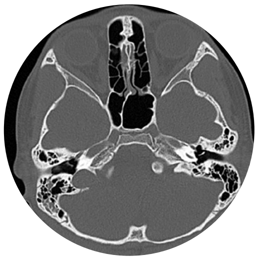


Listening with your eyes: computed tomography assessment of hearing loss

Escuchar con los ojos: evaluación por tomografía axial computarizada de la pérdida auditiva

Felipe Aluja-Jaramillo[1]
Sebastián Cifuentes-Sandoval[2]
Nicole Erazo-Morera[3]
Lucía Vargas-Mora[4]

DOI: https://doi.org/10.53903/01212095.177

Key words (MeSH)

Hearing loss
Ear ossicles
Tomography, X-ray computed
Magnetic resonance imaging

Palabras clave (DeCS)

Pérdida auditiva
Osículos del oído
Tomografía computarizada por rayos X
Imagen por resonancia magnética

Summary

Multiple pathologies can affect the function of the auditory apparatus. Anatomical knowledge of the temporal bone compartments on computed tomography leads to a better understanding of these entities and improves the clinical approach toward conductive or sensorineural hearing loss. An accurate diagnosis means a rapid initiation of treatment, which can change the patient's prognosis.

Resumen

Múltiples patologías pueden afectar el funcionamiento del aparato auditivo. El conocimiento anatómico de los compartimentos del hueso temporal en la tomografía axial computarizada (TAC) conduce a una mejor comprensión de estas entidades y mejora el enfoque clínico hacia la pérdida auditiva conductiva o neurosensorial. Un diagnóstico preciso significa un inicio rápido del tratamiento, lo cual puede modificar el pronóstico del paciente.

Introduction

Anatomical knowledge of the temporal bone is essential to accurately interpret computed tomography (CT) images of hearing impaired patients. Numerous pathologies affect the functioning of the auditory apparatus in its different compartments. Having a structured imaging approach to the suspicion of these entities leads to a timely diagnosis and consequently to the early initiation of treatment that translates directly into the patient's quality of life. The aim of this article is to review the anatomy of the ear, with critical points in CT and to propose an approach that encompasses the most common causes of hearing loss.

1. CT anatomy of the ear

The temporal bone houses the auditory system, which from a practical perspective is a complex of three chambers called the outer, middle and inner ear (1) (Figure 1).

The outer ear consists of the eardrum, the fibrocartilaginous and bony portions of the external auditory canal (EAC) and the tympanic membrane (TM) (2). The walls that make up the middle ear are: lateral -the scutum- the tympanic membrane; superior -tegmen tympani-, which separates the middle cranial fossa from the tympanic cavity; medial, the otic capsule that covers the cochlea, the vestibule and the three semicircular canals; inferior and anterior, essentially bony walls -the former surrounds the internal jugular vein, while the latter contains the epitympanic recess and the opening of the Eustachian tube-. The posterior wall has a bony protrusion called the pyramidal eminence and two recesses: the facial nerve and the sinus tympani (2, 3).

The main contents of the tympanic cavity are the ossicular chain, composed of the malleus, incus and stapes; Prussak's space, which is the superolateral portion of the tympanic cavity between the scutum and ossicles; and the stapedius and tensor tympani muscles (3).

The inner ear consists of the bony labyrinth, composed of the cochlea, the vestibule and the three semicircular canals (superior, posterior and lateral). These structures surround the membranous labyrinth, which is not visible on CT. The cochlea is a spiral-shaped structure formed by almost three gyri. Its center is the cone-shaped modiolus, which contains the spiral ganglion of the cochlear nerve. Each gyrus is separated by bony septa and its most prominent portion, the basal turn, forms the promontory (3, 4).

[1]Physician, Department of Radiology, Pontificia Universidad Javeriana, Hospital Universitario San Ignacio, Country Scan LTDA. Bogotá, Colombia.

[2]Physician, Department of Radiology, Pontificia Universidad Javeriana, Hospital Universitario San Ignacio. Bogotá, Colombia.

[3]Physician, Department of Radiology, Pontificia Universidad Javeriana, Hospital Universitario San Ignacio, Bogotá, Colombia.

[4]Medical Intern, Department of Radiology, Pontificia Universidad Javeriana, Hospital Universitario San Ignacio. Bogotá, Colombia.

The mastoid cells and the facial nerve canal are also major structures of the auditory system. The mastoid is composed mainly of bony septa and air-filled cells. The antrum is its upper limit, which communicates with the middle ear through the aditus ad antrum (4). The seventh cranial (facial) nerve crosses the temporal bone and has four main segments: labyrinthine, geniculate, tympanic and mastoid. Emergent branches arise from each segment that innervate the stapedius muscle, the lacrimal gland and the parasympathetic information duct of the taste buds (4).

2. Types of hearing loss

Hearing impairment is classified as conductive, sensorineural or mixed (5). In the conductive type, the transmission of sound from the external environment to the inner ear is deficient, resulting in a mechanical lesion in which the structures involved are the auricle, tympanic membrane and/or ossicular chain (5). Sensorineural hearing loss is characterized by the inability to transmit neural impulses from the inner ear structures to the brainstem. The mixed type of deafness consists of a combination of the two previous types (5).

3. Imaging assessment of hearing loss: the relevance of computed axial tomography

Hearing loss is a contributing factor to the burden of disease in industrialized countries and is one of the pathologies that most impairs quality of life (6). Currently, imaging diagnosis in patients with hearing loss can be performed by different modalities. CT is the modality of choice due to its short image acquisition times, added to its high sensitivity for subtle bone changes in the bony structures of the outer, middle and inner ear, and the possibility of evaluating other ear components such as the tympanic membrane (7, 8) (table 1). The suggested protocol for these cases includes axial acquisition with a high-resolution bone algorithm through the temporal bones with coronal reconstructions with a slice thickness of 0.5 to 0.625 mm and overlapping reconstructions. Complementary reconstructions in different planes (Pöschl, Stenvers and modified Stenvers views) can help to visualize the structural components of the inner ear - such as the vestibular aqueduct and semicircular canals - as well as the evaluation of the post-surgical electrode position after cochlear implant insertion (9, 10). Newer techniques, such as cone-beam CT, described in the literature provide higher spatial resolution with lower radiation doses (11).

It is relevant to say that data obtained with CT and magnetic resonance imaging (MRI) of the temporal bones are complementary and in selected patients with hearing loss both modalities should be considered (12, 13).

3.1. External ear

3.1.1. External auditory canal atresia

It consists of the total or partial absence of the external auditory canal. It directly affects sound conduction, while the inner ear is usually intact (14) (figure 2).

The recommended diagnostic and surgical planning method is CT of the temporal bone. It is usually bilateral in one third of patients (15). The volume of the middle ear (width greater than 3 mm required to consider surgical management), presence of the incus, incudomalleolar articulation, stapedius and its morphology, the presence of round and oval windows, the location of the internal carotid artery and jugular bulb should be described for surgical planning, as well as the course of the facial nerve (16, 17).

3.1.2. Acute/chronic otitis externa

It is a pathology of varied etiology, with multiple predisposing factors that favor bacterial growth. The main causative bacteria are Staphylococcus aureus and Pseudomona aeruginosa. It can also be caused by other microorganisms (viruses, Aspergillus and Candida) (18, 19).

Chronic otitis externa may predispose to narrowing of the CAE secondary to a chronic inflammatory process (20) (Figure 3).

In severe cases or when there is no improvement after treatment, imaging studies are necessary to determine the degree of inflammation or extension to adjacent structures and complications, such as necrotizing or malignant otitis externa (especially in diabetic patients or in direct trauma) (20, 21). They present as a thickening of the mucosa of the CAE and pinna, with enhancement after administration of contrast medium, bony compromise of the tympanum and mastoid, with cortical erosions visible on CT and infiltration of the temporomandibular fat in both imaging modalities. Posteromedial extension to the jugular foramen or carotid space are considered critical findings (21).

3.1.3. Myringosclerosis

It consists of hyaline collagen deposits and calcification of the tympanic membrane, resulting in decreased motility and conductive hypoacusis (21). Predisposing factors include previous insertion of a tympanostomy tube or myringotomy. On imaging studies, this pathology results in a thickened and calcified tympanic membrane (22).

Table 1. CT anatomical approach in cases of hearing loss.

Outer ear	Middle ear	Inner ear
External auditory canal atresia Acute/chronic otitis externa Myringosclerosis Exostosis and osteoma Squamous cell carcinoma	Acute and chronic otomastoiditis Cholesteatoma Paraganglioma tympanicum Trauma Fibrous dysplasia	Otosclerosis/ otospongiosis Dehiscence of the superior semicircular canal Schwannomas
Conductive hearing loss sensorineural		Sensorineural hearing loss

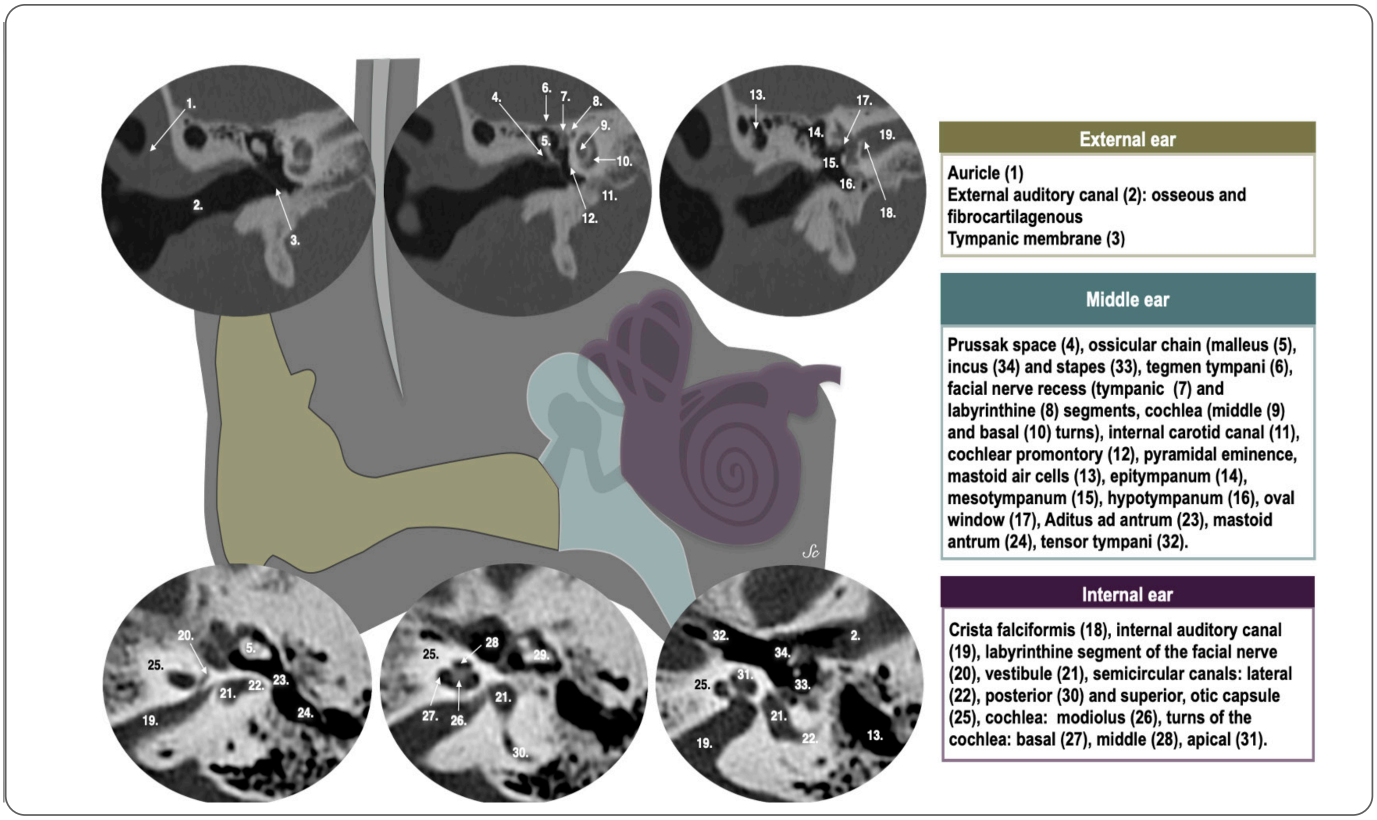


Figure 1. CT anatomy of the ear.
Source: authors' own.

Figure 2. CT, a, b) axial and c, d) sagittal reconstructions in high resolution CT bone window (HR-CT). 14-year-old patient with atresia of the left external auditory canal (arrowhead) with normal contralateral auditory canal (arrowhead). Partial pneumatization of the mastoid cells (arrow) and middle ear width greater than 3 mm. The oval and round window are present.

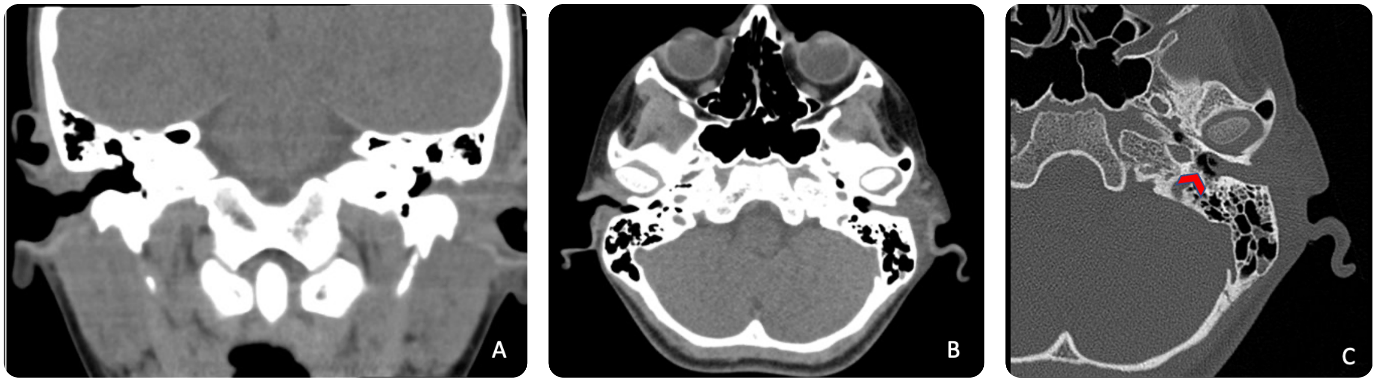


Figure 3. 3-year-old patient with acute otitis externa. HR-CT of the auditory canal, a) coronal reconstruction in soft tissue window, b) axial reconstruction in soft tissue window and c) bone. Occupation by soft tissue density material of the left external auditory canal and ear cleft, with internal bulging of the tympanic membrane (arrowhead). Slight enhancement and striation of adjacent fat indicative of edema. No bone erosion is identified.

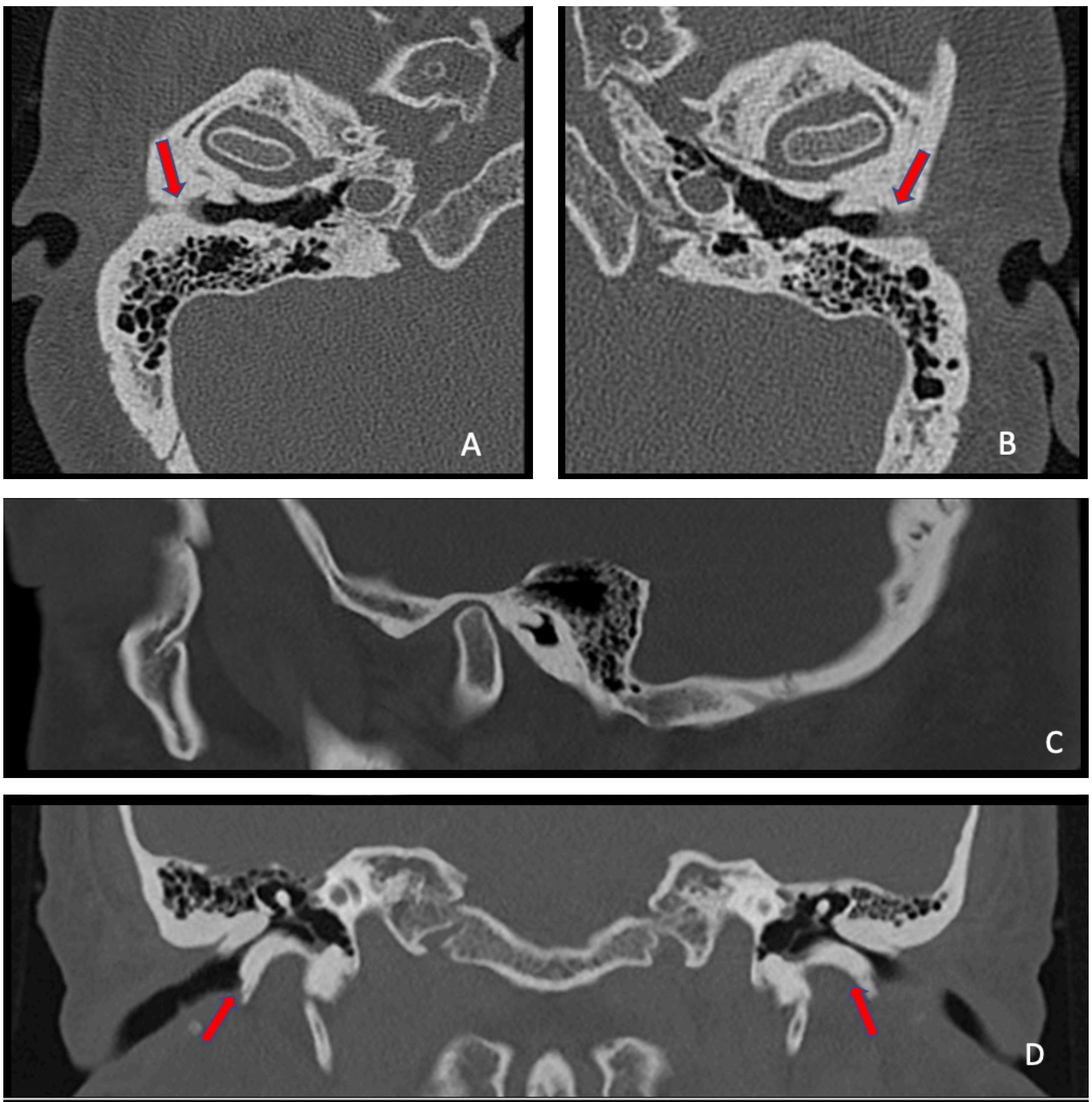


Figure 4. 32 years old patient. CT scan of ears in bone window: a, b) axial view, c) sagittal reconstruction and d) coronal reconstruction. Bilateral concentric periosteal and cortical thickening of the distal third of the external auditory canal is visualized, causing circumferential stenosis of the same (red arrows). There is no evidence of otitis media, mastoiditis or bony erosion. Findings related to external auditory canal exostosis.

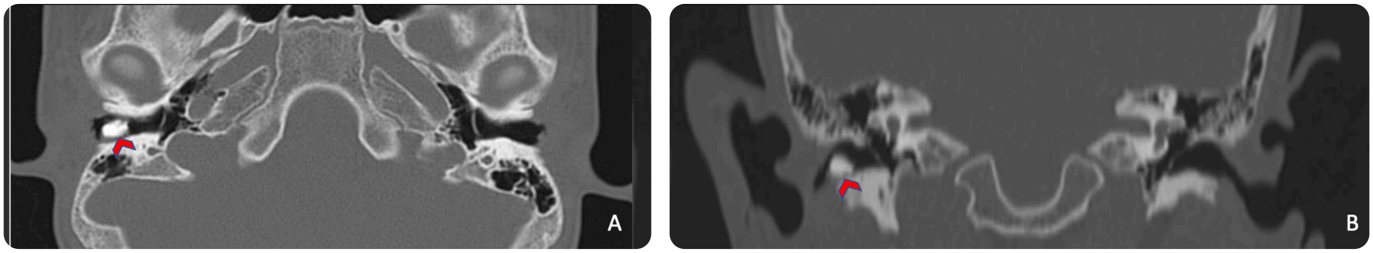


Figure 5. 41-year-old patient. Axial image of CT scan of ears in bone window: oval lesion with calcium density, pedunculated, with stalk seated in the inferior wall of the proximal third of the right external auditory canal obliterating its lumen (red arrow head). Unlike exostosis, osteomas of the external auditory canal are characteristically unilateral.

Figure 6. 76-year-old patient with history of mass sensation and otic fullness. CT with contrast medium: occupation of the right ear canal by an irregular mass with soft tissue density, with avid peripheral enhancement of the lesion and a center with markedly low density indicative of necrosis. Extensive bony erosion in the bone window (a) with loss of the auditory canal boundaries, extension into the adjacent mastoid cells and into the lateral portion of the carotid petrosal canal. Extension and destruction of the lesion to the posterior fossa, bilateral nasal fossa and maxillary sinus. Findings corresponding to squamous cell carcinoma of the CAE.

3.1.4 Exostosis and osteomas

Exostosis, known as surfer's ear, is an entity characterized by bony protrusions in the CAE secondary to repeated exposure to cold water. This pathology causes conductive hearing loss and episodes of otitis externa. CT findings include broad-based bony lesions contiguous to the tympanic ring, in the tympanomastoid and tympanosquamous sutures (23, 24) (Figure 4).

Osteoma is a rare, benign lesion affecting the temporal bone, especially the CAE. It is characterized by being unilateral, solitary, with a narrow base and adherent to the stem in CT images. It can be associated with conductive hypoacusis and cholesteatomas (23, 24) (figure 5).

3.1.5. Squamous cell carcinoma

Primary tumors of the CAE are rare. Of this subgroup, squamous cell carcinomas (SCC) represent 80% of primary tumors, and are the most common (25) (figure 6).

The main function of CT is to stage the tumor, which will be fundamental in the prognosis and management planning of these patients, to determine the feasibility and extent of surgical management (24). A system of tumor, nodal and metastatic staging known as T-staging can be used (Table 2).

Table 2. T-staging (University of Pittsburgh) for squamous cell carcinoma of the EAC

Stage	Characteristics
T1	Limited to the external auditory canal.
T2	Limited bony extension.
T3	Erosion of the entire thickness of the CAE, with involvement of adjacent soft tissues of less than 5 cm or tumors with involvement of the middle ear and/or mastoid.
T4	Involvement of soft tissues > 5 cm and bony structures such as the petrous apex, cochlea, medial wall of the middle ear, carotid canal, jugular foramen or dura.

A complete local resection is considered when the full extent of the tumor is removed, but the wall of the CAE is spared (25).

3.2 Middle ear

3.2.1. Middle ear infections: acute and chronic otitis media/otomastoiditis

Otitis media refers to inflammation and infection of the tympanic cavity. If the infectious process extends to the mastoid cells, it is called otomastoiditis. If the disease does not respond to conventional therapy, imaging studies are indicated to identify complications. The imaging technique of choice is CT. Findings of mild acute otitis media include opacification of the middle ear and mastoid cells indicating occupation by effusion (Figure 7).

Clinically, the patient presents with conductive hearing loss due to limited mobility of the tympanic membrane and ossicular chain (26, 27).

If the infection progresses, there may be complications such as acute coalescent otomastoiditis or subperiosteal mastoid abscesses (27) (Figure 8).

An episode of otitis media that persists for more than six weeks is considered chronic otitis.

These patients have more intense manifestations, such as conductive hearing loss. Imaging studies should be directed to look for alterations of the tympanic membrane (perforation, retraction, thickening), erosion of the scutum or tegmen tympani, soft tissue masses in Prussak's space (increasing the suspicion of cholesteatoma), erosion or post-inflammatory fixation of ossicles (more frequent in the malleus and incus) (28, 29) (figure 9).

3.2.2. Cholesteatoma

It is formed by stratified squamous epithelium that grows in the middle ear and mastoid space (30).

The acquired one (more frequent) can develop from medial or posterior retractions of the tympanic membrane (known as cholesteatoma of the pars flaccida and pars tensa, respectively).

Of these, the most common is the pars flaccida variety, which presents with conductive hearing loss due to both mass effect in the ossicular chain and erosion of the ossicles. Other manifestations include mastoid invasion, erosion of the tegmen tympani, erosion of the lateral semicircular canal and, in the pars tensa variety, erosion of the bony cover of the facial nerve canal with destruction of the stapes (30, 31).

In CT studies, the findings depend on the location of the cholesteatoma. Pars flaccida cholesteatoma is found in Prussak's space, accompanied by erosion of the scutum and ossicles, most frequently involving the long process of the incus (Figure 10).

A cholesteatoma of the pars tensa is located in the posterior quadrant of the tympanic membrane; it involves the tympanic sinus, the facial recess and the mastoid. This entity also affects the ossicles chain, most frequently the long process of the incus, stapes and malleus manubrium (31).

The literature recommends an exhaustive imaging evaluation of the erosion and displacement of the ossicles, the bony cover of the tegmen tympani and the lateral semicircular canal, the bony walls of the tympanic segment of the facial nerve, the extension towards the tympanic sinus and the involvement of the oval window (31, 32).

3.2.3. Paraganglioma tympanicum

It is the most frequent benign tumor of the middle ear. It originates in the tympanic plexus located in the cochlear promontory (33, 34).

Its clinical presentation is characterized by conductive hypoacusis secondary to a reddish, vascular, pulsatile, retrotympanic location mass. The imaging technique of choice is CT with and without contrast medium, to evaluate the relationship of the mass with the bony walls. In imaging studies, this type of tumor is characterized as a mass in the cochlear promontory that surrounds, but does not erode, the ossicles, there is no involvement of the jugular bulb and it presents an avid and rapid relapse after the administration of contrast medium (35, 36). Its severity is determined according to the involvement of the mastoid, tympanic membrane and the CAE (37, 38).

Figure 7. 45-year-old patient with hypoacusis. CT of the brain in bone window: occupation of the mastoid cells, with air bubbles inside (red arrowheads). Partial erosion of the bony septa of the posterior mastoid cells (red arrow), which establishes the diagnosis of acute coalescent mastoiditis.

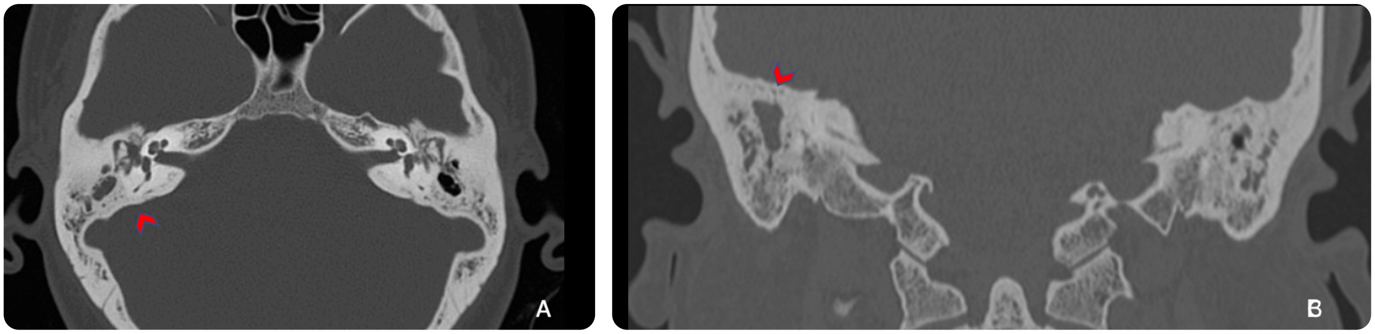
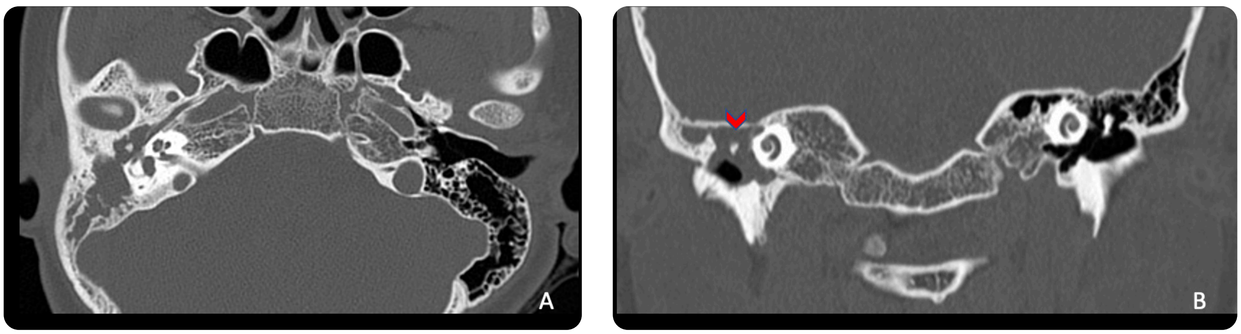


Figure 8. 66-year-old patient with a history of hearing loss of two years of evolution. a) HR-CT scan of the auditory canal in axial bone window, b) coronal reconstruction: occupation with soft tissue density in the right mastoid cells, associated with coalescence and cortical sclerosis (red arrowhead) when compared with the left mastoid cells, establishing the diagnosis of chronic otomastoiditis.



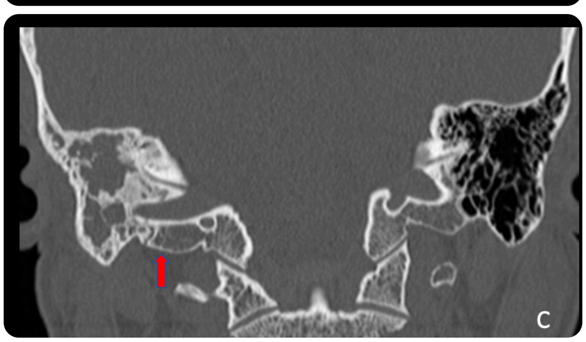


Figure 9. 53-year-old patient with a history of progressive right hearing loss and otic fullness of three years of evolution. Coronal HR-CT reconstructions of the ears in bone window: material with soft tissue density within the right middle ear, with traction of the tympanic membrane and erosion of the ossicles (b, red arrowhead). Adjacent there is an occupation with soft tissue density of the mastoid cells, bony erosions, coalescing mastoids and asymmetry with collapse due to a decrease in the height of the right temporal fossa compared to the contralateral one (c, red arrow). Chronic otomastoiditis is diagnosed.

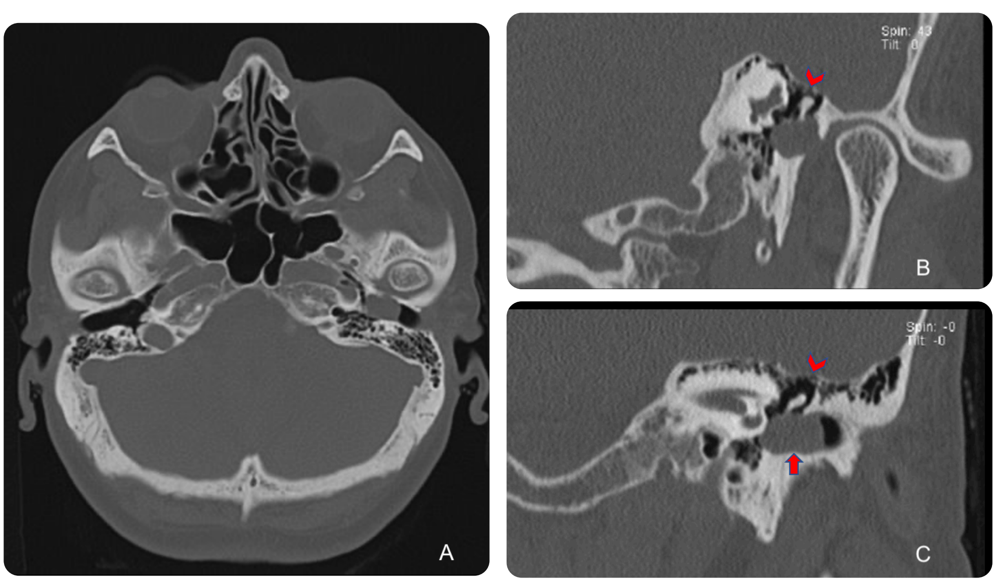


Figure 10. a-c). 48-year-old patient with left otic fullness. Lesion with soft tissue density in the left middle ear completely obliterating the left external auditory canal (c. red arrow). It originates in the mesotympanum and has a posteromedial extension. There is erosion and displacement of the ossicles towards Prussak's space corresponding to cholesteatoma (b and c. red arrowheads).

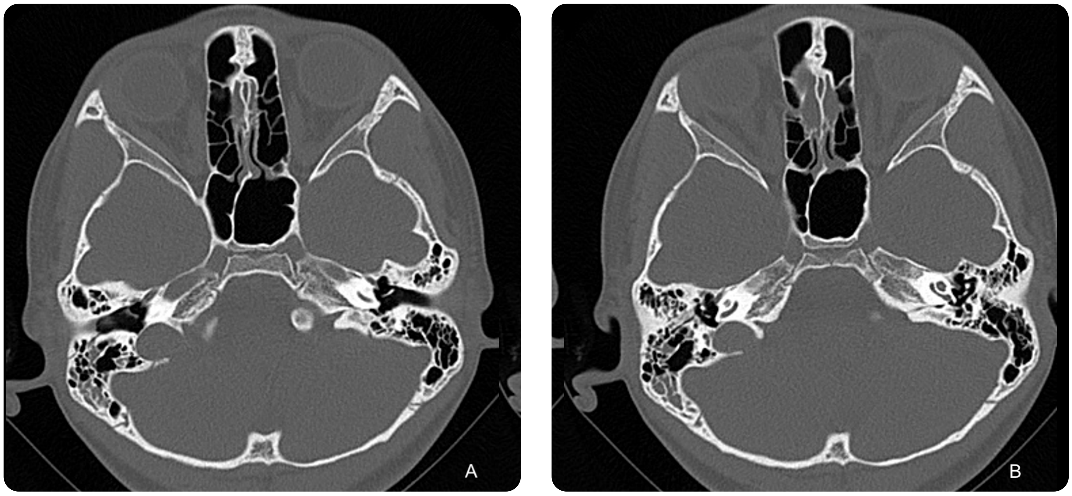


Figure 11. 26-year-old patient with trauma due to bicycle accident. Axial HR-CT scan in bone window with evidence of horizontal trace of fracture extending obliquely from the external auditory canal to the mastoid cells (red arrow). Occupation by soft tissue density material corresponding to hematic content.

3.2.4. Trauma

Hearing loss is a common consequence of blunt injury to the temporal bone, which may lead to conductive or sensorineural hearing loss. The former is secondary to an ossicular chain injury, while the latter involves trauma to the inner ear structures (39, 40).

CT is the technique of choice for the evaluation of cases of traumatic brain injury. When evaluating the images, radiologists should indicate the direction of the fracture, which predicts the possible involvement of the otic capsule which gives it its classification (present or not) (41). If the otic capsule is involved, possible dislocations of the ossicular chain should be evaluated. Likewise, it is necessary to describe the extension of the lesion, the involvement of the carotid canal, the facial nerve and actively search for secondary epidural hematomas (42, 43) (figure 11).

3.2.5. Fibrous dysplasia

Fibrous dysplasia is characterized by abnormal bone metabolism and replacement of normal bone marrow by fibro-osseous tissue (44, 45).

This condition has three forms of presentation, monostotic being the most common. Its clinical manifestation includes conductive hearing loss secondary to narrowing of the CAE or CAI with common alteration of the canal of the seventh cranial nerve.

Three patterns are observed in imaging studies: pagetoid, cystic and sclerotic. The latter is the most common pattern, mainly affecting the temporal bone. Its imaging characteristics include an increase in bone density and thickness, associated with loss of the regular trabecular pattern. The complications described are progressive obstruction of the CAE, which predisposes to infections, obturating keratosis, cholesteatoma formation; it can have extension to the jugular foramen and temporomandibular joint involvement (46, 47).

3.3. Inner ear

3.3.1. Otosclerosis / otospongiosis

Otosclerosis is a type of osteodystrophy of the inner ear, characterized by the replacement of the endochondral bone by cancellous bone, hence its name. The regions frequently involved are the fissula ante fenestram, the round window, the stapes base and the otic capsule (48, 49).

Impairment of hearing function depends on the location of the otosclerosis. If the involvement involves the mechanical fixation of the stapes, a conductive hearing loss is established. The disease may progress, involve inner ear structures, and result in sensorineural loss (49, 50).

Key findings of fenestral otosclerosis include low density of the fissula ante fenestram associated with reactive bone demineralization, which may extend to the oval and round windows, promontory and facial nerve canal (50) (Figure 12).

Evidence of involvement beyond the oval window, including the pericochlear region, vestibule, semicircular canals, and internal auditory canal, are findings secondary to retrofenestral or cochlear otosclerosis. A low-density ring in the pericochlear region, known as the “fourth ring” sign, is a distinctive feature on CT. One of the most common errors described in the literature is the presence of a cochlear cleft, a low density of the normal development surrounding the cochlea in children (51, 52).

In patients with otosclerosis, crucial points on CT include the size and location of the low-density lesions, the status of the oval and round windows, the relationship of the lesions to the canal of the seventh cranial nerve, bony changes of the ossicles, the integrity of the bony wall of the venous sinus and jugular bulb, associated anomalies in the middle and inner ear, and assessment of the contralateral ear (53-55).

3.3.2. Superior semicircular canal dehiscence

Superior semicircular canal dehiscence is the most frequent lesion of the third window anomalies (56). It consists of an abnormal communication of the superior semicircular canal with the middle cranial fossa, resulting in impaired auditory function due to dissipation of acoustic energy from the inner ear through the defect (57). The etiology of this condition remains unknown, although the predominance in the elderly population suggests an acquired origin (58).

The assessment of this entity should be, ideally, by means of CT with perpendicular and parallel reconstructions to the superior semicircular canal (Stenvers and Pöschl projections, respectively). The main

Figure 12. CT in bone window. Patient 54 years old with progressive hearing loss. Low bone density is seen in the right pericochlear area (arrow), with otosclerosis and compromise of the fissula ante fenestram.

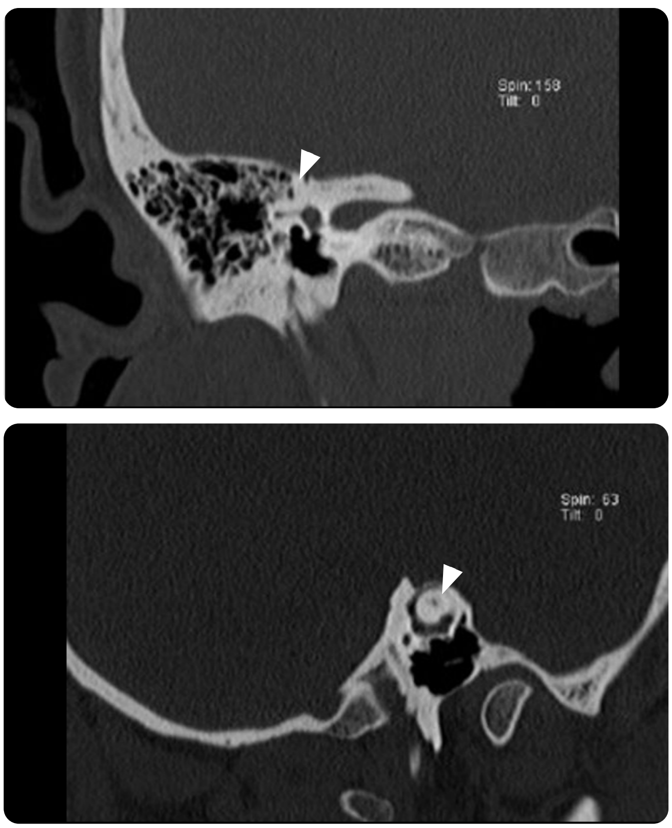


Figure 13. 59-year-old patient with progressive hearing loss. HR-CT scan of the ears in bone window demonstrating a dehiscence of the right superior semicircular canal (red arrowhead) characterized by a loss of coverage of the petrous bone between the superior semicircular canal and the skull.

characteristic of the image is the defect or dehiscence greater than or equal to 2 mm over the superior semicircular canal, most commonly located in its roof or arcuate eminence. Other described locations of involvement in the semicircular canal include its lateral ascending slope, the medial descending slope or the part close to the superior petrosal sinus (59, 60) (Figure 13).

3.3.3. Schwannomas

Schwannomas of the inner ear are rare. These are benign tumors that involve the branches of the eighth cranial nerve; they can be found in the cochlea, vestibule or semicircular canals (61 ,62). Clinical manifestations include tinnitus, vertigo and unilateral progressive sensorineural hearing loss (63).

Salzman et al. proposed, according to the portion involved, an anatomical classification of inner ear schwannomas into intracochlear, transmodiolar, intravestibular, transmacular, vestibulocochlear and transotic (64).

The imaging modality of choice for the study of schwannomas is MRI. (65) However, CT adds valuable information regarding the bony changes produced as a consequence of the involvement of the mass in the surrounding structures of the inner ear. If the tumor is large, bone erosion may be observed (66).

Conclusions

This review shows the wide spectrum of imaging findings in the temporal bone associated with different types of hearing loss. Adequate knowledge of the critical anatomical points ensures an optimal systematic approach between the auditory spaces, allows an adequate characterization of the lesions, as well as a possible differential diagnosis that can guide the clinical approach to the suspected pathology.

References

1. Nayak S. Segmental anatomy of the temporal bone. Semin Ultrasound CT MR. 2001;22(3):184-218.
2. Juliano AF. Cross sectional imaging of the ear and temporal bone. Head Neck Pathol. 2018;12(3):302-20.
3. Juliano AF, Ginat DT, Moonis Gul. Imaging review of the temporal bone: part I Anatomy and inflammatory and neoplastic processes. Radiology. 2013; 269(1):17-33.
4. Metwally MI, Alayouty NA, Basha MAA. Ear malformations: what do radiologists needs to know. Clin Imaging. 2020;66:42-53.
5. Cunningham LL, Tucci DL. Hearing loss in adults. N Engl J Med. 2017;377:2465-73.
6. Zanhert T. The differential diagnosis of hearing loss. Dtsch Arztebl Int. 2011;108(25):433-43.
7. Maqsood S, Dar IH, Bhat SA. Role of high resolution computed tomography in evaluation of temporal bone diseases. IAIM. 2018;5(12):15-22.
8. Jallu AS, Jehangir M, Hamid WU, Pampori RA. Imaging evaluation of pediatric sensorineural hearing loss in potential candidates for cochlear implantation. Indian J Otolaryngol Head Neck Surg. 2015;67(4):341-6.
9. Abele TA, Wigins RH. Imaging of the temporal bone. Radiol Clin N Am. 2015;53(1):15-36.
10. Robson CD. Congenital hearing impairment. Pediatr Radiol. 2006;36(4):309-24.
11. Gomes RLE. Review and update of temporal bone imaging. Radiol Bras. 2019;52(2):VII-VIII.
12. Palabiyik FB, Hacikurt K. Temporal high-resolution computed tomography and magnetic resonance imaging of congenital inner ear anomalies in children. J Craniofac Surg. 2016;27(7):632-6.

13. Zerny C, Franz P, Imhof H. Computertomographie und magnetresonanztomographie des normales schlafenbeines. Radiologe. 2003;43:200-6.
14. Dougherty W, Kesser BW. Management of conductive hearing loss in children. Otolaryngol Clin N Am. 2015;48(6):955-74.
15. Chatra PS. Lesions in the external auditory canal. Indian J Radiol Imaging. 2011;21(4):274-8.
16. Shonka DC, Livingston WJ, Kesser BW. The Jahrsdoerfer grading scale in surgery to repair congenital aural atresia. Arch Otolaryngol Head Neck Surg. 2008;134(8):873-7.
17. Jahrsdoerfer RA, Yeakley JW, Aguilar EA, Cole RR, Gray LC. Grading system for the selection of patients with congenital aural atresia. Am J Otol. 1992;13(1):6-12.
18. Raza SA, Denholm SW, Wong JC. An audit of the management of acute otitis externa in an ENT casualty clinic. J Laryngol Otol. 1995;109(2):130-3.
19. Szmuilowicz J, Young R. Infections of the ear. Emerg Med Clin N Am. 2019;37(1):1-9.
20. Sander R. Otitis externa: a practical guide to treatment and prevention. Am Fam Physician. 2001;63(5):927-37.
21. Hermans R. External ear imaging. En: Lemmerling M, De Foer B. Temporal bone imaging. Berlin: Springer; 2015. p. 35-50.
22. Nguyen T, Pulickal G, Singh A, Lingam R. Conductive hearing loss with a “dry middle ear cleft” a comprehensive pictorial review with CT. Eur J Radiol. 2019;110:74-80.
23. Brea B, Roldan-Fidalgo A. Diagnóstico por imagen de las lesiones benignas del conducto auditivo externo. Acta Otorrinolaringol Esp. 2013;64(1):6-11.
24. White RD, Ananthakrishnan G, McKean SA, Brunton JN, Hussain SSM, Sudarshan TA. Masses and disease entities of the external auditory canal: radiological and clinical correlation. Clin Radiol. 2012;67(2):172-81.
25. Xia S, Yan S, Zhang M, Cheng Y, Noel J, Chong V, et al. Radiological findings of malignant tumors of external auditory canal. Med (United States). 2015;94(35):e1452.
26. St Martin MB, Hirsch BE. Imaging of hearing loss. Otolayrngol Clin N Am. 2008;41(1):157-78.
27. Trojanowska A, Drop A, Trojanowski P, Rosinska-Bogusiewicz K, Klatka J, Bobek-Billewicz B. External and middle ear diseases: radiological diagnosis based on clinical signs and symptoms. Insights Imaging. 2012;3(1):33-48.
28. Shekdar KV, Bilaniuk LT. Imaging of pediatric hearing loss. Neuroimag Clin N Am. 2018;29(1):103-15.
29. Lemmerling MM, De Foer B, Verbis BM, VandeVyver V. Imaging of inflammatory and infectious diseases in the temporal bone. Neuroimag Clin N Am. 2009;19(3):321-37.
30. Touska P, Connor SEJ. Imaging of the temporal bone. Clin Radiol. 2020;75(9):658-74.
31. Campion T, Taranath A, Pinelli L, Ugga L, Nash R, Talent G, et al. Imaging of temporal bone inflammations in children: a pictorial review. Neuroradiology. 2019;61(9):959-70.
32. DeMarcantonio M, Choo DI. Radiographic evaluation of children with hearing loss. Otolaryngol Clin N Am. 2015;48(6):913-32.
33. Mafee MF, Raofi B, Kumar A, Muscato C. Glomus faciale, glomus jugulare, glomus tympanicum, glomus vagale, carotid body tumors and simulating lesions: role of MR imaging. Radiol Clin North Am. 2000;38(5):1059-76.
34. Devaney KO, Boschman CR, Willard SC, Ferlito A, Rinaldo A. Tumours of the external ear and temporal bone. Lancet Oncol. 2005;6:411-20.
35. Touska P, Juliano A. Temporal bone tumors: an imaging update. Neuroimag Clin N Am. 2019;29:145-72.
36. Jackson CG. Glomus tympanicum and glomus jugulare tumors. Otolaryngol Clin North Am. 2001;34(5):941-70.
37. Sweeney AD, Carlson ML, Wanna GB, Bennett ML. Glomus tympanicum tumors. Otolaryngol Clin N Am. 2015;48(2):293-304.
38. Jackson CG, Leonetti JP, Marz SJ. Surgery for benign tumors of the temporal bone. Glasscock-Shambaugh surgery of the ear. En: Gulya AJ, Minor LB, Poe DS, editors. Shelton (CT): People’s Medical Publishing House; 2010. p. 729-50.
39. Kenna MA. Acquired hearing loss in children. Otolaryngol Clin N Am. 2015;48(6):933-53.
40. Davidson HC. Imaging evaluation of sensorineural hearing loss. Semin Ultrasound CT MR. 2001;22(3):229-49.
41. Maillot O, AttyéA, Boyer E, Heck O, Kastler A, Grand A, Schmerbe S, et al. Post traumatic deafness: a pictorial review of CT and MRI findings. Insights Imaging. 2016;7:341-50.
42. JD Swartz. Temporal bone trauma. Semin Ultrasound CT MR. 2001;22(3):219-28.
43. Mazon M, Pont E, Albertz N, Carreres-Polo J, Mas-Estelles F. Imaging of postraumatic hearing loss. Radiologia. 2018;60(2):119-27.
44. Boyce AM, Brewer C, DeKlotz T, Zalewski C, King K, Collins M, et al. Association of hearing loss and otologic outcomes with fibrous dysplasia. JAMA Otolaryngol Head Neck Surg. 2018;144(2):102-7.
45. Kim D, Heetfeld A, Steffen IG, Hermann KG, Hamm B, Elgeti T. Magnetic resonance imaging features of craniofacial fibrous dysplasia. Pol J Radiol. 2019;84:16-24.
46. Brown EW, Megerian CA, McKenna MJ, Weber A. Fibrous dysplasia of the temporal bone: imaging findings. AJR. 1995;164(3):679-82.
47. Andreu-Arasa VC, Sung EK, Fujita A, Saito N, Sakai O. Otosclerosis and dysplasias of the temporal bone. Neuroimag Clin N Am. 2018;29(1):29-47.
48. Veillon F, Riehm S, Emachescu B, Haba D, Roedlich M, Greget M, et al. Imaging of the windows of the temporal bone. Semin Ultrasound CT MRI. 2001;22(3):271-80.
49. Krombach GA, Honnef D, Westhofen M, Di Martino E, Günther RW. Imaging of congenital anomalies and acquired lesions of the inner ear. Eur Radiol. 2008;18:319-30.
50. Kösling S, Plontke SK, Bartel S. Imaging of otosclerosis. Rofo. 2020;192(8):745-53.
51. Gredilla-Molinero J, Mancheño-Losa M, Santamaría-Guinea N, Arévalo-Galeano N, Grande-Barez M. Update on the imaging diagnosis of otosclerosis. Radiología. 2016;58(4):246-56.
52. Juliano AF, Ginat DT, Moonis G. Imaging review of the tempoal bone: part II. Traumatic, postoperative, and noninflammatory nonneoplastic conditions. Radiology. 2015;276(3):655-72.
53. Purohit B, Hermans R, Op de beeck K. Imaging in otosclerosis: a pictorial review. Insights Imaging. 2014;5(2):245-52.
54. Lee TC, Aviv RJ, Chen JM, Nedzelski JM, Fox AJ, Symons SP. CT grading of otosclerosis. AJNR Am J Neuroradiol. 2009;30:1435-39.
55. Marshall AH, Fanning, Symons, et al. Cochlear implantation in cochlear otosclerosis. Laryngoscope. 2005;115:1728-33.
56. Ho ML, Moonis G, Halpin CF, Curtin HD. Spectrum of third window abnormalities: semicircular canal dehiscence and beyond. AJNR Am J Neuroradiol. 2017;38(1):2-9.
57. Giesemann A, Hofmann E. Some remarks on imaging of the inner ear: options and limitations. Clin Neuroradiol. 2015;25:197-203.
58. Yew A, Zarinkhou G, Spasic M, Trang A, Gopen Q, Yang I. Characteristics and management of superior semicircular canal dehiscence. J Neurol Surg B. 2012;73:365-70.
59. Moonis G. Imaging of third window lesions of the temporal bone. Semin Roentgenol. 2019;54(3):276-81.
60. Ho ML. Third window lesions. Neuroimag Clin N Am. 2019;29:57-92.
61. Tieleman A, Casselman J, Somers T, Delanote J, Kuhweide R, Ghekiere J, De Foer B, et al. Imaging of intralabyrinthine schwannomas: a retrospective study of 52 cases with emphasis on lesion growth. AJNR Am J Neuroradiol. 2008;29(5):898-905.
62. Verbist BM. Imaging of sensorineural hearing loss: a pattern-based approach to diseases of the inner ear and cerebellopontine angle. Insights Imaging. 2012;3(2):139-53.
63. Pont E, Mazón M, Montesinos P, Sánchez MA, Mas-Estelles F. Diagnóstico por imagen: malformaciones congénitas lesiones adquiridas del oído interno. Acta Otorrinolaringol Esp. 2014;66(4):224-33.
64. Salzman KL, Childs AM, Davidson HC, Kennedy RJ, Shelton C, Harnsberger HR. Intralabyrinthine schwannomas: imaging diagnosis and classification. AJNR Am J Neuroradiol. 2012;33(1):104-9.
65. Plontke SK, Rahne T, Pfister M, Götze G, Heider C, Pazaiti N, et al. Intralabyrinthine schwannomas: surgical management and hearing rehabilitation with cochlear implants. HNO. 2017;65(2):136-48.
66. Lee KS, Choe MS. The CT and magnetic resonance imaging features of transotic schwannoma: a case report. J Korean Soc Radiol. 2013;68(4):281-4.

Correspondence

Nicole Erazo-Morera
Hospital Universitario San Ignacio
Pontificia Universidad Javeriana
Carrera 7 # 40-62
Bogotá, Colombia
erazo.n@javeriana.edu.co

Received for evaluation: February 17, 2022
Accepted for publication: April 26, 2022