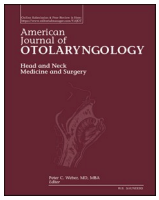
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# Electrocochleography in Chronic Tinnitus: Correlations with Audiological Profiles and Psychological Distress

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ABSTRACT

*Objectives:* This study aimed to explore the electrophysiological characteristics of patients with chronic tinnitus through electrocochleography (ECochG) findings and determine if these findings correlate with specific audiological patterns that could differentiate tinnitus patients from those without this condition.

*Materials and methods:* A retrospective analysis of medical records from patients who visited a tinnitus clinic at a tertiary university hospital between March 2020 and December 2023 was conducted. Inclusion criteria were non-pulsatile subjective tinnitus lasting over three months, and ECochG performed at initial evaluation. Audiological assessments and ECochG results were analyzed, with the SP/AP ratio being a focal point.

*Results:* Among 256 patients, an elevated SP/AP ratio was observed in 37.5 % of patients. No significant difference in ECochG outcomes was noted based on tinnitus laterality. Patients with an elevated SP/AP ratio reported more sleep disturbances, higher depression scores, attention problems, and aural fullness. These patients also exhibited lower loudness discomfort levels and low-frequency hearing losses. Significant correlations were found between elevated SP/AP ratios and DPOAE responses.

*Conclusions:* The findings highlight the SP/AP ratio in ECochG as a valuable biomarker for assessing clinical and psychological aspects of tinnitus, indicating its potential utility in tailoring treatment strategies. Elevated SP/AP ratios were associated with sleep disturbances, depression, attention problems, aural fullness, hyperacusis, and low-frequency hearing loss, suggesting a complex interplay between cochlear pathology and tinnitus perception. This study underscores the need for a nuanced understanding of ECochG results in the clinical evaluation of tinnitus, potentially guiding more personalized management approaches.

## 1. Introduction

Auditory deafferentation is commonly believed to be associated with the generation and maintenance of tinnitus [1]. Consequently, audiological tests are typically the first to be performed during the clinical evaluation process to confirm changes in the peripheral and central auditory systems. Standard tests include loudness discomfort level, extended high-frequency pure-tone audiometry, auditory brainstem response, and distortion product otoacoustic emissions [2].

Electrocochleography (ECochG) has traditionally been utilized as an ancillary diagnostic tool in Ménière's disease (MD), particularly for assessing endolymphatic hydrops. Its utility has recently expanded to investigate hidden hearing loss and cochlear synaptopathy. These conditions may not be evident through standard audiometric evaluations and may present with or without tinnitus [3,4]. Additionally, the feasibility of ECochG has been enhanced by its use in differentiating between cases of vestibular migraine and MD, where integrating ECochG with clinical criteria improves the predictive accuracy of symptom improvement in response to treatment [5].

ECochG measures the cochlear summating potential (SP), indicative of outer hair cell activity, and the action potential (AP), reflective of auditory nerve response. The SP/AP ratio is one of the most commonly used parameters. Furthermore, reports have indicated reduced AP amplitudes at 1 and 4 kHz in individuals with normal hearing and tinnitus compared to control groups, with no notable differences in the SP/AP amplitude ratio [6]. Recent use of tone burst or area under the curve analysis of SP and AP timing differences has provided more accurate assessments [7,8]. However, the variability of ECochG results and the lack of correlation with patients' symptoms have limited its role in clinical practice, highlighting the need for a nuanced understanding of

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ECochG results [9]. ECochG lacks a standardized cutoff for confirming endolymphatic hydrops (EH), with varying sensitivity and specificity, partly due to its inability to detect early cochlear changes in probable MD cases [10].

To the author's knowledge, there needs to be adequate discussion on the clinical significance of ECochG in patients presenting with chronic tinnitus without the typical vertigo associated with MD. Considering that tinnitus has multiple potential etiologies, the additional data from ECochG can contribute to more personalized treatment approaches. For example, an increased SP/AP ratio in chronic tinnitus that does not match MD may suggest a different therapeutic strategy than what would be used for tinnitus without such a finding. Consequently, this could lead to the refinement of existing treatment modalities and potentially the discovery of new ones, thereby improving patient outcomes.

This study aims to examine the electrophysiological characteristics of chronic tinnitus patients through ECochG findings and to determine if these findings correlate with specific audiological patterns that could differentiate tinnitus patients from those without this condition. The findings may provide valuable insights into the complex interplay between cochlear pathology and tinnitus perception, potentially guiding more tailored management strategies for this perplexing condition.

## 2. Material and methods

We retrospectively analyzed the medical records of patients who visited a tinnitus clinic in a tertiary university hospital from March 2020 to December 2023. The inclusion criteria were: 1) non-pulsatile subjective tinnitus lasting over three months, and 2) ECoG performed at initial evaluation. The exclusion criteria included: 1) diagnosis of definite Meniere's disease and 2) presence of brain malignancies and neurological deficits. The institutional review board approved this study, and the requirement for written informed consent was waived due to the retrospective nature of the study (IRB number: 2024-03-002).

We documented the patients' age, sex, duration of tinnitus, history of exposure to loud noise, and accompanying symptoms, including subjective hyperacusis, sleep disturbance, aural fullness, headache, attention problems, temporomandibular/neck pain, as well as comorbid conditions such as diabetes mellitus and hypertension. The following questionnaire results were also documented: Tinnitus Handicap Inventory (THI), Beck's Depression Inventory (BDI), Beck's Anxiety Inventory (BAI), the Brief Encounter Psychosocial Instrument (BEPSI), and Numerical Rating Scale (NRS) for tinnitus awareness, annoyance, loudness, impact on life, along with the Mini-Mental State Examination (MMSE).

Audiological assessments included pure-tone audiometry, speech audiometry, auditory brainstem response (ABR), loudness discomfort

**Table 1**
Patient characteristics.

| | Total | Normal SP/AP ratio (n = 159) | Elevated SP/AP ratio in the right side (n = 29) | Elvated SP/AP ratio in the left side (n = 37) | Bilaterally elevated SP/AP ratio (n = 31) | *P* value |
|---|---|---|---|---|---|---|
| Age (years old) | 54.30 ± 14.14 | 53.60 ± 14.60 | 53.07 ± 14.29 | 55.06 ± 13.07 | 58.16 ± 12.68 | 0.349 |
| Sex (male/female) | 133/123 | 75/82 | 16/13 | 24/13 | 17/14 | 0.284 |
| Tinnitus duration (month) | 44.19 ± 68.54 | 42.48 ± 63.74 | 38.62 ± 51.16 | 52.35 ± 68.34 | 43.29 ± 96.39 | 0.846 |
| Tinnitus laterality (Rt/Lt/ bilateral/non-lateralized) | 46/58/ 126/26 | 29/32/83/15 | 9/3/14/3 | 2/19/13/3 | 6/4/16/5 | 0.002 |
| Hearing level (right) | 21.46 ± 15.87 | 20.49 ± 16.01 | 20.76 ± 12.53 | 20.69 ± 16.16.05 | 25.61 ± 15.37 | 0.415 |
| Hearing level (left) | 20.39 ± 13.89 | 18.91 ± 12.84 | 18.83 ± 11.23 | 23.06 ± 16.61 | 24.45 ± 15.82 | 0.103 |
| THI | 48.50 ± 23.68 | 49.04 ± 24.03 | 44.69 ± 22.06 | 47.84 ± 24.52 | 48.48 ± 23.04 | 0.840 |
| BDI | 10.66 ± 8.56 | 10.61 ± 8.13 | 7.45 ± 6.17 | 11.14 ± 9.42 | 13.68 ± 10.80 | 0.044 |
| VAS | | | | | | |
| Awareness | 7.68 ± 2.99 | 7.51 ± 3.11 | 7.89 ± 3.00 | 8.14 ± 2.72 | 7.67 ± 2.76 | 0.688 |
| Annoyance | 6.88 ± 2.74 | 6.82 ± 2.79 | 6.41 ± 3.03 | 7.56 ± 2.24 | 6.61 ± 2.67 | 0.337 |
| Loudness | 6.59 ± 2.26 | 6.51 ± 2.28 | 6.28 ± 2.09 | 6.89 ± 2.20 | 6.68 ± 2.34 | 0.720 |
| Effect on life | 5.50 ± 2.50 | 5.37 ± 2.44 | 5.14 ± 2.66 | 5.97 ± 2.40 | 5.65 ± 2.62 | 0.498 |
| Somatic modulation | 31 (12.1 %) | 14 (8.8 %) | 1 (3.4 %) | 5 (13.5 %) | 11 (35.5 %) | <0.001 |
| Associated symptoms | | | | | | |
| Subjective hyperacusis | 51 (19.9 %) | 31 (19.5 %) | 6 (20.7 %) | 6 (16.2 %) | 8 (25.8 %) | 0.803 |
| Sleep disturbance | 72 (28.1 %) | 45 (28.3 %) | 5 (17.2 %) | 7 (18.9 %) | 15 (48.4 %) | 0.022 |
| Headache | 63 (24.6 %) | 43 (27.0 %) | 4 (13.8 %) | 8 (21.6 %) | 8 (25.8 %) | 0.477 |
| TMJ discomfort | 50 (19.5 %) | 33 (20.8 %) | 3 (10.3 %) | 6 (16.2 %) | 8 (25.8 %) | 0.438 |
| Attention problem | 31 (12.1 %) | 16 (10.1 %) | 3 (10.3 %) | 4 (10.8 %) | 8 (25.8 %) | 0.101 |
| Aural fullness | 64(25.0 %) | 36 (22.6 %) | 5 (17.2 %) | 10 (27.0 %) | 13 (41.9 %) | 0.101 |
| Accompanying disease | | | | | | |
| Diabetes mellitus | 14 (5.5 %) | 16 (10.1 %) | 0 (0.0 %) | 3 (8.1 %) | 4 (12.9 %) | 0.303 |
| Hypertension | 61 (23.8 %) | 40 (25.2 %) | 5 (17.2 %) | 10 (27.0 %) | 6 (19.4 %) | 0.720 |

level (LDL) test, and distortion product otoacoustic emission (DPOAE) tests. For ABR, we measured threshold wave V, V/I amplitude ratio, and latencies of waves I, III, and V. A tinnitogram was performed to measure tinnitus's pitch, loudness, and residual inhibition (RI). An ECochG result of 0.4 or above was defined as a high SP/AP ratio. The average PTA utilized the mean hearing levels at 500, 1000, 2000, and 4000 Hz.

A total of 256 patients were included in this study (Table 1). They consisted of 133 men (52.0 %) and 123 women (48.0 %), with an average age of 54.30 ± 14.14 years (range: 16–83 years). The average hearing levels were 21.46 ± 15.87 dB for the right side and 20.39 ± 13.89 dB for the left side, with a mean tinnitus duration of 44.19 ± 68.54 months (range: 3–480 months). The tinnitus laterality was 49.2 % (n = 126) bilateral, 22.7 % (n = 58) on the left side, 18.0 % (n = 46) on the right side, and 10.2 % (n = 26) non-lateralized. The pitch and loudness of tinnitus were 3.71 ± 3.50 kHz, 7.10 ± 8.76 dBSL for the right side, and 4.25 ± 3.64 kHz, 6.79 ± 8.62 dBSL for the left side. RI was measurable in 133 individuals for the right side and 151 for the left side, with 52.6 % (n = 70) showing no RI, 45.9 % (n = 61) displaying complete RI, and 1.5 % (n = 2) exhibiting partial RI for the right side. For the left side, 55.0 % (n = 83) had no RI, 42.4 % (n = 64) had complete RI, and 2.6 % (n = 4) had partial RI. Among the accompanying symptoms, sleep disturbance was most common at 28.1 % (n = 72), followed by aural fullness (25.0 %, n = 64), headache (24.6 %, n = 63), subjective hyperacusis (19.9 %, n = 51), and attention problems (12.1 %, n = 31). A history of loud noise exposure was noted in 10.5 % (n = 27) of the patients, with comorbid diabetes mellitus and hypertension present in 9.0 % (n = 23) and 23.8 % (n = 61), respectively.

Statistical analysis was performed using IBM SPSS Statistics for Macintosh, version 29.0 (IBM Corp., Armonk, NY, USA). Differences in ECoG outcomes based on tinnitus laterality were analyzed using One-way ANOVA, with post-hoc comparisons conducted using Tukey's HSD test when significant differences were identified. Differences in ECoG results based on the presence or absence of accompanying symptoms such as sleep disturbance were analyzed using a two-sided Fisher's exact test. Additionally, scores from the THI, NRS, BAI, BEPSI, and MMSE were compared using independent sample *t*-tests. For BDI and somatic modulation, differences based on the direction of the elevated SP/AP ratio were evaluated using One-way ANOVA, with post-hoc analysis conducted where significant results were obtained. Pure-tone averages, LDLs, ABR, and DPOAEs were compared using independent Students' *t*-tests or one-way ANOVA by groups. Spearman correlation analysis was utilized to assess the relationships between SP/AP ratios and clinical parameters, including audiological measures and questionnaire scores. A *p*-value of $<0.05$ indicated statistical significance for all statistical tests. All data are presented as mean ± standard deviation or number (percentages).

## 3. Results

The ECochG results were 0.31 ± 0.14 (range: 0.12–0.77) for the right side and 0.33 ± 0.16 (range: 0.10–0.90) for the left side. An elevated SP/AP ratio was observed in 37.5 % (n = 96) of patients, either unilaterally or bilaterally. According to the ECochG findings, results were normal in 62.5 % (n = 160) of cases; an elevated SP/AP ratio for the right ear was seen in 11.3 % (n = 29), for the left ear in 14.1 % (n = 36), and for both ears in 12.1 % (n = 31). No significant difference in ECoG outcomes was noted based on the laterality of tinnitus (One-way ANOVA, $p > 0.05$).

With regard to accompanying symptoms, a difference in ECochG results was observed based on the presence or absence of sleep disturbances ($p = 0.025$, two-sided Fisher's exact test). Sleep disturbances were most commonly reported by 48.4 % of patients with an elevated SP/AP ratio in both ears. In contrast, sleep disturbances were reported by 28.1 % (n = 45) of patients with a normal ECochG. No significant differences in ECochG were found concerning other accompanying symptoms or a history of noise exposure ($p > 0.05$). In addition, Spearman correlation analysis revealed that the right SP/AP ratio was significantly correlated with attention problems ($r = 0.155$, $p = 0.013$), and the left SP/AP ratio was significantly correlated with aural fullness ($r = 0.154$, $p = 0.014$) and attention problems ($r = 0.327$, $p < 0.001$).

The questionnaires revealed no significant differences based on the elevated SP/AP ratio for THI, VAS, BAI, or BEPSI ($p > 0.05$). However, MMSE scores were significantly higher in patients with an elevated SP/AP ratio, averaging 28.29 ± 1.82, compared to 27.00 ± 2.91 in patients with a normal SP/AP ratio ($p = 0.031$). For BDI scores, a difference was noted according to the direction of the elevated SP/AP ratio ($p = 0.043$, One-way ANOVA). The post-hoc test indicated that the average BDI was lowest at 7.45 ± 6.17 for the elevated SP/AP ratio for the right ear and highest at 13.68 ± 10.80 for the elevated SP/AP ratio for both ears. These differences were statistically significant ($p = 0.025$). Spearman correlation also showed no correlation between ECochG and all of the questionnaires.

Significant differences were also observed in somatic modulation based on the elevated SP/AP ratio ($p = 0.033$). Positive findings were seen in 17.7 % (n = 17/79) of patients with an elevated SP/AP ratio, compared to 8.8 % (n = 14/146) in patients with normal ECochG. Specifically, 35.5 % (n = 11/20) of patients with an elevated SP/AP ratio for both ears exhibited somatic modulation. In contrast, rates were 8.8 % (n = 14/146) for a normal SP/AP ratio, 3.4 % (n = 1/28) for an elevated SP/AP ratio for the right ear, and 13.9 % (n = 5/31) for an elevated SP/AP ratio for the left ear ($p < 0.001$).

No significant difference was observed in the pure-tone average based on the elevated SP/AP ratio status ($p < 0.05$). Frequency-specific comparisons between the elevated SP/AP ratio group and the normal SP/AP ratio group revealed that the right ear at 125 Hz ($p < 0.001$) and 250 Hz ($p = 0.024$) and the left ear at 125 Hz ($p = 0.010$) and 8 kHz ($p = 0.040$), had significantly poorer hearing thresholds in the elevated SP/AP ratio group (Fig. 1). Spearman correlation analysis showed that the right SP/AP ratio was significantly correlated with pure-tone audiometry thresholds at 125 Hz ($r = 0.305$, $p < 0.001$), 250 Hz ($r = 0.201$, $p = 0.001$) and 500 Hz ($r = 0.143$, $p = 0.023$). The left SP/AP ratio was significantly correlated with pure-tone audiometry thresholds at 125 Hz ($r = 0.312$, $p < 0.001$), 250 Hz ($r = 0.277$, $p < 0.001$), and 500 Hz ($r = 0.155$, $p = 0.014$).

Significant differences between the elevated SP/AP ratio and the normal SP/AP ratio were noted across all tested frequencies in the LDL test. Patients with an elevated SP/AP ratio showed significantly lower LDL values (Fig. 2).

ABR V wave thresholds and V/I amplitude ratios did not differ significantly based on the elevated SP/AP ratio status ($p > 0.05$). However, a trend towards shorter latencies was observed in both sides for the elevated SP/AP ratio, with the left side wave III latency being significantly shorter in patients with an elevated SP/AP ratio (3.67 ± 0.22 ms) than in those with a normal SP/AP ratio (3.73 ± 0.22 ms, $p = 0.033$). Other wave I and V latencies did not show significant differences.

Regarding DPOAE, at all tested frequencies on both sides, patients with an elevated SP/AP ratio demonstrated a significantly higher DPOAE response compared to those with a normal SP/AP ratio ($p < 0.001$) (Fig. 3).

## 4. Discussion

This study delves into the intricate relationship between chronic tinnitus and clinical and psychological factors. Our objective is to shed light on the underlying mechanisms and identify potential biomarkers that could facilitate personalized treatment strategies. Central to our research is the significance of the SP/AP ratio, a marker potentially indicative of endolymphatic hydrops, and its correlation with various dimensions of tinnitus and related conditions.

We discovered that patients with chronic tinnitus exhibiting an elevated SP/AP ratio report more sleep disturbances and a greater susceptibility to somatic modulation. Intriguingly, this elevation impacts

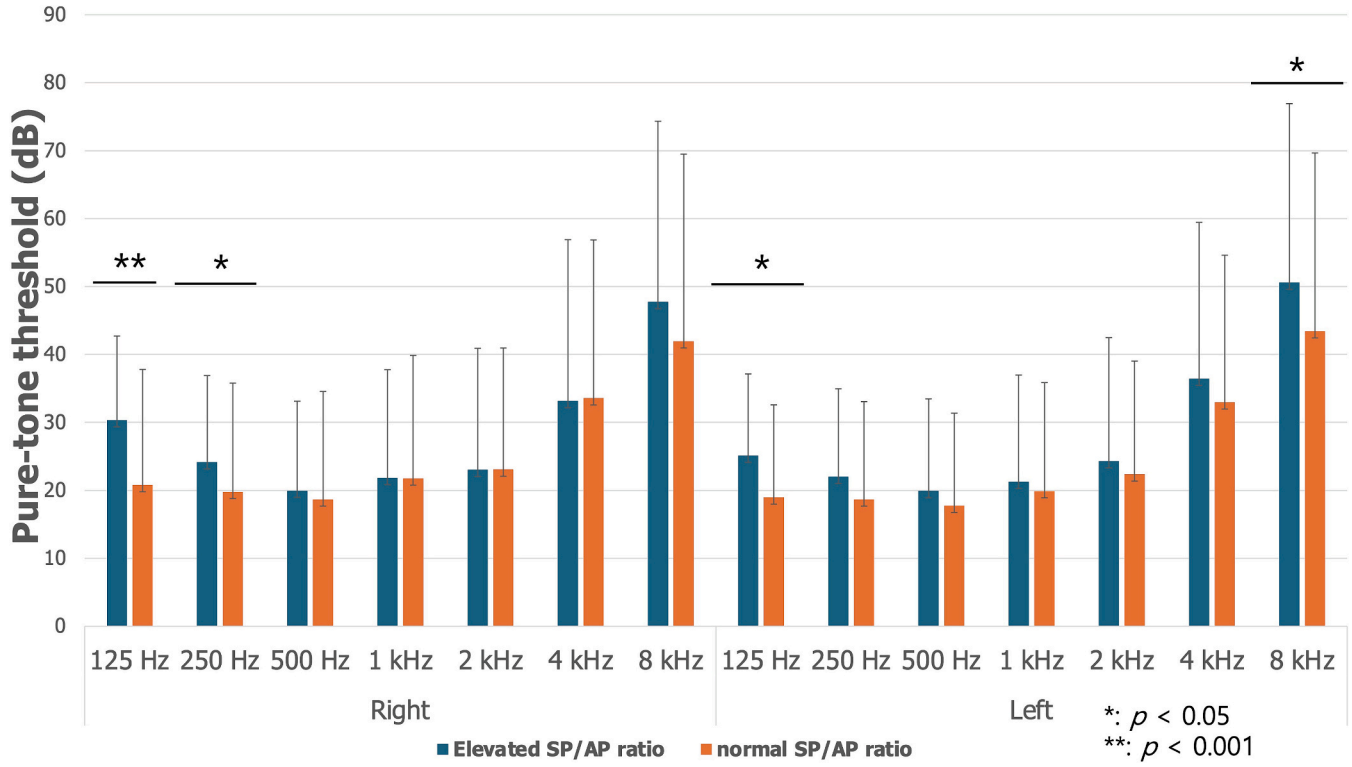



**Fig. 1.** Comparison of pure-tone threshold between tinnitus patients with elevated SP/AP ratio and normal SP/AP ratio.

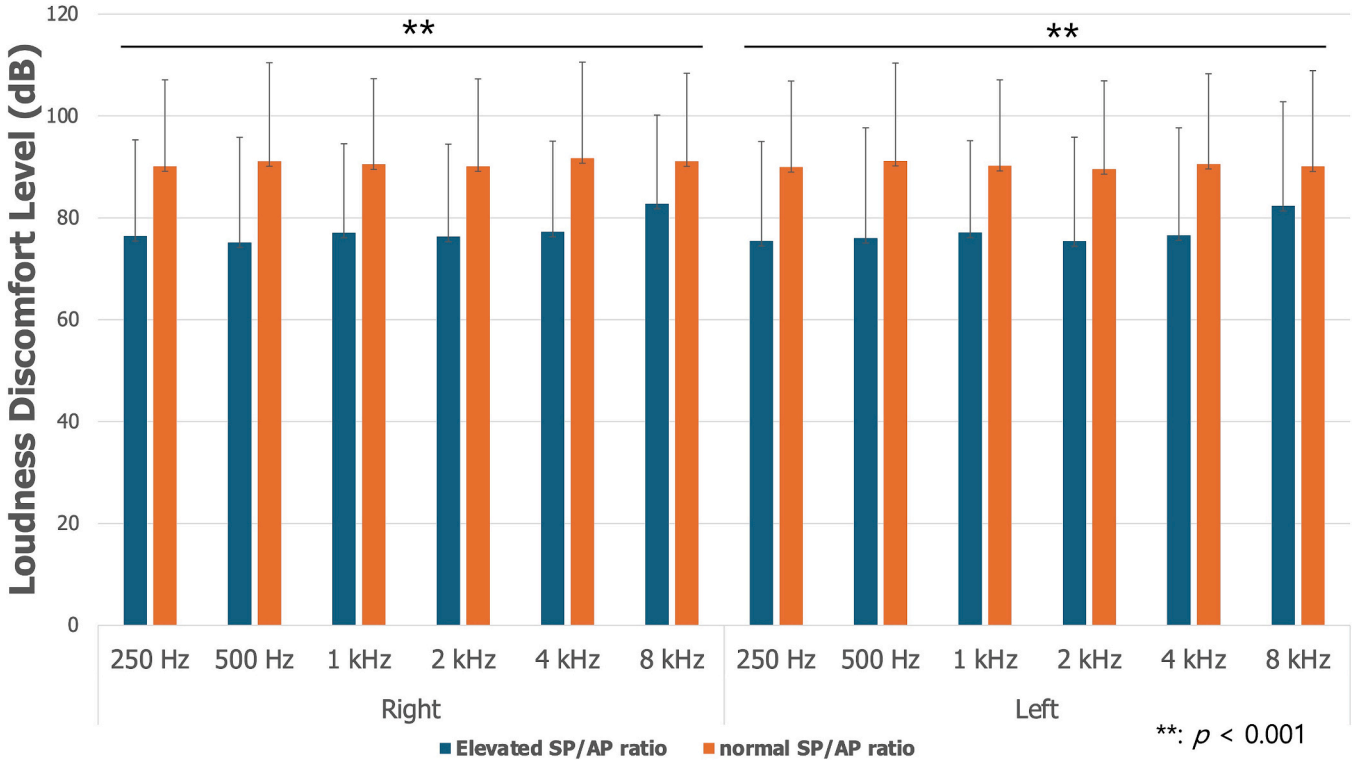



**Fig. 2.** Comparison of loudness discomfort level between tinnitus patients with elevated SP/AP ratio and normal SP/AP ratio.

BDI scores, with a bilateral elevation associated with higher scores. This study also highlights the significance of lower LDL levels and specific low-frequency hearing losses in patients with an elevated SP/AP ratio, suggesting hyperacusis and indicating altered cochlear mechanics, as evidenced by increased DPOAE responses. These findings propose the SP/AP ratio as a valuable biomarker for the clinical and psychological evaluation of tinnitus patients, potentially aiding in crafting personalized treatment strategies.

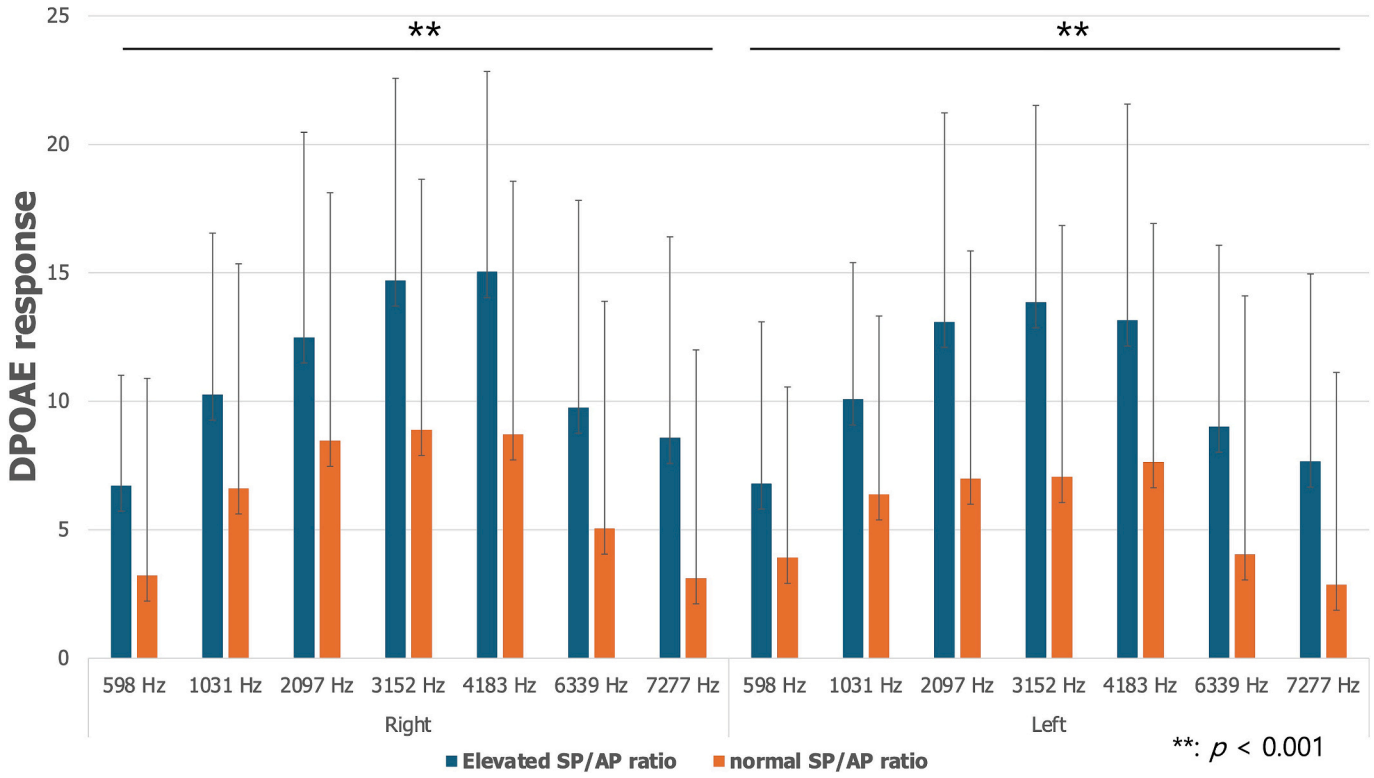



**Fig. 3.** Comparison of distortion product otoacoustic emission response between tinnitus patients with elevated SP/AP ratio and normal SP/AP ratio.

The association between elevated SP/AP ratios and symptoms such as sleep disturbances, depression, attention problems, and aural fullness may reflect underlying cochlear dysfunction that leads to aberrant neural signals being sent to the central auditory pathways. This abnormal input may contribute to maladaptive plasticity in the central auditory system, resulting in heightened auditory sensitivity and increased stress levels. This continuous strain may activate the hypothalamic-pituitary-adrenal axis, leading to elevated cortisol levels and subsequent sleep disturbances and depressive symptoms [11]. The significant correlations observed between SP/AP ratios and attention problems indicate that higher SP/AP ratios may be associated with increased sensory sensitivity or hypervigilance, which could manifest as attention difficulties and perceptual load [12]. The interplay between heightened auditory sensitivity, stress response, and neural plasticity disruptions provides a plausible explanation for the observed associations with these symptoms.

In terms of audiological parameters, the SP/AP ratios showed significant positive correlations with pure-tone audiometry thresholds in the low-frequency range (125–500 Hz) and with DPOAE responses. This suggests that SP/AP ratios are related to auditory function, particularly in the low-frequency range, which is indicative of endolymphatic hydrops. The correlation between SP/AP ratios and DPOAE responses may be interpreted as reflecting the status of outer hair cell function in the cochlea. Higher SP/AP ratios could indicate greater endolymphatic hydrops, which in turn could affect the function of outer hair cells, leading to the observed correlations with DPOAE responses.

The SP/AP ratio indicates endolymphatic hydrops but not MD, especially since hydrops might not be present in the early stages of MD [13]. Magnetic resonance imaging (MRI) can intuitively visualize endolymphatic hydrops into cochlear or vestibular hydrops [14]. A recent MRI study showed positive correlations between hearing loss levels, cochlear hydrops, and ECochG results with visible cochlear hydrops severity [14]. The severity of visible vestibular endolymphatic hydrops has been linked to anxiety and depression states [14].

MD patients often face anxiety and depression stemming from vertigo, disability, and vestibular dysfunction [14]. The presence of saccades, decreased gain in video head impulse tests, and caloric weakness have been correlated with depression and/or anxiety in MD patients [15]. Notably, tinnitus alone was not strongly correlated with depression or anxiety in these patients [15]. Anxiety and depression tend to be more severe in patients with MD or vestibular migraine compared to those with benign paroxysmal positional vertigo or vestibular neuritis, likely due to the unpredictability of attacks leading to a vicious cycle of anxiety/depression and social withdrawal [16–18]. However, these psychiatric symptoms could also be triggered by the conditions themselves, or conversely, individuals prone to depression might be more susceptible to developing MD [18].

Emotional issues such as depression, anxiety, and stress, prevalent even among healthy individuals, may significantly contribute to the onset of tinnitus [1,19]. Our results suggest that the SP/AP ratio reflects both endolymphatic hydrops and auditory instability and correlates with the psychological distress associated with inner ear disorders. While endolymphatic hydrops do not directly cause vertigo, they are associated with instability, obviously potentially culminating in MD or similar fluctuating auditory symptoms without vertigo [20]. Further investigation is needed to understand these conditions and their treatment implications fully.

Our study also observes that, while the average pure-tone average did not significantly vary with ECochG, specific low-frequency hearing loss was notable in patients with an elevated SP/AP ratio, indicating a vulnerability in these frequency ranges. The cause of low-frequency hearing loss in endolymphatic hydrops remains unclear. The severity of endolymphatic hydrops correlates with the degree of low-frequency hearing loss, and it is hypothesized that mechanical disruption of the organ of Corti may be the underlying cause [21]. Notably, endolymphatic hydrops in the middle turn of the cochlear have been reported to be associated with middle-frequency hearing loss [22]. Other research indicates that cochlear synaptic loss is unrelated to low-frequency hearing loss [23]. Patients experiencing low-frequency hearing loss alongside tinnitus may have an increased risk of progressing to MD,

necessitating careful follow-up observations [20]. Interestingly, some patients in this study who received treatments with betahistine or diuretics did not significantly improve tinnitus (data not shown). This suggests a need for further exploration of personalized treatment options for patients who present with chronic tinnitus, low-frequency hearing loss, and an elevated SP/AP ratio.

Significantly, patients with elevated SP/AP ratio showed considerably lower LDLs across all frequencies than those with a normal SP/AP ratio. This suggests that the SP/AP ratio can be used to detect the possibility of hyperacusis in tinnitus patients. Sound intolerance, indicated by lower LDL, represents one of the most frequent abnormalities in tinnitus sufferers and correlates with an increase in the severity of tinnitus distress [24]. Furthermore, our study observed that tinnitus patients with a high SP/AP ratio exhibited an increased DPOAE response. This aligns with the authors' previous findings that patients with auditory hypersensitivity demonstrated higher DPOAE amplitudes, reduced latency, and a lower threshold for the ABR wave V, mirroring similar findings [25].

In addition to endolymphatic hydrops and auditory hypersensitivity, recent researches highlight the diagnostic potential of ECochG in diagnosing hidden hearing loss, specifically cochlear synaptopathy, among individuals with normal audiometric thresholds, including those with and without tinnitus. One study differentiated college students into low-risk and high-risk groups for hidden hearing loss based on noise exposure and hearing protection habits, finding that the high-risk group, despite normal audiometric thresholds, displayed elevated thresholds at high frequencies, poorer word recognition in challenging listening environments, and hyperacusis symptoms, with a significantly different SP/AP ratio in ECochG results suggesting neural degeneration [4]. In our study, the significant increase in hearing threshold at 8 kHz on the left side in the elevated SP/AP ratio group may be related to cochlear synaptopathy, but further study is needed. Another study found that individuals with tinnitus showed increased SP/AP ratios, particularly in the right ears, pointing to cochlear synaptopathy and dead regions as underlying factors of tinnitus, even when audiometric thresholds appear normal [3]. Furthermore, a study involving participants with tinnitus revealed significantly smaller action potential amplitudes at specific frequencies, indicating potential neural degeneration associated with tinnitus despite normal audiometric results [6].

This study has several limitations. First, the retrospective study design may weaken the results and interpretation of our findings. Prospective, longitudinal studies are needed to confirm our findings and assess the efficacy of individualized treatment modulated by ECochG results and patient-reported outcomes. Specifically, understanding the proportions and characteristics of patients who progress to MD among tinnitus patients with a high SP/AP ratio during long-term follow-up will be beneficial for initial management and selection of treatment regimens. Second, our tertiary clinical setting may reflect something other than the general population. Third, a more objective measurement of tinnitus in patients should have been performed, such as quantitative electroencephalograms (qEEG), fMRI, or PET-CT. We recorded qEEG from some patients but did not analyze the results due to the small sample size.

## 5. Conclusion

Chronic tinnitus patients with a high SP/AP ratio have a higher tendency for depression, sleep disturbances, attention problems, and aural fullness. They are more likely to have hyperacusis as well as low-frequency hearing loss. Elevated SP/AP ratios also correlate with increased DPOAE responses, suggesting a relationship with altered cochlear mechanics. ECochG can be helpful in assessing tinnitus patients' psychoacoustics and understanding related symptoms, and it may provide valuable clues for individualized treatment.

## CRediT authorship contribution statement

**Ho Yun Lee:** Writing – original draft, Visualization, Validation, Supervision, Software, Methodology, Funding acquisition, Formal analysis, Data curation, Conceptualization. **Seung-Ho Shin:** Validation, Supervision, Methodology, Formal analysis. **Sung Wan Byun:** Visualization, Validation, Resources, Methodology, Formal analysis, Data curation.

## Declaration of competing interest

None to declare.

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