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Current Trends in Radiological Diagnostics and Treatment of the Temporal Bone Pyramid Pathologies

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Abstract

Diseases of the middle ear and the temporal bone pyramid remain among the most common diseases in the structure of otorhinolaryngological pathologies, significantly impacting the quality of patients' life. Exudative processes and their consequences become one of the main causes of persistent hearing loss and are characterized by an asymptomatic course. Timely and complete diagnosis and high-quality follow-up are leading to preventing the development of conductive hearing loss and other complications.

Purpose of the study. To study the main predisposing factors, methods of radiological diagnosis, and dynamic observation of patients, as well as some modern aspects of treating the most common pathologies of the temporal bone pyramid.

Methodology. We analyzed open-access sources from scientific databases such as Scopus, PubMed, Google Scholar, Web of Science, DisserCat, and CyberLeninka. Keywords used for the search: "chronic otitis media," "cholesteatoma," "mastoiditis," "complications," "magnetic resonance imaging," "DWI," and "computed tomography." Publications included in the literature review were full-text articles in English and Russian and dissertations in Russian. Exclusion criteria: brief reports, newspaper articles, and personal communications. The search range was five years (2018-2023). A total of 114 sources were analyzed, of which 48 met the research objectives and inclusion criteria.

Results and conclusions. In diagnosing temporal bone pathologies, computed tomography is the gold standard for diagnosis, but non-ionizing research techniques such as magnetic resonance imaging are increasingly used. In treating complicated diseases, endoscopic and laser correction methods are used in foreign practice, helping to reduce the risk of recurrence and postoperative complications.

Keywords: chronic otitis media, cholesteatoma, magnetic resonance imaging, computed tomography, treatment.

Introduction

Diseases of the middle ear and the pyramid of the temporal bone are among the most serious diseases in the ENT (Ear, nose and throat) stage, which significantly impact the quality of life of adults and children. Exudative processes and their consequences become one of the main causes of persistent hearing loss and are characterized by low-symptomatic forms with a gradual evolution to chronic forms. It should be noted that in childhood, the risk of disorders of speech and intellectual development increases, leading to psycho-emotional effects, social maladaptation of the child, and a decrease in the quality of life. The most common diseases of the temporal bones are chronic otitis media, middle ear cholesteatoma, and mastoiditis. At the same time, these cases are now increasingly found in pediatric practice, which is associated with untimely provision of outpatient otorhinolaryngological care. Timely and complete diagnosis and high-quality follow-up play a leading role in preventing the development of conductive hearing loss and other complicated pathologies of the temporal bone pyramids.

Methodology

The purpose of the study was to study predisposing factors, modern methods of radiological diagnosis and dynamic monitoring of patients, as well as some modern aspects of treatment of the most common pathologies of the temporal bone pyramids. We analyzed open sources based on scientific databases Scopus, Google Scholar, PubMed, DisserCat, Web of Science, and CyberLeninka. Keywords used for the search: "chronic otitis media," "cholesteatoma," "mastoiditis," "magnetic resonance imaging," "DWI," and "computed tomography." Publications included in the literature reviews were full-text articles in English and English, as well as abstracts in English. Exclusion criteria: brief reports, newspaper articles, and personal communications. Depth was looking for a career for five years (2019-2023). One hundred eight sources were analyzed, of which 50 included research objectives and inclusion criteria.

Search results and their analysis

Predisposing factors

Chronic otitis media is a heterogeneous condition characterized by persistent inflammation of the middle ear and/or mastoid cavity, widespread in both adult and pediatric populations. Common symptoms of this disease include otorrhea, hearing loss, and dizziness [1,2]. Worldwide, people with moderate to profound hearing loss increased from 225.3 million in 1990 to 403.3 million in 1990. It is predicted that by 2050, 2.45 billion (2.35–2.56) people will have hearing loss, an increase of 56.1% from 2019 [3]. Chronic otitis media can be divided into chronic suppurative otitis media and chronic otitis media with cholesteatoma formation [4]. The most common causes of otitis media are:

1) changes in the mucous membrane of the auditory tube due to acute diseases of the nose, paranasal sinuses, and nasopharynx as a result of a decrease in general immunity;

2) Eustachian tube dysfunction;

3) anatomical and physiological features of the development of the auditory tube in childhood;

4) rhinitis of an allergic nature;

5) ineffective therapy for acute otitis media;

6) blockage of the mouth of the Eustachian tube with adenoid vegetations;

7) benign and malignant formations of the nasopharynx [1,4].

In the context of the sources studied some particular causes of the development of chronic otitis media can be identified. In the pathogenesis of eosinophilic otitis media, the leading role is played by a history of bronchial asthma, which is explained by the similar histological structure of the walls of the middle ear and bronchi [5,6]. Andreeva G.A. reports the establishment of a high correlation between the occurrence of complicated forms of exudative otitis media in children born with a median cleft palate [7]. A study by Youngrak Jung et al. suggests an increased risk of developing otitis media and hearing impairment in patients after total laryngectomy and gastrostomy tube placement [8]. The above examples indicate that impaired swallowing and, as a consequence, Eustachian tube dysfunction are predictors of the development of chronic otitis media and its complications. The literature provides some examples of the influence of atypical flora in the occurrence of exudative otitis media. While receiving immunosuppressive therapy, otitis media complicated by Bell's palsy was caused by mycoplasma hominis in a patient with a history of multiple sclerosis [9]. In this regard, when selecting antibiotic therapy in the treatment of protracted forms of otitis media, clinicians need to remember the possible impact of atypical flora in conditions of immunosuppression.

The term cholesteatoma was first used in a case report in 1838 to describe a "tumor" presumably composed of cholesterol and fat (chole- for cholesterol, steate- for fat, and -oma for tumor) [10]. Cholestatoma is often a complication of long-term chronic otitis media. It is localized in the middle ear with possible spread to the mastoid process, which is surrounded by critical intracranial structures, the involvement of which can cause serious neurological complications (facial palsy, labyrinthine fistula, brain abscess, and sigmoid sinus thrombosis). Cholesteatoma has locally destructive growth, which can lead to conductive hearing loss. In rare cases, cholesteatoma can cause sensorineural hearing loss when it spreads to the inner ear [10].

Cholesteatoma is often secondary, but primary (congenital) forms also occur. Secondary cholesteatoma most often develops against the background of chronic inflammation of the middle ear, less frequently the paranasal sinuses, as a result of the transfer of stratified squamous epithelium, which produces keratin, to areas where this tissue is not usually present. Secondary cholesteatoma can also be iatrogenic, associated with inadequately performed revision of the tympanic cavity, especially after repeated radical operations on the ear, forming a large trepanation cavity. [eleven]. The main, and often the only symptom of iatrogenic cholesteatoma is progressive hearing loss. Thus, in a case observation from Anikin I.A., in a patient with repeated sanitizing operations on both ears and complaints of hearing loss, according to MRI (magnetic resonance imaging), a giant cholesteatoma of the mastoid process measuring 34x37x30.4 mm with extension to the posterior cranial fossa and compression of the hemisphere was discovered cerebellum [12]. In some cases, the development of cholesteatoma is induced by trauma. J. Ajduk reports a case of cholesteatoma, which was discovered and removed from a patient 29 years after receiving a gunshot wound to the head, in which the bullet passed through the left mastoid process and the cavity of the inner ear. The patient underwent reconstructive surgery, and almost three decades later, when the patient complained of otorrhea and hearing loss, an MRI revealed cholesteatoma of the mastoid process. [13]. Scott Mayer and co-authors established a significant relationship between the occurrence of chronic otitis media and exudative otitis and cholesteatoma in patients with Langerhans cell histiocytosis, which is presumably due to the lytic nature of the lesions of all skeletal bones in this pathology [14]. There are rare examples in the literature describing cholesteatoma of the paranasal sinuses, confirmed by biopsy. According to CT (computed tomography) data, cholesteatoma had a nonspecific picture and was defined as a total shadowing of the frontal sinus of heterogeneous density, destroying the wall of the orbit [15].

Congenital cases of cholesteatoma are extremely rare. Congenital cholesteatoma results from improper formation of the ectoderm rudiment in the early stages of embryogenesis [16]. Congenital cholesteatomas are diagnosed more often in children under three years of age. Severe congenital concomitant pathology is a risk factor for the occurrence of congenital cholesteatoma and also contributes to the unfavorable course of the process. According to a study by Chernogaev E.A., congenital cholesteatoma is most often observed in children with severe neurological pathology as part of congenital syndromes. Congenital cholesteatomas are bilateral [17]. There is a belief that cholesteatoma in children has a more aggressive growth than in adults: the well-pneumatized mastoid processes in children contribute to more extensive damage compared with the more sclerotic mastoid processes in adults [18].

Mastoiditis develops when the infection spreads into the cells of the mastoid process. Mastoiditis most often occurs as a complication of untreated acute or chronic otitis media caused by an infection of the middle ear.

Radiological diagnostics: current trends

Radiation research methods in diagnosing middle ear diseases in otorhinolaryngological departments are used not only as a method of standard primary diagnosis but also as a mandatory point in preoperative preparation. The "golden" preoperative standard is a computed tomography scan of the temporal bones [19]. Otosurgeons rely on CT scans as an anatomical and structural map before surgery. However, the use of CT is not always appropriate in acute clinical conditions, such as acute mastoiditis in children. The usefulness of temporal bone CT in trauma evaluation may also be limited. Temporal bone fractures usually don't require urgent surgical intervention in the absence of complete facial paralysis. Carrying out CT scans in young children involves anesthesia, which is associated with certain risks, especially in children with severe symptoms of intoxication due to purulent-destructive processes [21]. Moreover, the use of general anesthesia with hardware support is recommended only after fasting for 4-5 hours, which may delay the start of surgery and increase the risk of intracranial complications. Thus, although CT of the temporal bones is an essential method of X-ray examination in acute processes, its use requires additional evaluation due to the peculiarities of pediatric practice. A detailed assessment of temporal bone pathology may not be necessary for clinical decision-making and nonsurgical management. In addition, according to Kosyakov et al., CT makes it challenging to differentiate cholesteatoma with granulations, fibrous changes, and inflammatory and purulent contents [22].

There is evidence of the use of dual-energy CT, which represents a promising imaging tool in patients with contraindications to MRI. At a cost and relatively low radiation exposure, DECT (dual energy computed tomography) is a cheaper, faster examination with the added benefit of providing high-resolution anatomical detail [22].

In modern practice, clinicians tend to minimize studies with ionizing radiation. The MRI technique has become an integral addition to computed tomography data in the preoperative period, and in cases of diagnosing intracranial complications and long-term dynamic monitoring of patients, MRI confidently occupies a leading position in foreign practice. Venous sinus thrombosis as a complication of acute mastoiditis was encountered in a case series by Eleni Vergadi et al. [23]. At the same time, neurological symptoms predominated in children, and when they worsened, patients underwent MRI and MR venography of the brain. Subsequently, according to MRI data, signs of venous sinus thrombosis were revealed in 5 out of 20 patients, which played a leading role in further treatment tactics.

Various MRI techniques utilizing diffusion-weighted imaging (DWI) are employed for cholesteatoma detection. DWI captures the random motion of water molecules within tissue, known as Brownian motion. While free water molecules exhibit constant random motion due to thermal kinetic energy, the movement of water molecules within cellular environments is constrained by interactions with cellular structures like cell walls and organelles. This restriction correlates with tissue cellularity levels. DWI proves particularly valuable in tumor and cerebral ischemia diagnosis. Cholesteatoma detection on DWI images has a threshold of 2–3 mm. On MRI-DWI sequences with a b-value of 1000, cholesteatomas appear as hyperintense signals, notably brighter than brain parenchyma, especially within surrounding cerebrospinal fluid, facilitating easy identification. DWI MRI is pivotal in staging cholesteatomas larger than 5 mm and assessing the presence of granulation tissue. The DWI PROPELLER sequence, utilized in high-field MRI systems abroad, is extensively employed in temporal bone cholesteatoma diagnosis. Based on a multiple fast spin echo (FSE) technique, this sequence mitigates B0-related artifacts and enhances signal intensity by periodically rotating parallel lines during each repetition period. It diminishes blur typical in single-shot and fast spin echo sequences with a relatively short echo time, while its b-value of 1500 heightens diffusion sensitivity with a slight signal-to-noise ratio reduction.

Recent research has highlighted the significance of MRI in identifying indications of inflammation within the temporal bone, including its deterioration. During acute mastoiditis, MRI can reveal bone structures more distinctly due to intramastoid mucosal edema and inflammatory exudation, which displace air, generating a high-intensity background for the signal-cavity bone structures on T2-weighted images. Moreover, contrast enhancement and restricted diffusion of mastoid contents are probable indicators of the extent of mastoid inflammation [28]. For the purpose of postoperative assessment and diagnosis of possible complications, CT is the method of choice for assessing the condition of the ossicular chain and incus-stapedius joint, and contrast-enhanced MRI is preferable when assessing soft tissue anatomical structures after removal of expansive lesions, incl. cholesteatoma [29]. In addition, the leading role of DWI MRI is emphasized for dynamic monitoring to exclude recurrence and residual lesions. After extensive open debridement

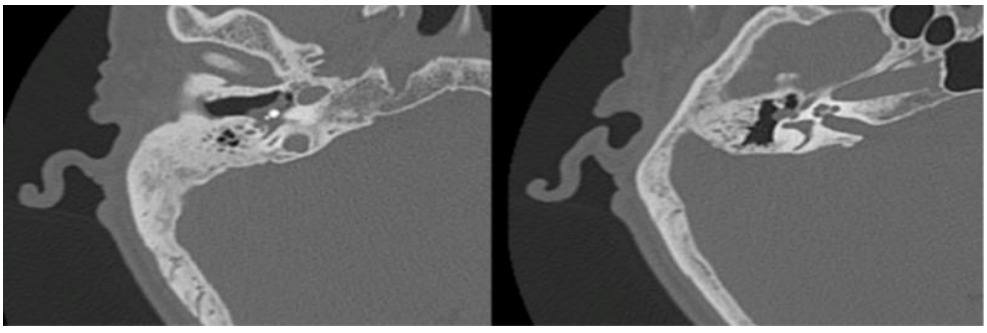

Figure 1 – Computed tomograms of the temporal bones, axial projection. Condition after cochlear implantation on the right. CT signs of right-sided otitis media with cholesteatoma and signs of osteolysis of the auditory ossicles

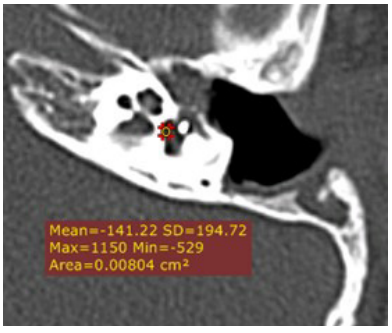

Figure 2 – Computed tomograms of the temporal bones, axial view. Condition after stapedectomy and stapedoplasty. Cholesteatoma masses of the tympanic cavity

operations for temporal bone cholesteatoma, the risk of recurrence remains. This fact dictates the need for regular long-term monitoring of this group of patients in the postoperative period.

The invasive nature of cholesteatoma growth, its prolonged asymptomatic phase, and the potential for intracranial complications underscore the need for routine, repeated middle ear MRI scans in DWI mode during the postoperative period to promptly detect relapse. Delrue et al. conducted a study examining the long-term outcomes of subtotal petrosectomy with blind external auditory canal closure for extensive cholesteatoma and chronic suppurative otitis media, utilizing diffusion-weighted magnetic resonance imaging (DWI MRI) for clinical and diagnostic follow-up. Out of 48 patients, seven exhibited residual cholesteatoma, with an average interval of 3.7 years between surgery and detection. Among those with chronic suppurative otitis media, three patients had residual cholesteatoma, detected on average 4.5 years post-surgery. This highlights DWI MRI's effectiveness in early detecting recurrent cholesteatoma, owing to its non-invasiveness and high resolution. Consequently, many experts advocate for CT and MRI assessments of temporal bone pathologies, with MRI being prioritized for long-term follow-up due to its comprehensive and dependable imaging capabilities

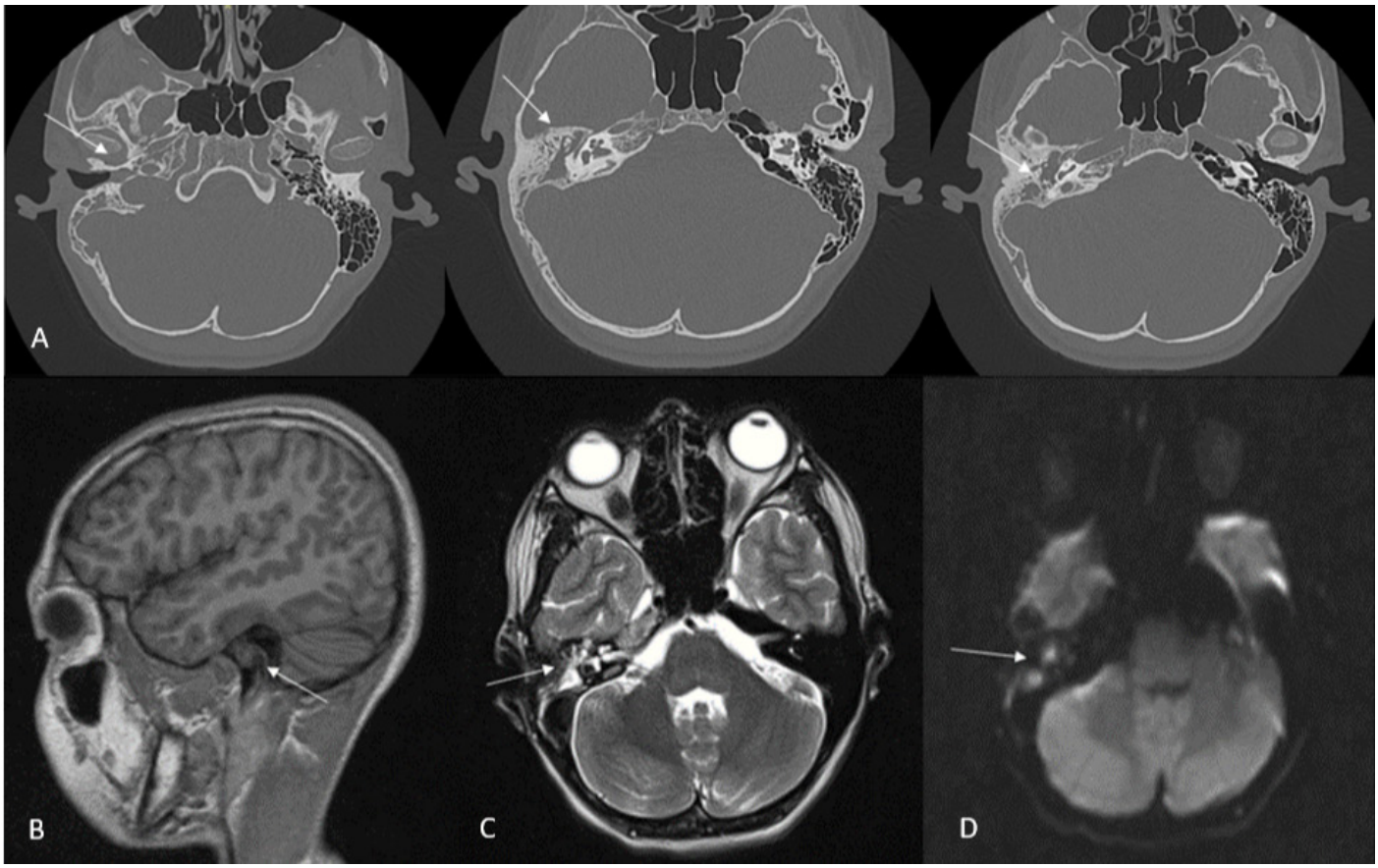

Figure 3 – Computer and magnetic resonance tomograms of the temporal bones of a 15-year-old patient with complaints of unilateral hearing loss on the right, frequent episodes of otitis media. A – Computer tomograms of the temporal bones in the axial projection. In the external auditory canal, parietal contents are determined. The mastoid process, antrum and attic are filled with pathological contents, the contours of the mastoid cells have marginal erosions. The density of the auditory bones is reduced, the incus has uneven contours. CT signs of external and otitis media on the right with signs of osteolysis of the auditory ossicles. To exclude the presence of cholesteatoma masses, MRI in DWI mode is recommended. The same patient, B – magnetic resonance imaging in T1-VI mode, sagittal projection, C – T2-VI mode, axial projection, D – DWI mode (b-1000), axial projection. In the area of the antrum and attic, against the background of increasing signal intensity on T2-VI, focal formations are determined, moderately hyperintense in the T2-VI mode (B), isointense in the T1 mode (A), irregular in shape with unclear uneven contours, moderately heterogeneous structure, these formations limit diffusion on DWI (b-1000) (C), confirming the presence of cholesteatoma masses in the middle ear cavity

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The same patient, B - magnetic resonance imaging in T1-VI mode, sagittal projection, C - T2-VI mode, axial projection, D - DWI mode (b-1000), axial projection. In the area of the antrum and attic, against the background of increasing signal intensity on T2-VI, focal formations are determined: moderately hyperintense in the T2-VI mode (B), isointense in the T1 mode (A), irregular in shape with unclear uneven contours, moderately heterogeneous structure, these formations limit diffusion on DWI (b-1000) (C), confirming the presence of cholesteatoma masses in the middle ear cavity.

Radiological diagnostics: additional techniques

Fusion of DWI MRI and CT images has been reported in studies in which high signal intensity cholesteatoma lesions on

DWI MRI were superimposed on corresponding CT temporal bone structures to improve preoperative detection, evaluation, and localization of cholesteatoma. The " fusion " technology of diffusion-weighted MRI and CT images allows us to determine the localization of MR hyperintense cholesteatoma within the bony anatomical details obtained on CT. This improves the diagnosis of the presence and precise localization of cholesteatoma. Diffusion-weighted MRI/CT fusion combines the advantages of detecting residual cholesteatoma and determining its exact location [22]. A preoperative CT scan performed before the first surgery can be used for fusion with non-EPI (non-echo planar imaging) DWI to spare the patient unnecessary repeat CT scans and thus reduce radiation exposure [32]. Combined DW-T1W-CT imaging is a reliable tool for detecting cholesteatoma (sensitivity 92%, specificity 90%, and overall accurate predictive value 91.4% [33]. It is also useful for preoperative assessment of the cholesteatoma extent, which is critical for determining patient suitability for transcanal endoscopic middle ear surgery and assisting in surgical planning and patient consultation [33].

In addition to radiological diagnostic methods, doctors from the otorhinolaryngological service have proposed a faster, less expensive and non-invasive analogue, tympanometric measurement of middle ear volume, as a preoperative research method [34]. Since the degree of pneumatization of the mastoid process is a kind of “buffer” of pressure for the middle ear, it can be taken as a prognostically favorable factor in the effectiveness of the upcoming tympanoplasty. Temporal bone CT is the primary method for assessing mastoid aeration. However, due to radiation risks and the cost of the test, there is a need for a simpler, faster, and more reliable method in uncomplicated cases of chronic otitis media. For this purpose, it has been proposed that tympanometric volume measurements be used during tympanometry. When assessing the study results, it was found that the tympanometry volume values increased with an increase in the degree of aeration of the mastoid process. This shows the proportional relationship between the degree of mastoid pneumatization and the tympanometry volume measurement [34].

Specific cases

Tuberculous otitis media, a rare manifestation of extrapulmonary tuberculosis, constitutes a mere 0.1% of all tuberculosis cases and ranges from 0.04% to 0.9% of chronic suppurative otitis media cases [35]. Its pathogenesis typically involves contiguous spread via the Eustachian tube, hematogenous dissemination from the lungs or distant organs, or direct inoculation through the external auditory canal and tympanic membrane perforation. Clinical presentation often features the classic triad: painless otorrhea, multiple eardrum perforations upon otoscopic examination, and hearing impairment. However, its nonspecific symptoms often lead to misdiagnosis, resulting in treatment delays. Timely identification and intervention are crucial to prevent complications such as hearing loss, mastoiditis, labyrinthitis, osteomyelitis, abscess formation, and central nervous system involvement. In adults, the disease remains poorly understood, with clinical suspicion heightened by a history of tuberculosis, though cases without such history also occur [36].

Tuberculous otitis media may be overlooked when patients primarily present with otologic symptoms, especially given its rarity and insidious nature. Suspicion should arise in patients with suspected tuberculosis history or chronic otitis media in tuberculosis-endemic areas [37]. Histopathological examination of biopsy specimens offers a definitive diagnosis, often prompting surgical intervention for symptom relief. Prolonged tuberculous otitis media can result in complications like perforation, substantial hearing loss, and facial nerve paralysis, necessitating histological examination for accurate diagnosis in refractory chronic otitis cases. HE. Barkanova, provides a clinical observation demonstrating a rare manifestation of extrapulmonary tuberculosis in one ear in a patient without immunodeficiency, but with a previous history of pulmonary tuberculosis with residual changes in them. The patient's prolonged purulent otitis for 1.5 years was considered nonspecific, and only surgical intervention with histological analysis of the surgical material made it possible to establish the tuberculous nature of the process [38].

In a case series of tuberculous mastoiditis among children, all cases exhibited acute bacterial mastoiditis symptoms, with notable bone destruction evident in temporal bone CT scans and necrotizing granulomatous inflammation in mastoid specimens [39]. Delayed diagnosis and treatment exacerbate bone destruction and hearing impairment. Radiological and surgical findings indicative of tuberculous mastoiditis warrant urgent tissue sampling from the middle ear cavity for microscopic, PCR (polymerase chain reaction), and histological examination, potentially obviating the need for further mastoidectomy. In tuberculosis-endemic regions, children displaying typical signs and necrotizing granulomatous inflammation should be promptly considered for antituberculosis therapy initiation until definitive diagnosis via GeneXpert PCR, Ziehl-Neelson staining, or positive Mycobacterium tuberculosis culture is confirmed.

Modern treatment methods

Cholesteatoma treatment is primarily surgical with microscope using, with two conventional methods: canal wall up (CWU) and canal wall down (CWD). The CWU technique involves exposing the mastoid and middle ear while preserving the bony structure of the external auditory canal. In contrast, the CWD approach involves removing the ear canal up to the vertical facial ridge and the bone covering the facial nerve, resulting in an open mastoid bowl that necessitates regular debridement in a clinical or surgical setting and long-term water precautions. [40] In the pediatric population, the CWU technique provides better long-term post-operative care and facilitates improved hearing rehabilitation. However, a systematic review encompassing both children and adults found no significant differences in recurrence rates or residual disease between the techniques. However, the limited visibility offered by the microscope makes it challenging to detect lesions concealed in the anterior epitympanic recess and tympanic sinus, potentially resulting in residual lesions and cholesteatoma recurrence [41]. Apart from surgical resection, the emergence of endoscopic technologies has brought attention to transcanal endoscopic ear surgery as a treatment option for cholesteatoma, particularly in pediatric cases [42]. Utilizing angled endoscopes (30 and 45°), transcanal endoscopic ear surgery enables clear visualization of concealed areas like the retrotympanum, anterior epitypanum, facial recess, and sinus tympanum [43-44]. This minimally invasive approach employs a transcanal method, avoiding retroauricular incisions [45].

Meta-analysis of 13 studies made by Bo Li et al. showed that endoscopic ear surgery (EES) offered notable advantages for patients with middle ear cholesteatoma. Those who underwent EES had fewer residual lesions and lower recurrence rates compared to those who received conventional microscopic ear surgery (MES). However, there were no significant differences in operation times or other postoperative outcomes, such as graft success rates and auditory performance, between EES and MES. Additional high-quality prospective studies are needed to further validate the benefits of endoscopic techniques in

middle ear cholesteatoma surgery [46]. However, despite its potential benefits, transcanal endoscopic ear surgery has not seen widespread adoption in practice due to limitations such as single-handed maneuverability, depth perception challenges, difficulty in ossicular reconstruction, endoscope tip fogging, and the risk of facial nerve and chorda tympani damage [47].

Laser usage has become prevalent in cholesteatoma treatment over the past two decades, particularly in the United States. The potassium titanyl phosphate laser, operating at a wavelength of 532 nm, is commonly employed. Laser application enables atraumatic removal of middle ear cholesteatoma and the ossicular chain, along with precise hemostatic removal of affected tissues such as polyps, granulations, and adhesions [48]. Retrospective studies indicate a halved risk of residual cholesteatoma with laser treatment.

Conclusion

The review pays special attention to publications devoted to current trends in radiological diagnosis of temporal bone pathologies. In modern practice, clinicians try to give preference to non-ionizing research methods. Indications for using magnetic resonance imaging of the temporal bones are constantly expanding, and techniques for merging data with computed tomography data are being introduced. In treating complicated diseases in foreign practice, more gentle modern endoscopic and laser correction methods are also used, which help reduce the risk of recurrence and postoperative complications.

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