

Entalhe de Carhart na otosclerose: relevante ou mera curiosidade? Um estudo imagiológico e preditivo

Artigo Original

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Resumo

Objetivos: Avaliar a prevalência do entalhe de Carhart (EC) com base em três critérios audiométricos distintos, a sua associação com o estadiamento imagiológico e com o seu valor preditivo dos resultados audiométricos pós-operatórios.

Desenho de Estudo: Observacional retrospectivo.

Material e Métodos: Incluíram-se adultos submetidos a cirurgia estapédica por otosclerose (2017-2024). Analisaram-se os dados audiométricos segundo três definições do EC. O estadiamento imagiológico seguiu as classificações Symons-Fanning e Veillon. A associação entre o EC e o estadiamento imagiológico foi avaliada através dos testes do qui-quadrado ou do teste exato de Fisher. O valor preditivo foi analisado por análise univariada, procedendo-se a análise multivariada quando aplicável.

Resultados: Foram incluídos 108 ouvidos (99 doentes). A prevalência do EC variou de 46% a 66,7%, consoante as classificações. Não se verificou associação entre o EC e o estadiamento imagiológico ou os resultados pós-operatórios.

Conclusão: A definição heterogénea do EC compromete a sua deteção e estudo. A ausência de correlação com a imagiologia e os resultados clínicos questiona a sua relevância prática.

Palavras-chave: Otosclerose, cirurgia estapédica, entalhe de Carhart, tomografia computadorizada.

Introduction

Otosclerosis is an idiopathic disorder of the otic capsule, characterized by abnormal bone remodelling, presenting as regions of spongiosis or sclerosis¹. This pathological process typically initiates around the oval window, where progressive stapedial fixation disrupts the normal transmission of sound, culminating in conductive hearing loss. In more extensive cases, disease progression involves the intralabyrinthine structures, leading to sensorineural or mixed hearing loss. Clinically, this condition is suspected in patients

presenting with a progressive conductive hearing loss, abnormal acoustic reflexes, and a normal tympanic membrane. Schwartz's sign is a rare finding, described as a reddish discoloration over the promontory due to increased vascularity². Audiometrically, the hallmark of otosclerosis is the Carhart notch (CN) characterized by a distinct elevation in bone conduction (BC) thresholds within the 0.5 to 4 kHz range, most prominently at 2 kHz (3-5). Originally described by Carhart in 1950, this phenomenon was characterized by an improvement in BC thresholds following lateral semicircular canal fenestration surgery⁶. This finding provided key evidence that the impairment was not of cochlear origin but rather a consequence of the mechanical fixation of the stapes. Bone conduction to the cochlea follows multiple transmission pathways, including direct bone-cochlear conduction, bone-middle ear-cochlear conduction, and bone-external auditory canal-middle ear-cochlear conduction, with additional hypothesis proposing cerebrospinal fluid-mediated transmission routes⁷⁻⁹. Carhart notch results from the altered ossicular inertia, a key component of middle ear sound transmission⁸. Due to stapedial fixation at the oval window, there is no relative displacement of the ossicles, leading to reduced cochlear stimulation. Given that the structural resonance of the ossicular chain occurs at mid-range frequencies, this results in a characteristic elevation of BC thresholds in this frequency range¹⁰. However, this finding is neither pathognomonic for otosclerosis nor unanimously defined and its audiometric definition has been a subject of ongoing debate, making its clinical significance more challenging to assess^{7,11-14}. Furthermore, this audiometric finding can be commonly observed in other conditions, such as chronic otitis media, tympanic membrane perforation, tympanosclerosis, and other middle ear pathologies in which the ossicular chain mobility is restricted^{11, 12, 14, 15}. Imaging studies have gained increasing relevance in the diagnostic pathway of otosclerosis, primarily due to advances

in resolution enhancing sensitivity and specificity¹⁶. The identification of osseous *foci* has enabled the stratification of the disease extent in both the middle and inner ear, leading to the development of several classification systems, such as the Symons-Fanning and Veillon^{17,18}. These have demonstrated a strong correlation with preoperative audiometric alterations in air and BC thresholds, while also serving as valuable prognostic indicators for postoperative outcomes after stapes surgery^{19,20}. However, efforts to standardize the CN are challenged by its audiometric variability and the lack of consensus regarding its definition. Moreover, the relationship between these varying definitions, imaging findings of otosclerosis, and surgical outcomes is still not well understood. Within this framework, the present study explores the potential of the Carhart notch as a predictor of postoperative audiometric outcomes following stapes surgery. It also examines its prevalence according to three distinct diagnostic criteria and investigates its relationship with the radiological staging of otosclerosis.

Methods

A retrospective observational study was conducted including all adult patients (≥ 18 years) who underwent stapes surgery for otosclerosis in the otorhinolaryngology department of a tertiary hospital between January 2017 and December 2024. Patients were excluded if they had incomplete medical records, including missing pre or postoperative audiometric data, underwent revision stapes surgery or had any other associated otologic procedures. Preoperative and postoperative pure-tone audiometry (PTA) was performed in a soundproof environment using standard clinical audiometers by multiple audiologists. Air conduction (AC) and BC thresholds were measured, and pure-tone averages (PTA) were calculated based on frequencies of 500 Hz, 1000 Hz, 2000 Hz, and 4000 Hz. The air-bone gap (ABG) was determined by subtracting the BC threshold from the AC threshold. Surgical success was defined by either ABG

closure or a postoperative AC threshold ≤ 30 dB. Air-bone gap closure was defined as a postoperative ABG ≤ 10 dB. Postoperative sensorineural hearing loss (SNHL) was defined as a worsening of ≥ 10 dB in the BC PTA when compared to the preoperative BC PTA.

To assess the presence of CN, three distinct criteria were applied:

Classification A: minimum elevation of 7.5 dB in BC thresholds between 500 Hz and 2000 Hz, compared to the average of adjacent frequencies³.

Classification B: ≥ 10 dB rise at 2000 Hz in BC thresholds, relative to the mean thresholds at 1000 Hz and 4000 Hz¹⁴.

Classification C: ≥ 10 dB elevation in BC at any single frequency between 500 Hz and 4000 Hz, when compared to adjacent frequencies^{7,11-13}.

In addition, cases that did not meet the criteria for CN under any of the three classifications were separately identified and analysed - hereafter referred to as the triple-negative CN group.

Preoperative high-resolution computed tomography (HRCT) of the temporal bone was performed using a 64-section multidetector CT scanner with 0.64 mm slice thickness and 0.32 mm increments, reconstructed in axial and coronal planes aligned with the lateral semicircular canal. Two radiological classification systems were used to stage otosclerosis severity:

Symons-Fanning Classification (SFC) – Categorizes otosclerosis based on cochlear involvement, ranging from small lucent *foci* in the *fissula ante fenestram* (Grade 1) to severe confluent lucencies surrounding the cochlea (Grade 3)¹⁷.

Veillon Classification (VC) – Classifies the disease based on the presence of fenestral and pericochlear hypodensities, ranging from isolated footplate thickening (Type 1a) to extensive labyrinthine involvement (Type 4B)¹⁸.

Two neuroradiologists, blinded to audiometric results, retrospectively reviewed the CT images and assigned classification scores according

to these staging systems. The relationship between intralabyrinthine involvement detected on imaging in each classification (SFC $\geq 2a$, VC ≥ 3) and the presence or absence of CN was assessed. All surgeries were performed by four experienced otologic surgeons using standardized stapedotomy techniques. Procedures were conducted under general anesthesia using a transcanal or endaural approach. After elevating the tympanomeatal flap, the scutum was partially curetted to improve visualization of the oval window. The ossicular chain was palpated to confirm stapes fixation and assess the mobility of the malleus and incus.

A fenestration was created in the stapes footplate using either a skeeter drill or a manual perforator. The incudostapedial joint was separated, the stapedial tendon was sectioned, and the stapes suprastructure was fractured toward the promontory. The distance between the long process of the incus and the stapes footplate was measured, and a Teflon *Causse* piston prosthesis was inserted and manually crimped. The prosthesis length ranged from 4 to 4.5 mm (69.5% were 4.5 mm) and the diameter varied between 0.4 mm and 0.8 mm (75% were 0.6 mm). The oval window was mainly sealed using either gelfoam (37%), perichondrium (31.5%) or blood clots (25%). Prophylactic amoxicillin-clavulanic acid (2.2 g IV; 2000 mg + 200 mg) and methylprednisolone (2.5 mg IV bolus) were administered intraoperatively.

Statistical analysis was performed using IBM® SPSS® Statistics version 27 (IBM Corp., Armonk, NY, USA), with statistical significance defined as $p < 0.05$. Categorical variables were examined through absolute and relative frequencies. The Kolmogorov-Smirnov test was used to determine the normality of continuous variables. Continuous variables with normal distributions were analysed using mean and standard deviation and compared through t test for independent samples. For categorical variables, analysis was performed using the Chi-square test or Fischer's Exact test. To evaluate the predictive value of CN

for hearing outcomes, a univariate analysis was performed. If statistical significance was observed, a multivariate analysis would subsequently be conducted.

Results

A total of 171 cases were identified during the study period. Of these, 108 ears from 99 patients, met the inclusion criteria, including nine patients who underwent bilateral surgery. There was a female predominance (76.9%), with a mean age at the time of surgery of 46.2 ± 10.1 years. The right ear was the most frequently affected (51.9 %). The prevalence of CN varied according to the applied classification criteria. According to classification A, 66.7% of cases presented this audiometric phenomenon, whereas in classification B, it was identified in 50.9% of cases and following classification C criteria, the CN was observed in 46% of cases. A total of 30 cases (27.8%) were classified within the triple-negative CN group. No significant differences were observed in age, sex proportion and in surgical technical parameters—including canalplasty, prosthesis length, type and diameter of the piston, or type of sealing— across the three CN classifications and triple-negative CN group. **Table 1** illustrates the radiological staging of otosclerosis. The majority of otosclerosis cases were Grade 1 (71.3%) according to the SFC, and in Grade 2 (52.8%) based on VC. No significant association was found between the presence of CN, regardless of the classification system applied and radiological staging used ($p > 0.05$). The overall surgical success rate was 71.3% (77 cases) and eleven (10.2%) cases developed postoperative SNHL. CN did not demonstrate predictive value for surgical success or for the risk of SNHL, in any of the audiometric classifications applied ($p > 0.05$).
Classification A: minimum elevation of 7.5 dB in BC thresholds between 500 Hz and 2000 Hz, compared to the average of adjacent frequencies;
Classification B: ≥ 10 dB rise at 2000 Hz in BC thresholds, relative to the mean thresholds at 1000 Hz and 4000 Hz;

Table 1
Demographics, audiometric and imaging data

	N (%)
Female °	76.9 (83)
Right ear °	51.9 (56)
Carhart notch (CN) °	
Classification A	66.7 (72)
Classification B	50.9 (55)
Classification C	46 (50)
Triple-negative CN	30 (27.8)
Symmons-Fanning staging °	
0	9 (8.3)
1	77 (71.3)
2a	5 (4.6)
2b	13 (12)
3	4 (3.7)
Veillon staging °	
0	9 (8.3)
1a	1 (0.9)
1b	27 (25)
2	57 (52.8)
3	11 (10.2)
4a	3 (2.8)

Classification C: ≥ 10 dB increases in BC at any single frequency between 500 Hz and 4000 Hz, when compared to adjacent frequencies; CN: Carhart notch.

Discussion

Our study aimed to evaluate the clinical applicability of distinct definitions of the CN available in the literature, both in relation to radiological findings or their predictive values for stapes surgery outcomes. Depending on the applied CN criteria, the prevalence of this feature in our sample varied between 46% and 66.7%. The prevalence of CN remains difficult to determine due to the heterogeneity in its definition and depends on the adopted criteria, as illustrated by the triple-negative CN group, representing 27.8% of cases without CN despite the criteria used. Reported

rates vary between 31% and 80%, reflecting inconsistencies in its definition³. Although originally described as a phenomenon focused at 2000 Hz, its presence has been documented at frequencies spanning from 500 Hz to 4000 Hz, highlighting variability in its characterization^{4, 6}. Conversely, some authors argue that the reduction in BC is most pronounced at 2000 Hz, thereby maintaining the classification of CN⁵. This lack of standardization hinders the systematic and rigorous application of a definitive criterion in research, thereby limiting the ability to delineate its true audiometric significance and potential clinical implications.

Given the variability in CN characterization, additional tools, such as imaging, have been explored to enhance diagnostic precision and staging in otosclerosis by assessing osseous *foci* involvement. However, from a histopathological perspective, the association between endosteal involvement and BC thresholds remains controversial^{21, 22}. One proposed explanation is that the sensorineural component in these cases arises from hyalinization of the spiral ligament due to cytotoxic enzyme activity, rather than being directly caused by lytic lesions in specific cochlear sites²³. Furthermore, as highlighted by Marx (2011), the time interval between the patient's last audiometric evaluation and post-mortem histopathological analysis may influence the interpretation of these findings¹⁶. Therefore, imaging offers a more precise temporal alignment for audio-radiological correlations. The elevation in BC thresholds in otosclerosis primarily results from stapes fixation, with the most pronounced attenuation occurring at 2000 Hz, the resonant frequency of the human ossicular chain for bone-conducted auditory signals⁵. In cochlear otosclerosis, the sensorineural impairment is attributed to a mechanism distinct from the stapes fixation process responsible for CN²⁴. Cochlear otosclerosis may primarily affect 500 Hz and 1000 Hz, although all frequencies may be involved²⁵. To the best of our knowledge, this is the first study aimed at investigating

the relationship between CN and radiological staging in otosclerosis. Our findings revealed no significant associations between these parameters, regardless of the three distinct audiometric criteria applied. This lack of correlation may be attributed to the absence of a direct association between CN and cochlear otosclerosis. Beyond its role in diagnosis and staging, imaging may also provide important insights into the surgical context, by predicting intraoperative challenges and in the assessment of facial nerve stimulation risk in cases requiring cochlear implantation^{26, 27}.

The prognostic role of CN remains a subject of ongoing debate, with conflicting evidence regarding its impact on postoperative outcomes. In 2021, Lamblin *et al.* reported that its presence could be associated with better outcomes for BC thresholds at 500 and 2000 Hz, while being associated with a poorer prognosis at higher frequencies and an elevated risk of sudden sensorineural hearing loss³. Differently, Job L *et al.* suggested that its preoperative presence would be predictive of greater postoperative auditory gain¹⁵. Moreover, severe sensorineural hearing loss in patients without CN on pure-tone audiometry (PTA) has been identified as a negative prognostic factor for speech audiometry outcomes¹⁵. Our study did not demonstrate predictive value regarding the surgical outcomes or the risk of sudden sensorineural hearing loss, underscoring its limited clinical relevance and reinforcing the need for a multimodal approach that integrates audiometric, radiological, and clinical parameters. One of the limitations of this study is its retrospective nature, which led to the exclusion of cases with incomplete data, resulting in a reduced sample size. Additionally, the surgical procedures were performed by multiple surgeons, each employing slightly differing techniques, although this variability was not found to be statistically significant. Overall, these findings suggest that CN lacks significant relevance when correlating it with imaging staging and surgical outcomes. Future studies should aim for larger, prospective cohorts with standardized

imaging and audiometric protocols to further elucidate its current clinical relevance.

Conclusion

The lack of correlation between the CN and both imaging staging and surgical outcomes challenges its role as an isolated clinical marker in otosclerosis. Its variability across definitions and limited prognostic value emphasizes the need for a multimodal approach incorporating audiometric, radiological, and clinical parameters to ensure accurate evaluation and management.

Conflict of Interests

The authors declare that they have no conflict of interest regarding this article.

Data Confidentiality

The authors declare that they followed the protocols of their work in publishing patient data.

Human and animal protection

The authors declare that the procedures followed are in accordance with the regulations established by the directors of the Commission for Clinical Research and Ethics and in accordance with the Declaration of Helsinki of the World Medical Association.

Privacy policy, informed consent and Ethics committee authorization

The authors declare that they have obtained signed consent from the participants and that they have local ethical approval to carry out this work.

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Scientific data availability

There are no publicly available datasets related to this work.

Bibliography

1. Ealy M, Smith RJH. Otosclerosis. *Adv Otorhinolaryngol*. 2011;70:122-129. doi: 10.1159/000322488.
2. Nakashima T, Sone M, Fujii H, Teranishi M, Yamamoto H, Otake H. et al. Blood flow to the promontory in cochlear otosclerosis. *Clin Otolaryngol*. 2006 Apr;31(2):110-5. doi: 10.1111/j.1749-4486.2006.01151.x.
3. Lamblin E, Karkas A, Jund J, Schmerber S. Is the Carhart notch a predictive factor of hearing results after stapedectomy? *Acta Otorhinolaryngol Ital*. 2021 Feb;41(1):84-90. doi: 10.14639/0392-100X-N0213.
4. Gatehouse S, Browning GG. A re-examination of the Carhart effect. *Br J Audiol*. 1982 Nov;16(4):215-20. doi: 10.3109/03005368209081465.
5. Cook JA, Krishnan S, Fagan PA. Quantifying the Carhart effect in otosclerosis. *Clin Otolaryngol Allied Sci*. 1995 Jun;20(3):258-61. doi: 10.1111/j.1365-2273.1995.tb01862.x.
6. Carhart R. Clinical application of bone conduction audiometry. *Arch Otolaryngol* (1925). 1950 Jun;51(6):798-808. doi: 10.1001/archotol.1950.00700020824003
7. Perez R, de Almeida J, Nedzelski JM, Chen JM. Variations in the "Carhart notch" and overclosure after laser-assisted stapedotomy in otosclerosis. *Otol Neurotol*. 2009 Dec;30(8):1033-6. doi: 10.1097/MAO.0b013e31818bedf00.
8. Tonndorf J. A new concept of bone conduction. *Arch Otolaryngol*. 1968 Jun;87(6):595-600. doi: 10.1001/archotol.1968.00760060597008.
9. Freeman S, Sichel JY, Sohmer H. Bone conduction experiments in animals - evidence for a non-osseous mechanism. *Hear Res*. 2000 Aug;146(1-2):72-80. doi: 10.1016/S0378-5955(00)00098-8.
10. Homma K, Du Y, Shimizu Y, Puria S. Ossicular resonance modes of the human middle ear for bone and air conduction. *J Acoust Soc Am*. 2009 Feb;125(2):968-79. doi: 10.1121/1.3056564.
11. Yasan H. Predictive role of Carhart's notch in pre-operative assessment for middle-ear surgery. *J Laryngol Otol*. 2007 Mar;121(3):219-21. doi: 10.1017/S0022215106003343.
12. Shishegar M, Faramarzi A, Esmaili N, Heydari ST. Is Carhart notch an accurate predictor of otitis media with effusion? *Int J Pediatr Otorhinolaryngol*. 2009 Dec;73(12):1799-802. doi: 10.1016/j.ijporl.2009.09.040.
13. Ahmad I, Pahor AL. Carhart's notch: a finding in otitis media with effusion. *Int J Pediatr Otorhinolaryngol*. 2002 Jun 17;64(2):165-70. doi: 10.1016/S0165-5876(02)00080-0.
14. Kashio A, Ito K, Kakigi A, Karino S, Iwasaki S, Sakamoto T. et al. Carhart notch 2-kHz bone conduction threshold dip: a nondefinitive predictor of stapes fixation in conductive hearing loss with normal tympanic membrane. *Arch Otolaryngol Head Neck Surg*. 2011 Mar;137(3):236-40. doi: 10.1001/archoto.2011.14.
15. Job K, Wiatr A, Skladzien J, Wiatr M. The audiometric assessment of the effectiveness of surgical treatment of otosclerosis depending on the preoperative incidence of Carhart's notch. *Ear Nose Throat J*. 2024 Apr;103(4):241-247. doi: 10.1177/01455613211043685
16. Marx M, Lagleyre S, Escudé B, Demeslay J, Elhadi T, Deguine O. et al. Correlations between CT scan findings and hearing thresholds in otosclerosis. *Acta Otolaryngol*. 2011 Apr;131(4):351-7. doi: 10.3109/00016489.2010.549841.
17. Lee TC, Aviv RI, Chen JM, Nedzelski JM, Fox AJ, Symons SP. CT grading of otosclerosis. *AJNR Am J Neuroradiol*.

2009 Aug;30(7):1435-9. doi: 10.3174/ajnr.A1558.

18. Veillon F, Stierle JL, Dussaix J, Ramos-Taboada L, Riehm S. [Otosclerosis imaging: matching clinical and imaging data]. *J Radiol*. 2006 Nov;87(11 Pt 2):1756-64. doi: 10.1016/s0221-0363(06)74157-9.

19. Pinto JV, Almeida AI, Andrade A, Vales F, Moura CP, Marques P. Comparison between the Veillon and the Symons-Fanning CT classification systems for otosclerosis. *Otol Neurotol*. 2024 Oct 1;45(9):e618-e623. doi: 10.1097/MAO.0000000000004311.

20. Meranger A, David A, Beigner BM, Charpiot A, Tavernier L. Audiometric results of stapedotomy surgery for otosclerosis: influence of the radiological stage. *Otol Neurotol*. 2019 Feb;40(2):e75-e81. doi: 10.1097/MAO.0000000000002109.

21. Elonka DR, Applebaum EL. Otosclerotic involvement of the cochlea: a histologic and audiologic study. *Otolaryngol Head Neck Surg*. 1981 Mar-Apr;89(2):343-51. doi: 10.1177/019459988108900239.

22. Hueb MM, Goycoolea MV, Paparella MM, Oliveira JA. Otosclerosis: the University of Minnesota temporal bone collection. *Otolaryngol Head Neck Surg*. 1991 Sep;105(3):396-405. doi: 10.1177/019459989110500308.

23. Parahy C, Linthicum FH Jr. Otosclerosis: relationship of spiral ligament hyalinization to sensorineural hearing loss. *Laryngoscope*. 1983 Jun;93(6):717-20. doi: 10.1288/00005537-198306000-00003.

24. Cureoglu S, Baylan MY, Paparella MM. Cochlear otosclerosis. *Curr Opin Otolaryngol Head Neck Surg*. 2010 Oct;18(5):357-62. doi: 10.1097/MOO.0b013e32833d11d9.

25. Kawase S, Naganawa S, Sone M, Ikeda M, Ishigaki T. Relationship between CT densitometry with a slice thickness of 0.5 mm and audiometry in otosclerosis. *Eur Radiol*. 2006 Jun;16(6):1367-73. doi: 10.1007/s00330-005-0128-7.

26. Wong D, Copson B, Gerard JM, Hill F, Leigh J, Dowell R. Cochlear implantation in advanced otosclerosis: utility of pre-operative radiological assessment in predicting intra-operative difficulty and final electrode position. *J Laryngol Otol*. 2023 Nov;137(11):1248-1255. doi: 10.1017/S0022215123000609.

27. Marshall AH, Fanning N, Symons S, Shipp D, Chen JM, Nedzelski JM. Cochlear implantation in cochlear otosclerosis. *Laryngoscope*. 2005 Oct;115(10):1728-33. doi: 10.1097/01.mlg.0000171052.34196.ef.