Sensorineural hearing loss: radiologic diagnosis

Authors

Associação Brasileira de Otorrinolaringologia e Cirurgia Cérvico-facial (Brazilian Association of Otorhinolaringology and Cervicofacial Surgery), Colégio Brasileiro de Radiologia (Brazilian College of Radiology)

Participants

Santos AF, Felix F, Martins GSQ, Hausen Pinna M, Bento RF, Monteiro TA, Gebrim EMS, Daniel MM, Gomes RLE, Haetinger R, Toyama C, Cevasco FKI, Mello SBM, Passos UL, Andrada NC

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Conflict of interest

None.

Description of the evidence collection method

This guideline was developed by searching the primary database MEDLINE (Pubmed) and other research sources, without time constraint. The search strategy was based on structured questions in the "PICO format" (an acronym for "Patient", "Intervention", "Control", "Outcome"). The descriptors used were: hearing loss; neuroma, acoustic; meningioma; otosclerosis; otospongiosis; ear, neoplasm/diagnosis; ear, inner/abnormalities; ear, inner/radiography; cochlear nerve/abnormalities; cochlear nerve/radiography; tomography; tomography, X-ray computed; pneumoencephalography; magnetic resonance imaging; echo planar imaging; follow-up studies; false positive reaction; sensitivity and specificity; diagnosis; differential diagnosis; team factors; cochlear implantation.

Degree of recommendation and strength of evidence

A: Experimental or observational studies of higher consistency.

B: Experimental and observational studies of lesser consistency.

C: Case reports (non-controlled studies).

D: Opinions without critical evaluation, based on consensus, physiological studies, or animal models.

Objective

the purpose of this guideline is to provide orientation on the use of radiological examinations for hearing loss diagnosis and monitoring. It includes directions for examination and evidence of benefits warranting them. Deafness' acquired causes (trauma) and infections (mean chronic otitis) were not addressed in this guideline. Clinical and audiological diagnoses of deafness will be addressed in another guideline. Target audience: otorhinolaryngologists and pediatricians.

Introduction

Radiologic diagnosis plays a crucial role in assessing various otorhinolaryngologic problems. The most used tests are computed tomography (CT), magnetic resonance imaging (MRI), scintigraphy, and angiography. The temporal bone anatomy is complex and has important vascular and nervous structures. Therefore, in order to obtain information using these advanced tests, a thorough knowledge of this architecture is required. Most otologists are already well-acquainted with bone details that can be assessed on high-resolution CT scans of the temporal bone, including the inner ear, ossicular chain, and oval window. However, MRI has advantages in detecting soft tissue abnormalities, such as cochlear obliteration, cochlear nerve aplasia, endolymphatic sac enlargement, and retrocochlear lesions. Analysis of the current evidence in literature contributes to the proper use of these tests. Nevertheless, it is always important to emphasize that the subsidiary tests only help to confirm the diagnosis and must be ordered according to clinical suspicion.

1. What is the role of CT in suspected cases of schwannoma of the eighth cranial nerve?

CT with contrast had been widely used in clinical suspicion of schwannoma of the eighth cranial nerve, when MRI was not yet a standard technique, with a sensitivity of 58%[1] (**B**).

At that time, when the contrast-enhanced CT was negative, air CT cysternography was performed, increasing the test sensitivity to 100%. However, because this technique is more complicated, invasive, and exposes patients to radiation, it lost ground to MRI[1] (**B**).

Regarding internal auditory canal tumors, the sensitivity of contrast-enhanced CT was 36% and MRI 100%, and for cerebellopontine angle tumors the sensitivity was 68% and 100%, respectively[1] (**B**).

Recommendation

In suspected cases of schwannoma of the eighth cranial nerve, contrast-enhanced CT may be used as the initial screening when MRI is not available. It is emphasized that the negative result of CT does not exclude the presence of retrocochlear lesions, due to its low sensitivity. Confirmation with MRI is required, especially when the lesion is restricted to the internal auditory canal[1] (**B**).

2. What test is indicated for diagnosis of suspected cases of schwannoma of the eighth cranial nerve?

MRI with gadolinium contrast on T1 has been considered the gold standard for diagnosis of schwannoma of the eighth cranial nerve since the late 1980s[2] (**A**). It allows for the clear identification and visualization of the seventh and eighth cranial nerves within the internal auditory canal[3] (**A**). In patients with clinical suspicion of schwannoma of the eighth cranial nerve, images of non-contrasted MRI fast spin echo (FSE T2) were compared with those contrasted with gadolinium (T1). A 54.5% sensitivity was achieved in non-contrasted images, in addition to failure in the diagnosis of intracanalicular tumors and impaired interpretation in cases of narrow internal auditory canal[3](**A**). The association of images obtained in contrasted and non-contrasted MRI can bring further information to suspicion of other etiologies that clinically mimic schwannoma of the eighth cranial nerve, in addition to detecting all cases of schwannoma[3](**A**). Currently, it is believed that the most cost-effective strategy for diagnosis of suspected cases of schwannoma of the eighth cranial nerve (performed after audiometry) is high-resolution non-contrasted MRI using three-dimensional volumetric acquisition with balanced gradient-echo (steady state), which allows detailing of the structures of the membranous labyrinth, as well as of the nerves within the internal auditory canal (IAC)[4-8] (**B**). On some units, the volumetric submillimeter T2 fast spin echo (FSE) sequences allow for a better evaluation of the inner ear structures[8] (**B**). Sometimes it is necessary to use a paramagnetic contrast agent (gadolinium) for lesion identification within the IAC[3] (**A**); failure to use this contrast delays the diagnosis of small lesions and increases the rate of false negatives in the diagnosis of schwannomas[7] (**B**). When the balanced gradient-echo (FSE) T2 sequence shows changes in the internal auditory canal or in the membranous labyrinth, the patient should be recalled for an additional post-contrast T1 sequence[6] (**B**). Patients with audiovestibular symptoms should undergo post-contrast fast spin echo sequences T2 and T1, as this technique allows greater detection of acoustic neuroma and/or identification of its differential diagnoses[4] (**B**). MRI with balanced gradient echo (ESF) T2 sequence provides excellent anatomic representation of the temporal bone and cerebellopontine angle, with identification of the seventh and eighth cranial nerves, and identifies which branch is affected by schwannoma of the eighth cranial nerve and its extension in the inner ear. The definition of normality using this technique is given by the proper identification of the seventh and eighth cranial nerves without changes to the internal auditory canal and cerebellopontine angle, cochlea, and labyrinth structures[4] (**B**). The disadvantages are the non-identification of inflammation and other processes in the brain and temporal bone (meningioma, metastasis, lipoma, cavernoma, and vascular loop), which may present the same symptoms of a schwannoma of the eighth cranial nerve;non-identification of a schwannoma of the eighth cranial nerve smaller than 5 mm if the nerve branches of the seventh and eighth cranial nerves are not properly identified, or by the presence of artifact, or if the tumor has not distorted the anatomy of the inner ear structures[4] (**B**). Thus, cases presenting changes or doubtful cases should be recalled for MRI contrast to further elucidate the diagnosis. Using this strategy, 86% negative tests are expected, of which 1% will be false negative, and 14% positive results, of which 0.9% will be false positives and 3% to 5% of suspected cases will not be confirmed by the adopted sequence[4] (**B**).

Recommendation

The indicated test for suspected cases of schwannoma of the eighth cranial nerve is the MRI, which should include FSE T2 sequences, pre- and post-contrast T1 sequences, and three-dimensional volumetric acquisition with balanced gradient-echo (steady state)[4-8] (**B**). Contrast-enhanced MRI remains the reference test, recommended in suspected (indeterminate) cases, and in those patients with initial change, to better elucidate the diagnosis[3] (**A**)[4-6] (**B**).

3. How to distinguish schwannoma of the eighth cranial nerve from cerebellopontine angle meningioma observed radiographically?

Schwannomas of the eighth cranial nerve and meningioma are the most common tumors in the cerebellopontine angle, corresponding to 80-90% and 10-15%, respectively[9] (**C**). The radiological findings suggestive of a schwannoma of the eighth cranial nerve are: globular shape; tumor with adjacent petrous surface and presence of cystic areas; intracanalicular component with enlargement of the internal auditory canal; and acute angle between the anterolateral or posterolateral portions and the adjacent petrous bone[10] (**C**). For meningioma, the suggestive radiological signs are: sessile tumor with broad base on the petrous or tentorium bone; obtuse angle with the petrous bone; homogeneous contrast enhancement; dural tail; intratumoral calcification; and hyperostosis. However, of these radiological signs described in literature, the presence of hyperostosis on CT is the only specific to meningioma[10] (**C**). On MRI, the presence of intratumoral microhemorrhages has a sensitivity of 93.8% and specificity of 100%, positive predictive value of 100%, and negative predictive value of 83.3% ($p < 0.01$) in the T2-weighted FSE sequence (gradient-echo) for vestibular schwannoma[11](**B**). This provides a high positive likelihood ratio with LR + = 94 (95% CI; 13.36-661.23%), increasing the diagnostic certainty from 2% (estimated

prevalence of the tumor before the test) to a 66% probability of having schwannoma in the presence of an abnormal test result. Meningiomas usually present no microhemorrhages but calcifications, which can be punctiform or coarse, sparse or diffuse. Microhemorrhages may be difficult to differentiate from calcifications on gradient-echo T2 sequence MRI images because both present with areas of no signal, reinforcing the need for paramagnetic contrast (gadolinium) or three-dimensional volumetric acquisition with balanced gradient-echo sequence (steady state). However, the use of T2-weighted turbo spin echo (TSE) sequence or fluid-attenuated inversion recovery (FLAIR) presented low sensitivity, identifying only 12.5% cases[11] (**B**). Up to 25% of meningioma cases may be confused with eighth cranial nerve schwannoma preoperatively[12] (**C**). The differentiation between these tumors will primarily influence the therapeutic decision and tumor prognosis. The chances of hearing preservation are higher in meningioma, as well as in its recurrence.

Recommendation

The use of T2-weighted gradient-echo (FSE) MRI may pose difficulties in differentiating schwannoma of the eighth cranial nerve from meningioma[11] (**B**). Identification of microhemorrhages in this sequence presents high sensitivity and specificity in diagnosing schwannoma of the eighth cranial nerve, increasing the diagnostic certainty from 2% to 66% in the presence of an abnormal test result.

4. How often should MRI be performed in patients with schwannoma of the eighth cranial nerve who are conservatively treated?

The choice for conservative treatment of schwannoma of the eighth cranial nerve may be taken for several reasons (initial tumor size, lack of symptoms, age, option of the patient, comorbidities that contraindicate other treatments). In these patients' follow-up, the frequency of imaging tests is important in detecting tumors that are growing and require other therapeutic resources[13] (**C**). Patients with schwannoma of the eighth cranial nerve initially managed with conservative treatment and clinically followed-up for ten years had tumor growth above 2 mm/year in the largest diameter in 22% of cases. Of these, 53% showed an increase in the first MRI, performed six months after diagnosis; 29% in the second MRI, performed 18 months after diagnosis; 11% in the third MRI, performed 30 months after initial diagnosis; 5% in the fourth MRI, performed 42 months after initial diagnosis; and 2% showed an increase in the MRI performed 66 months after diagnosis[13] (**C**). The follow-up imaging is suggested in the following frequency: six months after initial diagnosis, repeated annually for two years; then repeated after two years; finally, every five years thereafter[13] (**C**). Cystic tumors account for 6% of followed-up schwannomas and for 15% of those with growth. They tend to grow rapidly and unpredictably, so it is suggested that greater attention should be paid if the option is for a conservative treatment[13] (**C**). Schwannomas presenting with cystic tumor require reevaluation in less than six months.

Recommendation

MRI should be performed during conservative follow-up of schwannomas of the eighth cranial nerve in the following frequency: six months, annually for two years (18 and 30 months), then after two years (42 months), and finally every five years thereafter[13] (**C**). Schwannoma presenting with cystic tumor is the fastest growing, and requires reevaluation in less than six months.

5. Which MRI should be performed in patients with schwannoma of the eighth cranial nerve who underwent complete surgical resection of the tumor?

complete surgical resection is the treatment of choice for schwannoma of the eighth cranial nerve; however, the choice of partial resection may be made to preserve the adjacent structures. Patients undergoing surgery for excision of a schwannoma of the eighth cranial nerve were followed-up for four years to assess recurrence. On examination, 95.3% patients were found to be within normal limits one year after surgery, 3.3% had linear enhancement, 1% had nodular enhancement, and 0.3% had cholesterol granuloma. On examination after five years of surgery, all patients within normal limits in the first year remained as such, as well as the patients with linear enhancement. Cholesterol granuloma also remained stable. Of the three patients with nodular enhancement, two presented growth. Of these, one was left with residual tumor at surgery to preserve the facial nerve, and the other had recurrence (0.33%)[14] (**B**). MRI should be repeated one year after surgery, a sufficient time for the inflammatory process inherent to the surgical procedure to resolve. If the MRI is normal after one year, there is no need for further imaging[14] (**B**). If there is enhancement in the region of the internal auditory canal in the first scan, imaging should be repeated after two years. If linear enhancement remains stable, there is no need for further imaging. If the nodular enhancement remains stable, another scan is performed in 2 years, due to the increased risk of growth. If this new scan remains stable, then it is recommended to repeat the MRI every five years, as this group has a higher risk of recurrence[14] (**B**).

Recommendation

MRI is recommended in the postoperative follow-up of patients undergoing complete resection of a schwannoma of the eighth cranial nerve, to evaluate recurrence after one year in all cases[14](**B**). Patients who present with

enhancement in the region of the internal auditory canal should repeat the scan in two years[14] (**B**). Thereafter, the radiological follow-up will depend on the type of enhancement found. If the linear enhancement is stable, there is no need for further scans. If the nodular enhancement is stable, the scan should be repeated in two years and, thereafter, every five years[14] (**B**).

6. Which is the effective method for detecting radiological tumor growth in patients with schwannoma of the eighth cranial nerve who opt for the non-surgical management of the injury?

With the advancement of imaging techniques, many surgeons have opted for expectant management in some specific cases of patients with schwannoma of the eighth cranial nerve. This approach is called "wait-and-scan", and must be individually evaluated. Some studies have monitored patients who opt for this conservative approach to assess tumor growth, the consequences of "wait-and-scan", and the radiological methods used. It is important, however, that a simple and single standard of measurements is adopted from the MRI images, so that future control scans are comparable and reproducible, as the ideal rarely happens: scans performed by the same professional, in the same institution, and in the same medical equipment. Tumor volume must be known at its maximum diameter, including the intracanalicular portion. For this purpose, patients with schwannoma of the eighth cranial nerve were followed-up for 20 years, and their radiologic images were blindly analyzed by neuroradiologists. Tumor growth was measured by annual evaluation of the tumor diameter and volume, and relative growth rate of tumor volume[15] (**C**). In 20 years, the results were: 74% of patients had tumor growth, 18% had no growth, and 8% had negative growth[16] (**C**). In the 27-year follow-up of the same population, tumor growth rate was 85%, no growth 11%, and negative growth 6%. In the latter period, 42% of patients remained alive and tumor growth did not require intervention, 28% were treated surgically, and 19% died of causes unrelated to the tumor[16] (**C**). In the small and medium conservatively managed tumors that presented growth, there was no statistically significant difference regarding age, gender, initial tumor size, intra- or extracanalicular tumor, and presence of symptoms[17] (**B**). Besides, progression of hearing loss is not correlated with tumor growth, since 50% of patients with hearing loss progression had stable tumors[18] (**B**) [19] (**C**). Cystic tumors are known to be more likely to grow and and in an unpredictable way[13] (**C**), and young patients have faster growth rates[20] (**C**). Patients who opt for nonsurgical treatment should be monitored with MRI, with evaluation of tumor volume and not only tumor diameter, and these patients should maintain follow-up, even if the tumor volume is stabilized for two years[14] (**B**). MRI with volumetric evaluation of the tumor is the most accurate method for early detection of tumor progression. Growth is statistically significant when the tumor grows at least 50%; however, it is important to emphasize that the absence of radiological progression does not necessarily mean the absence of tumor growth[21] (**B**).

Recommendation

There is no clinical data capable of predicting tumor growth, hence the importance of radiological follow-up[17] (**B**). In patients who opt for nonsurgical follow-up of schwannoma of the eighth cranial nerve, the annual assessment of the tumor's volumetric growth with MRI is the most accurate radiologic examination to evaluate tumor growth[21] (**B**). These patients should be informed that, during follow-up, it is possible that the prognosis of the lesion will change[15] (**C**).

7. Is MRI likely to provide false positive results for schwannomas of the eighth cranial nerve?

MRI is the most sensitive method for early identification of small schwannomas of the eighth cranial nerve. T1 images with gadolinium identify lesions up to 2 mm[22] (**B**). However, this test may result in false positives. A prospective study of MRI three-dimensional volumetric acquisition with balanced gradient-echo (steady state) performed by two independent observers found sensitivity, specificity, and accuracy of 100%, 99.5%, and 99.5%, respectively, according to the first observer, and 99.7%, 99.7%, and 99.8%, respectively, according to the second observer[23] (**B**). This provides LR+ = 99 (95% CI; 14.08-696.03), increasing the diagnostic probability from 2% to 67%. The presence of false positive results is higher for small intracanalicular tumors, and may reach 32%[24] (**B**). In all tests that showed false positive results, the observed image was always at the bottom of the IAC, with a size smaller than 6 mm at its maximum diameter. In those patients who underwent surgery, an image suggestive of neoplasia was not seen during the procedure, and the material sent for paraffin also excluded the diagnosis of schwannoma of the eighth cranial nerve. In patients who opted for conservative management, sequential MRI showed partial or complete regression of the lesion, excluding the possibility of schwannoma[24,25] (**B**).

Recommendation

Although MRI with gadolinium and MRI three-dimensional volumetric acquisition with balanced gradient-echo sequence (steady state) are the most sensitive diagnostic methods for early identification of cerebellopontine angle tumors[22,23] (**B**), the results of these tests should never be evaluated separately. In small lesions, the performance of sequential MRIs should be considered, in order to confirm the diagnosis before any surgical procedure[24,25] (**B**).

8. What is the accuracy of temporal bone CT scan in the diagnosis of otosclerosis?

Otosclerosis is a primary focal osteoarthritis of unknown etiology involving the optic capsule. It can evolve with progressive conductive hearing loss, mixed or sensorineural, when the junction stapedius-vestibular and/or inner ear structures are affected[26] **(B)**. Definitive diagnosis is made by identification of macroscopic foci in the oval window with fixation of the stapes footplate[27] **(B)**. High-resolution computed tomography (HRCT) is a method used to identify foci of otosclerosis in patients with clinical suspicion, with a sensitivity of 95.1%, specificity 99.5%, LR+ = 95% (95% CI; 13.51-668.19%), and diagnostic certainty of 66%. Low-resolution computed tomography has 91.3% sensitivity[27] **(B)**. The most common focus is located in the anterior fenestral region (96.6% of cases)[27] **(B)**. Isolated fenestral focus can be identified in 69.04% of patients[19] (**C**). In 78.7% of cases, the foci are bilateral and may be symmetric (38.3%) or asymmetric (40.4%)[26] **(B)**. Cases not detected radiologically and intraoperatively identified correspond to isolated and superficial foci at the *fissula ante fenestram*. These cases may be associated with increased mobility of the stapes and risk of floating stapes footplate. Therefore, the negative cases on HRCT do not exclude otosclerosis, and may indicate greater difficulty during surgery due to problems with the stapes footplate[27] **(B)**. Obliterative focus of the stapes footplate was identified in 5.55% of the ears, and its identification is important to alert the surgeon about greater technical difficulty during surgery[26] **(B)**. The role of HRCT is not only to confirm clinical suspicion, but to anticipate possible technical difficulties, identify associated diseases (ossicular chain malformation, hammer fixation, superior semicircular canal dehiscence, etc.), and advise patients about increased risk of sensorineural hearing loss due to the otosclerotic foci extension[26,27] **(B)**. HRCT is used for temporal bone imaging with collimating (thickness between 0.6-1 mm), with bone reconstruction algorithm[27] **(B)**.

Recommendation

CT of the temporal bones is recommended with collimation (thickness) between 0.6-1 mm, with bone reconstruction algorithm [27] (**B**) in patients with clinical suspicion of otosclerosis to confirm the diagnosis, and for surgical planning[26] (**B**).

9. What is the best way to evaluate inner ear and internal auditory canal malformations?

Congenital malformations of the inner ear are the result of changes in this structure development that may be due to hereditary, genetically acquired mutations, or other factors that are still poorly explained. Malformations can appear anywhere in the inner ear; they occur in the bone structure in 20% of cases, and most of the remainder consists of cellular changes, and therefore are not identifiable on imaging studies[28] (**C**). Currently, with the use of increasingly accurate tests to diagnose cochlear malformations, a new classification has been established[28] (**C**) dividing these changes as following: a) Michel's deformity - complete absence of cochlear and vestibular structures; b) cochlear aplasia - complete absence of cochlear structures, with or without vestibular change; c) common cavity - cochlea and vestibule form a single cavity; d) incomplete partition type I - both cochlea and vestibule acquired cystic aspect; e) Incomplete partition type II - sizes are normal, but the cochlea has only 1.5 turns, also known as Mondini's deformity, which is accompanied by increased vestibule with normal semicircular canals and vestibular aqueduct dilation; f) cochleovestibular hypoplasia - as the name implies, both structures are hypoplastic. The diagnosis of Michel's aplasia can be done with HRCT. This test is still useful for differential diagnosis of labyrinthitis ossificans, as in the latter, the lateral wall convexity of the lateral semicircular canal is maintained, as well as the promontory, unlike Michel's aplasia, in which everything is flat[29] (**C**). Vestibular aqueduct enlargement is the most commonly observed malformation in imaging studies of children with sensorineural hearing loss. Vestibular aqueduct enlargement is considered when its size is greater than 1.5 mm (measured in the middle of this structure). HRCT scan shows vestibular aqueduct enlargement and T2-weighted MRI shows its membranous content dilation, endolymphatic duct, and endolymphatic sac[30] (**D**). Mondini's deformity, or incomplete partition type II (IP-II), is one of the best-known malformations and evolves with fusion of middle and apical turns of the cochlea, while preserving the basal turn. Thus, on HRCT, instead of observing 2.5 turns of the cochlea, only 1.5 turns are observed. This change may be associated with other inner ear malformations in 20% of cases, and often involves the modiolus[31] (**B**). In the internal auditory canal stenosis, HRCT leads to suspicion of vestibulocochlear nerve hypoplasia or aplasia, with 42% sensitivity and 89% specificity[32] (**B**). T2-weighted MRI confirms the diagnosis. Apparently normal internal auditory canal on CT does not exclude the diagnosis of cochlear nerve hypoplasia[33] (**B**) [34] (**D**).

Recommendation

HRCT may identify some of the inner ear malformations[29] **(C).** The presence of the vestibulocochlear nerve in the internal auditory canal can only be confirmed through MRI with T2-weighted sequence by three-dimensional volumetric acquisition with balanced gradient-echo. The likelihood ratios between these tests are similar.

10. Which imaging studies should be performed in candidate patients for cochlear implant?

Imaging evaluation of the temporal bone provides important data for cochlear implant candidates, such as cochlear lumen patency, presence or absence of cochlear nerve,

inner ear malformations, and facial nerve anatomy[35] (**B**). This evaluation also influences the decision on the side to be operated, surgical technique, and choice of beam electrodes to be used[36] (**B**). MRI is a more suitable method for the diagnosis of abnormalities in inner ear soft tissues compared with CT[35,37] (**B**). MRI provides excellent visualization of the membranous labyrinth; endolymphatic sac; cochlear, facial, and vestibular nerves; and central nervous system[36] (**B**). HRCT is important for assessing the otic capsule bony, middle ear structures, and fallopian tube[35] (**B**). When comparing changes identifiable by HRCT with those observed by high-resolution MRI with three-dimensional reconstruction (fast spin echo T2-weighted), HRCT diagnoses 88% of the vestibular abnormalities, 42% of the cochlear alterations, 35% of the modiolous alterations, 6% of the endolymphatic sac abnormalities, and 100% of the endolymphatic duct anomalies[35] (**B**). Regarding cochlear ossification, three-dimensional high-resolution MRI (fast spin echo T2-weighted) shows sensitivity of 94.1% (95% CI; 71-99%) and specificity of 87.5% (95% CI; 47-99) to detect cochlear obstruction in patients with a history of bacterial meningitis[36] (**B**). In the largest multicenter retrospective assessment, HRCT demonstrated 94.6% accuracy, 100% specificity, and 71% sensitivity in identifying cochlear ossification. HRCT has limitations in detecting fibrous tissue within the cochlea, as well as its compartments[36] (**B**). This change of soft tissue inside the cochlea is best evaluated by MRI, especially in cases of labyrinthitis ossificans[36,37] (**B**). Three-dimensional MRI with constructive interference in steady state (CISS), also called fast imaging employing steady-state acquisition (FIESTA), is a method that also shows the inner ear structures with good definition, and can be used in the evaluation of candidates for cochlear implant. This technique has disadvantages regarding greater presence of artifact and sensitivity to movement, but when performed well, it has a higher image resolution for assessing the cochlear nerve integrity in the internal auditory canal[38] (**B**). In patients with labyrinthitis ossificans, paramagnetic contrast agent is useful in assessing the nature of fibrosis of the membranous labyrinth. If enhancement is present, a proliferative phase of labyrinthitis ossificans should be considered, and the implant must be prioritized[39] (**D**). There is controversy in the literature regarding which is the best imaging test for preoperative evaluation of cochlear implant candidates: CT alone, MRI alone, or the combination of both methods[40] (**B**).

Recommendation

There is still controversy on which is the best imaging test for preoperative evaluation of cochlear implant candidates[40] (**B**). A candidate for cochlear implants should perform temporal bone CT with collimation (thickness) between 0.6-1 mm, with bone reconstruction algorithm[27,35] (**B**). The investigation should be complemented with MRI, not only with T2, but including T2 and T1 sequences pre- and post-contrast and, if possible, three-dimensional volumetric acquisition with balanced gradient-echo (steady state) for the diagnosis of abnormalities of the soft tissues in the inner ear, visualizing the membranous labyrinth, defining cochlear lumen obstruction by fibrosis and/or ossification, endolymphatic sac abnormalities, and presence or absence of the cochlear nerve[35,36] (**B**).

References

1. Curati WL, Graif M, Kingsley DP, King T, Scholtz CL, Steiner RE. MRI in acoustic neuroma: a review of 35 patients. Neuroradiology. 1986;28:208-14.
2. Haughton VM, Rimm AA, Czervionke LF, Breger RK, Fisher MM, Papke RA, et al. Sensitivity of Gd-DTPA enhanced MR imaging of benign extraaxialtumours. Radiology. 1988;166:829–33.
3. Zealley IA, Cooper RC, Clifford KM, Campbell RS, Potterton AJ, Zammit-Maempel I, et al. MRI screening for acoustic neuroma: a comparison of fast spin echo and contrast enhanced imaging in 1233 patients. Br J Radiol. 2000;73:242-7.
4. Fortnum H, O'Neill C, Taylor R, Lenthall R, Nikolopoulos T, Lightfoot G, et al. The role of magnetic resonance imaging in the identification of suspected acoustic neuroma: a systematic review of clinical and cost effectiveness and natural history. Health Technol Assess. 2009;13:1-154.
5. Casselman JW, Kuhweide R, Deimling M, Ampe W, Dehaene I, Meeus L. Constructive interference in steady state-3DFT MR imaging of the inner ear and cerebellopontine angle. AJNR Am J Neuroradiol. 1993;14:47-57.
6. Held P, Fellner C, Seitz J, Graf S, Fellner F, Strutz J. The value of T2(*)-weighted MR images for the diagnosis of acoustic neuromas. Eur J Radiol. 1999;30:237-44.
7. Stuckey SL, Harris AJ, Mannolini SM. Detection of acoustic schwannoma: use of constructive interference in the steady state three-dimensional MR. AJNR Am J Neuroradiol. 1996;17:1219-25.
8. Hermans R, Van der Goten A, De Foer B, Baert AL. MRI screening for acoustic neuroma without gadolinium: value of 3DFT-CISS sequence. Neuroradiology. 1997;39:593-8.
9. Nakamura M, Roser F, Dormiani M, Matthies C, Vorkapic P, Samii M. Facial and cochlear nerve function after surgery of cerebellopontine angle meningiomas. Neurosurgery. 2005;57:77–90.
10. Lalwani AK, Jackler RK. Preoperative differentiation between meningioma of the cerebellopontine angle and acoustic neuroma using MRI. Otolaryngol Head Neck Surg. 1993;109:88–95.
11. Thamburaj K, Radhakrishnan VV, Thomas B, Nair S, Menon G. Intratumoral microhemorrhages on T2-weighted gradient echoimaging helps differentiate vestibular schwannoma from meningioma. Am J Neuroradiol. 2008;29:552-7.
12. Grey PL, Moffat DA, Hardy DG. Surgical results in unusual cerebellopontine angle tumours. Clin Otolaryngol Allied Sci. 1996;21:237–43.
13. Martin TP, Senthil L, Chavda SV, Walsh R, Irving RM. A protocol for the conservative management of vestibular schwannomas. Otol Neurotol. 2009;30:381-5.
14. Bennett ML, Jackson CG, Kaufmann R, Warren F. Postoperative imaging of vestibular schwannomas. Otolaryngol Head Neck Surg. 2008;138:667-71.
15. Charabi S, Thomsen J, Mantoni M, Charabi B, Jorgensen B, Borgesen SE, et al. Acousticneuroma (vestibular schwannoma): growth and surgical and nonsurgical consequences of the wait-and-see policy. Otolaryngol Head Neck Surg. 1995;113:5-14.
16. Charabi S, Tos M, Thomsen JC, Charabi BW, Mantoni MY. Vestibular schwannoma. A new interpretation of tumor growth. Ugeskr Laeger. 2000;162:5497-500.
17. Godefroy WP, Kaptein AA, Vogel JJ, van der Mey AG. Conservative treatment of vestibular schwannoma: a follow-up study on clinical and quality-of-life outcome. Otol Neurotol. 2009;30:968-74.
18. Hajioff D, Raut VV, Walsh RM, Bath AP, Bance ML, Guha A, et al. Conservative management of vestibular schwannomas: third review of a 10-year prospective study. Clin Otolaryngol. 2008;33:255-9.
19. Stangerup SE, Caye-Thomasen P, Tos M, Thomsen J. Change in hearing during wait and scan management of patients with vestibular schwannoma. J Laryngol Otol. 2008;122:673-81.
20. Smouha EE, Yoo M, Mohr K, Davis RP. Conservative management of acoustic neuroma: a meta-analysis and proposed treatment algorithm. Laryngoscope. 2005;115:450-4.
21. Luppino FS, Grooters E, de Bruïne FT, Zwinderman AH, van der Mey AG. Volumetrical measurements in vestibular schwannoma, the influence of slice thickness and patient's repositioning. Otol Neurotol. 2006;27:962-8.
22. Strasnick B, Glasscock ME 3rd, Haynes D, McMenomey SO, Minor LB. The natural history of untreated acoustic neuromas. Laryngoscope. 1994;104:1115-9.

23. Arriaga MA, Carrier D, Houston GD. False-positive magnetic resonance imaging of small internal auditory canal tumors: a clinical, radiologic, and pathologic correlation study. Otolaryngol Head Neck Surg. 1995;113:61-70.
24. Naganawa S, Ito T, Fukatsu H, Ishigaki T, Nakashima T, Ichinose N, et al. MR imaging of the inner ear: comparison of a threedimensional fast spin-echo sequence with use of a dedicated quadrature-surface coil with a gadolinium-enhanced spoiled gradient-recalled sequence. Radiology. 1998;208:679-85.
25. Don M, Kwong B, Tanaka C, Brackmann D, Nelson R. The stacked ABR: a sensitive and specific screening tool for detecting small acoustic tumors. Audiol Neurootol. 2005;10:274-90.
26. Vicente Ade O, Yamashita HK, Albernaz PL, Penido NO. Computed tomography in the diagnosis of otosclerosis. Otolaryngol Head Neck Surg. 2006;134:685-92.
27. Lagleyre S, Sorrentino T, Calmels MM, Shin YJ, Escude B, Deguine O, et al. Reliability of high-resolution ct scan in diagnosis of otosclerosis. Otol Neurotol. 2009;30:1152-9.
28. Sennaroglu L, Saatci I. A new classification for cochleovestibular malformations. Laryngoscope. 2002;112:2230-41.
29. Klingebiel R, Bockmuhl U, Werbs M, Freigang B, Vorwerk W, Thieme N, et al. Visualization of inner ear dysplasias in patients with sensorioneural hearing loss. Acta Radiol. 2001;42:574-81.
30. Krombach GA, Honnef D, Westhofen M, Di Martino E, Gunther RW. Imaging of congenital anomalies and acquired lesions of the inner ear. Eur Radiol. 2008;18:319-30.
31. Ma H, Han P, Liang B, Tian ZL, Lei ZQ, Kong WJ, et al. Multislice spiral computed tomography imaging in congenital inner ear malformations. J Comput Assist Tomogr. 2008;32:146-50.
32. Adunka OF, Jewells V, Buchman CA. Value of computed tomography in the evaluation of children with cochlear nerve deficiency. Otol Neurotol. 2007;28:597-604.
33. Cerini R, Faccioli N, Cicconi D, Schenal G, Cugini C, Giarbini N, et al. Role of CT and MRI in the preoperative evaluation of auditory brainstem implantation in patients with congenital inner ear pathology. Radiol Med. 2006;111:978-88.
34. Casselman JW, Offeciers EF, De Foer B, Govaerts P, Kuhweide R, Somers T. CT and MR imaging of congenital abnormalities of the inner ear and internal auditory canal. Eur J Radiol. 2001;40:94-104.
35. Parry DA, Booth T, Roland PS. Advantages of magnetic resonance imaging over computed tomography in preoperative evaluation of pediatric cochlear implant candidates. Otol Neurotol. 2005;26:976-82.
36. Isaacson B, Booth T, Kutz JW Jr, Lee KH, Roland PS. Labyrinthitis ossificans: how accurate is MRI in predicting cochlear obstruction? Otolaryngol Head Neck Surg. 2009;140:692-6.
37. Nair SB, Abou-Elhamd KA, Hawthorne M. A retrospective analysis of high resolution computed tomography in the assessment of cochlear implant patients. Clin Otolaryngol Allied Sci. 2000;25:55-61.
38. Lane JI, Ward H, Witte RJ, Bernstein MA, Driscoll CLW. 3-T Imaging of the cochlear nerve and labyrinth in cochlear – implant candidates: 3D fast recovery fast spin-echo versus 3D constructive interference in the steady state techniques. Am J Neuroradiol. 2004;25:618-22.
39. Marsot-Dupuch K, Meyer B. Cochlear implant assessment: imaging issues. Eur J Radiol. 2001;40:119-32.
40. Gleeson TG, Lacy PD, Bresnihan M, Gaffney R, Brennan P, Viani L. High resolution computed tomography and magnetic resonance imaging in the pre-operative assessment of cochlear implant patients. J Laryngol Otol. 2003;117:692-5.