

Association Between Hearing Threshold and Cochlear Dysfunction in Patients with Tinnitus

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Publication Date: 2026/10/22

Abstract:

➤ *Background:*

Tinnitus can be present at measurable hearing loss or even when hearing thresholds are within the audiometric ranges that are expected. Pure-tone audiometry measures hearing sensitivity, while OAE test measures outer hair-cell function of the cochlea. Together, they can help to detect subtle cochlear dysfunction in tinnitus patients.

➤ *Aim:*

This study aims to investigate the relationship between hearing threshold and cochlear dysfunction in tinnitus patients.

➤ *Materials and Methods:*

This is a cross sectional study with 200 patients who attended the Department of Otorhinolaryngology, Index Medical College, Hospital and Research Centre, Indore for tinnitus. Subjective and objective clinical and demographic data were taken, followed by puretone audiometry and transient-evoked and distortion-product otoacoustic emission testing. OAE results were scored as PASS or REFER. Descriptive statistics and logistic regression were carried out, where $p < 0.05$ was taken as statistically significant.

➤ *Results:*

There were 200 patients, 60.0% were male, and 40.0% were female. The age group with the highest percentage was aged 41-60 (36.5%). 40.0% had bilateral tinnitus and 51.5% reported they had constant tinnitus. The mean PTA was 34.78 ± 14.89 dB HL. Of the 132 test patients, 132 (66.0%) had an OAE REFER result and 68 (34.0%) had an OAE PASS result. PTA significantly predicted the OAE outcome ($\beta = 0.167$, $p < 0.001$). The likelihood of having a REFER result increased by approximately 18% for every 1 dB HL.

➤ *Conclusions:*

There was a significant association between poorer hearing thresholds with increased likelihood of cochlear outer hair-cell dysfunction. Combined PTA and OAE testing offers tinnitus patient a more complete picture than either test alone.

Keywords: Tinnitus, Hearing Threshold, Cochlear Dysfunction, Pure-Tone Audiometry, Otoacoustic Emissions, Outer Hair Cells.

How to Cite: Dr. Gunjan Bhabar; Dr sanjay Gupta; Dr. Chhavi Agrawal; Dr. Ajinkya Raverkar; Dr. Isha Shrivastava (2026) Association Between Hearing Threshold and Cochlear Dysfunction in Patients with Tinnitus. *International Journal of Innovative Science and Research Technology*, 11(10), 1197-1203. <https://doi.org/10.38124/ijisrt/26oct774>

I. INTRODUCTION

Tinnitus is the experience of hearing sound when there is no sound present [1, 2]. It can negatively impact on sleep, attention, mental health and quality of life. Audiological tests are often performed in tinnitus patients to determine auditory function. Pure tone audiometry could show either conductive, sensorineural or mixed hearing loss, but about 30% of the tinnitus patients have normal audiometric thresholds [3]. Thus, subtle auditory dysfunction may not be detected through a conventional audiometric assessment.

In patients with normal audiogram, tinnitus should be investigated further since its mechanism is not fully understood. Abnormalities can happen anywhere along the auditory pathway, from abnormalities in the cochlea, back of the cochlea, the auditory nerve, or the central auditory system. Dysfunction may also be present at more than one anatomical location. Thus, a normal hearing threshold does not necessarily reflect normal cochlear function and pure-tone audiometry alone may not be enough to determine where and how tinnitus is caused [1, 4].

It has been suggested that damage to the outer hair cells of the cochlea is an important mechanism in the onset of tinnitus. This damage can change cochlear micromechanics and cause abnormal neural activity prior to the first measurable change on the traditional audiogram. Otoacoustic emissions (OAE) is an objective measure of outer hair-cell (OHC) function and may offer an objective method to identify subclinical cochlear dysfunction in patients with tinnitus and a seemingly normal audiogram.

It has previously been shown that tinnitus patients have abnormalities in their otoacoustic emission measurements. In one study with tinnitus patients with normal hearing thresholds, 64% passed the transient-evoked otoacoustic emissions and 90% passed the distortion-product otoacoustic emissions tests [5]. Ami et al. noted decreased DPOAEs in about 93% of the tinnitus patients who had normal hearing thresholds and 96% of those who had hearing loss [6]. The findings here indicate that outer hair cell dysfunction can take place regardless of whether conventional audiometry reveals the presence of good or poor hearing.

In addition to cochlear abnormalities, other abnormalities have been reported. The incidence of abnormal results from brainstem evoked response audiograms have been found to be 47% in one study in patients with normal audiograms but tinnitus, and an estimated 31-40% in other studies. In a subset of patients with apparently normal BERA, prolongation of waves I, III and V, widening of the III-V interval and increase in the amplitude of V/I were reported when compared to those who had normal hearing without tinnitus [7]. Such observations suggest that tinnitus could be due to an

interaction between cochlear and retrocochlear auditory mechanisms.

Tinnitus is not a standalone illness, but a sign of an underlying auditory problem. It can be linked with conductive external or middle ear disorders, sensorineural disorders (cochlear hair cells, retrocochlear and central auditory pathways) [8, 9]. Breakdown of the outer hair cells can affect the mechanical and electrophysiological function of the cochlea and cause abnormal spontaneous OAE that can contribute to tinnitus [10, 11]. Likewise, spontaneous neural activity changes in the auditory nerve fibres caused by the metabolic or neural dysfunction can play a role in the development of tinnitus from retrocochlear auditory system [2, 12].

Pure tone audiometry is the most common test to measure hearing sensitivity, but this may not be good at detecting early or mild outer hair-cell damage. Otoacoustic emission testing can be useful in giving more information about the cochlear status and could detect dysfunction in tinnitus patients with normal hearing threshold. In this regard, the present study was designed to identify the relationship between hearing threshold level and abnormalities of the cochlea on patients with tinnitus, based on the results of pure-tone audiometry and otoacoustic emission.

II. MATERIALS AND METHODS

➤ Study Design and Setting

It was a cross-sectional study carried out in the department of Otorhinolaryngology, Index Medical College, Hospital and Research Centre, Indore Madhya Pradesh, India in a hospital setting. The study was performed with the approval from the Institutional Ethics Committee for 15 months from October 2022 to December 2023.

➤ Study Population and Sample Size

A total of 200 patients seen in the ENT OPD with the symptom of tinnitus were included in the study. All ages and both sexes were eligible for study. Informed consent was obtained in writing from all participants, or parent/legal guardian if applicable, prior to enrolment.

➤ Sample Selection Criteria

• Inclusion Criteria

- ✓ Patients included if they:
 - ✓ Hallucination of the ear problem;
 - ✓ Are willing to complete pure-tone audiometry and OAE testing; and
 - ✓ Provided informed written consent to participate

- *Exclusion Criteria*

Conditions that excluded patients were:

- ✓ Denied pure tone audiometry and/or OAE testing;
- ✓ Did not give informed consent;
- ✓ Previously diagnosed psychiatric disorder that might affect the perception or reporting of tinnitus.

- *Clinical Evaluation*

All participants had a detailed clinical history taken. Data was collected on age, sex, occupation, educational and socioeconomic status, onset, duration and severity of the tinnitus, associated hearing loss, dizziness, earache and other otological symptoms. Other histories including: relevant noise exposures, ear infections, head injuries, ototoxic drug therapies, hypertension and diabetes mellitus and cardiovascular disease were also noted.

Full examination of the ears, nose and throat has been conducted. Otoloscopic examination was performed to detect different abnormalities of the external auditory canal and tympanic membrane such as cerumen impaction, infection and perforation. Dietary history and occupational history were taken to determine what factors included caffeine, alcohol, excess salt consumption, etc., were present.

- *Tinnitus Handicap Assessment*

The Tinnitus Handicap Inventory was used to evaluate how participants' tinnitus affected their life. The questionnaire assessed the functional, emotional and catastrophic impacts of tinnitus. The severity and impact of tinnitus were categorised based on the obtained score.

- *Audiological Assessment*

The audiological assessment was carried out by pure tone audiometry and otoacoustic emission testing. Tests were carried out in an ISO 8253-1 compliant sound-treated room.

- *Pure-Tone Audiometry*

Pure-tone audiometry was conducted with a portable stand-alone audiometer model MA 42 made by MAICO. Air and bone conduction hearing thresholds were obtained over the range of frequencies 250 Hz to 8,000 Hz. The minimum intensity that the participant could hear at least 50% of the time was noted as the threshold.

The modified Hughson-Westlake procedure was used for threshold estimation according to the “down 10 dB and up 5 dB” method. Audiometric results were used to identify type of hearing loss, its degree and its presence.

- *Otoacoustic Emission Testing*

Transient-evoked OAE and distortion-product OAE were used to assess the outer hair-cell function of the cochlea. The two tests were performed on a Neuro-Soft Audio neurophysiological system for evoked potentials and otoacoustic emissions (Neurosoft Ltd., BSI Group Deutschland GmbH, Germany, version 2010).

The findings from the otoacoustic emission were noted as "PASS" or "REFER". A PASS result showed measurable OAE and relatively normal function of the outer hair cells, while a REFER result showed a lack or a loss of OAE and probably cochlear outer hair-cell dysfunction.

- *Data Collection Procedure*

Patients from the ENT out-patient department were recruited for this study. After obtaining informed consent, demographic, clinical, medical, dietary and occupational information was recorded using a predesigned case-record proforma. All participants then received an ENT exam, a Tinnitus Handicap Inventory assessment, pure tone audiometry, TEOAE and DPOAE testing. The data collected was recorded on a master chart for statistical analysis.

- *Outcome Measures*

The main result was the relationship between the hearing threshold obtained by pure-tone audiometry (PTA) and cochlear dysfunction identified by the results of otoacoustic emission (OAE).

Other secondary outcome measures included:

- Patients with tinnitus and distribution of hearing thresholds;
- Percent of patients with PASS and REFER OAE results;
- Abnormal cochlear function in patients with normal hearing levels;
- Relationship between degree of hearing loss and OAE results; and
- Correlation of tinnitus with some demographic and clinical parameters

- *Statistical Analysis*

Descriptive and inferential statistical techniques were used in analysis of the collected data. Data for continuous variables were given as mean, median and standard deviation, and data for categorical variables were given as frequencies and percentages. Comparisons between relevant groups were made by using the appropriate statistical tests.

Logistic regression analysis was conducted to determine if the pure-tone average (dB HL) could predict the likelihood of getting a REFER result on otoacoustic emission testing. The regression coefficient, standard error, z-value, p-value and 95% confidence interval were determined. P values < 0.05 were regarded as being statistically significant. Data was displayed in tables and suitable graphical displays.

- *Ethical Considerations*

The study protocol was approved by Institutional Ethics Committee, Index Medical College, Hospital and Research Centre, Indore. All participants (or their legally assigned representatives) provided written informed consent. Data from the participants was anonymised and kept securely and only employed for research purposes. The confidentiality of all participants was maintained during the study.

III. RESULTS

The age and gender distribution of the 200 patients with tinnitus is shown in Table 1. The age group 41–60 had the highest number of patients with 73 (36.5%) patients followed closely by the age group of 21–40 with 70 (35.0%) patients. Patients aged 61–80 years constituted 33 (16.5%)

of the sample, while those aged 0–20 years accounted for 24 (12.0%). As for gender, 120 (60.0%) patients were male and 80 (40.0%) were female giving a male to female ratio of 1.5:1. The results of the present study suggest that higher prevalence of tinnitus was seen in males and the middle-aged group of the population studied.

Table 1 Age and Gender Distribution of Patients with Tinnitus (N = 200)

Characteristics	Frequency (n)	Percentage (%)
Age group (years)		
0–20	24	12.0
21–40	70	35.0
41–60	73	36.5
61–80	33	16.5
Gender		
Male	120	60.0
Female	80	40.0

The duration of tinnitus of patients is presented in table 2. 104 patients (52.0%) had been suffering from tinnitus for up to 12 months. Among the 65 patients (32.5 percent), tinnitus duration was 13–24 months, and 26 patients (13.0 percent) reported a duration of tinnitus of 25–60 months.

There were 5 (2.5%) patients who reported tinnitus duration greater than 60 months. The results indicate that the majority of participants were suffering from tinnitus for two years or less, and few for such a long period as more than five years.

Table 2 Duration of Tinnitus Among the Study Participants (N = 200)

Duration of tinnitus	Frequency (n)	Percentage (%)
0–12 months	104	52.0
13–24 months	65	32.5
25–60 months	26	13.0
More than 60 months	5	2.5
Total	200	100.0

Table 3 shows the clinical features of tinnitus laterality, manifestation and family history. The most common presentation was bilateral tinnitus which occurred in 80(40.0%) patients. Sixty-five (32.5%) patients reported tinnitus on the right side and 55 (27.5%) patients on the left side. Of all the patients, 103 (51.5%) complained of constant

tinnitus and 97 (48.5%) of intermittent tinnitus. Twenty-two (11.1%) patients had a family history of tinnitus, and 181 (90.5%) did not. The bilateral and persistent nature of tinnitus was slightly more frequent, however, the familial occurrence was relatively rare.

Table 3 Clinical Characteristics of Tinnitus Among the Participants (N = 200)

Clinical characteristic	Frequency (n)	Percentage (%)
Laterality		
Bilateral	80	40.0
Right ear	65	32.5
Left ear	55	27.5
Pattern of tinnitus		
Constant	103	51.5
Intermittent	97	48.5
Family history of tinnitus		
Present	19	9.5
Absent	181	90.5

The occupational distribution of the study participants is presented in table 4. Labourers made up the largest occupational group, with 50 (25.0%) patients, followed by 38 (19.0%) who worked in factories, and 34 (17.0%) who were farmers. Homemakers accounted for 26 (13.0%) patients, students for 20 (10.0%) and shopkeepers for 16 (8.0%). There were 6 (3.0%) drivers, 5 (2.5%) plumbers and

5 (2.5%) tailors. The fact that labourers and factory workers were more represented indicates that tinnitus was reported more frequently in groups of people who were exposed to noise in the workplace through their occupation or work environment. But, there is no clear causal association from the descriptive findings.

Table 4 Occupational Distribution of Patients with Tinnitus (N = 200)

Occupation	Frequency (n)	Percentage (%)
Labourer	50	25.0
Factory worker	38	19.0
Farmer	34	17.0
Homemaker	26	13.0
Student	20	10.0
Shopkeeper	16	8.0
Driver	6	3.0
Plumber	5	2.5
Tailor	5	2.5
Total	200	100.0

The pure tone audiometric results of patients with tinnitus are summarised in Table 5. The mean pure-tone average was 34.78 dB HL (standard deviation = 14.89 dB HL). The mean value means that on average, the hearing thresholds of the study population were in the mild hearing-loss range. The relatively high standard deviation shows that

there is a great variation in hearing thresholds, meaning that patient hearing impairment was variable. When comparing the genders, the P value is 0.70, indicating no statistically significant difference between the male and female patients' PTA values.

Table 5 Pure-Tone Audiometry Findings Among Patients with Tinnitus (N = 200)

Audiometric parameter	Value
Mean pure-tone average	34.78 dB HL
Standard deviation	14.89 dB HL
Gender-based comparison of PTA	p = 0.70

The distribution of findings for otoacoustic emission is shown in Table 6. 132 (66.0%) of the patients had a REFER result, while 68 (34.0%) had a PASS result. So in about two thirds of the patients, there was no or reduced otoacoustic emissions, indicating possible dysfunction of outer hair-cells

in the cochlea. Around a third, however, showed relatively preserved OAE, but had tinnitus. The results showed that cochlear dysfunction occurred in many, but not all, of the tinnitus patients.

Table 6 Distribution of Otoacoustic Emission Findings Among Patients with Tinnitus (N = 200)

OAE finding	Frequency (n)	Percentage (%)
REFER	132	66.0
PASS	68	34.0
Total	200	100.0

Table 7 shows logistic regression analysis of the association between PTA and OAE outcome. PTA was revealed to be a statistically significant predictor of the presence of a REFER when tested with OAE ($\beta = 0.167$, SE = 0.024, $z = 6.934$, $p < 0.001$). The adjusted odds ratio of 1.18 means that, for every 1 dB HL increase in PTA, the odds of getting a REFER OAE result increased by about

18%. The 95% confidence interval for the PTA coefficient was between 0.120 and 0.214, which shows that it is a statistically significant association not to be mistaken. Thus, there was a significantly higher likelihood of cochlear dysfunction among tinnitus patients with poorer hearing thresholds.

Table 7 Logistic Regression Analysis of the Association Between Hearing Threshold and OAE Result

Predictor	β	Standard error	z-value	p-value	Adjusted OR	95% CI for β
Intercept	-4.355	0.688	-6.332	<0.001	—	-5.703 to -3.007
PTA (dB HL)	0.167	0.024	6.934	<0.001	1.18	0.120 to 0.214

Dependent Variable: OAE Result Coded as PASS = 0 and REFER = 1. PTA: Pure-Tone Average; OAE: Otoacoustic Emission; OR: Odds Ratio; CI: Confidence Interval.

IV. DISCUSSION

Tinnitus is a complex symptom of sound perception that can be accompanied by measurable hearing loss or when hearing levels are within the normal range of hearing. The highest age group of patients included 41-60 years age group (36.5%) followed by 21-40 years age group (35.0%).

The 60.0% of the participants were male. Similarly, Ukaegbe et al. [13] found tinnitus in different age groups in adults, and noted poor audiometric thresholds in patients with tinnitus. Another study, by Båsjö et al. [14] also reported on tinnitus and hearing thresholds among younger people. While males had a higher prevalence in the present study, there was no significant difference in PTA values

between males and females ($p = 0.70$). Fredriksson et al. [15] also stressed the need for objective audiological testing in support of demographic and self-reported auditory characteristics.

Over half of the patients (52.0%) said that they had been suffering from tinnitus for 12 months or less, while 32.5% said it had been present for 13–24 months. Bilateral tinnitus (40.0%) was the most common presentation followed by right-sided tinnitus (32.5%) and left-sided tinnitus (27.5%). 51.5% of the patients reported constant tinnitus, and 48.5% of them reported intermittent tinnitus. Labourers (25.0%), factory workers (19.0%) and farmers (17.0%) were the largest occupational groups. The pattern indicates possible occupational and environmental noise exposure but there is no causal relationship because the exposure levels of noise intensity and exposure time were not recorded.

Mean pure-tone average was 34.78 ± 14.89 dB HL, which means that the participants, on average, had hearing thresholds in the mild hearing-loss range. There was a relatively large standard deviation indicating that there was a great variation in hearing sensitivity. Similarly, Can et al. [16] reported that tinnitus can affect people with normal and impaired hearing and that there may be audiometric profiles that are differently affected by tinnitus. Conventional audiometry is thus needed to assess hearing sensitivity and might not be enough to detect subtle cochlear changes that occur in tinnitus.

A total of 132 patients (66.0%) had a REFER result, while 68 patients (34.0%) had a PASS result in OAE testing. The percentage of REFER results suggests that tinnitus patients had outer hair-cell dysfunction in their cochlea. Some patients with tinnitus had lower DPOAE amplitudes and normal conventional thresholds as Alshabory et al. [17] reported. In addition, Modh et al. [18] reported abnormal DPOAE results in tinnitus patients with normal hearing and Khan et al. [19] showed the clinical value of DPOAE testing in identifying probable cochlear involvement. The presence of PASS in about one-third of the patients, however, suggests that tinnitus can also stem from neural, retrocochlear or central auditory mechanisms.

Logistic regression showed that there was a significant relationship between PTA and OAE outcome ($\beta = 0.167$, $p < 0.001$). The PTA decreased by approximately 18% for every 1 dB increase in the OAE result. Hence, the less a person hears, the more likely he or she is to have cochlear dysfunction. Morgan et al. [20] also showed that longer audiograms combined with OAE testing can be used to detect either hidden or subclinical cochlear dysfunction in patients with subjective tinnitus. Overall, the results indicate that PTA and OAE should be used together since they can give complementary measures of hearing sensitivity and cochlear outer hair-cell function.

V. CONCLUSION

This study showed that hearing Threshold correlated with cochlear dysfunction for patients with tinnitus. The mean pure-tone average was 34.78 ± 14.89 dB HL, which is a mild hearing loss on average. In 66.0% of the patients, the otoacoustic emission test result was REFER, indicating that outer hair cell dysfunction of the cochlea occurred in this population. Logistic regression revealed that higher PTA values were significantly related to an abnormal OAE outcome ($\beta = 0.167$, $p < 0.001$). 34.0% of patients, however, were PASS despite tinnitus, suggesting that mechanisms other than "outer hair-cell dysfunction" may be involved in tinnitus. The results corroborate the integrated application of pure tone audiometry and OAE for a thorough evaluation of tinnitus patients. Early identification of hearing loss and cochlear dysfunction may help in early counselling, hearing conservation and proper clinical management.

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