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Advanced Hearing and Balance Evaluation in Otitis Media

Rafael da Costa Monsanto, Leandro Guena de Castro, Matheus Saito, José Carlos Convento Junior, and Norma de Oliveira Penido

Introduction

Otitis media, defined as the presence of middle ear inflammation or infection, is a highly burdening disease [1]. The high burden of otitis media is aggravated by its high worldwide incidence: acute otitis media (AOM) affects ~709 million people yearly, and it was estimated that over 31 million new cases of chronic otitis media (COM) are diagnosed worldwide [1, 2]. The World Health Organization (WHO) estimated that complications of otitis media are responsible for 28,000 deaths every year. These complications include (but are not limited to) intratemporal (acute mastoiditis, labyrinthitis, labyrinthine fistula and petrous apicitis, for example) and intracranial complications (sigmoid sinus thrombosis, intracranial abscess, and meningitis) [2].

The association of otitis media and inner ear lesions has been extensively studied in the past 4 decades. Adam Politzer, in 1894, was the first to hypothesize that patients with otitis media might be at risk of developing hearing loss [3]. Many experimental studies then dedicated to understanding the pathophysiological mechanisms involved with auditory sequela secondary to otitis media. However, it was only in 1972 that Paparella et al. [4] published a pioneer translational study corroborating the presence of sensorineural hearing loss, also demonstrating its otopathological correlates. The authors showed high-frequency hearing loss in patients with COM, which correlated otopathologically with loss of cochlear hair cells in the basal turn of the cochlea. These findings were later corroborated by many experimental and clinical studies. More recently, the WHO [5] demonstrated that otitis media is the third leading cause of hearing impairment, and Cordeiro et al. [6] revealed that a single episode of uncomplicated AOM may result in permanent hearing loss. Tinnitus is also a frequent complaint in patients with otitis media: a cohort study of 30 years including over 2000 participants revealed that children who had recurrent AOM or chronic otitis media with effusion (OME) had worse hearing and a higher prevalence of tinnitus in adulthood as compared with controls [7].

Based on the observations of cochlear/auditory sequela of otitis media, the presence of an associated peripheral vestibular lesion was also hypothesized. As vestibular problems are not major complaints of most patients with otitis media, this hypothesis has not been explored in depth [8] Many authors associated dizziness or vertigo in otitis media patients with the presence of perilymphatic fistula, variation in the middle ear pressure, or other associated clinical problems (such as metabolic diseases and benign paroxysmal postural vertigo) Nonetheless, clinical and experimental evidence demonstrated that otitis media can independently result in vestibular damage [9]. Histopathological studies in human temporal bones demonstrated loss of vestibular hair cells in the saccular and utricular macula of temporal bones with COM [10]. A cohort study showed that adults with a history of recurrent AOM or COM in childhood had a much higher prevalence of self-reported dizziness as compared with ones without a history of otitis media [11]. Thus, it seems that although the vestibular sequela of otitis media may be less burdening than auditory symptoms, these should be assessed to allow prevention and assertive treatment as required [12].

R. da Costa Monsanto (✉)
Department of Otolaryngology, Head & Neck Surgery, Banco de Olhos de Sorocaba Hospital, Sorocaba, SP, Brazil

Department of Otolaryngology, Head & Neck Surgery, Universidade Federal de São Paulo/Escola Paulista de Medicina (UNIFESP/EPM), São Paulo, SP, Brazil

Department of Otolaryngology, Head & Neck Surgery, University of Minnesota, Minneapolis, MN, USA
e-mail: rdacosta@umn.edu

L. G. de Castro · M. Saito · J. C. C. Junior
Department of Otolaryngology, Head & Neck Surgery, Banco de Olhos de Sorocaba Hospital, Sorocaba, SP, Brazil

N. de Oliveira Penido
Department of Otolaryngology, Head & Neck Surgery, Universidade Federal de São Paulo/Escola Paulista de Medicina (UNIFESP/EPM), São Paulo, SP, Brazil

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However, assessing vestibular function in patients with otitis media is challenging: the results of several vestibular function tests (such as caloric test, and Vestibular Evoked Myogenic Potential—VEMPs) are negatively influenced by the presence of the middle ear abnormalities (tympanic membrane perforation, fibrosis, effusion, and cholesteatoma) and the presence of conductive hearing loss [8]. Therefore, it is arguable whether the findings demonstrate the presence of vestibular deficiency or are the result of these technical artifacts. Other vestibular tests that are not influenced by these limitations (e.g., rotatory chair, video-head impulse test, and posturography) are expensive and unavailable in some locations [10].

The inner ear sequelae of otitis media may result in varying degrees of hearing and vestibular problems. The high-frequency hearing loss, which is commonly observed in patients with otitis media, may result in deterioration in music perception, sound localization and speech perception problems (especially in noisy environments), and tinnitus [6]. The hearing loss associated with unaddressed otitis media also results in language and development delays and may lead over time to academic underachievement, higher rates of unemployment, lower salary, and even increase the risks of neurodegenerative diseases, including Alzheimer and dementia [13, 14]. The impact of vestibular impairment secondary to otitis media has been less explored in the literature; however, children with otitis media are reported as "clumsy" and tend to fall more often than controls. Additionally, the development of gross and fine motor skills is delayed, and the posturography results are much worse in children with otitis media [15]. In adults, COM leads to a high prevalence of vestibular symptoms (40-60%), abnormal caloric and cervical vestibular-evoked myogenical potentials (cVEMP) tests, lower limit of stability and increased sway in posturographic evaluation [12].

In this chapter, we will explore in detail the auditory and vestibular function tests that are available in the clinical practice to evaluate patients with otitis media.

Anamnesis and Physical Examination

Anamnesis

The most frequent symptoms of acute otitis media (AOM) are otalgia and fever, followed by the presence of otorrhea. Adequate treatment results in resolution of the infection without any further complications. Potential sequelae of AOM include chronic perforation of the tympanic membrane, hearing loss, tinnitus, and vestibular symptoms. The presence of a chronic eardrum perforation is a frequent cause of recurrent otorrhea and middle ear infections, requiring surgical treatment over time. AOM may also result in intracranial and intratemporal complications such as mastoiditis, labyrinthitis, petrositis, meningitis, cerebellar abscess, and sigmoid sinus thrombosis. In AOM patients presenting with severe vestibular symptoms, diplopia, facial paralysis, severe headache, high fever, lethargy, vomiting, or neck stiffness should be thoroughly investigated for the presence of intratemporal or intracranial complications (Fig. 44.1).

Otitis media with effusion (OME) results from the presence of middle ear fluid for more than 3 months. The accumulation of middle ear effusion may occur for several reasons, the most frequent being Eustachian tube dysfunction. OME has a peak incidence in children, as the Eustachian tube in this population is shorter, more horizontal, and has a smaller lumen as compared with adults – it was observed that virtually 100% of preschool children will experience at least one transitory episode of OME [16]. As in most cases, the middle ear effusion is sterile, the presence of symptoms related with an acute infection are infrequent in OME. However, the accumulation of fluid may result in increased susceptibility for developing AOM through the course of the disease. Adults with OME frequently present with aural fullness, and less frequently with tinnitus and vestibular symptoms. In children, the symptoms may be less specific than in adults. Most frequently, OME is suspected in children with difficulties in speech and reading, delayed

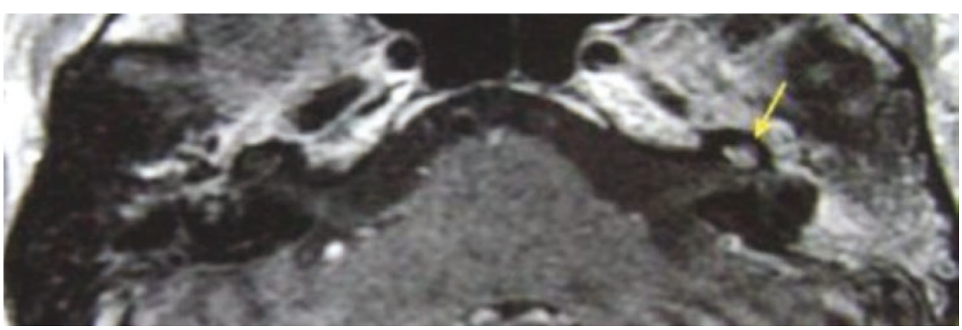

Fig. 44.1 Magnetic resonance imaging of a 23-year-old female patient with acute otitis media (AOM) who presented with a severe hearing loss in the left ear and vertigo. In hear physical examination, otoscopy revealed the presence of intense erythema and bulging of the left ear. Clinical vestibular examination revealed the presence of left-beating nystagmus, and Romberg test revealed a tendency fall to her left side. T1- weighted MRI with contrast showed intense enhancement of the cochlea (yellow arrow), suggesting acute labyrinthitis.

response to auditory input, limited vocabulary, and disturbances in attention. It was observed that the most frequent symptoms reported by the caregivers of children with OME are otalgia (76%), sleep disruption (64%), behavioral problems (49%), speech or hearing impairment (33-62%), and disequilibrium (15%) [16].

Chronic otitis media (COM), defined as the presence of chronic (>3 months) inflammation of the middle ear, may result in a myriad of clinical symptoms. Several authors have attempted to categorize COM to facilitate development of pathology-oriented diagnosis and treatment algorithms. Most frequently, studies report COM as either (1) nonsuppurative COM, defined as cases with a chronic perforation of the tympanic membrane secondary to otitis media with infrequent otorrhea; (2) chronic suppurative otitis media (CSOM), encompassing cases with frequent or intractable otorrhea; and (3) COM with cholesteatoma, defined as cases presenting with cholesteatoma identified in the middle ear or mastoid [17]. Paparella [18], also introduced the concept of "silent otitis media,", comprising patients who have tissue abnormalities in the middle ear cleft and mastoid (such as fibrosis, cholesterol granuloma, ossicular chain erosion, granulation tissue, or cholesteatoma) behind an intact eardrum. Considering the numerous potential sites of middle ear lesion secondary to otitis media, the clinical presentation of COM may significantly vary among patients. The most frequent clinical symptom described by patients with COM is hearing loss, affecting over 95% of the patients [12]. Other frequent symptoms are tinnitus, otorrhea, otalgia, dizziness, or vertigo. Less frequently, COM may result in deafness and facial nerve paralysis. COM also associates with intracranial and intratemporal complications, being more frequent (80%) than AOM-associated (20%) complications [19]. de Oliveira Penido et al. [2] estimated the incidence of intracranial complications of COM at 0.8%. Therefore, symptoms that may indicate an intracranial complication (such as the onset of profound hearing loss, severe vestibular symptoms, facial or abducens nerve paralysis, and other neurological symptoms) should be thoroughly investigated (Fig. 44.2).

Although vestibular symptoms are less frequent complaints as compared with hearing impairment in otitis media,

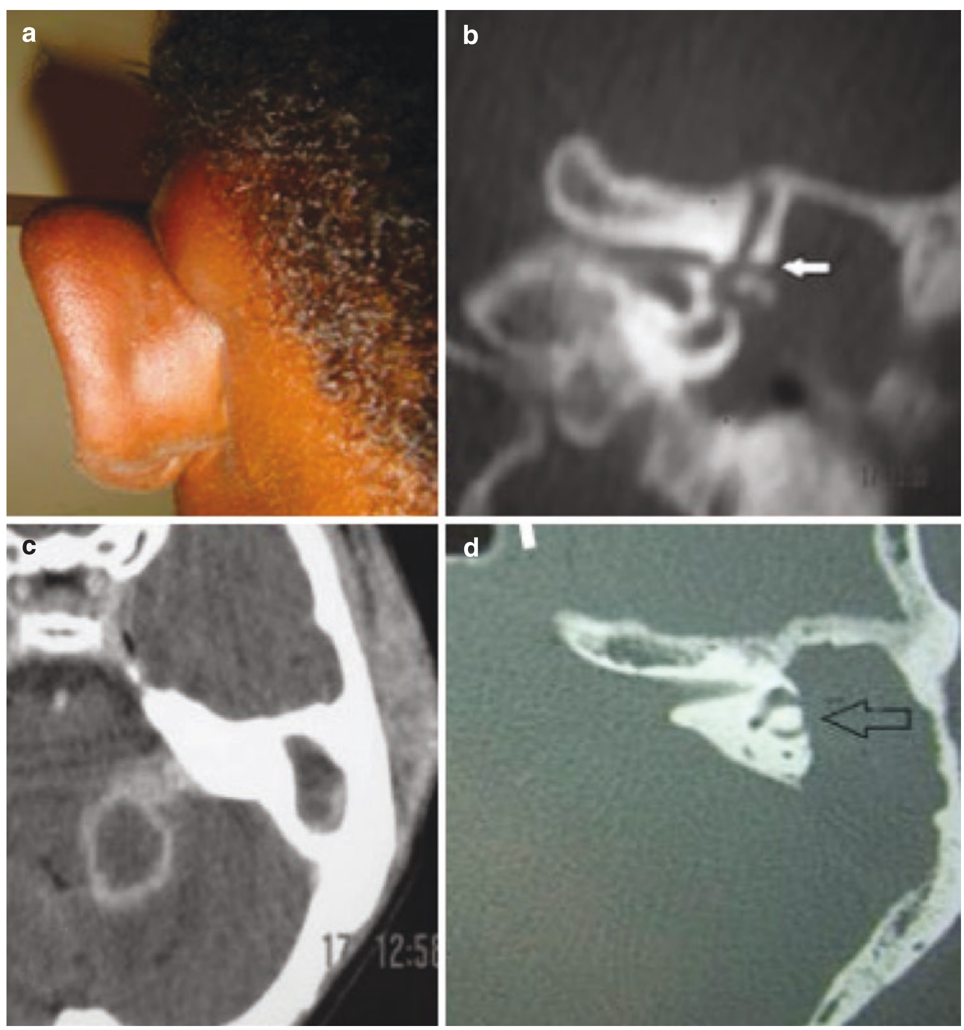

Fig. 44.2 A 13-year-old with chronic otitis media presented with a retroauricular edema in the left ear (**a**), associated with a profound hearing loss in the left ear and intense disequilibrium. Computed tomography (CT) revealed soft tissue filling the middle ear and mastoid, with an associated erosion of the left semicircular canal (white arrow, **b**) and a large opening of the mastoid with the posterior cranial fossa (black arrow, **d**). Contrast-enhanced CT revealed a subperiosteal and cranial abscess (**c**)

it has been demonstrated that over 50% of patients with AOM and COM report symptoms that are attributable to vestibular dysfunction [12]. Therefore, it is critical that the presence and characteristic of these symptoms are objectively assessed through structured anamnesis. Most patients with COM refer to the vestibular symptoms as disequilibrium, which is frequently triggered or worsened by the presence of otorrhea. In patients with AOM or COM exacerbations, patients may present vertigo and nystagmus, suggesting an acute vestibular lesion and the presence of labyrinthine fistula, especially in cases of cholesteatomatous COM (Fig. 44.2). In children, assessing vestibular symptoms can be challenging, as these are rarely reported by the patients and may not be perceived by the caregivers [20]. Children with OME or COM are more prone to falling and have delayed fine and gross motor development as compared with children without otitis media.

Physical Examination

The physical examination is critical to the diagnosis of otitis media. A precise diagnosis allows for timely and adequate treatment, in addition to prevention of sequelae and complications. The hearing evaluation in patients with otitis media initiates with an adequate otoscopy. As otitis media may result in hearing loss through a variety of pathophysiological mechanisms, these must be carefully examined to increase the chances of an adequate diagnosis and indicate potential treatment and prevention strategies.

The tympanic membrane (TM) should be examined thoroughly. The TM is abnormal in virtually 100% of patients with otitis media. However, the presence of a near-normal tympanic membrane may not indicate the absence of an underlying disease: patients with Eustachian tube dysfunction and chronic middle ear inflammation may present with only mild opacity and retraction of the eardrum. In these cases, the physician must also consider the clinical symptoms in the equation, in addition to audiometric results and imaging tests (when required). The otoscopy may indicate the type of otitis media and the adequate treatment. AOM is suspected in patients with erythema and bulging of the TM, in association with the presence of clinical symptoms such as otalgia, fever and/or otorrhea. In patients with aural fulness and hearing loss presenting with chronic (>3 months) retrotympanic middle ear effusion, in association with bulging or retraction of the tympanic membrane, must be screened for otitis media with effusion or silent otitis media. Pneumatic otoscopy is an important adjuvant in the diagnosis of OME in children, as a recent clinical practice guideline from the AAO [16] has demonstrated its efficacy in comparison to other diagnostic tools.

Cases presenting with a chronic tympanic membrane perforation with persistent or intractable suppuration are indicative of CSOM. Cholesteatoma can be in the otoscopic examination, and it may associate with the findings of middle ear inflammation and erosion of the scutum and ossicular chain. The absence of a TM perforation does not exclude the possibility of COM: Paparella et al. [18, 21] have demonstrated, through histological temporal bone and clinical studies, the presence of tissue changes that indicate chronic otitis media (fibrosis, granulation tissue, bone erosion, cholesterol granuloma, and cholesteatoma) in patients with an intact membrane. Also, the otoscopy may indicate potential abnormalities resulting in conductive hearing loss and indicate potential strategies for hearing restoration. The extension of the bony erosion and ossicular chain abnormalities secondary to otitis media may indicate the need for ossicular reconstruction or the use of prosthesis to allow optimal hearing restoration in cases where otologic surgery is warranted.

A thorough neurotologic examination is critical to evaluate potential vestibular impairment secondary to otitis media. Although many tools and devices are available in the clinical practice to evaluate vestibular function, the presence of conductive hearing loss and the middle ear abnormalities that are frequent in otitis media has a negative impact in some of these tests (such as caloric tests and VEMPs). Thus, the vestibular evaluation should be performed with tests that are not influenced significatively by the presence of these abnormalities. In this regard, clinical vestibular tests are essential to the diagnosis of vestibular impairment in patients with otitis media, as they may indicate the presence of vestibular dysfunction with minimal influence of the middle ear status. Among the tests used are the static (Romberg test) and dynamic (gait and Fukuda stepping tests) equilibrium tests, cerebellar function tests (index-index, index-nose, and diadochokinesis), assessment of the presence of nystagmus (spontaneous with and without visual fixation), head impulse and head-shaking tests, muscular tone and strength, examination of cranial nerves, and positional tests (Dix-Hallpike and head roll). In cases of noncomplicated AOM, OME, and COM, the clinical vestibular function tests frequently yield normal results; in some cases, patients may present mild instability in the Romberg test or lateral shifts in the Fukuda stepping test. In cases of more severe AOM and CSOM, some patients may present spontaneous nystagmus and an abnormal head impulse test in the side of the affected ear. The presence of spontaneous nystagmus and an abnormal head impulse test, in association with severe vestibular symptoms (including vertigo or postural instability) may indicate an increased risk of labyrinthitis, labyrinths fistula, an intracranial complication. Thus, these patients should be monitored closely to allow timely treatment if an intracranial complication is detected.

Hearing Evaluation

The gold-standard test to assess hearing in patients with otitis media is the pure-tone audiometry and speech tests. The tuning fork tests can be used to evaluate the type of hearing loss in the affected ears, being are especially useful in cases where an inner ear complication is suspected or in cases where a pure-tone audiometry is not readily available. Otitis media result in hearing loss in virtually 100% of the cases, with the most frequent type of hearing deficit being conductive, present in almost all forms of otitis media. However, it has been extensively demonstrated that some patients with otitis media develop sensorineural hearing loss, being most frequent in patients with CSOM.

Tonal Audiometry

The pure-tone audiometry is the most frequently used test for evaluating hearing thresholds, and it could be tested through air and bone conduction. Hearing thresholds are defined, as per the "American National Standards Institute" (2004) as "the minimum effective sound pressure level of an acoustic signal producing an auditory sensation in a specified fraction of the trials. The most accepted classification of the severity of hearing loss is: (1) mild (thresholds ranging from 26 to 40 dBHL); (2) moderate (41–55 dBHL); (3) moderately severe (56–70 dBHL); severe (71–90 dBHL); and profound (thresholds exceeding 90 dBHL).

Pure-Tone Air-Conduction Testing

The air-conduction testing measures the function of the external, middle, and inner ears. The pure tones are tested in the frequencies of 250–8000 Hz, in octave spacings. Although the pure-tone air conduction testing is potentially the most valuable hearing test, it does not provide specific information regarding the etiology of the auditory pathology when used in isolation. Thus, in the event of the air-conduction testing reveals thresholds exceeding 25 (adults) or 15 (children) dBHL, the test must be complemented by the bone-conduction testing.

Pure-Tone Bone-Conduction Testing

The bone-conducted stimulus reaches the cochlea directly, without going through the external and middle ears, through the skull bones, as the signal of a pure tone is presented to the patient through a bone vibrator that is placed on the mastoid to obtain hearing thresholds. Thus, the bone-conduction audiometry is remarkably useful in patients with a suspected conductive or mixed hearing loss. When the bone-and air-conduction audiometry is performed in association, a difference between the measured thresholds exceed 10 dBHL indicates the presence of a conductive hearing loss, which may or may not associate with a sensorineural hearing loss.

Speech Testing

Speech testing ("vocal audiometry") aims to assess the ability to perceive and recognize speech. A basic audiometric evaluation should routinely include speech testing. Among the tests used are the speech detection thresholds (SDT), speech reception thresholds (SRT), and speech discrimination scores. Both the SDT and SRT can be obtained using either air- or bone-conduction.

- Speech detective threshold (SDT): Measures the lowest sound intensity that the patient can detect the presence of 50% of the speech signals that are presented through the headphone. This test does not evaluate the recognition of speech, but the sound intensity that the patient acknowledges that he is listening to the speech signal. The SDT usually coincides with the pure-tone average, which is the average of the thresholds obtained with the pure-tone audiometry in the frequencies of 500, 1000, and 2000 Hz.
- Speech reception threshold (SRT): Corresponds to the lowest intensity that the patient can repeat 50% of the speech material. The SRT is usually 8–9 dB higher than the SDT.
- Speech discrimination: Determination of the speech discrimination is a more complex task as it evaluates the listener's ability to recognize speech. In conjunction with the pure-tone audiometry, it can help determine the differential diagnosis of hearing loss, provide information regarding the ability to communicate effectively, provide information regarding central auditory function, and provide insights about effectiveness of certain hearing rehabilitation strategies. The most frequent test used to evaluate discrimination is to present monosyllabic words in an open-set format. Patients with a pure conductive hearing loss frequently achieve optimal speech discrimination scores when the test is conducted using an adequate sound intensity. In patients with sensorineural hearing loss, the results may vary significantly among patients: patients with loss of sensorial cochlear cells frequently have lower discrimination scores as compared with nondiseased peers. In patients with lesions affecting the vestibulocochlear nerve, central auditory pathway, or even the auditory cortex, the discrimination scores are even lower, and this phenomenon can be seen even in patients with a normal or mild-to-moderate hearing loss in the pure-tone audiometry. In patients with otitis media, it has been demonstrated that their neural apparatus is frequently spared from the lesion secondary to the middle-ear inflammation. Therefore, even in patients with more severe degrees of mixed hearing loss, the discrimination

scores are within normal range or mildly abnormal. However, cases who had suffered an otitis media-related inner ear complication may present with very low discrimination scores.

Extended High-Frequency Audiometry

The extended high-frequency audiometry is performed in an acoustic booth using earphones that are calibrated to emit sounds at frequencies ranging from 8000 to 16,000 Hz. Theoretically, the extended high-frequency audiometry might constitute an ideal exam to evaluate initial hearing loss secondary to otitis media, as it has been demonstrated that the hook of the cochlea, which is adjacent to the round window membrane, is the primary lesion site secondary to otitis media [22]. However, the extended high-frequency audiometry is not yet validated for clinical use, as there are no normality values defined for these frequencies, and a wide variation in their results is seen in the normal population [6].

Despite these limitations, some authors dedicated to testing potential hearing losses affecting the extended high frequencies in patients with otitis media. Kasemodel et al. [22] revealed that patients with acute otitis media present with sensorineural hearing loss affecting the extended high frequencies in the first seven days from the onset of the disease. Cordeiro et al. [6] further revealed that a single episode of acute otitis media causes a significant and permanent elevation of hearing thresholds in the extended high frequencies (8–16 kHz) as compared with the non-diseased contralateral side.

Acoustic Immittance

The acoustic immittance aims to perform an objective measurement of the functional integrity of the tympanic-ossicular ensemble. The screening test named "acoustic immittance" test was based on the phenomena of "acoustic admittance," which is the amount of energy flowing through a system, and "acoustic impedance,", which is an opposition to the flow of sound energy. Measuring the acoustic immittance allows for identification and classification of peripheral (middle ear) and central auditory disorders. The most frequently used tests to evaluate acoustic immittance are the tympanometry and stapedial reflex measures.

Tympanometry

The tympanometry test was developed based on the observation that in cases where the middle ear and eustachian tube are normal, the best complacency of the tympanic membrane/ossicular chain system will occur when the pressure within the external auditory canal tends to equal the atmospheric pressure. Thus, in this test, an air-tight sealed probe is inserted into the ear canal, and it provides both positive and negative pressures onto the eardrum. Then, the probe measures the amount of acoustic energy reflected from the eardrum, providing information regarding transmission characteristics of the middle ear.

The result obtained with the tympanometry test is a direct estimate of the magnitude of the reflected acoustic energy. In a normal ear, the acoustic admittance is maximal when the pressure in the external auditory canal is equal to the atmospheric pressure. In cases presenting with an abnormal middle ear pressure, Eustachian tube dysfunction, ossicular chain abnormalities, or presence of middle ear effusion, the acoustic impedance increases, and the admittance decreases. To provide a more visual and intelligible demonstration of the results, Jerger [23] classified the potential results in a graphic representation. The types of tympanograms were classified as follows:

- Type A: Indicates a normal middle-ear pressure, in cases where the peak is at 0daPa. There are two sub-categories of A-type curves: As, which indicates a pressure peak at 0 that is reduced in amplitude, suggestive of ossicular chain fixation; and Ad, which indicates an unusually high-pressure peak at 0, suggesting ossicular chain discontinuity.
- Type B: Constitutes a "flat line" tympanogram, which indicates no point of maximum compliance. It indicates a mass-pressure effect behind the eardrum, which is seen in cases of serous or mucoid otitis media, space-occupying lesions of the middle ear (such as cholesteatoma or tumors), or a perforation of the tympanic membrane with a sealed Eustachian tube.
- Type C: Is graphically represented by the peak of compliance located in a negative pressure area, suggestive of the presence of negative middle ear pressure. It is frequently seen in early stages of otitis media without a significant amount of effusion.

The tympanometry is extremely useful in cases of otitis media with effusion and silent otitis media, as it reveals the presence of middle ear effusion and negative pressure in the middle ear, as well as the presence of tissue abnormalities in the middle ear. In cases of acute otitis media, as the tympanometry is not essential as a diagnostic tool, it is not recommended as it could result in worsening of the otalgia and discomfort of the patient. In patients with chronic otitis media presenting with a tympanic membrane perforation, the tympanometry offers a very limited benefit, being used in selected cases to evaluate the function of the Eustachian tube.

Stapedial Reflexes

The stapedial reflex is a protective mechanism dedicated to lower the sound intensity in cases of exposure to loud sounds. When the reflex pathway is activated, the stapedius muscle in both ears' contracts, stiffening the ossicular chain, resulting in a change in immittance. This pathway is composed of the cochlea, the VIII nerve, the ventral cochlear nucleus, the superior olive complex, the facial motor nucleus, and the facial nerve motor branch. Stapedial reflexes are useful in the differential diagnosis of hearing loss as they suggest the location of the injury.

Although testing the stapedial reflexes is useful for a complete audiologic diagnosis, it offers limited benefits in cases of otitis media. The test of the stapedial reflex is negatively influenced by the presence of middle ear disorders, as they prevent the tympanic membrane from showing a change in compliance when the stapedial muscle is contracted. Therefore, both ipsilateral and contralateral reflexes are bilaterally absent when the patient has a conductive hearing loss in the tested ear.

Otoacoustic Emissions

The active motility of outer hair cells serves as an amplifier of the displacement of the cochlear partition, which results in sound waves (termed "cochlear echoes") that are detectable at low intensities. These emissions may be detected spontaneously, or with a higher intensity following a sound stimulus, which is the "evoked otoacoustic emission". As spontaneous emissions may be absent in some patients, the evoked otoacoustic emissions are consistently detected in patients who have intact cochlear and middle ear apparatus. The evoked emissions can be tested using a transient, brief stimulus (such as a click or a brief tone burst (transient evoked otoacoustic emissions—TEOE) or using pure-tones separated by a specific frequency difference (distortion-product otoacoustic emissions—DPOE).

Testing the otoacoustic emissions is critical for an adequate audiological diagnosis in the present days. However, it offers very limited benefits when applied to patients with otitis media, as the presence of middle ear effusion, ossicular chain erosion or fixation, middle-ear tissue pathology, and tympanic membrane abnormalities do not allow for adequate detection of the otoacoustic emissions.

Auditory Brainstem Responses

The auditory brainstem response (ABR) represents the electric activity of the distal portion of the auditory pathway. The electrical impulses are recorded with surface electrodes, and they are represented graphically as "waves" as the impulses are transmitted through central auditory pathway landmarks. The ABR might be recorded using standard or disposable surface electrodes positioned on the forehead or at the vertex, on the medial surface of the ipsilateral or contralateral earlobe; the ground electrode is placed on the center of the forehead.

A normal ABR is comprised of 5–7 peaks that occur within a time frame of less than 10ms; however, only the first 5 peaks are considered within the test. The waves are elicited as they are captured in central auditory landmarks: wave I is originated at the level of the distal cochlear nerve, and the wave V at the level of lateral lemniscus in the midbrain. In a normal person, the latency of the waves I, III, and V (which are the most consistently identified waves) is consistent and can be used for evaluating normality of the electrical conduction of the stimuli. Abnormal values might occur when there is presence of middle ear pathology interfering with the conduction of the sound wave (occasion where the latency of the wave I is prolonged, but the interpeak interval between waves I–III–V are normal), or when a neural abnormality is present (resulting in complete absence of ABR waves, increased interpeak intervals and/or latency between waves I–III–V, or absence of one or more waves). It is also possible to evaluate the hearing thresholds at the tested frequencies, being considered as hearing thresholds the minimum sound intensity where the wave V is still detected in the ABR.

Considering patients with otitis media, the ABR is extremely useful to evaluate and diagnose children with otitis media with effusion or chronic otitis media who cannot perform the audiogram adequately. In these cases, the ABR can provide an adequate differential diagnosis between the presence of other potential causes of hearing loss (cochlear and central) from a pure conductive deficit caused by middle ear pathology. It can also indicate the best hearing rehabilitation strategy in cases presenting with a more intense hearing loss, being extremely useful in cases where a cochlear implant may be indicated. In older patients with otitis media, the ABR might be used only in selected cases, as the pure-tone audiometry is frequently sufficient to provide optimal evaluation of hearing.

Vestibular Function Tests

Caloric Tests

Caloric tests have been widely used in the study of vestibular function. However, the use of the caloric tests in patients with otitis media has not been extensively used for several reasons. First, the initially proposed caloric tests using water stimulation was not adequate to patients with otitis media, as it was not well tolerated by young children, and the application of water in patients with ventilation tubes, tympanic membrane perforations, and open mastoid cavities could result in extreme discomfort and infection. Paparella et al. [24] were the first authors to propose the use of air caloric tests to evaluating vestibular function in patients with otitis media. In their preliminary study, the authors observed that (1) patients with ventilation tubes and small perforations of the tympanic membrane had similar caloric test results as compared with the contralateral, nondiseased ear; (2) patients with large tympanic membrane perforations showed hyperactive responses, including shorter latency, increased amplitude, and higher frequency of nystagmus; and (3) in patients who had large perforations and moist ear, an inverted or contralateral nystagmus was observed. The authors conclude that the air caloric test can be safely used in patients with otitis media. Recent studies have also shown the high prevalence of caloric test abnormalities in patients with CSOM. The results of air caloric tests in patients Siampara et al. [25] observed the prevalence of canal paresis at 5.3% in patients with chronic suppurative otitis media. In the studies of Mostafa et al. [26] and Gianoli and Soileau [27], however, the prevalence of canal paresis was much higher (61.6% and 72%, respectively).

Some considerations must be made regarding the use of caloric test to evaluate peripheral vestibular function in patients with otitis media. As otitis media may result in a variety of abnormalities affecting the middle ear structures, the results of the caloric test might not fully represent the vestibular function. Furthermore, the results of the caloric tests in patients with middle ear pathology have not yet been validated, and therefore it is not possible to affirm whether an “abnormal” result is indicative of vestibular dysfunction or the result of a hyper- or hypo- stimulation of the labyrinth due to the middle ear abnormalities [8, 12]. However, it has been suggested that caloric tests can be used to evaluate the presence and progression of inner ear complications of otitis media such as suppurative labyrinthitis: in an initial phase, inflammation of the labyrinthine structures result in hyperexcitation, progressing over time to an absolute hypofunction (more frequent). Even in these cases, however, the presence of middle ear effusion can attenuate the caloric response, causing a false-positive result. In conclusion, it seems that although caloric tests can be used in patients with otitis media, their results must be interpreted with caution and correlated with clinical data.

Rotatory Chair Testing

The rotatory chair testing is one of the potential vestibular function tests that may be used in patients with otitis media, as the presence of middle ear abnormalities and sound conduction deficits do not influence significantly in their results. Additionally, the rotational testing is less bothersome to the patients than caloric testing. However, unlike caloric tests, both ears are stimulated simultaneously. In this test, a high-torque motor-driven chair and a specific software to analyze the results are needed.

In this test, the patient is placed in a dark environment, and is subjected to 10 cycles of sinusoidal head-velocity stimulus for each tested frequency, typically ranging from 0.01 to 0.7Hz. Then, the eye movements through the exam are recorded using video-oculography goggles. The results are averaged over successive cycles, and gain, phase, asymmetry, and bias velocity are calculated. While phase refers to the temporal shift in eye velocity relative to head velocity, the gain is the amplitude of the maximum slow-phase eye velocity divided by amplitude of the maximum stimulus velocity. Directionally dependent asymmetries can indicate relative weakness of function in one of the labyrinths in relation with the other.

In patients with otitis media, the rotatory chair test can be an alternative to the caloric tests to evaluating peripheral vestibular abnormalities, especially in patients with unilateral disease. Nonetheless, a few critical aspects must be taken into consideration. First, both labyrinths are stimulated simultaneously, and therefore it is not possible to study each ear separately. Second, patients with chronic, compensated vestibular losses (which seems to be the case of most patients with otitis media) [12], patients may exhibit minimal asymmetries, having normal gain and phase. And last, the rotatory chair is an expensive device, being unavailable in some locations. On the other hand, the rotatory chair test can be used to corroborate an abnormal caloric test result in a patient with otitis media. Moreover, it evaluates the vestibuloocular reflex in a different test frequency as compared with the caloric test, providing a more comprehensive evaluation of the function of the semicircular canals as compared with each test in isolation.

A recent systematic review [8] has indicated only two studies involving rotatory chair testing in patients with otitis media. Ben-David et al. [28] evaluated 50 children with OME: in their study, no significant differences in the rotatory chair test was found as compared with healthy children. Mostafa et al. [26] and Gianoli and Soileau [27] evaluated patients with CSOM: in both studies, the authors estimated the prevalence of rotatory chair abnormalities at 70% and 72%, respectively. Interestingly, both studies showed that there was a significative correlation between the presence of phase defects in the rotatory chair with the presence of caloric weakness, suggesting that these results are indicative of peripheral vestibular dysfunction secondary to chronic suppurative otitis media.

Electrooculography (EOG) and Videooculography (VOG)

A device can be used to detect and measure eye movements using a variety of stimuli, providing important information regarding vestibular function. The EOG device was the most used for many years, being still used in some centers. In this test, the eye acts as an electric dipole oriented along its long axis, and movements of the dipole in relation to the surface electrodes produce an electric signal that correspond to eye position [29]. It is possible to detect and record horizontal and vertical eye movements; the vertically aligned electrodes, however, sense voltage associated with eye and lid movement, limiting the use of the device in assessing vertical eye movement. One limitation of the EOG is that it cannot measure torsional eye movements, and therefore these should be evaluated directly by the examiner or using Frenzel lenses [30]. Although the ENG is a simple, noninvasive, and reasonably accurate procedure for routine vestibular assessment, it has some disadvantages, such as interference from muscle electrical activity and ambient electric noise [29]. The VOG has become widely used in recent years, as it provides a three-dimension recording of eye movements by using infrared cameras. It has the advantage of being noninvasive, easy to position, and do not associate with the position drifts seen with the EOG.

The use of EOG/VOG to evaluate vestibular function in patients with otitis media has been reported in the past. A systematic review of the literature demonstrated that—in patients with OME—there was a significantly higher prevalence of abnormal EOG results as compared with controls: from the EOG tests on 334 children with OME, abnormal findings were reported in 120 (25.9%) [8]. In patients with AOM, the prevalence of abnormal EOG results was much higher: abnormalities were demonstrated in 93% of the patients in the acute phase of AOM, all suggestive of peripheral pathology. Most patients with spontaneous nystagmus (92.8%) had irritative-type nystagmus beating toward the affected ear; only one patient had paretic type nystagmus beating toward the contralateral ear. In patients with CSOM, the same systematic review revealed that 56% of 175 patients had spontaneous nystagmus identified in their EOG. The abnormal ENG results in patients with AOM and CSOM possibly reflect the presence of labyrinthine dysfunction secondary to passage of inflammatory mediators from the middle to the inner ear [4, 9, 10, 18, 21, 31].

Subjective Vertical Visual Test

The subjective vertical visual (SVV) is one of the vestibular function tests that is not influenced by the presence of conductive hearing loss. This test was conceived based on the premise that a normal person can maintain the sense of verticality even without visual cues. The subjective vertical visual is a promising test aimed to evaluating vestibular dysfunction secondary to otitis media for several reasons. Histopathological and clinical studies demonstrated that the otolithic organs are the most frequent lesion sites secondary to otitis media [10], while semicircular canals are spared until more advanced stages of disease [10, 32]. Thus, the SVV comprises a test dedicated to evaluating otolithic function that is not significantly influenced by the presence of middle ear pathology and conductive deficits, which is the case of vestibular evoked myogenic potentials (VEMPs), for example. Although initially proposed SVV tests evaluated both labyrinths simultaneously, dynamic protocols (such as the off-vertical axis rotation) can differentiate the laterality of the lesion.

It has been suggested that the SVV test should be used in the following situations [33]: (1) In all patients presenting with acute vertigo, as a pathologic SVV deviation is a highly sensitive indicator of acute damage of the peripheral or central graviceptive pathways and (2) in all cases in which acute brainstem infarction is suspected, even in the absence of perceptual or postural symptoms. SVV tilts due to unilateral brain stem lesions are of topographic value for they indicate the level or the side of the lesion; (3) in patients with ocular motor symptoms, as testing for monocular and binocular SVV can help to differentiate between a peripheral and a central origin of the symptoms. Apart from its clinical use in the differentiation of central vestibular disorders, the SVV results is a strong indicator of the function of otolithic organs in cases where a peripheral vestibular lesion is suspected, which seems to be the case of otitis media.

Although the SVV test might constitute a reliable method to assessing peripheral vestibular function in patients with otitis media, this has not yet been studied in depth. Lee et al. [34] used a computer software to show a vertical line that patients with CSOM should put into the vertical position using a remote control. The authors observed abnormal SVV results in 20% of the patients with CSOM. More recently, Monsanto et al. [12] observed an abnormal tilting of the SVV (>2.0^{o}) in 68.6% of the 51 patients with CSOM, and the mean deviation of the true vertical was also higher in patients with CSOM as compared with controls (CSOM, 3.66^{o}; controls, 0.76^{o}). Additionally, the authors observed a significant correlation between the presence of abnormal SVV results with the presence of vestibular symptoms. Assuming (based on previous clinical observation and results of histopathological studies) that otitis media result in a peripheral vestibular lesion, these results seem to indicate otolithic dysfunction. However, these results must be interpreted with caution, as 1) the SVV test does not evaluate peripheral vestibular function in isolation and 2) it has limitations in assessing peripheral vestibular function in patients with chronic vestibular symptoms. Different SVV testing methods have been proposed:

Off-vertical Axis Rotation (OVAR)

In the OVAR test, deviations of the true vertical are determined using static or dynamic protocols. A device is used to present a luminous line in a dark environment – then, the patient is asked to rotate the luminous line at the point they perceive that is aligned with the vertical axis.

In the dynamic protocol, the patient subjected to a rotation of 300 deg/sec [35]. Once the patient has been rotating at a constant velocity for approximately one minute and the per-rotary nystagmus has subsided, the patient is asked to manipulate a laser line on the wall (using a handheld remote) until it is perceived in the true vertical position. The most critical advantage of this method is that it allows testing of each utricle independently, as the centripetal acceleration applied to either the right or left labyrinth allows for independent utricular evaluation without influence from the other ear [36].

In the static protocol, the test is performed similarly but without spinning the patient off axis. Although this test may be technically easier to perform and more comfortable to the patient, it has been shown that the static SVV protocol may result in simultaneous stimulation of both otolithic organs.

Virtual Reality Goggles

Many manufacturers have developed virtual reality goggles that aims to digitally determine the subjective vertical visual. In all these devices, the patient is placed in a dark environment, and the virtual reality goggles are placed in position. The patients are then asked to move a fluorescent line using a remote control until the position that it is perceived at the vertical position.

Hemispheric Dome Method

In this test, [33] patients sit with their chin resting on a fixed pad and are instructed to look at a horizontal line placed in a hemispheric dome, 60 cm in diameter, which is rotated around their line of sight. To avoid influence of external orientation references, the dome covers the entire visual field of the patients and is covered with a random pattern of colored dots. A rotating linear target is then placed 30 cm in front of the patient—the target and dome are then rotated to a randomized offset position, and the patients are instructed to align the target in the vertical position using a remote control. The angle between the adjusted orientation and the true spatial vertical is then determined by a computer software.

Bucket Test

The bucket test [33] is a simple and inexpensive method to assess the SVV. In this test, a bucket is modified to measure deviations of the true vertical. The bucket test has been shown to be a reliable method for assessing the presence of central or peripheral vestibular lesions, with more than 90% intratest and intertest reliability [33, 37]. In this method, the authors used a 15.0-L bucket (rim diameter = 35.5 cm; depth = 33.0 cm; bottom diameter = 31.5 cm). A fluorescent tape was used to draw a vertical line in its internal base, and in the outer base of the bucket, a string with a small weight was pinned to the center. In the rim of the external base of the bucket, a protractor scale was taped, in which 0° coincided with the straight line drawn inside of the bucket; the 0° position was defined as the true vertical (Fig. 44.1b). As the bucket was rotated, the straight line was pulled down by the weight, which indicated the angle of deviation (in degrees) from the true vertical. The examiner rotates the bucket in a clockwise or counterclockwise direction until the string pointed to a deviation of ±20°, and then the bucket was slowly rotated back toward the 0° position. Patients are instructed to verbalize "stop" in the moment the internal line reaches the true vertical position. The angular deviations of the true vertical were measured in degrees (clockwise direction was labeled with a "positive" sign and deviations in the counterclockwise directions as "negative")

The main advantages of the bucket method [33] in assessing the SVV are (1) the tool uses inexpensive material and easy to assemble; (2) it does not require extensive training; (3) the results are easy to interpret; (4) the test is easy to perform, and the results have been validated; and (4) it could be used in virtually all types of vestibular problems.

Posturography

The posturography provides a quantitative measurement of the integration of vestibular, visual, and proprioceptive inputs that maintain postural balance control. The posturography may be performed either using dynamic or static platforms. The most widely used device is the computerized dynamic posturography named Equitest®. In this test, the patient stands on a movable platform and is subjected to a movable visual surround. The center of pressure position is recorded by pressure-sensitive gauges located in the platform, which is also used to evaluate the postural sway. Static posturography tests are less commonly reported in the literature. The most frequently used static posturography device is the Balance Rehabilitation Unit® (BRU) [38]. The BRU has a force platform that measures displacement of the center of pressure, while patients are exposed to somatosensorial (eyes closed, standing on a medium density foam mattress with eyes closed), vestibular and visual (saccadic, optokinetic) stimuli through virtual reality goggles. The postural control is analyzed under 3 parameters: (1) limit of stability (LOS) = area in which the volunteers can intentionally dislocate their center of pressure (cm^2); (2) sway area = area comprising 95% of the dislocations of the center of pressure in each specific test (cm^2); and (3) sway velocity = total distance of dislocation divided by the duration of the test (cm/s).

The posturography is useful in several situations, especially those involving unilateral or bilateral vestibular hypofunction, brainstem stroke, cerebellar ataxia, extrapyramidal disorders, and cerebellopontine angle neoplasms. The results reveal specific aspects that could result in a tailored vestibular rehabilitation strategy. In this regard, although posturography test does not evaluate peripheral vestibular function in isolation and does not directly provide identification of the specific site of lesion, it has been hypothesized that the specific tests that deprives the patients from visual cues and proprioception (such as the sensory organization test of the Equitest device) might reflect utricular function [39]. Liu et al. [39] observed a significant positive correlation between the results of the sensory organization test with the ocular VEMP, a finding that seems to support this hypothesis.

As the results of the posturography are not influenced by the presence of middle ear pathology or conduction deficits, many authors have used the posturography to evaluate equilibrium in patients with otitis media. In children with OME, posturography results revealed higher mean velocity, more falls during the exams, and increased sway amplitude during high-frequency stimuli as compared with healthy children (24, 36). In most of these studies, the posturography abnormalities seemed to complete subside after insertion of ventilation tubes. Gawron et al. [40], however, showed that where despite improvements, OME subjects still performed worse than controls after 4 weeks of grommet insertion.

In patients with CSOM, Mostafa et al. [26] did not observe significant abnormalities in the posturography test. The authors, however, did not include a control group for comparison purposes. Monsanto et al. [12], in a controlled study including 126 patients with CSOM, observed that patients had worse limit of stability and increased sway as compared with controls. The authors also observed a significant correlation between the abnormal posturography results with the presence of vestibular symptoms, abnormal clinical vestibular function tests, and increased deviations in the SVV test ($P < 0.05$).

Video Head Impulse Test: Video-HIT

The video-HIT is a bedside test used to evaluate function of the semicircular canals, providing objective measures of the gain of the vestibuloocular reflex (VOR) for each canal separately [41]. The quantitative testing allows recording of short-latency eye movements that may be missed under bedside conditions. In comparison with the caloric and rotatory chair tests, it evaluates movements that are much faster, which makes the video-HIT a great addition to the matter of vestibular function testing. The video-HIT test requires goggles with a high-resolution video camera that will capture the movement of the eyes during the head tilt. The examiner proceeds with the head movements toward the direction of each specific semicircular canals. The movements of the eyes and head are recorded graphically in a computer software, and individual impulses with artifacts can be excluded to ensure consistency of the results. The software evaluates the presence of corrective saccades and calculates the VOR gain by providing the ratio of the amplitude of the eye movements by the amplitude of the head movement.

Testing the vestibular function in patients with otitis media is challenging, as many of the tests that are available in the daily practice (such as VEMPs and caloric tests) do not have their results validated for the use in patients with middle ear pathology and conductive deficits. As the video-HIT does not suffer the influence of the middle ear pathology and allows for testing each semicircular canal individually, the video-HIT constitutes a remarkable asset in objectively evaluating the VOR.

As the video-HIT test has only become widely available more recently, not many studies dedicated to using this diagnostic tool in patients with otitis media. Tomaz et al. [42] observed a higher prevalence of corrective saccades in patients with chronic suppurative otitis media with and without cholesteatoma as compared with controls. The authors also demonstrated a significantly lower gain of the anterior semicircular canal of the affected ear of patients with cholesteatoma as compared with controls ($P < 0.001$), but no significant differences were observed in the gain of the lateral and posterior canals between patients with chronic otitis media and controls ($P > 0.05$). D'Albora et al. [43] described video-HIT test results in two patients with a cholesteatoma-induced lateral semicircular canal erosion, revealing an abnormally low vestibuloocular reflex gain and the presence of corrective saccades in both patients. Covelli et al. [44] also suggested that the video-HIT test could constitute a useful tool to evaluate residual vestibular function in patients with labyrinthine fistula caused by CSOM that will be later operated.

Although the video-HIT is a promising tool in the evaluation of peripheral vestibular function in patients with otitis media, some limitations that are inherent to the test should be highlighted [12]: (1) the sensitivity of video-HIT may not allow accurate detection of chronic, compensated abnormalities affecting the semicircular canals, [45]; (2)

because VHIT measures the VOR at high frequency, it is possible that abnormalities affecting the semicircular canal function in the lower frequencies could have been missed [46]; and (3) semicircular canals seem to be less affected by the inflammatory damages caused by COM than the otolithic organs, as suggested by histopathological evidence [12, 32, 47]

Vestibular-Evoked Myogenic Potentials (VEMP)

VEMPs are electromyographic responses derived from the vestibular labyrinth evoked by sound, vibration, or electrical stimulation [48]. In healthy subjects, auditory stimulation results in a relaxation of the ipsilateral sternocleidomastoid muscle. These cervical VEMP (cVEMP) responses occur at a short latency (12 ms) in reaction to the click stimulus. After the c-VEMP was proposed, it was observed the extraocular musculature also respond to vestibular stimulation through bone-conducted stimuli – this test modification was named ocular VEMP (oVEMP) [49]. While the cVEMP responses are result of selective activation of the sacculus, the oVEMP corresponds to the utricular function [48, 50].

The VEMP tests have become cornerstones of laboratory diagnosis of vestibular problems. It has been widely used to diagnose Meniere's disease, vestibular Migraine, and superior semicircular canal dehiscence. In the specific case of otitis media, as it has been observed that the otolithic organs are the most critical lesion sites secondary to otitis media, many authors have dedicated to study the use of VEMPs as a diagnostic tool to evaluate vestibular function. A systematic review [8] identified a total of 10 studies that evaluated the VEMP results in patients with otitis media with effusion (3 studies) and chronic suppurative otitis media (7 studies). In the studies involving patients with OME, a total of 101 children were included: VEMP tests using air-conducted stimuli did not elicit detectable responses in most patients with OME, and bone-conducted stimuli VEMP results varied greatly among studies (2–30% of absence of responses). Critical analysis of the amplitude and latency of p13 and n26 waves was very inconsistent among these studies using bone-conduction stimuli, varying from no significant differences in both latencies or in amplitude to delayed latencies and significantly smaller amplitudes as compared with controls. The studies including patients with chronic suppurative otitis media comprised a total of 277 patients (317 ears), most of which used cVEMPs (217 patients and 257 ears) in isolation, and 1 study (85 patients, 117 ears) tested both cVEMPs and oVEMPs. Assuming abnormal VEMPs as the absence of response or delayed latency/decreased amplitude of the waves p13-n26, the oVEMP was abnormal in 72 of 106 ears (68%). The cVEMP test yielded abnormal results in 160 of 317 ears (50.4%). There was also a great controversy regarding the association between abnormal VEMP results with the presence of vestibular symptoms, with some authors observing a significant positive correlation between these two variables while others did not.

Although a vestibular testing that would allow evaluation of the function of otolithic organs would be critical in patients with otitis media, the VEMPs should be used with caution. The VEMP results suffer a great negative influence of conductive hearing deficits that are hallmarks of otitis media, as the standard test battery includes air-conducted vestibular stimuli. An alternative that was proposed was the use of bone-conduction stimuli, which could potentially circumvent the negative influence of the conductive hearing loss. However, it has been observed that the use of bone-conductive stimuli seems to stimulate both labyrinths simultaneously, which can compromise the validity of the results. Therefore, it seems that the VEMP might be used only in selected cases, and their results should be interpreted in association with the clinical symptoms and results of other vestibular tests in conjunction.

Imaging Evaluation of the Cochlea and Peripheral Vestibular System

Imaging tests are rarely necessary to the diagnosis of uncomplicated otitis media, as a positive clinical history, in association with the physical examination findings, are sufficient to seal the diagnosis in most cases. However, some situations require the use of imaging tests, especially cases requiring surgical treatment or those in which a complication of otitis media is suspected.

Cases of AOM and COM may associate with a variety of inner ear complications. These are suspected in cases presenting with persistent fever, significant or abrupt hearing loss, intense tinnitus, vestibular symptoms, facial paralysis, and/or signs of increased intracranial pressure or altered mental state. A cohort [19] showed that intracranial complications are much more frequent in patients with COM (80%) as compared with AOM (20%). The bone erosion resulting from chronic middle ear inflammation and the presence of cholesteatoma seems to be the cause for such higher incidence of complications in patients with COM (Fig. 44.3). Nonetheless, otitis media may cause auditory and vestibular symptoms even in the absence of a clear erosion of the bony labyrinth due to passage of inflammation products through the round window membrane [51, 52].

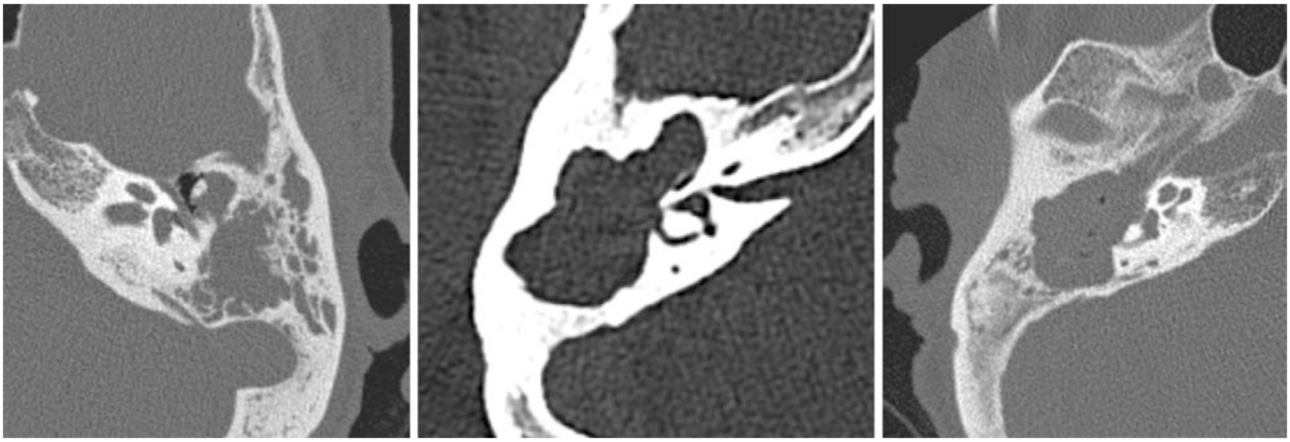

Fig. 44.3 Three computed tomography scans of the temporal bone from three different patients with cholesteatoma showing erosion of the middle ear and mastoid. The first image shows a bony erosion restricted to the scutum and mastoid antrum. The second image shows intense erosion of the temporal bone with a small communication between the membranous portion of the lateral semicircular canal and the mastoid. The last picture shows the presence of a large erosion of the lateral semicircular canal

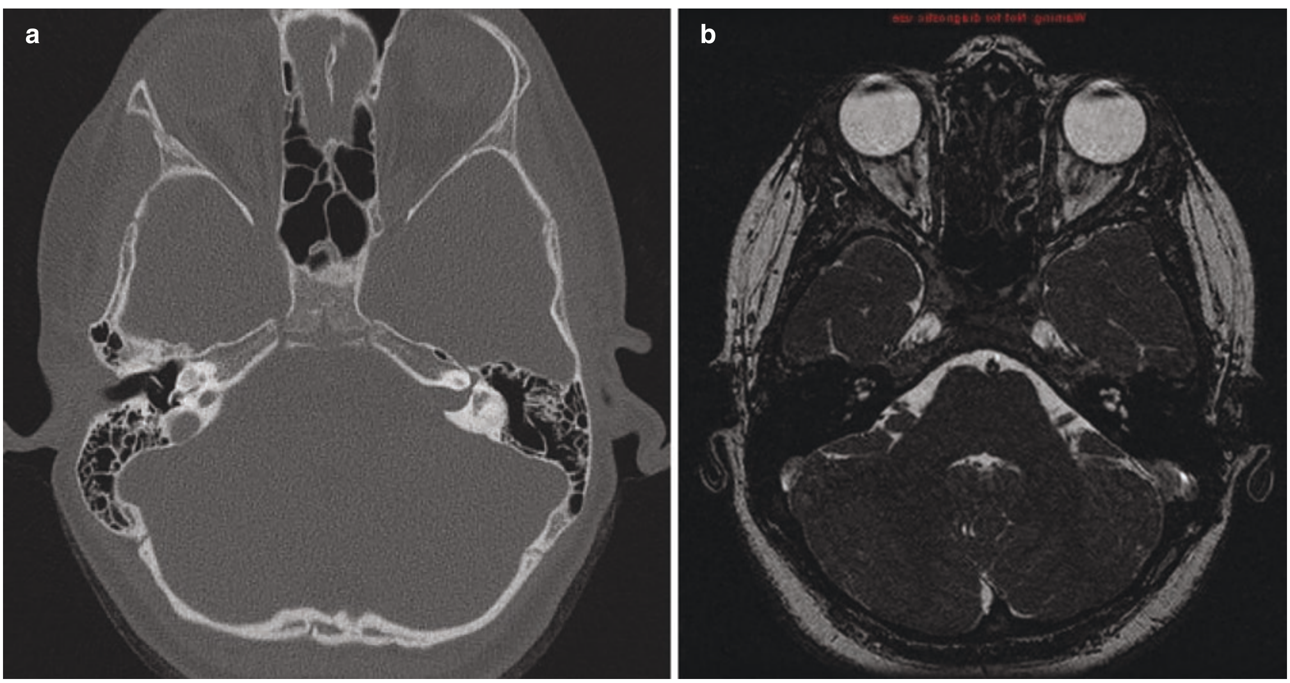

Fig. 44.4 (**a**) A computed tomography scan of a patient with cochlear ossification as consequence of otitis media-associated labyrinthitis ossificans in the right ear. (**b**) T2WI MRI scan of the same patient, revealing a decreased T2 signal in the cochlea

The presence of acute auditory and vestibular symptoms in patients with otitis media must be thoroughly assessed for the presence of an intratemporal or intracranial complication. If these complications are suspected, the MRI is preferred to the CT scan. However, the use of CT scans may be useful to evaluate the presence of cochlear or vestibular ossification in cases of labyrinthitis ossificans and meningitis (Fig. 44.4), and contrasted CTs can identify an intracranial abscess (Fig. 44.2) if an MRI is not readily available.

The MRI scans are particularly useful in the evaluation of labyrinthitis secondary to otitis media: in patients with labyrinthitis, gadolinium T1-weighted images (T1WI) show cochlear and vestibular enhancement, and a cochlear hyperintensity is also observed in the T2-flair (Fig. 44.5).

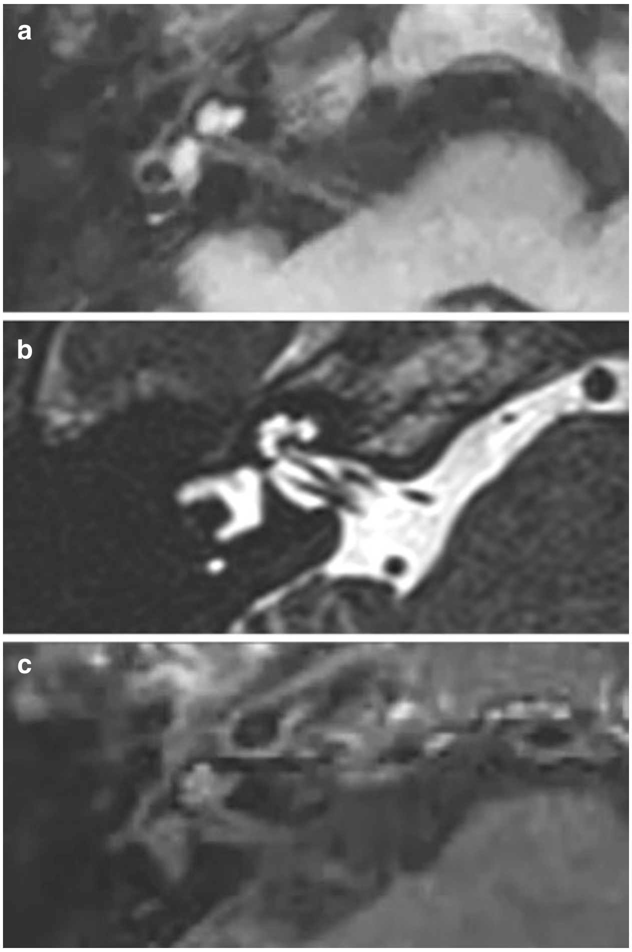

Fig. 44.5 Three coplanar magnetic resonance imaging pictures of a patient with acute otitis media presenting with vertigo and profound hearing loss. (**a**) A T1WI with fat suppression and gadolinium MRI showing a cochlear and vestibular enhancement. (**b**) T2WI showing an isointense signal of the cochlea and vestibule in relation to the cerebrospinal fluid. (**c**) T2-flair imaging showing increased cochlear signal, suggestive of acute labyrinthitis

Conclusions

As it has been extensively demonstrated that otitis media can result in significant hearing loss and abnormal peripheral vestibular function, it is critical that patients with different forms of otitis media are subjected to a comprehensive study of the hearing and vestibular function. Although hearing can be easily assessed using standard pure-tone audiometry and speech tests, evaluating the vestibular symptoms is challenging for several reasons. Some vestibular function tests are negatively influenced by the presence of conductive hearing loss and middle ear pathology (VEMPs and caloric tests), some stimulate both labyrinths simultaneously (rotatory chair, SVV, and bone-conducted VEMPs), some do not evaluate vestibular function in isolation (posturography), and others are expensive and unavailable in some centers (rotatory chair, posturography, and video-HIT). Despite these many difficulties, the results of these vestibular tests complement the anamnesis and physical examination and can provide remarkable clues toward the magnitude of the vestibular impairment. These tests also might indicate the presence of an inner ear complication secondary to otitis media and provide information that can result in a pathology-oriented development of rehabilitation strategies. Imaging tests such as CT scans and MRIs may be used in the evaluation of potential labyrinthine and intracranial complications of otitis media.

References

1. Monasta L, Ronfani L, Marchetti F, Montico M, Brumatti LV, Bavcar A, Grasso D, Barbiero C, Tamburlini G. Burden of disease caused by otitis media: systematic review and global estimates. PLoS One. 2012;7:e36226. https://doi.org/10.1371/journal.pone.0036226.
2. de Oliveira Penido N, Chandrasekhar SS, Borin A, de Albuquerque Maranhão AS, Testa JRG. Complications of otitis media—a potentially lethal problem still present. Braz J Otorhinolaryngol. 2016;82:253–62. https://doi.org/10.1016/j.bjorl.2015.04.007.
3. Politzer A, Ballin MJ. Politzer's text-book of the diseases of the ear for students and practitioners. Ind Med Gaz. 1927;62:410–1.
4. Paparella MM, Oda M, Hiraide F, Brady D. Pathology of sensorineural hearing loss in otitis media. Ann Otol Rhinol Laryngol. 1972;81:632–47. https://doi.org/10.1177/000348947208100503.
5. World Health Organization. (2018). Addressing the rising prevalence of hearing loss.
6. Cordeiro FP, da Costa Monsanto R, Kasemodel ALP, de Almeida Gondra L, de Oliveira Penido N. Extended high-frequency hearing loss following the first episode of otitis media. Laryngoscope. 2018;128:2879–84. https://doi.org/10.1002/lary.27309.
7. Aarhus L, Tambs K, Kvestad E, Engdahl B. Childhood otitis media: a cohort study with 30-year follow-up of hearing (The HUNT Study). Ear Hear. 2015;36:302–8. https://doi.org/10.1097/AUD.0000000000000118.
8. Monsanto RDC, Kasemodel ALP, Tomaz A, Paparella MM, Penido NDO. Current evidence of peripheral vestibular symptoms secondary to otitis media. Ann Med. 2018;50:391–401. https://doi.org/10.1080/07853890.2018.1470665.
9. da Costa Monsanto R, Erdil M, Pauna HF, Kwon G, Schachern PA, Tsuprun V, Paparella MM, Cureoglu S. Pathologic changes of the peripheral vestibular system secondary to chronic otitis media. Otolaryngol Head Neck Surg. 2016;155:494–500. https://doi.org/10.1177/0194599816646359.
10. da Costa Monsanto R, Schachern P, Paparella MM, Cureoglu S, de Oliveira Penido N. Progression of changes in the sensorial elements of the cochlear and peripheral vestibular systems: the otitis media continuum. Hear Res. 2017;351:2–10. https://doi.org/10.1016/j.heares.2017.05.003.
11. Aarhus L, Tambs K, Hoffman HJ, Engdahl B. Childhood otitis media is associated with dizziness in adulthood: the HUNT cohort study. Eur Arch Otorhinolaryngol. 2016;273:2047–54. https://doi.org/10.1007/s00405-015-3764-9.

12. Monsanto RDC, Kasemodel ALP, Tomaz A, Abrahão Elias TG, Paparella MM, de Oliveira Penido N. Evaluation of vestibular symptoms and postural balance control in patients with chronic otitis media. J Vestib Res. 2020; https://doi.org/10.3233/VES-200691.
13. Lin FR, Metter EJ, O'Brien RJ, Resnick SM, Zonderman AB, Ferrucci L. Hearing loss and incident dementia. Arch Neurol. 2011;68:214–20. https://doi.org/10.1001/archneurol.2010.362.
14. Livingston G, Sommerlad A, Orgeta V, Costafreda SG, Huntley J, Ames D, Ballard C, Banerjee S, Burns A, Cohen-Mansfield J, Cooper C, Fox N, Gitlin LN, Howard R, Kales HC, Larson EB, Ritchie K, Rockwood K, Sampson EL, Samus Q, Schneider LS, Selbæk G, Teri L, Mukadam N. Dementia prevention, intervention, and care. Lancet. 2017;390:2673–734. https://doi.org/10.1016/S0140-6736(17)31363-6.
15. Casselbrant ML, Furman JM, Rubenstein E, Mandel EM. Effect of otitis media on the vestibular system in children. Ann Otol Rhinol Laryngol. 1995;104:620–4. https://doi.org/10.1177/000348949510400806.
16. Rosenfeld RM, Shin JJ, Schwartz SR, Coggins R, Gagnon L, Hackell JM, Hoelting D, Hunter LL, Kummer AW, Payne SC, Poe DS, Veling M, Vila PM, Walsh SA, Corrigan MD. Clinical practice guideline: otitis media with effusion (update). Otolaryngol Head Neck Surg. 2016;154:S1–S41. https://doi.org/10.1177/0194599815623467.
17. Bluestone CD, Gates GA, Klein JO, Lim DJ, Mogi G, Ogra PL, Paparella MM, Paradise JL, Tos M. 1. Definitions, terminology, and classification of otitis media. Ann Otol Rhinol Laryngol. 2002;111:8–18. https://doi.org/10.1177/00034894021110S304.
18. Paparella MM, Shea D, Meyerhoff WL, Goycoolea MV. Silent otitis media. Laryngoscope. 1980;90:1089–98. https://doi.org/10.1288/00005537-198007000-00003.
19. Penido ND, Borin A, Iha LCN, Suguri VM, Onishi E, Fukuda Y, Cruz OLM. Intracranial complications of otitis media: 15 years of experience in 33 patients. Otolaryngol Head Neck Surg. 2005;132:37–42. https://doi.org/10.1016/j.otohns.2004.08.007.
20. Casselbrant ML, Villardo RJM, Mandel EM. Balance and otitis media with effusion. Int J Audiol. 2008;47:584–9. https://doi.org/10.1080/14992020802331230.
21. Paparella MM, Schachern PA, Cureoglu S. Chronic silent otitis media. Orl-J Oto-Rhino-Laryngol Rel Specialties. 2002;64:65–72. https://doi.org/10.1159/000057783.
22. Kasemodel ALP, Costa LEM, Monsanto RDA, Penido NDO. Sensorineural hearing loss in the acute phase of a single episode of acute otitis media. Braz J Otorhinolaryngol. 2020;86(6):767–73. https://doi.org/10.1016/j.bjorl.2019.06.001.
23. Jerger J, Speaks C, Trammell JL. A new approach to speech audiometry. J Speech Hear Disord. 1968;33:318–28. https://doi.org/10.1044/jshd.3304.318.
24. Paparella MM, Rybak L, Meyerhoff WL. Air caloric testing in otitis media. (preliminary studies). Laryngoscope. 1979;89:708–14.
25. Siampara L, Mann SBS, Panda NK, Mehra YN. Audiovestibular profile in unilateral chronic suppurative otitis media. Indian J Otolaryngol Head Neck Surg. 1997;49:107–11. https://doi.org/10.1007/BF03023784.
26. Mostafa BE, Shafik AG, El Makhzangy AMN, Taha H, Abdel Mageed HM. Evaluation of vestibular function in patients with chronic suppurative otitis media. ORL J Otorhinolaryngol Relat Spec. 2013;75:357–60. https://doi.org/10.1159/000357475.
27. Gianoli GJ, Soileau JS. Chronic suppurative otitis media, caloric testing, and rotational chair testing. Otol Neurotol. 2008;29:13–5. https://doi.org/10.1097/mao.0b013e31815c2589.
28. Ben-David J, Podoshin L, Fradis M, Faraggi D. Is the vestibular system affected by middle ear effusion? Otolaryngol Head Neck Surg. 1993;109:421–6. https://doi.org/10.1177/019459989310900306.
29. Blakley BW, Chan L. Methods considerations for nystagmography. J Otolaryngol Head Neck Surg. 2015;44:25. https://doi.org/10.1186/s40463-015-0078-2.
30. Ben-David Y, Hafner H, Fradis M, Krasnitz G, Podoshin L. Do Frenzel glasses have a place in the modern electronystagmography laboratory. Am J Otol. 1996;17:89–92.
31. Paparella MM. Interactive inner-ear/middle-ear disease, including perilymphatic fistula. Acta Otolaryngol Suppl. 1991;485:36–45.
32. Chang C-W, Cheng P-W, Young Y-H. Inner ear deficits after chronic otitis media. Eur Arch Otorhinolaryngol. 2014;271:2165–70. https://doi.org/10.1007/s00405-013-2714-7.
33. Zwergal A, Rettinger N, Frenzel C, Dieterich M, Brandt T, Strupp M. A bucket of static vestibular function. Neurology. 2009;72:1689–92. https://doi.org/10.1212/WNL.0b013e3181a55ecf.
34. Lee D-H. How to improve the accuracy of diagnosing otitis media with effusion in a pediatric population. Int J Pediatr Otorhinolaryngol. 2010;74:151–3. https://doi.org/10.1016/j.ijporl.2009.10.029.
35. Akin FW, Murnane OD. Subjective visual vertical test. Semin Hear. 2009;30:281–6. https://doi.org/10.1055/s-0029-1241128.
36. Clarke AH, Schönfeld U, Hamann C, Scherer H. Measuring unilateral otolith function via the otolith-ocular response and the subjective visual vertical. Acta Otolaryngol Suppl. 2001;545:84–7. https://doi.org/10.1080/000164801750388180.
37. Böhmer A, Rickenmann J. The subjective visual vertical as a clinical parameter of vestibular function in peripheral vestibular diseases. J Vestib Res. 1995;5:35–45.
38. Cusin FS, Ganança MM, Ganança FF, Ganança CF, Caovilla HH. Balance Rehabilitation Unit (BRUTM) posturography in Menière's disease. Braz J Otorhinolaryngol. 2010;76:611–7. https://doi.org/10.1590/S1808-86942010000500013.
39. Liu J, Zhou R, Liu B, Leng Y, Liu J, Liu D, Zhang SL, Kong WJ. Sensory organization test principally reflects utricular function. Acta Otolaryngol. 2017;137:1143–8. https://doi.org/10.1080/00016489.2017.1342143.
40. Gawron W, Pośpiech L, Orendorz-Fraczkowska K. An evaluation of postural stability and the effects of middle-ear drainage on vestibulo-spinal reflexes of children with chronic otitis media with effusion. Int J Pediatr Otorhinolaryngol. 2004;68:1175–9. https://doi.org/10.1016/j.ijporl.2004.03.017.
41. MacDougall HG, Weber KP, McGarvie LA, Halmagyi GM, Curthoys IS. The video head impulse test. Neurology. 2009;73:1134–41. https://doi.org/10.1212/WNL.0b013e3181bacf85.
42. Tomaz A, Monsanto RDC, Cusin FS, Kasemodel ALP, Penido NDO. Evaluation of the vestibulo-ocular reflex in patients with chronic otitis media. Braz J Otorhinolaryngol. 2022;88(5):675–82. https://doi.org/10.1016/j.bjorl.2020.09.006.
43. D'Albora R, Silveira L, Carmona S, Perez-Fernandez N. Diagnostic bedside vestibuloocular reflex evaluation in the setting of a false negative fistula test in cholesteatoma of the middle ear. Case Rep Otolaryngol. 2017;2017:2919463. https://doi.org/10.1155/2017/2919463.
44. Covelli E, Talamonti R, Benincasa AT, Filippi C, Marrone V, Tarentini S, Monini S, Barbara M. Video head impulse test in labyrinthine fistula due to middle ear cholesteatoma. J Int Adv Otol. 2019;15:283–8. https://doi.org/10.5152/iao.2019.5678.
45. Mezzalira R, Bittar RSM, do Carmo Bilécki-Stipsky MM, Brugnera C, Grasel SS. Sensitivity of caloric test and video head impulse as screening test for chronic vestibular complaints. Clinics (Sao Paulo). 2017;72:469–73. https://doi.org/10.6061/clinics/2017(08)03.
46. Ramos BF, Cal R, Carmona S, Maia FZE. VVOR and VORS testing as a tool in the diagnosis of unilateral and bilateral vestibular hypofunction. Rev ORL. 2018;9:1–2. https://doi.org/10.14201/orl.18856.
47. Kodama A, Ishii T, Oka Y, Uebo K. Inner ear histopathology of human temporal bone with chronic otitis media. Equilibrium Res. 1988;47(Suppl. 4):94–100. https://doi.org/10.3757/jser.47.Suppl-4_94.

48. Murofushi T, Kaga K. Recording and assessing VEMPs. In: Vestibular evoked myogenic potential: its basics and clinical applications. Tokyo: Springer Japan; 2009. p. 25–33. https://doi.org/10.1007/978-4-431-85908-6_4.
49. Chihara Y, Iwasaki S, Ushio M, Murofushi T. Vestibular-evoked extraocular potentials by air-conducted sound: another clinical test for vestibular function. Clin Neurophysiol. 2007;118:2745–51. https://doi.org/10.1016/j.clinph.2007.08.005.
50. Colebatch JG, Halmagyi GM, Skuse NF. Myogenic potentials generated by a click-evoked vestibulocollic reflex. J Neurol Neurosurg Psychiatry. 1994;57:190–7.
51. Goycoolea MV. Clinical aspects of round window membrane permeability under normal and pathological conditions. Acta Otolaryngol. 2001;121:437–47.
52. Goycoolea MV, Paparella MM, Goldberg B, Carpenter AM. Permeability of the round window membrane in otitis media. Arch Otolaryngol. 1980;106:430–3.