Carhart notch in otosclerosis: relevant finding or pure curiosity? An imaging and predictive study

Original Article

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Abstract

Objective: To assess the prevalence of the Carhart notch (CN) using three distinct audiometric criteria, investigate its association with radiological staging and assess its predictive value for postoperative audiometric outcomes following stapes surgery.
Study Design: Retrospective observational.
Material and Methods: Adult patients who underwent stapes surgery for otosclerosis (2017–2024) were included. CN was assessed using three audiometric criteria. Radiological staging followed the Symons-Fanning and Veillon classifications. The relationship between CN and imaging staging was tested using Chi-square or Fisher's Exact test, and predictive value was assessed through univariate analysis, and multivariate if applicable.
Results: A total of 108 ears from 99 patients met the inclusion criteria. CN prevalence ranged from 46% to 66.7%, depending on classification criteria. No significant association was found between CN and imaging staging or surgical outcomes.
Conclusion: Variability in CN definition compromises its detection and standardization. The lack of correlation with radiological findings and clinical outcomes questions its practical relevance in otosclerosis evaluation.
Keywords: otosclerosis, stapes surgery, Carhart notch, tomography, x-ray computed

Introduction

Otosclerosis is an idiopathic disorder of the otic capsule, characterized by abnormal bone remodelling, presenting as regions of spongiosis or sclerosis[1]. 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. Schwartze's sign is a rare finding, described as a reddish discoloration over the promontory due to increased vascularity[2]. 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 surgery[6]. 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 routes[7-9]. Carhart notch results from the altered ossicular inertia, a key component of middle ear sound transmission [8]. 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 range[10]. 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 specificity[16]. 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 frequencies [3].

Classification B: ≥ 10 dB rise at 2000 Hz in BC thresholds, relative to the mean thresholds at 1000 Hz and 4000 Hz [14].

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 ≥ 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 (IBMCorp., 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 definition [3]. 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 CN $_5$. 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 sites [23]. 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 findings[16]. 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 signals[5]. In cochlear otosclerosis, the sensorineural impairment is attributed to a mechanism distinct from the stapes fixation process responsible for CN [24]. Cochlear otosclerosis may primarily affect 500 Hz and 1000 Hz, although all frequencies may be involved [25]. 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 loss[3]. Differently, Job L *et al.* suggested that its preoperative presence would be predictive of greater postoperative auditory gain[15]. 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 outcomes[15]. 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.

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