatoma was done by yearly otomicroscopy. Recurrent cholesteatoma occurred in 1.9% (1/52). We concluded that the use of the BOT technique led to a marked improvement of the cholesteatoma recurrence rate in comparison with non-BOT techniques, at least at short-term to mid-term evaluation. This encouraged us to use the BOT technique in the majority of cholesteatoma cases. The results of this study also suggested that the screening for residual cholesteatoma can be successfully and safely done by non-EP DW MRI, without the need for combining it with HRCT.

Chapter 6.1 reports on the long-term results of our BOT technique (19-20).

An important concern when performing bony obliteration is the risk of burying residual cholesteatoma underneath the obliteration material. Therefore, accurate and reliable imaging follow-up of obliterated mastoids is mandatory to prevent late complications, which may take many years to appear. Fifty-one patients presenting with a cholesteatoma or a troublesome cavity had CWU-BOT or CR-BOT surgery, and were evaluated by follow-up non-EP DW MR imaging at a mean

of 76.4 months post-operatively (Chapter 6.1) (19). Imaging revealed the presence of one residual, one recurrent and one congenital petrosal apex The non-EP DWI sequence clearly identified all three cholesteatoma. cholesteatomas, and differentiated them from other associated soft tissues. No cholesteatoma was found within the obliterated mastoids. Our long-term clinical and radiological follow-up after BOT surgery for cholesteatoma shows that this is a safe surgical treatment for primary and recurrent cholesteatoma, and for the reconstruction of unstable cavities. Its meticulous application in our department greatly reduced the incidence of recurrent cholesteatoma. After CWU-BOT surgery, long-term imaging follow-up frequently shows associated soft tissue in the obliterated mastoid and middle-ear cavity. This soft tissue can be easily differentiated using non-EP DW MRI. Following this study we concluded that exploratory second-look surgery can now be safely replaced by MRI scanning, provided the non-EP DW MRI sequence is used. We no longer use CT to screen for residual cholesteatoma. We now order a CBCT only in cases scheduled for surgery, to be used as a surgical road map.

Chapter 6.2. concerns an adult patient group (n=50) with troublesome cavities after CWD surgery. We applied the BOT technique in all patients for the reconstruction of their cavity (CR-BOT: Cavity Reconstruction BOT). The paper discusses the outcome after a long-term mean follow-up of 101.8 months (20). The CWD mastoidectomy technique yields lower cholesteatoma recurrence and residual rates than conventional CWU mastoidectomy techniques without obliteration. However, it often requires regular cavity cleaning and is associated with recurrent otorrhea because of inflammation/infection, water intolerance, caloric-induced vertigo, and the diminished ability to comfortably wear a hearing aid. The problem of recurrent inflammation and infection is mainly caused by the loss of the self-cleaning capacity of the ear, which leads to accumulation of epithelial debris and thus necessitates regular cleaning of the mastoid cavity. When a cavity is unstable, it is often perceived by the patient as a major inconvenience. By reconstructing such cavities with the BOT technique, our aim is to create a stable hygienic condition. This obviates the need for regular suction cleaning, allows the patient to comfortably wear an air conduction hearing aid and eventual even an open canal fitting when needed and makes the ear water resistant. However, since this patient group represents the worst category of cholesteatoma cases, it is important to document the long-term outcome and stability of our reconstructive BOT technique. At a mean follow-up of 101.8 months, the CR-BOT resulted in a safe ear without recurrent or residual

cholesteatoma in 96% (49/50) of the ears. A residual cholesteatoma was detected by imaging in 2% (1/50) of the patients. We observed a recurrent cholesteatoma in 2% (1/50). A safe dry, and trouble-free graft and a selfcleaning EAC were achieved in 94% (47/50). The 1 and 5-year imaging follow-up revealed no other recurrent or residual disease. We concluded that the CR-BOT is a safe and very effective option for the management of problematic, unstable CWD cavities, resulting in dry, trouble-free ears.

Additional research questions to be addressed

- 1. Adequate imaging follow-up after primary cholesteatoma surgery is necessary to prevent late complications caused by residual cholesteatoma. The application of non- EP DW MRI monitoring has become a standard evaluation protocol in our department at 1 and 5 years post-operatively (2-5, 12, 14-21). In case of doubt we repeat the examination after 1 year. Also clinical monitoring by micro-otoscopy and audiometry remains mandatory to exclude recurrent disease. Therefore, we advise yearly otoscopy for at least 10 years, and 3-yearly micro-otoscopic and audiometric follow-up later on. Some authors therefore advocate more frequently repeated MR follow-up to rule out a growing residual cholesteatoma (22-24). The implementation of an optimal follow-up scheme has not yet been established, but is subject to further research.
- 2. Chronic otitis media remains a common disease that has a serious health impact on up to 2% of the population (25). In the assessment of healthcare, patient-based measuring instruments regarding the quality of life and perceived handicap have become increasingly important. Patient-related outcome questionnaires such as the COMQ-12 (26) aim at obtaining detailed information on the subjective impact of the patient's symptoms. They allow the treating clinician to get an idea of the patient's expectations regarding therapy and help him to choose the management strategy best-fitted to these expectations. The analysis of patient-related questionnaires before and after BOT surgery will be relevant to fine-tune our surgical management to the individual cholesteatoma case. These studies are currently carried out in our department and will be published in the near future.
- 3. As stated in our conclusions, MRI has effectively replaced exploratory secondstage surgery in our department (17). Off-setting the cost of surgical staging to the cost of twice-repeated MRI when screening for residual cholesteatoma, our

imaging protocol is not only less burdening to the patient on a practical and emotional level, but it also compares most favourably on the budgetary level for both the patient and the public health system. This has become even more significant as the use of gadolinium has been omitted since 2010 further reducing again the costs for the public health system. A short analysis showed that the full CT and MRI protocol, repeated twice, is six times cheaper than exploratory second-look surgery within the Belgian context. The implementation of the CWU-BOT technique in cholesteatoma management diminishes the re-operation risk. This positively contribute to a higher costeffectiveness of the cholesteatoma management. In-depth cost-effectiveness studies comparing MRI screening for residual cholesteatoma to second-look surgery and comparing the BOT technique to non-BOT techniques might be of great value to the public health administrators.

- 4. One of the goals of chronic ear surgery is the improvement or the preservation of the preoperative hearing level. Although hearing results have not been extensively described in this thesis, further investigation and reporting of the long-term functional outcome of the BOT technique is necessary. The functional results of CWU-BOT are expected to be correlated, as in every type of chronic ear surgery, with the extent and severity of the pathology, the quality of the surgical act, the applied surgical technique and the nature of the reconstructive materials, the quality of the healing process and the postoperative biological behaviour of the ear (2). The implementation of our follow-up protocol using MR instead of a second-look procedure emphasises the importance of the ossicular reconstruction during primary surgery in order to lower the re-operation risk. A lot of yet unkown variables will need further investigation in order to improve the long-term hearing results for our patients.
- 5. The short-term results of our paediatric patients operated with the single-stage CWU-BOT yielded good results and proved that this technique is reliable and safe (18). The evaluation of the 5 and 10-year long-term results of our BOT technique in the paediatric cohort is currently under way at our department.

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Samenvatting

De hoofddoelstellingen van de chirurgische behandeling van het middenoor cholesteatoom zijn: 1 / de volledige eradicatie van de pathologie; 2 / de preventie van recurrente cholesteatomen; 3 / het herstel van de hygiënische toestand van het oor; 4 / het behoud en/of verbetering van het gehoor (1). Een aantal variabelen zijn van invloed op de lange termijn resultaten van de uitgevoerde middenooroperatie. Hoe uitgebreider de pathologie en destructie bij initiële klinische presentatie, hoe slechter de uiteindelijke uitkomst van deze pathologie. Andere belangrijke variabelen zijn onder andere de kwaliteit van de chirurgische akte, die zelf afhankelijk is van verschillende factoren waaronder de persoonlijke ervaring van de opererende chirurg, de adequate keuze van de chirurgische techniek, het materiaal gebruikt voor de reconstructie en de anatomische variabiliteit van het rotsbeen inclusief mastoid en dan meer specifiek het middenoor. Met betrekking tot de keuze van de chirurgische techniek, zijn er twee fundamenteel verschillende chirurgische benaderingen ontwikkeld in het verleden: de Canal wall up techniek (CWU) en de Canal wall down techniek (CWD). De CWU techniek wordt gekenmerkt door de aanwezigheid van een intacte benige achterwand van de uitwendige gehoorgang. De CWD techniek wordt gekenmerkt door de afwezigheid van de benige achterwand aan het einde van de operatie. Zowel CWU en CWD hebben beiden gekende voor- en nadelen. Vóór 1997, gebruikten we binnen onze dienst de CWU techniek in ongeveer 95% van alle cholesteatomen. De chirurgische benadering die we aanvankelijk hanteerden was om aanvankelijk de pathologie volledig te eradiceren waarna vervolgens het middenoor werd geconstrueerd naar een liefst zo normaal mogelijke anatomische situatie. Daarmee hoopten we dat de biologische functie van het slijmvlies van middenoor en de huid van de uitwendige gehoorgang zou gaan normaliseren om op lange termijn een fysiologische en structurele stabiliteit te bekomen (2-3). De zorgvuldige en consequente toepassing van deze CWU techniek gaf in de meeste gevallen goede resultaten. Desondanks dat waren we nog teleurgesteld in sommige gevallen, en dit omwille van de volgende redenen: 1 / de niet te verwaarlozen hoeveelheid van recurrente cholesteatomen, waargenomen in 8,4% in een reeks van 422 patiënten (18% in 103 kinderen, 5% in 319 volwassenen) (2-3); 2 / de absolute noodzaak om een 2^{de} tijdsheelkunde uit te voeren waardoor veel operaties onnodig werden uitgevoerd; 3 / onvoldoende functionele winst in een aantal gevallen; 4 / de noodzaak om een CWU techniek te veranderen in een CWD mastoïdectomie in gevallen met uitgebreide, snel terugkerende pathologie (5%).

Deze minder goede resultaten waren uiteindelijke de beslissende factor om onze chirurgische benadering aan te passen en te veranderen in een nieuwe en gemodificeerde chirurgische techniek. Na 1997 hebben we aldus besloten, in navolging van Ulf Mercke (4-5) die de beenderige obliteratie techniek succesvol had kunnen implementeren in zijn cholesteatoom heelkunde, om ook onze aangepaste beenderige obliteratie techniek (CWU-BOT) op een consequente manier uit te gaan voeren.

Een residueel of achtergelaten cholesteatoom is een probleem inherent aan elke type cholesteatoom chirurgie, ongeacht welke chirurgische benadering er ook wordt toegepast. Wanneer obliteratieve technieken in cholesteatoom chirurgie worden toegepast is de problematiek van residuele cholesteatomen nog belangrijker. Daarom kunnen deze obliteratieve technieken enkel uitgevoerd worden wanneer deze ook veilig kunnen worden opgevolgd worden met betrouwbare beeldvorming. De nauwkeurige en betrouwbare opvolging van een beenderige geoblitereerd mastoid moet voornamelijk late complicaties van residuele cholesteatomen, welke mogelijk zouden achtergebleven zijn in de geoblitereerde caviteit, voorkomen. Dergelijke complicaties kunnen pas na vele jaren zichtbaar worden en resulteren in potentieel levensbedreigende complicaties zoals de intracraniële of intralabyrinthaire extensie van een cholesteatoom.

In het eerste hoofdstuk van dit proefschrift (hoofdstuk 1) beschrijf ik na een algemene introductie (hoofdstuk 1.1), een algemene toelichting over de hedendaagse diagnostiek en therapie in cholesteatoma chirurgie (hoofdstuk 1.2), de chirurgische principes (hoofdtuk 2) - en de beeldvormingsaspecten (hoofdstuk 3) van een cholesteatoom. In het chirurgisch deel wordt de eerste beschrijving van onze versie van de CWU-BOT (hoofdstuk 2.1) gerapporteerd (6). Een overzicht van de literatuur betreffende de indicaties van de cholesteatoom heelkunde, de algemene en meer specifieke chirurgische aspecten van de CWU-BOT, de chirurgische resultaten met inbegrip van de recurrente en residuele cholesteatomen, de functionele resultaten van de CWU-BOT, de hygiënische uitkomsten van het operatief gedeelte van de CWU-BOT alsook de follow-up strategieën met beeldvorming worden besproken. Een uitgebreid overzicht van beeldvormende technieken betreffende het cholesteatoom worden beschreven in hoofdstuk 3.1, 3.2 en 3.3. (7-9). Initieel werd de computer tomografie (CT) beschouwd als de enige manier om een cholesteatoom adequaat te diagnosticeren. De komst van nieuwe MRI sequenties maakte de specifieke karakterisering van een cholesteatoom wel mogelijk. Op MRI kon een

cholesteatoom duidelijk onderscheiden worden van andere weke weefsels zoals bijvoorbeeld littekenweefsel, cholesterol granuloma, granulatieweefsel en vocht. Duidelijke verbeteringen in MRI technieken hadden ondertussen geleid tot een nauwkeurigere diagnose van het cholesteatoom en dit gebruik makende van T1-gewogen MR met intraveneuze gadolinium. Ondanks dat konden residuele cholesteatomen na een eerdere primaire heelkunde niet gedetecteerd worden vanwege de slechte gevoeligheid van zowel hoge resolutie CT (10-12) als de MR beeldvorming (13-15). In *Hoofdstuk 3.3* geef ik een overzicht over de waarde van diffusie-gewogen MRI bij de beoordeling van rotsbeenpathologie. Het belicht tevens het gebruik van diffusie-gewogen MRI beelden voor de detectie primaire en/of recurrente cholesteatoom heelkunde en voor 2^{de} tijdsheelkunde (9).

In *hoofdstuk 4* onderzoeken we de toegevoegde waarde en de bijdrage van diffusie gewogen beeldvorming in de diagnose van cholesteatomen.

In onze eerste klinische studie (hoofdstuk 4.1) worden patiënten met een cholesteatoom pre-operatief geëvalueerd door middel van echo-planaire diffusiegewogen MRI (EP DW MR) (13). Onze patiëntenpopulatie bestaat enerzijds uit een eerste groep patiënten (n = 55) met een klinisch suspect primaire verworven cholesteatoom en anderzijds uit een tweede groep patiënten (n = 45) die werden onderzocht door middel van MRI op de mogelijke aanwezigheid van een residueel cholesteatoom 8 - 18 maanden na primaire sanatie voor een cholesteatoom en dit net voor een geplande 2^{de} tijdsheelkunde. De chirurgische bevindingen werden vergeleken met preoperatieve bevindingen van diffusie-gewogen beeldvorming (DWI). In de groep van primaire chirurgie patiënten werd een cholesteatoom radiologisch bevestigd in 89% (49/55) met een sensitiviteit, specificiteit, positieve en negatieve voorspellende waarde voor DWI van 81, 100, 100 en 40%, respectievelijk. In de 2^{de} groep werd slechts één van de zeven chirurgisch bevestigde residuele gevallen correct gediagnosticeerd met behulp van DWI, met aldus een gevoeligheid, specificiteit, positieve en negatieve voorspellende waarden van 12.5, 100, 100 en 72%, respectievelijk. Op basis van onze resultaten konden we concluderen dat EP DW MR zeker een bijgevoegde waarde heeft bij beoordeling van primaire verworven middenoor cholesteatomen. De gevoeligheid voor de detectie kon evenwel worden verhoogd wanneer deze EP DW geassocieerd werden met standaard MRI sequenties. Maar de resultaten toonden ook een lage gevoeligheid bij de detectie van residuele cholesteatomen. Dit was voor een grootste deel te wijten aan de geringe omvang van residuele cholesteatomen, maar ook door de lucht-bot artefacten van EP DW MR ter hoogte van het tegmen tympani, de lage resolutie en de relatieve dikke coupes van DWI. Als conclusie konden we stellen dat de gerapporteerde standaard MRI sequenties en EP DW MR een tweede tijdsheelkunde niet konden vervangen.

In de tweede klinische studie (hoofdstuk 4.2) onderzoeken we de waarde van hoge-resolutie computertomografie (HRCT) en van MRI, met inbegrip van laattijdige contrast T1-gewogen beelden en EP DW MRI beelden, voor de detectie van residuele cholesteatomen na het uitvoeren van een CWU-BOT (17). In deze studie werden 23 patiënten geïncludeerd welke een 2^{de} tijdsheelkunde kregen 8-18 maanden na initiële heelkunde. Alle patiënten werden door middel van HRCT en MRI geëvalueerd pre-operatief voor een geplande 2^{de} tijdsheelkunde. In deze studie werden 2 patiënten gediagnosticeerd met een residueel cholesteatoom, beiden in de middenoorholte. Er werden geen residuele cholesteatomen in de geoblitereerde caviteit gevisualiseerd op EP DW MR. Op MRI, werd slechts één cholesteatoom gedetecteerd met behulp van laattijdige contrast T1-gewogen MRI. Aldus toonde deze studie aan dat EP DW MR niet betrouwbaar was voor detectie van residuele cholesteatomen in het middenoor en de beenderige geoblitereerde caviteit waardoor HRCT de beeldvormingstechniek naar keuze was voor de evaluatie van een beenderig geoblitereerde caviteit. Een residueel cholesteatoom zou op HRCT herkend kunnen worden als een punch-out letsel binnen een homogeen geoblitereerde caviteit. Deze studie bevestigde tevens de lage sensitiviteit en specificiteit van HRCT en van post-contrast T1-gewogen beeldvorming en EP-DW voor ter detectie van kleine residuele cholesteatomen na een CWU-BOT.

In *hoofdstuk 4.3* onderzoeken we de waarde van non-EP DW als een veilig, nietinvasief alternatief voor een 2^{de} tijdsheelkunde (18). In deze studie werd de non-EP DW sequentie gebruikt voor het opsporen van residuele cholesteatomen na eerdere uitgevoerde CWU mastoïdectomie voor dat een eventuele 2^{de} tijdsheelkunde zou kunnen worden uitgevoerd en dit bij een consecutieve reeks van cholesteatomen (n =32). In deze studie werd door middel van non-EP DW negen van de tien residuele cholesteatomen opgespoord. Een klein residueel cholesteatoom van 2 mm werd gemist en dit ten gevolge van een bewegingsartefact. De sensitiviteit, specificiteit, positief en negatief voorspellende waarde waren 90, 100, 100, en 96%, respectievelijk. Hieruit konden we concluderen dat non-EP DW MRI in staat is om zelfs zeer kleine residuele cholesteatomen op te sporen. Dit gaf ons de mogelijkheid om patiënten voor een eventuele 2^{de} tijdsheelkunde te selecteren waardoor in vele malen een onnodige 2^{de} tijdsheelkunde kon vermeden worden.

In *hoofdstuk 4.4* onderzoeken we in een retrospectieve klinische studie de waarde van verschillende MR sequenties voor de detectie van primaire of residuele cholesteatomen. Hierbij werden non-EP DW, laattijdige gadolinium T1-gewogen magnetische resonantie (MR) beeldvorming en de combinatie van beide technieken gebruikt in de evaluatie van patiënten met een cholesteatoom (19). Wij concludeerden in deze studie dat de detectie van een middenoor cholesteatoom kan uitgevoerd door enkel gebruik te maken van de non-EP DW sequenties. Het gebruik van de non-EP DW beeldvormingssequentie gecombineerd met een laattijdige gadolinium T1-gewogen sequentie gaf geen significante toename van de sensitiviteit, specificiteit, negatief of positieve voorspellende waarde over het gebruik van de non-EP DW alleen.

In *hoofdstuk 5* worden de eerste klinische resultaten van CWU-BOT onderzocht in een pediatrische cholesteatoom populatie (n = 52) (20). De resultaten geven aan dat de CWU-BOT of CR-BOT, uitgevoerd bij kinderen met een primair of recurrent cholesteatoom en bij caviteitreconstructies, een zeer valabele techniek is om het aantal residuele en recurrente cholesteatomen te verminderen. In deze studie werd er één recurrent (1/52) en één residueel cholesteatoom (1/52) gedetecteerd. Op basis van deze analyse blijkt dat door het consecutief uitvoeren van deze CWU-BOT de incidentie van recurrente cholesteatomen drastisch is afgenomen in vergelijking met onze vorige klinische pediatrische cholesteatoom studie (2).

In *hoofdstuk* 6 worden radiologische en klinische lange termijn resultaten gerapporteerd na het uitvoeren van een CWU-BOT.

Wanneer de CWU - BOT techniek wordt uitgevoerd, is één van de belangrijkste potentiële gevaren de mogelijke aanwezigheid van een residueel cholesteatoom in de geoblitereerde mastoid caviteit. Het gebruik van accurate en betrouwbare beeldvorming zijn aldus verplicht om late complicaties, die vele jaren kunnen duren om klinisch zichtbaar te worden, te vermijden. In deze studie werden patiënten (n = 51) met een cholesteatoom of radicaal holte geopereerd door middel van een CWU – BOT of CR – BOT techniek en werden verder postoperatief geëvalueerd door middel van beeldvorming met een gemiddelde follow-up van 76,4 maanden na initiële heelkunde *(hoofdstuk 6.1)* (21).

Beeldvorming kon één residueel (1/51), één recurrent (1/51) en een congenitaal apex petrosum cholesteatoom (1/51) detecteren, en dit door middel van non-EP DW sequenties. Er werd geen enkel cholesteatoom binnen de geoblitereerde caviteit gevisualiseerd. Deze lange termijn studie bevestigde dat CWU-BOT een veilige heelkundige techniek is mits er een adequate non-EP DW MRI follow-up protocol geïmplementeerd kan worden.

In *hoofdstuk 6.2* worden de lange termijn resultaten van de kanaal wand reconstructies met beenderige obliteratie techniek (CWR-BOT) in problematische caviteiten na eerder uitgevoerde CWD techniek geanalyseerd en dit in een volwassen populatie (n = 50)

CWD technieken worden vaak gekenmerkt door minder recurrente pathologie, doch eisen vaker een frequente reiniging van de caviteit. Zeer frequent worden deze CWD technieken geassocieerd met periodes van recidiverende oorloop ten gevolge van begeleidende inflammatie en/of infecties. Deze caviteiten zijn dikwijls niet water bestendig en kunnen calorische geïnduceerde duizeligheid veroorzaken. Ook is het vaak niet mogelijk om op een comfortabele manier een luchtgeleidingshoortoestel te dragen (22). In deze studie toonden de lange termijn dat 96% (n= 49/50) veilige oren zonder recidief of residuele pathologie bekomen werden na het uitvoeren van een CWR-BOT en dit na een gemiddelde follow-up periode van 101,8 maanden. Eén recurrent cholesteatoom en één residueel cholesteatoom werden gedetecteerd in de studiepopulatie. Een veilige, waterbestendig en rustig trommelvlies met een zelfreinigende uitwendige gehoorgang werd bereikt in 94% (47/50). De 1 en 5-jaars imaging follow-up kon geen andere recurrente of residuele cholesteatomen aantonen. Aldus konden we concluderen dat de CWR-BOT een veilige en zeer effectieve heelkundige techniek is voor de behandeling van een problematische instabiele caviteit.

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Summary

The main objectives of the surgical treatment of cholesteatoma are: 1 / the complete eradication of the pathology; 2 / prevention of recurrent cholesteatoma; 3 / rehabilitation of the hygienic status of the ear; 4 / preservation and / or improvement of the hearing (1). Many variables influence on the long-term outcome of middle ear surgery. The more extensive the disease and damage at initial presentation, the poorer the outcome. Another important variable influencing the outcome of surgery of COM is the quality of the surgical act, which depends on different factors including the surgeon's personal experience, the adequate choice of the surgical technique and of the material used for the reconstruction and the anatomical variability of the petrous bone including mastoid and more specifically the middle ear cavity.

Concerning the choice of the surgical technique, two basically different surgical approaches have been and still are advocated to reach these goals: the canal wall up technique (CWU) and the canal wall down technique (CWD). The CWU technique is defined by the presence of an intact or restored bony canal wall at the end of the operation. The CWD technique is defined by the absence of the bony canal wall at the end of the operation. Both CWU and CWD both have known advantages and disadvantages.

Before 1997, we used a CWU technique in approximately 95% of our cholesteatoma cases. Our surgical philosophy was: 1/ first eradicate the pathology; 2/ then reconstruct the normal anatomy by means of sculpted cortical bone for rebuilding the canal wall and by means of tympano-ossicular allografts (TOA) for rebuilding the middle ear; 3/ finally hope that the biological behaviour of the middle ear's mucosal lining and of the EAC's skin is normal enough to allow long-term physiological and structural stability (2-3). The meticulous and consequent application of this CWU technique yielded good results in the majority of the cases, but we were still somewhat disappointed, for the following reasons: 1/ the non-negligible rate of recurrent cholesteatoma, observed in 8,4 % in a series of 422 patients (18 % in 103 children, 5 % in 319 adults) (2-3); 2/ the necessity of staging, leading to an important number of unnecessary operations; 3/ insufficient functional gain; 4/ the necessity to change a CWU into a CWD mastoidectomy in cases with extensive, rapidly recurrent pathology (approx. 5%). Inspired by the work of Ulf Mercke (4-5) we changed our surgical philosophy concerning cholesteatoma surgery, which led to the adaptation of the surgical technique. In 1997 we decided to find out whether it was possible to combine the advantages and at the same time avoid the disadvantages of both the CWU and CWD

techniques, by applying one surgical approach: the Bony Obliteration Technique (BOT), which is by definition a CWU technique. This surgical technique of bony mastoid obliteration is nowadays used in the majority of cholesteatoma cases in our department.

Residual cholesteatoma is defined as a cluster of viable keratinising squamous epithelium, left behind at the primary surgery, which has regrown into a cholesteatoma. The problem is inherent in all cholesteatoma surgery, regardless of the applied surgical approach and reconstructive technique. Therefore, the long-term safety of the ear is of primary concern in cholesteatoma surgery. Therefore obliteration techniques in cholesteatoma management can only be safely used when either staging is done or when reliable imaging techniques are available. Accurate and reliable imaging follow-up of obliterated mastoids is necessary to prevent late complications due to residual cholesteatoma buried underneath the obliteration material. It may then take years before the residual pathology becomes clinically evident, and major destruction and complications may ensue. Because of potential labyrinthine and intracranial involvement, they can cause important morbidity and even death.

In *chapter 1* of this thesis a general introduction (*chapter 1.1*), a leading-edge editorial concerning current diagnostic and therapeutic practice management in cholesteatoma surgery (chapter 1.2), a comprehensive review of the surgical principles (chapter 2) and imaging aspects (chapter 3) of cholesteatoma have been outlined. In the surgical section, the first description of our version of the CWU-BOT (chapter 2.1) has been reported (6). An overview of the literature on the indications of the cholesteatoma surgery, general and specific surgical aspects of the CWU-BOT, the surgical results including recurrent and residual cholesteatoma, the functional results of the CWU-BOT, hygienic outcomes of the CWU-BOT and the imaging follow-up strategies have been outlined. A comprehensive overview of imaging techniques on cholesteatoma is described in chapter 3.1, 3.2 and 3.3. (7-9). Initially, the computer tomography (CT) was considered as the only way to adequately diagnose a cholesteatoma. The advent of new MRI sequences made possible to specifically characterise cholesteatoma. MRI cholesteatoma could be clearly distinguished from other soft tissue such as scar tissue, cholesterol granuloma, granulation and moisture. Despite this fact, residual cholesteatoma was often not detected due to the poor sensitivity of both high-resolution CT (10-12) and MR imaging (13-15). Clear improvements in MRI techniques have now led to a more accurate diagnosis of cholesteatoma and this using T1-weighted MR with intravenous gadolinium

Chapter 3.3 summarizes the value of diffusion-weighted magnetic resonance imaging in the evaluation of temporal bone pathology. It highlights the use of different types of diffusion-weighted MR imaging in the different types of cholesteatoma, prior to first and second-look surgery. The value of diffusion-weighted MR imaging in the evaluation of pathology of the apex of the petrous bone and the cerebellopontine angle is also discussed.

In *chapter 4*, we evaluated the added value and contribution of diffusion-weighted imaging in the diagnosis of cholesteatoma.

In our first imaging study (chapter 4.1), one hundred patients were preoperatively evaluated by magnetic resonance (MR) imaging using echo-planar diffusion weighted MR imaging (EP DW MR) (13). The patient population consisted of a first group of 55 patients preoperatively evaluated in order to detect the presence of a clinically suspect primary acquired cholesteatoma. In the second group, 45 patients were evaluated for the presence of a residual cholesteatoma 8-18 months after cholesteatoma surgery, prior to scheduled second-look surgery. Surgical findings were compared with preoperative findings on diffusion- weighted imaging (DWI). In the group of primary surgery patients, a hyperintense signal compatible with cholesteatoma was found in 89% of cases with sensitivity, specificity, positive and negative predictive value for DWI of 81, 100, 100 and 40%, respectively. In the group of second-look surgery patients, only one of seven surgically verified residual cases was correctly diagnosed using DWI, with a sensitivity, specificity, positive and negative predictive values of 12.5, 100, 100 and 72%, respectively. On the base of our results, we conclude that DWI has an important role in the evaluation of primary acquired middle ear cholesteatoma. Its sensitivity can be augmented when associated with standard MR imaging sequences. But the results also showed a low sensitivity in the detection of residual cholesteatoma. This was due to a majority of the small amount of residual cholesteatoma, but also by the air-bone artefacts EP DW MR at the level of the tegmen tympani, the low resolution and the relatively thick sections of DWI. With the current reported MR imaging techniques (standard MR imaging sequences and EP DW MR) second look cannot be replaced by MR imaging.

In our second imaging study *(Chapter 4.2)* we tried to assess the value of high-resolution computed tomography (HRCT) and of magnetic resonance imaging (MRI), including postcontrast T₁- weighted images and echo-planar diffusion-

weighted (EP-DW) images, in the detection of residual cholesteatomas after primary bony obliteration of the mastoid (14). In this study 23 patients underwent a second-look surgery 8 to 18 months after a primary bony obliteration technique was performed. All patients were evaluated by HRCT and MRI before their second-look surgery. In these 2 patients, residual cholesteatoma was found in the middle ear cavity and not in the obliterated mastoid. In all cases, HRCT showed a homogeneous obliteration of the mastoid cavity. On MRI, only one cholesteatoma pearl was detected using contrast-enhanced T1- weighted imaging. Findings from the EP-DW imaging were negative for all cases. This study demonstrates that HRCT is still the imaging technique of choice for the evaluation of bony obliterated mastoids. It shows the low sensitivity and specificity of HRCT for the characterization of an associated opacified middle ear and those of contrastenhanced T1- weighted imaging and EP-DW imaging for the detection of small residual cholesteatomas after primary bony obliteration.

In our second imaging study (Chapter 4.2) we investigated the value of highresolution computed tomography (HRCT) and that of magnetic resonance imaging (MRI), including postcontrast T₁- weighted images and echo-planar diffusionweighted (EP-DW) images, in the detection of residual cholesteatomas after primary bony obliteration of the mastoid (12). In this study 23 patients underwent a second-look surgery 8 to 18 months after they underwent a primary bony obliteration technique. All patients were evaluated by HRCT and MRI before their second-look surgery. In 2 patients, residual cholesteatoma was found in the middle ear cavity and not in the obliterated mastoid. In all cases, HRCT showed a homogeneous obliteration of the mastoid cavity. On MRI, only one cholesteatoma pearl was detected using contrast-enhanced T1- weighted imaging. Findings from the EP-DW imaging were negative for all cases. In this study, HRCT is the imaging technique of choice for the evaluation of bony obliterated mastoids. It shows the low sensitivity and specificity of HRCT for the characterization of an associated opacified middle ear and those of contrast-enhanced T1- weighted imaging and EP-DW imaging for the detection of small residual cholesteatomas after primary bony obliteration.

In *chapter 4.3* we investigated the value of non-EP DW imaging in combination with delayed post-gadolinium T1-weighted sequences as a safe, non-invasive, selective, sensitive and comparatively cheap alternative to exploratory second-look surgery (18). Non-EP DW MRI in combination with delayed post-gadolinium T1-weighted sequences was used to screen for residual cholesteatoma after CWU

mastoidectomy, prior to planned second-look surgery in a consecutive series of patients (n = 32). The non-EP DWI sequence in combination with delayed postgadolinium T1-weighted sequences identified 9 out of 10 residual cholesteatoma pearls found during surgery. The only lesion missed was a 2-mm cholesteatoma pearl in an examination degraded by motion artifacts in a child. The other diagnosed residual pearls measured between 2 and 6 mm. Sensitivity, specificity, positive predictive value, and negative predictive value were 90, 100, 100, and 96%, respectively. We concluded that, except for motion artefact-degraded examinations, non-EP DW MRI in combination with delayed post- gadolinium T1-weighted sequences could detect even very small residual cholesteatoma pearls. These results gave us the possibility to select patients for a second surgical staging and thus avoiding unnecessary second-look surgery.

In *Chapter 4.4* we retrospectively compared non-EP DWI, delayed gadoliniumenhanced T1-weighted MRI, and the combination of both sequences for the evaluation of patients with cholesteatoma (19). Non-EP DWI sequences have a thinner section thickness and a higher imaging matrix and are less prone to susceptibility artifacts than EP DWI sequences. We concluded that combining both the non-EP DW imaging sequence and the delayed gadolinium-enhanced T1weighted sequence yields no significant increase in sensitivity, specificity, negative predictive value, or positive predictive value over the use of the non-EP DW imaging sequence alone. The Non-EP DWI sequence suffices.

In **Chapter 5**, the first clinical results of mastoid and epitympanic obliteration in a paediatric cholesteatoma population (n = 52) were reported (20). We found a recurrent cholesteatoma in 1,9% (n = 1/52) and a residual cholesteatoma in 15,4% (n = 8/52) of all cases. The results indicate that the CWU-BOT or CR-BOT carried out in children with primary or recurrent cholesteatoma or in unstable cavity is a valid technique to reduce the number of residual and recurrent cholesteatoma. Based on this analysis, the incidence of recurrent cholesteatoma is drastically reduced by the consecutive execution of the CWU-BOT compared with our previous clinical paediatric cholesteatoma study (2). Promising short-term results and a marked reduction in recurrent/residual disease encouraged to use this surgical technique in the majority of cholesteatoma cases.

Chapter 6 reports on the long-term results of the CWU-BOT.

In *Chapter 6.1* fifty-one patients presenting with a cholesteatoma or a troublesome cavity were operated by means of the CWU-BOT or CR-BOT and were evaluated by follow-up imaging with a mean of 76.4 months post-operatively (21). Imaging could detect a residual (n = 1/51), a recurrent (n = 1/51) and congenital petrosum apex cholesteatoma (n = 1/51) by means of non-EP DW sequences. Non-EP DW imaging clearly identified all three cholesteatomas, and differentiated them from other associated soft tissues. No cholesteatoma was found within the obliterated mastoids. Long-term clinical and radiological follow-up after canal wall up bony obliteration technique procedures for cholesteatoma shows that CWU -BOT is a safe surgical treatment for primary and recurrent cholesteatoma, and for the reconstruction of unstable cavities. Its meticulous application in our department greatly reduced the incidence of recurrent pathology. This long-term study confirmed that CWU-BOT is a safe surgical technique provided there is an adequate non-EP DW MRI follow-up protocol can be implemented.

Long-term results of mastoid and epitympanic obliteration with a canal wall reconstruction technique (CWR - BOT) in troublesome cavities after prior canal wall down surgery for extensive cholesteatoma in an adult population (n = 50) are discussed in chapter 6.2 (22). The canal wall down (CWD) mastoidectomy yields lower recurrence rates, but often requires regular cavity cleaning and is associated with recurrent otorrhea because of inflammation/infection. These cavities are often not water resistant, can cause caloric induced dizziness and often are characterized by the diminished ability to comfortably wear an air-conduction hearing aid. The problem of recurrent inflammation and infection is mainly caused by the loss of the self-cleaning capacity of the ear, which leads to accumulation of epithelial debris and thus necessitates regular cleaning of the mastoid cavity. Long-term surgical outcome of the bony mastoid and epitympanic obliteration technique with canal wall reconstruction (CWR-BOT) resulted 96% of the ears (n = 49/50) remaining safe without recurrent or residual disease after CWR-BOT after a mean follow-up time of 101.8 months. Recurrent cholesteatoma occurred in 2% (n = 1/50) and a residual cholesteatoma was detected in 2% (n = 1/50) of the patients. A safe dry, and trouble-free graft and self-cleaning EAC was achieved in 94% (n = 47/50). The 1 and 5-year imaging follow-up revealed no other recurrent or residual disease. The CWR-BOT is a safe and very effective option for treatment of problematic unstable canal wall-down mastoid cavities, resulting in dry trouble-free ears.

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Resumé

Les objectifs principaux du traitement chirurgical du cholestéatome de l'oreille moyenne sont: 1 / l'éradication complète de la pathologie; 2 / la prévention du cholestéatome récurrenciel; 3 / le rétablissement d'un conduit auditif sain et auto-nettoyant; 4 / la conservation et / ou l'amélioration de l'audition (1).

Un certain nombre de variables peuvent influencer les résultats à long terme dans cette chirurgie du cholestéatome. Quand la pathologie est étendue et la destruction est importante à la présentation initiale du cholestéatome, le résultat chirugical sera moins favorable que quand la lésion au diagnostic est limitée. D'autres variables pouvant influencer les résultats sont entre autre: la qualité de l'acte chirurgical (dépendant de plusieurs facteurs, y compris l'expérience du chirurgien), le choix adéquat de la technique chirurgicale, le matérial utilisé pour la reconstruction et la variabilité de l'anatomie de l'os pétreux et de l'oreille moyenne.

En ce qui concerne le choix de la technique chirurgicale, il existe deux approches chirurgicales fondamentalement différentes: la tympanoplastie en technique fermée et la tympanoplastie en technique ouverte. La tympanoplastie en technique fermée se caractérise par la preservation de la paroi postérieure du conduit auditif osseux. La tympanoplastie en technique est caractérisée par l'absence de la paroi arrière osseuse à la fin de intervention avec la création d'une cavité dite d'évidement.

Avant 1997, nous utilisions principalement la tympanoplastie en technique fermée càd dans environ 95% des cholestéatomes diagnostiqués. L'approche chirurgicale qu'on employait avait pour but d'éradiquer complètement la pathologie et de reconstruire les éléments détruits de telle façon qu'après chirurgie l'état anatomique de l'oreille serait aussi proche de la normale que possible. De surcroît nous espérions que la fonction physiologique de l'oreille moyenne et de sa muqueuse ainsi que le revêtement épidermique du conduit auditif osseux se soit normalisés et ceci également au long terme (2-3). L'utilisation de la tympanoplastie en techniques fermée nous a procuré de bons résultats dans la plupart des cas. Néanmoins, nous étions aussi déçus dans certains autres cas et ceci principalement pour les raisons suivantes: 1 / la quantité non négligeable de cholestéatomes récurrenciels observés (c.à.d. dans 8,4% des cas dans une série de 422 patients: 18% parmi 103 enfants, 5% parmi 319 adultes) (2-3); 2 / la nécessité de devoir effectuer une chirurgie dite en un 2ième temps et de ce fait de nombreuses opérations inutiles ont été effectuées; 3/ un bénéfice fonctionnel insuffisant dans bon nombre de cas; 4 / la nécessité de convertir une technique fermée en technique ouverte dans des cas de cholestéatome recurrenciels rapides (5%).

Ces résultats de moins bonne qualité nous ont pousser à adapter notre approche chirurgicale et de transformer la technique existante. A la suite de la publication d'Ulf Mercke (4-5), qui a demontré avec succès une technique de l'oblitération osseuse dans la chirurgie du cholestéatome, à partir de 1997 nous avons également modifier cette technique pour adopter notre propre technique oblitération osseuse (nommé CWU-BOT qui veut dire "Canal Wall Up with Bony Obliteration Technique").

Le cholestéatome résiduel est un problème intrinsèque à tout type de chirurgie du cholestéatome. Lorsque des techniques dites d'oblitération sont effectuées, le problème du cholestéatome résiduel devient encore plus important. En principe les techniques d'oblitérations ne pourraient être effectuées que si le suivi à l'aide de l'imagerie est parfaitement fiable. Sinon l'on risque dans cette cavité oblitérée un cholestéatome résiduel qui laissé seul peut conduire à des complications et ceci par envahissement intralabyrinthique, du nerf facial ou même intracranien.

Dans le premier chapitre de cette thèse (*chapitre 1*) sont décrits: après une introduction générale (*section 1.1*), un éditorial actuel concernant la gestion du suivi et de la chirurgie du cholestéatome (*section 1.2*) les principes chirurgicaux (*section 2*) - et les aspects d'imagerie du cholestéatome (*section 3*). Dans la section chirurgicale nous décrivons notre variante de la technique de technique fermée d'oblitération osseuse (*section 2.1*) (6). Un aperçu de la littérature est donné avec les indications de la chirurgie du cholestéatome, les aspects spécifiques de la technique d'oblitération CWU-BOT, les résultats chirurgicaux, y compris le percentage de récurrences et de cholestéatomes résiduels, les résultats fonctionnels (auditifs) de la technique CWU-BOT, les résultats anatomiques, ainsi que les stratégies de suivi par l'imagerie sont discutées. Un exposé des techniques d'imagerie du cholestéatome est fait dans la *section 3.1, 3.2 et 3.3. (7-9)*.

Initialement, la tomodensitometrie (CT-scan) était considérée comme le seul moyen de diagnostiquer correctement le cholestéatome par imagerie. L'apparition des nouvelles séquences d'IRM nous a aidé à caractériser de façon spécifique le cholestéatome. Le cholestéatome à l'IRM peut à l'aide de cette séquence être clairement différenciée d'autres tissus tels que le tissu cicatriciel fibro-inflammatoire, le granulome à cholesterine et la formation de granulation de type inflammatoire aigu.

Des innovations dans les techniques d'IRM nous ont conduit à un diagnostic plus précis du cholestéatome par l'utilisation de IIRM en séquences T1 avec l'injection de gadolinium. Malgré cela le cholestéatome résiduel, n'était souvent pas détecté et ceci était souvent du à une trop faible sensibilité et spécificité de la tomodensitometrie (10-12) ainsi que par IRM en T1 après injection de gadolinium (13-15).

Dans la **section 3.3** un aperçu est donné des séquences IRM par diffusion dans l'évaluation de la pathologie de l`os temporal (9).

Dans le second chapitre (*Chapitre 4*), nous examinons la valeur et la contribution de l'imagerie de diffusion dans le diagnostic du cholestéatome.

Dans la première étude (section 4.1), les patients présentant un cholestéatome sont évalués en étude préopératoire par séquences IRM de diffusion echoplanaire (EP DW MR) (13). La population des patients consiste d'un premier groupe de patients (n = 55) avec un choléstéatome acquis primaire et d'autre part d'un second groupe de patients (n = 45) evalué 8 - 18 mois après un première opération de cholestéatome. Le resultat chirurgical à été comparé au résultat de la séquences de diffusion echo-planaire. Dans le premier groupe de patients le cholestéatome a été confirmée dans 89% (49/55) avec une sensibilité, la spécificité et la valeur prédictive positive et négative pour DWI de 81, 100, 100, et 40%. Dans le second groupe seulement un des sept cholestéatome residuel confirmé dans le chirurgie 2ième temps ont correctement éte diagnostiqués en utilisant DWI avec une sensibilité, la spécificité et les valeurs prédictives positives et négatives de 12,5, 100, 100, et 72%, respectivement. En conclusion le cholestéatome acquis primaire est bien détecté en utilisant les séquences IRM de diffusion echo-planaire. La sensibilité peut cependant être amelioré si EP DW sont associées à des séquences d'IRM classiques. Cependant les résultats dans le second groupe ont également montré une faible sensibilité dans la détection de cholestéatome résiduel.

Les séquences IRM classiques et EP DW MR ne savent en conclusion pas remplacer un second look.

Dans la seconde étude (**section 4.2**), nous examinons la valeur de la tomodensitometrie (HRCT) et de l'IRM, y compris l'IRM avec injection de gadolinium et les clichés tardifs en séquence T1 (45 min après l'injection) ainsi que les séquences IRM de diffusion echo-planaire (EP DW IRM), pour but de détecter un cholestéatome résiduel éventuel, après avoir effectué une technique d'obliteration osseuse (CWU-BOT) (17). Dans cette étude, 2 patients ont été

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diagnostiqués avec un cholestéatome résiduel, tout les deux dans la cavité moyenne de l'oreille. Aucun cholestéatome résiduel a été visualisé dans la cavité oblitérée avec le EP DW MR. Le seule cholestéatome detecté avec l'IRM avec injection de gadolinium et les clichés tardifs IRM était localisé dans la cavité moyenne. Ainsi, cette étude a demontré que EP DW MR n'est pas fiable pour la détection du cholestéatome résiduel dans l'oreille moyenne et dans la cavité osseuse oblitèré. En conséquence la conclusion est: la tomodensitometrie était encore toujours la technique d'imagerie de choix pour l'évaluation d'une cavité osseuse. Un cholestéatome résiduel peut être décelé au ct-scan pourrait être reconnue sur tomodensitometrie comme une lésion translucante dans une cavité oblitérée homogène. Cette étude a également confirmé la faible sensibilité et spécificité de la tomodensimetrie et de l'IRM T1 après contrast tardif ainsi que la séquence IRM de diffusion echo-planaire pour la détection du cholestéatome résiduel après une technique d'obliteration osseuse.

Dans la **section 4.3**, nous examinons la valeur d'une nouvelle séquences IRM de diffusion non-echo-planaire (non-EP DW) comme alternative plus sûre et non invasive ayant pour but de remplacer la chirurgie de 2ième temps (18). Dans cette étude, la séquence IRM de diffusion non-echoplanaire a été utilisée pour la détection du cholestéatome résiduel apres avoir réalisée une tympanoplastie par de technique fermée dans une série consécutive de 32 cholestéatomes. Le séquence non-EP DW a détecté les neuf des sur dix cholestéatomes résiduels. Un choléstéatome résiduel de 2 mm a été manqué probablement due à un mouvement du patient. La sensibilité, la spécificité, les valeurs prédictives positives et négatives sont respectivement de 90%, 100%, 100%, et 96%. Nous concluons que la séquence IRM de diffusion non-echoplanaire est capable de détecter même de très petits cholestéatomes résiduels. Ces nouvelles données nous font évité les deuxièmes temps systématiques et l'opportunité de cibler les deuxièmes temps. De ce fait, par conséquence la chirurgie de 2ième temps inutile pourrait être évité dans la majorité des cas.

Dans la **section 4.4**, nous étudions dans une étude rétrospective la valeur des différentes séquences IRM pour la détection du cholestéatome primaire ou résiduel. Les differentes sequences sont: la sequence IRM de diffusion non-echoplanaire, la séquence IRM en séquence T1 tardive après injection de gadolinium (45 min après l'injection) et la combinaison des deux techniques (19). L'utilisation de la combinaison des séquences n'a pas donné de plus-value significative de la sensibilité, la spécificité, la valeur prédictive positive et négative

en comparaison avec l'utilisation de la seule séquence IRM non echo-planaire seule. En conséquence nous pouvions conclure que avons conclu que la détection du choléstéatome de l'oreille peut être effectuée en utilisant uniquement les séquences non-echo-planaire de diffusion.

Dans le *chapitre* 5, les premiers résultats cliniques de la tympanoplastie de technique fermée avec obliteration osseuse (CWU-BOT) sont rapporté dans une population du cholestéatome chez l'enfant (n = 52) (20). Les premiers résultats indiquent que la technique d'obliteration réalisée chez les enfants avec un cholestéatome primaire ou récurrent et dans la reconstruction d'une cavité d'èvidement est une technique valable qui donne une reduction signicative du nombre des cholestéatomes résiduels et récurrenciels. Dans cette étude on a détecté seulement un cholestéatome résiduel (1/52) ainsi qu'un seul cholestéatome a été considérablement réduite après avoir réalisé la tympanoplastie par technique fermée avec obliteration osseuse systématique en comparaison avec une étude clinique pédiatrique de cholestéatomes effectués sans obliteration osseuse (2).

Dans le **chapitre 6**, les résultats cliniques et radiologiques à long terme sont présentés après tympanoplastie de technique fermée avec obliteration osseuse.

Un des danger potentiel avec la tympanoplastie en technique fermée avec obliteration osseuse est la présence éventuelle d'un cholestéatome résiduel dans la cavité osseuse oblitérée. En conséquences l'utilisation de l'imagerie doit être précise et fiable pour éviter de complications tardives, qui peuvent prendre de nombreuses années avant de devenir apparantes cliniquement.

Dans cette étude **(section 6.1)**, 51 patients avec un cholestéatome ou avec une cavité problematique ont été operé au moyen d'un CWU - BOT ou CR - technique et ont été ultérieurement évalués avec un suivi de 76,4 mois (moyenne) après chirurgie initiale (21). L'imagerie a détecté un cholestéatome résiduel (1/51), un cholestéatome recurrentiel (1/51) et un cholésteatome dans l'apex petreux (1/51). Il n'y avait pas de cholestéatome dans la cavité oblitérée. Cette étude a confirmé que la CWU-BOT est une technique chirurgicale fiable et sûre pour autant que le chirurgien puisse avoir accès au technique assurant un suivi avec les séquences non-EP DW IRM.

Dans le *chapitre 6.2*, les résultats à long terme de la réhabilitation de l'oreille moyenne par reconstruction de la paroi du conduit auditif osseux avec l'oblitération

osseuse sont présentés. Cette technique est indiquée pour traiter des cavités problématiques dans une population adulte (n = 50). Les techniques ouvertes ont la réputation de s'accompagner de moins de pathologie récurrencielle, mais par contre ces cavités nécessitent plus souvent un nettoyage fréquent de la cavité. Ces techniques sont associées à des périodes d'écoulements répétées dues a de l'inflammation et / ou une infection concomitante. Ces cavités sont souvent problematiques à l'appareillage et peuvent provoquer des vertiges.

Les résultats nous ont démontré que 96% (n = 49/50) de oreilles operées sont stables après un suivi en moyennne de 101,8 mois. Un cholestéatome récurrent et un cholestéatome résiduel ont été détectés dans cette série. Un tympan postopératif sain et pouvant être exposé à l'eau a été obtenu dans 94% des cas (47/50). L' IRM effectué après 1 et 5 ans n'à démontré aucun signe récurrence ou cholestéatome résiduel. On peut donc conclure que la CWR-BOT est une technique chirurgicale sûre et très efficace pour le traitement d'une cavité instable et problématique.

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A PhD is a personal achievement and I am proud of it!
Curriculum Vitae

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List of abbreviations

3D:	Three-dimensional	
ADC:	Apparent diffusion coefficient	
BOT:	Bony obliteration technique	
CBCT:	Cone Beam Computed Tomography	
CI:	Confidence interval	
COMQ:	Chronic Otitis Media Questionnaire	
CR-BOT:	Cavity Reconstruction – Bony Obliteration Technique	
CT:	Computed Tomography	
CWD:	Canal wall down	
CWU-BOT: Canal wall up Bony Obliteration Technique		
CWU:	Canal wall up	
DW:	Diffusion-weighted	
DWI:	Diffusion-weighted imaging	
EAC:	External auditory canal	
ENT:	Ear, nose and throat	
EP DW:	Echo-planar diffusion-weighted	
EP:	Echo-planar	
FN:	False negative	
Fov:	Field of view	
FP:	False positive	
HASTE:	Half-Fourier acquisition single-shot turbo spin-echo	
HRCT:	High resolution computed tomography	
kg:	Kilogram	
kV:	Tube voltage	
mAs:	Tube current time product	
min:	Minutes	
mm:	Millimeter	
mmol:	Millimol	
MR:	Magnetic resonance	
MRI:	Magnetic resonance imaging	
msec:	Milliseconds	
Non EP:	Non-echo-planar	
NPV:	Negative predictive value	
PBOT:	Primary bony obliteration technique	
PPV:	Positive predictive value	
SE:	Spin-echo	

sec:	Seconds
sec/mm2:	Seconds per square millimeter
TE:	Echo-time
TM:	Tympanic membrane
TP:	True positive
TR:	Repetition time
COM:	Chronic otitis media
TOA:	Tympano-ossicular allografts
CSF:	Cerebrospinal fluid
dB:	Decibel
AB:	Air-bone
TSE:	Turbo spin-echo
FSE:	Fast spin echo
CPA:	Cerebellopontine angle
NEX:	Number of acquisitions
PTA:	Pure tone average
AC:	Air conduction
BC:	Bone conduction
SNHL:	Sensorineural hearing loss
BAHD:	Bone anchored hearing device



