Received: 10 May 2019 | Revised: 9 September 2019 | Accepted: 14 September 2019

DOI: 10.1111/coa.13435

WILEY

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Hidden hearing loss and tinnitus: Utility of the high-definition audiograms in diagnosis

1 | INTRODUCTION

Tinnitus, defined as a phantom sensation of sound, is experienced by between 10% and 15% of the adult population. A recent study in the UK determined that the average cost of tinnitus treatment is about GB£750 million per year.[1] The Royal National Institute for Deaf People (RNID) referred to hearing loss and tinnitus as 'the hidden healthcare time bomb'.[2]

Patients with hearing loss and tinnitus can benefit from hearing aids depending on the precise determination of the hearing loss and tinnitus characteristics. However, tinnitus is not always associated with hearing loss.[3] In daily practice, the pure tone hearing threshold is measured at octave or half-octave intervals from 250 through 8000 Hz.[4] This technique can miss hearing loss on a narrow frequency bandwidth[5] and referred to as 'hidden hearing loss' (HHL).[6]

Generally, tinnitus occurs over a broad frequency range with a peak shape that falls within the hearing loss range, and this is visible on the audiogram.[7] If the peak of the tinnitus is not broad, and the hearing loss frequency range is narrow, however, then the classical audiogram can miss the hearing loss associated with the tinnitus.

The aim of the study was to validate a protocol to ensure correct diagnosis of HHL associated with tinnitus and to optimise the characterisation of the tinnitus in order to improve the treatment of these patients.

2 | MATERIALS AND METHODS

2.1 | Ethical considerations

This retrospective study was performed in a tertiary care centre and approved by the local ethics committee. All participants gave their informed consent prior to inclusion in the study.

2.2 | Patient cohort

Sixty-six patients presenting with unilateral or bilateral chronic tinnitus (more than 6 months) of high-frequency sound ringing type and tone-like were included over a 2-year period. Patients were examined by an ENT specialist to eliminate objective tinnitus and were never treated before. We also tested 24 volunteers without any tinnitus. All patients completed a questionnaire concerning the characteristics of the tinnitus: onset, character, laterality and duration of the tinnitus.

2.3 | Audiometric tests

High-definition audiograms were obtained for all 90 participants. For the 66 patients with tinnitus, a high-resolution pitch and intensity analysis was performed. Hearing loss was classified according to the pure tone average (PTA) in dB hearing level (HL) at four frequencies: 500, 1000, 2000 and 4000 Hz (International Bureau for Audiophonology recommendations).

The high-definition audiogram protocol was developed using the audiometer MADSEN Astera[2] (GN Otometrics®) with the HDA 300 audiometric headphone (Sennheiser®). Its precision was 1 dB in intensity and 1 Hz in frequency [125-20 000 Hz].

Tinnitus was defined by four psychoacoustic measures: pitch, loudness, masking and residual inhibition.[5] For analysis of pitch, pure tones were used for patients with a tone-like type of tinnitus. Loudness was expressed in dB sensation level (SL). Tinnitus was characterised using a modified tinnitus spectrum procedure.[7] The masking was performed with a narrow noise band centred on the identified tinnitus frequency. The residual inhibition corresponded to the period of reduction of tinnitus intensity or the period of absence of tinnitus. For this measure, the same masking noise was used at an intensity of 20 dB over the tinnitus threshold during 1 minute; the time of residual inhibition was measured after masking noise was stopped.

2.4 | Questionnaires

All patients complete the THI and a VAS based on two items: annoyance and loudness of the tinnitus.

2.5 | Statistical analysis

Outcomes are reported as means ± standard deviation. Correlations were determined using a Pearson correlation coefficient. The level of statistical significance was set at 0.05 and was determined using Prism 5 software (GraphPad).

3 | RESULTS

3.1 | Patient characteristics

The 66 patients with tinnitus included 24 women and 42 men (age 53 ± 15 years) [19-80]. The 24 healthy (tinnitus free) participants

from the control group (16 women and 8 men) were 31 ± 12 years [21-60]. A hyperacusis was reported by 17% of patients. The duration of the tinnitus was 41 ± 48 months [6-216]. The tinnitus was bilateral for 50% of patients, unilateral on the left side for 35% or on the right side for 15%.

3.2 | Audiometric data

The 24 subjects without tinnitus had normal hearing when tested with both classical and high-definition audiograms. For the patients with tinnitus, 30 patients (46%) were normal and 36 (54%) had mild hearing loss when evaluated with the classical audiogram. For the 36 patients with a mild hearing loss, the PTA was 28.1 ± 12.18 dB [21-35.8].

With the high-definition audiogram, we isolated three different types of hearing loss associated with tinnitus: (a) tinnitus located in a micro-notch (Figure 1A); (b) tinnitus located in a micro-slope (Figure 1B); (c) tinnitus located in a normal region of the audiogram (Figure 1C).

Of the 30 patients with normal hearing on the classical audiogram, 25 had the first type and five had the second type (Figure 2).

For the 36 patients with a mild hearing loss, 16 patients had the first type of hearing loss with a PTA of 17 ± 12 dB [0-38]. Eight patients had the second type with a PTA of 21 ± 5 dB [4-39] and 10 patients the third type of tinnitus with no hearing loss in the tinnitus region and a PTA of 25 ± 6dB [7-36].

Of the patients who had hearing loss, the tinnitus was located in a HHL region of the classical audiogram for 81.8%. Of these, 62.1% of patients had hearing loss in a micro-notch and 19.7% in a micro-slope on the high-definition audiogram (Table 1). The characteristics of the micro-notch were an intensity of 9 ± 4.7 [4-25] dB and a frequency of 6580 ± 3544.9 [2000-18 000] Hz. The bandwidth of the micro-notch was 1746 ± 268.7 [380-6000] Hz. The micro-notch was bilateral for 33 patients, including nine patients with symmetric tinnitus frequency. We found a high correlation between the micro-notch and the tinnitus frequencies (r^2 = 0.9801, P < .0001) (Figure 3). The tinnitus intensities and frequencies were determined for each single ear in all the 66 patients. The tinnitus frequency was 6199 ± 3142 Hz [1000-18 000]; in 76.3% of ears, the frequency was above 4 kHz. The tinnitus intensity was 4 ± 3.5 dB SL [0-17].

The effect of masking on tinnitus was explored for 57 ears of 40 patients. The masking effect was partial or complete for 97% of the patients with complete masking for 93%. The residual inhibition was 39 ± 28.9 seconds [1-183]. The remaining subjects had a hyperacusis (10 patients) or could not complete the masking test (16 patients).

3.3 | Questionnaires

The THI was 51 ± 17 [12-80] with 75.7% of the patients at grade 3 or above. The VAS score for the annoyance of the tinnitus was 6 ± 1.7 [2-10], and the VAS score for its loudness was 6 ± 1.6 [2-10].

Key points

- Tinnitus may be associated with a normal conventional audiogram
- High-definition audiogram (1 dB in intensity and 1 Hz in frequency precision) can diagnose hidden hearing loss.
- Tinnitus is often associated with a micro notch or a micro slope on a high-definition audiogram
- Tinnitus frequency is highly related to micro-notch frequency
- High-definition audiogram provides better characterisation of tinnitus testing than the classically used test and could lead to improved treatment guidance.

4 | DISCUSSION

4.1 | Synopsis of key/new findings

Here, we evaluated hearing loss in 66 patients with tinnitus using a high-definition audiogram from 1/24 octave to 1 Hz in terms of frequency precision and at 1 dB HL in terms of intensity precision. With this protocol, HHL was discovered in 81.8% of patients; no HHL was detected in volunteers without tinnitus.

4.2 | Comparisons with other studies

In 2003, Vernon et al reported that the tinnitus frequency in 75% of patients evaluated was above 4 kHz with a mean frequency of 6 kHz as found in our cohort.[8]

In 2011, Schaette et al reported tinnitus in a population with normal hearing function and associated that with HHL or synaptopathy.[6] Like most studies of tinnitus, they used a classical audiogram procedure. This technique didnot exclude the possibility to find hearing loss as described with our protocol.

In 2017, Lee et al reported the audiological characteristics of 1000 Hz audiometric notch patients based on testing with a classical audiogram.[9] The hearing threshold at 1000 Hz exceeds 25 dB; this threshold is 15 dB larger than the lower half-frequency (500 Hz) and is 10 dB larger than the higher frequency. The precision we obtained with our protocol was higher with a thinner bandwidth (1746 Hz) and smaller depth of intensity threshold (9 dB) compared with previously reported evaluation.[9] For this reason we called it micro-notch.

The cut-off frequency of the hearing loss between the normal region and regions in the cochlea with no (or few) functioning inner hair cells and/or neurons ('dead regions') is defined as the lowest frequency for which the absolute threshold is greater than 15 dB and for which the slope of the threshold curve at higher frequencies is greater than or equal to 50 dB/octave.[10] We discovered a more abrupt slope and were able to more precisely define hearing loss around the tinnitus pitch with our method.

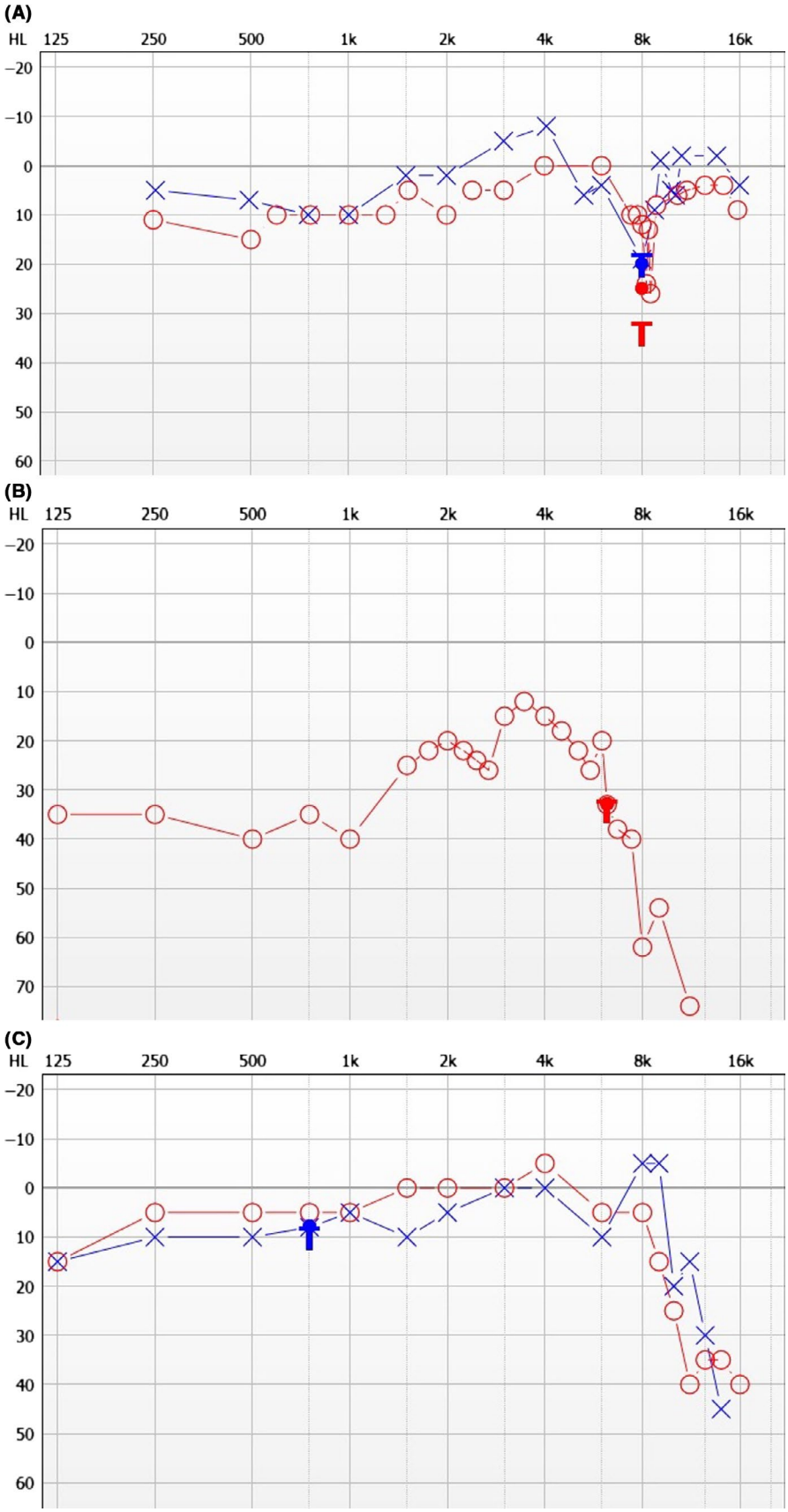

FIGURE 1 Examples of three different types of hearing loss associated with tinnitus isolated with the high-definition audiogram. A, Example of an audiogram of a patient with hearing loss of the micro-notch type, which is defined as a notch of a width inferior to half of an octave and of a depth superior to 5 dB of hearing loss. B, Example of an audiogram of a patient with hearing loss of the micro-slope type, which is defined as a steep fall of the audiogram curve of at least 2.5 dB over 1/12 of an octave. C, Example of an audiogram of a patient without hearing loss. The high-definition audiograms were performed with steps of 1 dB HL and 1 Hz

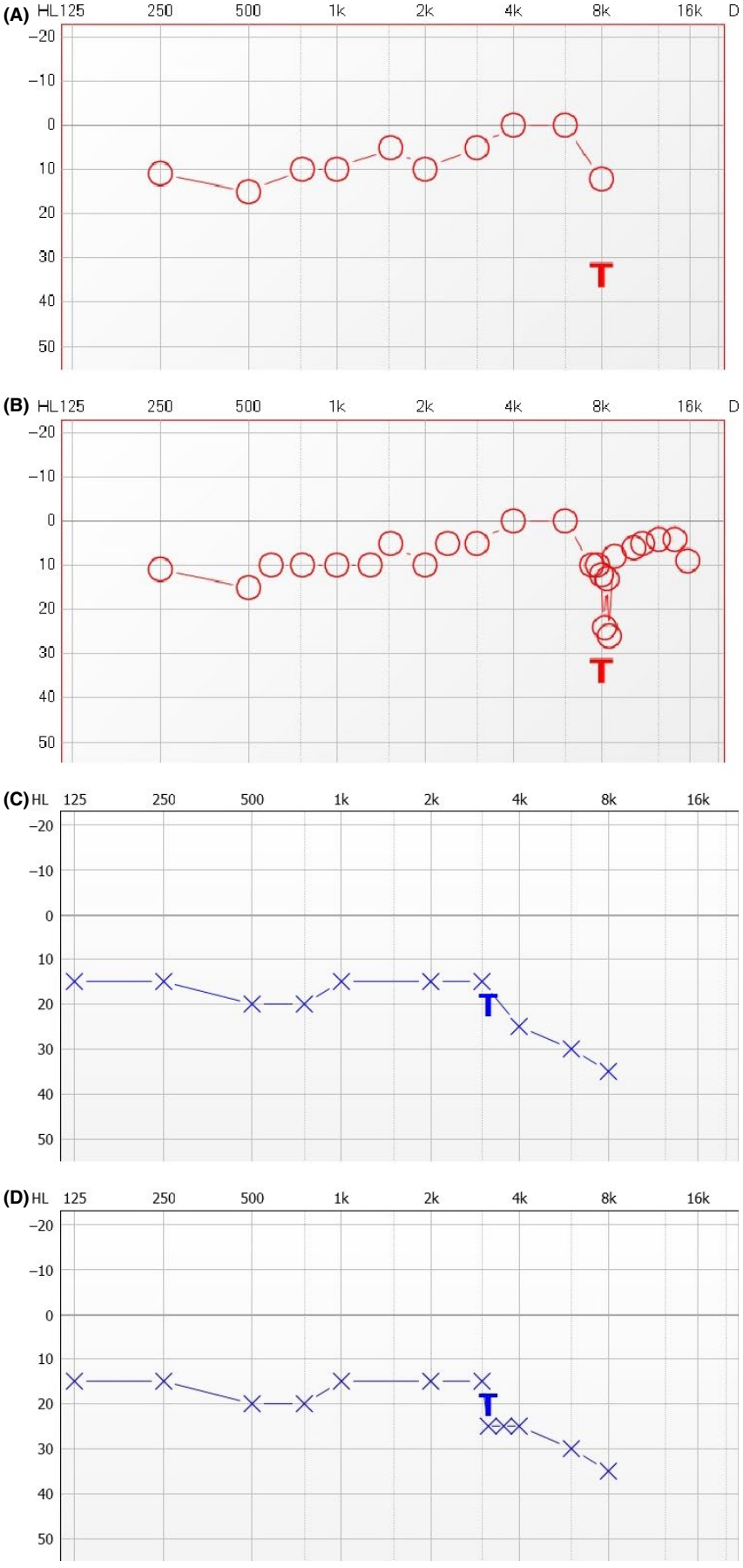

FIGURE 2 Two example of classical audiogram and high-definition audiogram. A, Classical audiogram for a patient with a micro-notch. B, High-definition audiogram for the same patient evaluated in panel A. C, Classical audiogram for a patient with a micro-slope. D, High-definition audiogram for the same patient evaluated in panel C

TABLE 1 Characteristics of tinnitus and hearing loss in the patient group

Tinnitus location in the audiogram	Micro-notch	Micro-slope	Other
Number of patients (%)	41 (62.1%)	13 (19.7%)	12 (18.2%)
Mean PTA (dB HL)	17 ± 12 [0-38]	21 ± 5 [4-39]	25 ± 6 [7-36]
Mean frequency of the maximum hearing loss (Hz)	7545 ± 219.2 [3200-18000]	12 000	12 000
Mean intensity of tinnitus (dB SL)	3.5 ± 1.4 [1-15]	6.5 ± 2.1 [1-14]	5.5 ± 0.7 [1-14]
Mean frequency of tinnitus (Hz)	5260 ± 155 [2000-12200]	8750 ± 3604 [2400-11200]	7500 ± 2121 [2400-11200]
Mean THI score	49 ± 18 [22-80]	58 ± 16 [36-78]	48 ± 14 [22-58]

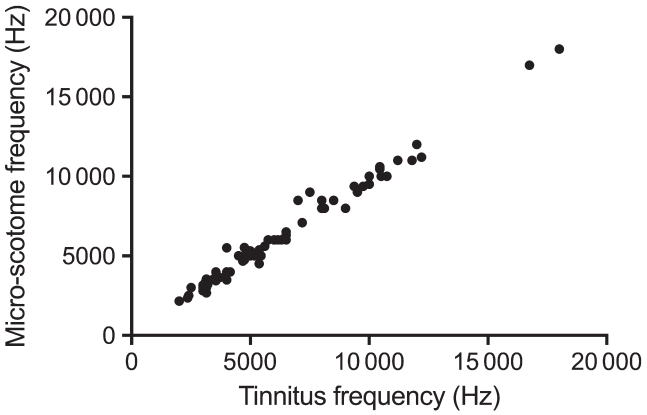

FIGURE 3 Correlation between the tinnitus frequency (Hz) and micro-notch frequency (Hz) on 33 patients (r^2 = 0.9801, P < .0001)

4.3 | Clinical applicability of the study

The protocol presented in this study allows audiologists to obtain the precise information on hearing loss and tinnitus characteristics to improve tinnitus treatment with hearing aids.

5 | CONCLUSION

The high-definition audiogram was used to detect HHL associated with tinnitus and to determine pitch and frequency of the tinnitus. Altogether, our results demonstrate that the high-definition audiogram provides better characterisation of tinnitus testing than the classically used test and should be used to improve treatment guidance.

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