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Research Article

Subclinical Cochlear Dysfunctions in Migraine Patients Assessed by Otoacoustic Emissions

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Abstract

Background: Migraine is a common neurovascular condition that is increasingly recognized to affect the auditory system, even in the presence of normal hearing thresholds. Subclinical cochlear dysfunction, particularly affecting outer hair cells, has been hypothesized but not well understood. ***Objective***: To investigate cochlear function in migraine patients utilizing transient-evoked and distortion product otoacoustic emissions and to evaluate their relationship with migraine clinical characteristics and sex. ***Methods***: This case-control study involved 120 participants (60 migraine patients and 60 age/sex-matched healthy controls) aged 18–45 years. All individuals had normal otoscopy, a type A tympanogram, and normal hearing thresholds on pure tone audiometry. Cochlear function is evaluated by transient-evoked and distortion product otoacoustic emissions (TEOAE, DPOAE). Migraine severity and disability were assessed using the Visual Analog Scale (VAS) and Migraine Disability Assessment (MIDAS). ***Results***: Migraine patients had a significantly higher proportion of abnormal TEOAE responses (50.8%) than controls (0%) ($p<0.05$). DPOAE amplitudes were decreased significantly in migraine patients at all frequencies (2000-8000 Hz) while lower frequencies (1000-1500 Hz) remained unaffected. Signal-to-noise ratio values were significantly lower in migraine patients at most frequencies. Migraine patients with aura, longer illness duration, higher severity, and disability score had more cochlear damage. ***Conclusions***: Migraine is associated with frequency-dependent subclinical cochlear impairment, primarily affecting higher frequencies. This dysfunction correlates with disease severity and clinical burden, suggesting that otoacoustic emissions are a sensitive technique for evaluating and monitoring migraine-induced auditory impairment.

Keywords: Cochlear dysfunction; DPOAE; Migraine; Subclinical hearing impairment; TEOAE.

اضطرابات القوقعة تحت السريرية لدى مرضى الصداع النصفي التي تم تقييمها بواسطة الانبعاثات السمعية

الخلاصة

الخلفية: الصداع النصفي هو حالة عصبية وعائية شائعة تؤثر على الجهاز السمعي، حتى في وجود عتبات سمع طبيعية. تم افتراض خلل الوظائف القوقعية تحت السريري، خاصة الذي يؤثر على خلايا الشعر الخارجية، لكنه لم يفهم بشكل جيد. **الهدف**: دراسة وظيفة القوقعة لدى مرضى الصداع النصفي الذين يتعرضون لانبعاثات صوتية عابرة ومشوهة من المنتجات السامية النصفية وتقييم علاقتها بالخصائص السريرية والجنس للصداع النصفي. **الطرق**: شملت هذه الدراسة بين الحالة والشاهد 120 مشاركا (60 مريضا بالصداع النصفي و60 ضابطا صحيا مطابقا للعمر/الجنس) تتراوح أعمارهم بين 18 و45 عاما. جميع الأفراد خضعوا لتنظير أذن أذن طبيعي، وطيف أذن من النوع A، وعتبات سمع طبيعية في قياس السمع النقي. يتم تقييم وظيفة القوقعة بواسطة الانبعاثات الصوتية السمعية المؤقتة و بمنتجات التشوه (TEOAE, DPOAE). تم تقييم شدة الصداع النصفي والإعاقة باستخدام مقياس التناظري البصري (VAS) وتقييم إعاقة الصداع النصفي (MIDAS). **النتائج**: كان لدى مرضى الصداع النصفي نسبة أعلى بشكل ملحوظ من الاستجابات غير الطبيعية ل (50.8٪) TEOAE مقارنة بالضابطين (0٪) ($p<0.05$). انخفضت سعات DPOAE بشكل ملحوظ لدى مرضى الصداع النصفي على جميع الترددات (2000-8000 هرتز) بينما بقيت الترددات المنخفضة (1000-1500 هرتز) غير متأثرة. كانت قيم نسبة الإشارة إلى الضوضاء أقل بشكل ملحوظ لدى مرضى الصداع النصفي عند معظم الترددات. كان لدى مرضى الصداع النصفي الذين يعانون من الهالة، ومدة المرض الأطول، والشدة الأعلى، ودرجة الإعاقة ضررا أكبر في القوقعة. **الاستنتاجات**: يرتبط الصداع النصفي بضعف القوقعة تحت السريري المعتمد على التكرار، ويؤثر بشكل أساسي على التكرارات الأعلى. يرتبط هذا الخلل بشدة المرض والعبء السريري، مما يشير إلى أن الانبعاثات السمعية الحساسة تتسبب في ضعف السمع الناتج عن الصداع النصفي.

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INTRODUCTION

Migraine is a common and disabling neurovascular disorder characterized by recurrent episodes of unilateral, throbbing headache of moderate to severe intensity, lasting 4 to 72 hours. It is approximately three times more common in individuals aged 18 to 44 years than in those 65 years or older. These attacks often come with a number of neurological and sensory symptoms, such as nausea, vomiting, photophobia, and phonophobia. Migraine was classified into migraine with aura and migraine without aura according to clinical characteristics [1]. Migraines occur in 14% of the general population [2], with a higher prevalence among females [3] and a significant hereditary influence estimated at 35% to 60% [4]. Although fluctuating or sudden development of hearing loss has been reported in some migraine patients [5], the majority of migraine patients show normal results on routine audiological tests such as pure tone audiometry [6]. This demonstrates that auditory dysfunction in migraine patients might be subtle and undetected on routine hearing tests [7]. The link between migraine and cochlear dysfunction is not thoroughly understood. Several mechanisms have been proposed, including vascular, neurochemical, genetic, and central sensory

processing issues [8]. During migraine attacks, neurovascular changes such as vasospasm and altered blood flow may reduce inner ear perfusion, while neuroinflammatory processes can contribute to auditory system dysfunction at both the peripheral and central levels [9,10]. Electrophysiological investigations have provided evidence of auditory pathway involvement in migraine patients [6,11]. Otoacoustic emissions (OAEs) offer an objective and non-invasive method for evaluating cochlear function by assessing outer hair cell integrity through low-level acoustic signals recorded from the external ear canal [12-14]. According to recent studies, migraine and inner ear dysfunction may comprise a spectrum of illnesses, including failure at many levels of the auditory system, ranging from the cochlea to higher cerebral regions [15,16]. Previous studies have used otoacoustic emissions to study cochlear involvement in migraine; reduced emission amplitudes and abnormal responses have been demonstrated despite normal thresholds at pure tone audiometry [17]; however, the pattern of subclinical cochlear dysfunction and the specific frequency ranges affected remain unclear. Furthermore, important clinical variables such as migraine severity, duration, and migraine type have not received sufficient consideration. Additionally, few studies have used both transient-evoked and distortion product otoacoustic emissions (TEOAE and DPOAE) to thoroughly measure peripheral auditory function in migraine patients. Therefore, the current study aims to address these gaps and to assess subclinical cochlear impairment in migraine patients by systematically assessing auditory function using TEOAE and DPOAE and to examine its association with clinical characteristics of migraine.

METHODS

Study design and setting

This case-control study was conducted was conducted at the Otolaryngology and Audio-Vestibular Outpatient Department, College of Medicine, Mustansiriyah University, Baghdad, Iraq, from December 2025 to April 2026. A total of 120 participants were enrolled and were equally distributed among two groups. The control group was composed of 60 healthy volunteers who had no history of migraine or other neurological disorders, while the migraine group consisted of 60 patients diagnosed according to the International Classification of Headache Disorders, third edition (ICHD-3). Convenience sampling was implemented to recruit participants. Cases were recruited from the Neurology Outpatient Clinic at the hospital, while controls were recruited as healthy volunteers from the community. Prior to enrollment, each participant executed an informed consent form.

Inclusion criteria

The inclusion criteria included patients aged 18 to 45 years of age, ICHD-3 migraine diagnosis, normal otoscopic findings, Tympanometry Type A curve, and Pure Tone Audiometry (PTA) in both ears with thresholds of ≤25 dB Hearing Level (dBHL) at 0.25–8 kHz.

Exclusion criteria

The exclusion criteria comprised evidence of otologic disease, ear surgery, significant noise exposure or history of acoustic trauma, ototoxic drug use, neurologic, systemic, or psychiatric disorders affecting hearing, or alcohol consumption within 24 hours prior to testing.

Intervention procedures

Prior to audiological testing, handheld otoscopy was used to examine the tympanic membrane and external auditory canal. For additional testing, only patients who had a normal otoscopic examination were included. Tympanometry is used to assess middle ear function measurement and is carried out using the nanoTymp™ Model TY-1 MU; PATH MEDICAL GmbH, Germany, which uses a pressure level between +200 and -400 daPa (decapascals) and a probe tone of 226 Hz at 85 *dB SPL (Sound Pressure Level).* Calibration was performed in accordance with *ANSI (American National Standards Institute) guidelines;* only participants with type A tympanograms are included. Jerger's classification was used to classify tympanograms [18]. Pure tone audiometry (PTA) was performed to assess hearing thresholds. We used the SENTI clinical audiometer (PATH Medical GmbH, Germering, Germany; Serial No. 451871). Audiometric data have been acquired and analyzed using MIRA (PATH Medical GmbH, Germering, Germany) in a Sibelmed sound booth at octave frequencies from 0.25 to 8 kHz, following the modified Hughson-Westlake method [19]. The average of frequencies 0.5, 1, and 2 kHz was calculated for each participant. Otoacoustic emission (OAE) was conducted. A portable OAE screening device (Sentiero Screening, PATH Medical, REF No. 100902, Germany) was used together with the accessory kit (Accessory Box AB06); the test was performed in a sound-treated environment to minimize ambient noise. Transient Evoked Otoacoustic Emissions (TEOAE) were recorded to evaluate cochlear outer hair cell function in response to transient acoustic stimuli. A rapid sequence of broadband clicks was delivered into the ear canal through the probe loudspeaker at an intensity of approximately 75–85 dB SPL and a rate of about 50 clicks per second. Alternating stimulus polarity was used to minimize stimulus artifact. Multiple responses (typically more than 260) were collected and divided into separate buffers. The averaged responses were then analyzed in the frequency domain to determine emission amplitude across frequencies, typically ranging from 500 Hz to 4000 Hz. A response was considered present when the signal-to-noise ratio (SNR) exceeded the required threshold (≥6 dB) in at least 3 out of 5 tested frequencies. Distortion Product Otoacoustic Emissions (DPOAE) were measured to assess cochlear function using two simultaneously presented pure tones. Two

primary tones, f_1 and f_2 (where $f_2 > f_1$), were delivered into the ear canal. The frequency ratio f_2/f_1 was maintained at approximately 1.22 to maximize the emission amplitude. The stimulus intensity levels were typically L_1 = 65 dB SPL and L_2 = 55 dB SPL. The nonlinear interaction of these two tones within the cochlea produced a distortion product, primarily at the frequency $2f_1 - f_2$. This distortion product was generated mainly by the activity of the outer hair cells and was recorded by the probe microphone in the ear canal. Measurements were obtained across a range of f_2 frequencies, typically from 500 Hz to 8000 Hz. The results show the amplitude of the distortion product $2f_1 - f_2$ as a function of the stimulus frequency f_2. A response was considered valid when the emission amplitude was clearly above the noise floor. DPOAE responses were evaluated by frequency and compared between migraine patients and health controls. No established diagnostic criteria were employed to identify cochlear impairment.

Outcome measurements

Data were recorded using a standardized case record form, including the following variables: Demographic information (sex, age); clinical information (duration of migraine, type of migraine, and migraine diagnosis according to ICHD-3). To verify inclusion and exclusion criteria, medical and otologic history is taken. Migraine severity was evaluated using the Visual Analog Scale (VAS). Migraine patients evaluated their usual pain intensity during migraine episodes, rather than an average of multiple episodes over a specified duration, and the score was computed accordingly. Pain intensity was categorized as low (1-3), moderate (4-6), or severe (7-10) [20]. To assess migraine-related disability for the previous three months, the MIDAS questionnaire was utilized. Disability was rated as follows based on the overall score: Grade I, little or no disability (0–5); Grade II, mild disability (6–10); Grade III, moderate disability (11–20); Grade IV, severe disability (≥21). Minimal and mild grades were merged together as mild for statistical purposes.

Ethical considerations

The study protocol was approved by the Local Scientific Committee of the College of Medicine, Mustansiriyah University on December 11, 2025 (Certificate ID No. 9411). The study was conducted in accordance with the principles of the Declaration of Helsinki (2013 revision). Each patient provided informed consent prior to data collection, and the information was anonymized.

Statistical analysis

The data were analyzed with SPSS version 28. Continuous data was reported as mean ± SD and categorical variables as frequencies and percentages. To prevent inter-ear correlation, in DPOAE measurements, each participant's right and left ear measurements were averaged prior to analysis. In contrast, TEOAE results were documented as categorical screening results ("Pass" or "Refer"), which did not allow for averaging across ears without impairing clinically significant information. Therefore, TEOAE results were assessed on an ear-specific basis, with each ear tested independently. Independent-samples The t-test was used for comparisons between two groups, whereas one-way ANOVA with Tukey's post-hoc test was employed for comparisons between more than two groups (VAS and MIDAS). Categorical variables were tested using the chi-square test or Fisher's exact test, if appropriate. TEOAE outcomes were calculated using odds ratios (ORs) and 95% confidence intervals. When there were zero cell counts, the Haldane-Anscombe adjustment was used. Effect sizes were given using Cohen's d for t-tests with corresponding 95% confidence intervals; effect sizes were interpreted according to Cohen's criteria as small (d = 0.20–0.49), medium (d = 0.50–0.79), and large (d ≥ 0.80). and eta squared (η^2) for ANOVA analyses. η^2 values are interpreted as small = 0.01, medium = 0.06, and large = 0.14, according to Cohen's criteria. A two-tailed *p*-value < 0.05 indicated statistical significance.

RESULTS

The current study comprised 120 participants, split evenly across two groups: 60 migraine patients and 60 healthy controls. The mean age of migraine patients was 27.56 ± 7.9 years, whereas the mean age of the control group was 25.68 ± 5.8 years, with no statistically significant difference observed between the two groups ($p > 0.05$). The highest proportion of patients in both groups was aged < 30 years. Regarding sex, the proportion of females was higher than males in case and control groups (30% *vs*. 70% and 35% *vs*. 65%, respectively). There were no significant differences ($p > 0.05$) between the two groups in terms of age and sex distribution (Table 1).

Table 1: Distribution of sociodemographic characteristics in study groups (n=60 in each group)

Variable	Study groups		*p*-value
	Case	Control	
Sex			
Male	18(30)	21(35)	0.518
Female	42(70)	39(65)	
Age (year)	27.57±7.88	25.68±5.80	0.139
Age group			
< 30 years	39(65)	43(71.7)	0.548
≥ 30 years	21(35)	17(28.3)	

Values were expressed as frequency, percentage, and mean±SD. A *p*-value < 0.05 was considered statistically significant.

In this study, migraine with aura was present in 61.7% of patients, while 38.3% had migraine without aura; the duration of migraine was less than five years in 56.7% of them; a family history of migraine was positive in 63.3%; 43.3% of patients with migraine complained of moderate pain intensity, and 38.3% had severe pain intensity according to the Visual Analog Scale (Table 2). Migraine severely affects the daily activity of 17 (28.3%) of patients and moderately affects 22 (36.7%) of them, according to the Migraine Disability Assessment score (Figure 1). The TEOAE test findings revealed that, in the migraine group, a total of 61 ears (50.8%) had a refer result, whereas 59 ears (49.2%) had

normal (pass) results. In comparison, all control subjects (100.0%) had normal TEOAE responses. The difference was highly significant ($p < 0.05$). Furthermore, migraine patients had significantly higher odds than healthy controls (OR = 249.0, 95% CI: 15.1–4104.9) (Table 3).

Table 2: Distribution of case group (patients with migraine) by clinical characteristics (n=60)

Variable	Result
Type of migraine	
With aura	37(61.7)
Without aura	23(38.3)
Duration of migraine (years)	
< 5	34(56.7)
5 – 10	17(28.3)
> 10	9(15)
Family history of migraine	
Yes	38(63.3)
No	22(36.7)
Pain intensity (VAS)	
Mild	11 (18.3)
Moderate	26 (43.3)
Severe	23 (38.3)

Categorical values were expressed as frequency and percentages, (VAS): Visual Analog Scale.

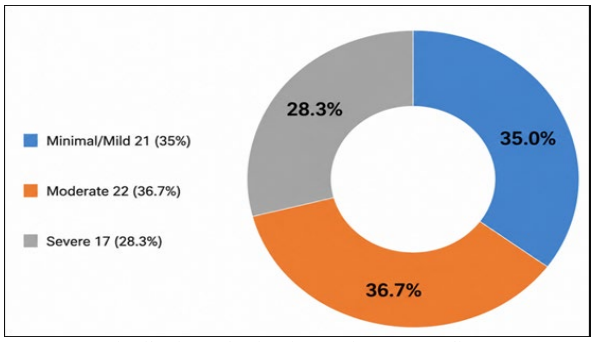

Figure 1: Distribution of migraine patients according to MIDAS disability categories. Combined minimal and mild disability grades were (n=21, 35.0%), while moderate and severe disability were (n=22, 36.7%) and (n=17, 28.3%), respectively.

Table 3: Distribution of study patients by TEOAE test (n=120 in each group)

TEOAE test	Case	Control	OR	95%CI	*p*-value
Refer	61(50.8)	0(0.0)	249	15.1-4104.9	<0.001
Pass	59(49.2)	120(100)			

(n) represents no. of ears, values were expressed as frequency, percentage, p-value < 0.05 was considered statistically significant. TEOAE: Transient Evoked Otoacoustic Emissions, OR: Odds Ratio; CI: Confidence Interval.

The DP level was significantly lower ($p< 0.05$) in cases than that in controls at frequencies ranging from 2000 to 8000 Hz ($p < 0.05$). However, no significant differences were seen at 1000 or 1500 ($p > 0.05$) (Table 4). The SNR level was significantly lower ($p < 0.05$) in cases than that in controls in all frequencies except in the frequency of 1000 Hz; no significant differences were detected ($p> 0.05$) between study groups (Table 4). There are no significant differences in DPOAE ($p\geq 0.05$) in all frequencies between males and females suffering from migraine (Table 5). Patients who had migraine with aura had significantly lower DP level ($p< 0.05$) in frequencies of 2000-8000 Hz (Table 6). Patients who had migraines for five years' duration or more had significantly lower DP levels ($p< 0.05$) in frequencies of 2000-8000 Hz (Table 7). Significant differences in DP levels were detected among VAS severity groups at frequencies between 2000 and 8000 Hz ($p< 0.05$); patients experiencing significant pain intensity exhibited the lowest mean DP amplitudes across these frequencies (Table 8). Patients with severe MIDAS scores in migraine had significantly lower DP levels ($p< 0.05$) in frequencies of 2000-8000 Hz than those who had mild or moderate MIDAS scores (Table 9).

Table 4: Comparison in DP level and SNR in DPOAE between study groups (n-60 in each group)

Frequency (Hz)	DP Level (dB SPL)		*p*-value	Effect size (Cohen's d)	95%CI
	Case	Control			
1000	6.29± 5.0	5.29±6.51	0.349	0.17	[-0.19, 0.53]
1500	8.42±4.84	8.60±4.35	0.831	-0.04	[-0.40, 0.32]
2000	5.29±5.63	7.55±4.0	0.013	-0.46	[-0.82, -0.10]
3000	3.46±4.38	5.21±4.04	0.025	-0.42	[-0.78, -0.06]
4000	3.18±5.54	10.06±4.72	<0.001	-1.34	[-1.74, -0.94]
5000	3.63±7.14	11.79±5.01	<0.001	-1.32	[-1.72, -0.92]
6000	1.21±7.31	7.27±5.12	<0.001	-0.96	[-1.34, -0.58]
8000	-6.2±8.33	-3.28±6.18	0.031	-0.40	[-0.76, -0.04]
Frequency (Hz)	SNR (dB SPL)		*p*-value	Effect Size (Cohen's d)	95%CI
	Case	Control			
1000	5.50±4.3	7.10±5.77	0.087	-0.32	[-0.68, 0.04]
1500	8.85±3.68	11.84±3.53	<0.001	-0.83	[-1.20, -0.46]
2000	8.60±3.8	12.72±2.77	<0.001	-1.24	[-1.63, -0.85]
3000	8.03±3.7	12.22±2.68	<0.001	-1.29	[-1.68, -0.90]
4000	8.71±2.82	13.10±3.14	<0.001	-1.47	[-1.87, -1.07]
5000	9.15±3.21	16.03±1.56	<0.001	-2.73	[-3.23, -2.23]
6000	8.84±4.94	15.64±2.5	<0.001	-1.74	[-2.16, -1.32]
8000	3.08±7.47	9.67±4.05	<0.001	-1.10	[-1.48, -0.72]

Values were expressed as mean±SD. A p-value < 0.05 was considered statistically significant. Cohen's d<0.20: Negligible, 0.20–0.49: Small ,0.50–0.79: Medium, ≥0.80: Large, CI: confidence interval, SNR: Signal to noise ratio, DPOAE: Distortion product otoacoustic emission.

DISCUSSION

It is important to assess cochlear function in migraine patients because auditory system involvement may reflect early neurovascular and sensory dysfunction, which may contribute to disease progression and increase symptom burden [21]. The majority of participants in the present study were young adults, which aligns with global epidemiological data indicating that migraine is particularly prevalent

among adolescents and young adults. This finding is consistent with previous studies showing that individuals aged 15–39 years represent a highly vulnerable group for the onset and burden of migraine [22,23].

Table 5: Comparison of DP level in the case group according to SEX

Frequency (Hz)	DPOAE according to SEX		*p*-value	Effect size (Cohen's d)	95%CI
	Male (n=18)	Female (n=42)			
	DP Level				
2000	4.64±3.42	5.56±6.36	0.468	-0.16	-0.69 to 0.37
3000	4.93±4.84	2.83±4.06	0.119	0.49	-0.05 to 1.03
4000	3.18±7.78	3.18±4.36	0.999	0.00	-0.53 to 0.53
5000	2.68±10.33	4.04±5.34	0.603	-0.19	-0.72 to 0.34
6000	0.24±8.27	1.62±6.92	0.537	-0.19	-0.72 to 0.34
8000	-6.67±8.65	-6.02±8.29	0.789	-0.08	-0.61 to 0.45

Values were expressed as mean±SD. A *p*-value < 0.05 was considered statistically significant. Cohen's d<0.20: Negligible, 0.20–0.49: Small, 0.50–0.79: Medium, ≥ 0.80: Large, CI: confidence interval.

Table 6: Comparison of DP level in the case group according to the type of migraine

Frequency	DPOAE according to migraine type		*p*-value	Effect Size (Cohen's d)	95%CI
	With aura (n=37)	Without aura (n=23)			
	DP Level				
2000	3.82±5.41	7.64±5.25	0.009	-0.71	-1.24 to -0.18
3000	1.99±3.26	5.83±4.94	0.002	-0.97	-1.54 to -0.40
4000	1.5±4.58	5.87±5.96	0.005	-0.85	-1.40 to -0.30
5000	1.74±6.33	6.67±7.45	0.012	-0.73	-1.27 to -0.19
6000	-1.44±5.1	5.46±8.37	0.001	-1.06	-1.65 to -0.47
8000	-9.07±6.53	-1.61±8.97	0.001	-0.99	-1.57 to -0.41

Values were expressed as mean±SD. A *p*-value< 0.05 was considered statistically significant. Cohen's d< 0.20: Negligible, 0.20–0.49: Small, 0.50–0.79: Medium, ≥ 0.80: Large, CI: confidence interval.

Table 7: Comparison of DP level in the case group according to the duration of migraine

Frequency (Hz)	DPOAE according to migraine duration (year)		*p*-value	Effect Size (Cohen's d)	95%CI
	<5 (n=34)	≥5 (n=26)			
	DP Level				
2000	6.71±5.01	3.54±5.93	0.032	0.58	0.05 to 1.11
3000	5.21±4.46	1.33±3.22	<0.001	0.98	0.40 to 1.56
4000	4.97±5.75	0.98±4.44	0.004	0.77	0.22 to 1.32
5000	5.53±7.38	1.30±6.2	0.019	0.62	0.08 to 1.16
6000	3.53±7.97	-1.63±5.28	0.004	0.75	0.20 to 1.30
8000	-4.25±8.84	-8.60±7.11	0.039	0.54	0.01 to 1.07

Values were expressed as mean±SD. A *p*-value< 0.05 was considered statistically significant. Cohen's d< 0.20: Negligible, 0.20–0.49: Small, 0.50–0.79: Medium, ≥ 0.80: Large, CI: confidence interval.

Table 8: Comparison of DP level in the case group according to (VAS)

Frequency (Hz)	DPOAE according to (VAS)			*p*-value	Effect size (η^2)
	Mild (n=11)	Moderate (n=26)	Severe (n=23)		
	DP Level				
2000	10.01±5.72	5.16±3.33	3.17±6.44	0.003	0.187
3000	8.12±5.42	4.58±2.14	-0.02±2.8	<0.001	0.487
4000	9.07±4.5	5.31±2.36	-2.05±3.91	<0.001	0.625
5000	10.76±4.36	6.26±3.12	-2.75±6.39	<0.001	0.557
6000	10.76±4.0	1.93±5.01	-4.17±5.57	<0.001	0.534
8000	0.23±9.17	-4.67±6.69	-11.03±7.01	<0.001	0.257

Values were expressed as mean±SD. A *p*-value< 0.05 was considered statistically significant, VAS: Visual Analogue Scale. η^2 values interpreted as small: 0.01, medium: 0.06, and large: 0.14, according to Cohen's criteria.

Table 9: Comparison in DP level in case group according to MIDAS

Frequency (Hz)	DPOAE according to MIDAS			*p*-value	Effect size (η^2)
	Severe (n=17)	Moderate (n=22)	Minimal/Mild (n=21)		
	DP Level				
2000	3.46±6.93	4.27±4.08	7.83±5.16	0.030	0.116
3000	-0.34±3.04	2.85±1.95	7.18±4.24	<0.001	0.481
4000	-2.54±4.43	3.27±3.11	7.72±3.88	<0.001	0.547
5000	-3.22±7.42	4.0±4.39	8.79±4.26	<0.001	0.452
6000	-5.23±5.66	-0.86±4.15	8.58±4.11	<0.001	0.615
8000	-13.56±5.85	-6.23±4.7	-0.24±8.42	<0.001	0.407

Values were expressed as mean±SD. A *p*-value< 0.05 was considered statistically significant, MIDAS: Migraine Disability Assessment. η^2 values interpreted as small: 0.01, medium: 0.06, and large: 0.14, according to Cohen's criteria. Minimal and mild grades merged together as mild for statistical purposes.

Females predominated in this study, which is consistent with the well-established epidemiological pattern of migraine and with prior studies reporting that migraine occurs in females approximately three times more frequently than in males, particularly during the reproductive years [24,25]. This sex difference is largely attributed to hormonal influences, as fluctuations in female sex hormones, particularly

estrogen, are known to play a significant role in triggering migraine attacks and modulating disease activity across different stages of a woman's life [26,27]. According to the current study, most patients reported migraines with aura. A previous study documented similar results, revealing that a significant percentage of migraine cases among patients visiting neurology clinics included aura [28]. In contrast, another study reported that around 15% to one-third of migraine patients experience aura [29]. Variations in diagnostic criteria, research populations, and healthcare-seeking behavior may account for differences in the reported prevalence of migraine with aura between studies, as patients with aura symptoms often seek medical attention due to neurological manifestations, such as visual disturbances or sensory symptoms, prior to migraine attacks. Nearly half of the migraine patients had a disease duration of less than five years. This finding is consistent with a previous study; the average disease duration among migraine patients was 57.7 months [30]. Several factors may explain this finding. First, patients are more likely to seek medical attention during the early stages of migraine, when symptoms are more frequent or severe. Second, the relatively young age of the study population might have contributed to the shorter disease duration reported. The higher prevalence of positive family history in our population further supports the well-established genetic contribution to migraine, as previous research has shown that migraine tends to cluster in families and is influenced by multiple genetic susceptibility factors [31]. A positive family history may contribute to the greater severity of migraines and the earlier age of onset. Most migraine patients in the current study experienced moderate-to-severe pain intensity, which is consistent with the findings of a previous study reporting that migraine patients' mean VAS score reflected moderate-to-severe headache intensity [32]. The prevalence of moderate to severe pain intensity may be explained by the underlying neurobiological mechanisms of migraine, such as trigeminovascular activation, calcitonin gene-related peptide (CGRP) release, and central sensitization, all of which contribute to enhanced pain perception [33]. Migraine has had a significant impact on daily activities, with most patients reporting moderate and others experiencing severe disabilities. This finding is consistent with a previous study, in which migraine patients had an overall mean MIDAS score of 14 [34], indicating moderate functional impairment based on MIDAS. The substantial impact of migraines on day-to-day activities may be explained by the recurrent pattern of migraine attacks and the accompanying symptoms, which include severe pain, phonophobia, and cognitive impairment. Migraine patients had a significantly higher proportion of abnormal transient evoked otoacoustic emission (TEOAE) responses compared to controls, indicating possible outer hair cell dysfunction. This finding is consistent with a previous study, which reported that migraine patients, when compared to healthy individuals were more likely to exhibit altered outcomes in OAE without having clinically evident hearing impairment [15]. Another study involving 94 participants reported that otoacoustic emissions were present only in 67.5% of migraine patients [17]; in contrast, another study showed no significant difference was found in the TEOAE test between migraine patients and controls [11]. These discrepancies may be attributed to differences in migraine characteristics, disease severity, study populations, and diagnostic criteria. Migraine is thought to have a vascular origin, and one of the underlying causes is reduced cerebral vascular reactivity. Recurrent vasospasm and reduced cochlear perfusion can cause ischemic damage to the outer hair cells, resulting in reduced otoacoustic emission responses in migraine patients [6]. The DP level was significantly lower in migraine patients compared to controls at mid- and high frequencies. These findings are consistent with a previous study, which reported that DPOAE amplitudes were significantly lower in migraine patients at frequencies of 1, 2, 3, and 5 kHz [35]. In contrast, another study found DPOAE amplitudes were lower in migraine patients compared to controls, but the difference was not statistically significant [36]. No significant differences were detected at low frequencies between study groups; these findings are consistent with a previous study in which DPOAEs, used to evaluate the cochlea in a frequency-specific manner, did not reveal any abnormalities in controls and migraine patients below 5 kHz frequency [17], suggesting that the lower frequency may be less sensitive in identifying early cochlear impairment. DPOAE is better at assessing higher frequency ranges and provides accurate frequency-specific detection of cochlear impairment. DPOAE is more useful in assessing higher frequencies because the basal turn of the cochlea is more sensitive to ischemia and inflammatory damage, making high-frequency alterations an early sign of cochlear malfunction [15]. The observed reduction in the signal-to-noise ratio (SNR) in migraine patients compared to controls at all examined frequencies is consistent with a previous study reporting that migraine patients had a lower SNR than the control group, suggesting potential subclinical cochlear impairment [37]. A decrease in SNR suggests that the emission signal is weaker relative to background noise, suggesting reduced efficiency of the cochlear amplifier. Migraine-related neurovascular and neuroinflammatory processes may explain cochlear abnormalities in this study. The trigeminovascular system and vasoactive neuropeptides, such as CGRP, can cause vasodilation, plasma extravasation, and acute cochlear hypoperfusion. These modifications can damage the metabolically active striae vascularis and outer hair cells, which are vulnerable to blood supply and metabolic stress. Thus, recurring migraine attacks may cause subtle cochlear impairment, such as diminished otoacoustic emission responses, despite normal hearing thresholds. Patients with longer disease duration, higher pain intensity, and greater disability have greater cochlear impairment, supporting migraine-related neurovascular dysfunction's cumulative effect on cochlear integrity [37,35].

Regarding sex differences among patients, the current study suggests that sex does not significantly influence outer hair cell function in migraine patients. Despite well-established sex differences in migraine incidence and clinical features [25,26], these variations did not appear to extend to auditory function as measured by DPOAE. These findings may suggest that cochlear outer hair cell malfunction in migraine is more closely linked to the underlying illness pathophysiology than to sex-related hormonal variations. Previous studies have mostly compared migraine patients to healthy controls and demonstrated evidence of cochlear involvement [6,17]. However, gender-based analysis within migraine populations remains limited. In patients with migraine with aura, the DP level was significantly lower than in those with migraine without aura, which is consistent with previous studies. At frequencies of 1, 3, 4, 5, and 6 kHz, patients with migraine with aura (MA) showed considerably lower DPOAE amplitudes than patients with migraine without aura (MoA) [15]. Another study also reported that DPOAE amplitudes in MA were significantly lower [17]. The more severe neurovascular and neuroinflammatory processes associated with migraine with aura, which can have a deleterious influence on cochlear blood flow and micromechanics, may explain the greater decline in DPOAE amplitude found in those with aura [36]. This finding further supports the hypothesis that migraine with aura may represent a more severe clinical subtype of migraine, affecting cochlear function more severely. Regarding patients with migraines of five years' duration or more, they exhibited significantly lower DP compared to those with a shorter disease duration. This finding is supported by a previous study that reported a strong association between the disease duration and hearing impairment (p= 0.023), indicating that prolonged migraine duration may have a role in the development of cochlear impairment [37]. The cumulative effect seen in this study is supported by the hypothesis that a prolonged disease duration may lead to gradual cochlear alterations that may be detected by otoacoustic emissions across multiple frequencies [38]; in contrast, a previous study identified significant negative correlations between disease duration and amplitude of DPOAE at 1000, 1500, 2000, 3000, and 5000 Hz [35]. The current study showed that individuals with severe disability in MIDAS scores and patients with higher pain intensity according to the VAS scale had significantly lower DPOAE amplitudes, suggesting greater cochlear dysfunction. Few studies have specifically looked at the relationship between MIDAS score, VAS scale, and DP level in DPOAE. The results of the current study are supported by studies reporting that lower otoacoustic responses are associated with greater clinical severity in migraine patients, which tends to be connected with increasing cochlear involvement. This relationship may be mediated by recurrent neurovascular and neuroinflammatory mechanisms that disrupt cochlear perfusion and outer hair cell integrity, resulting in reduced cochlear amplifier performance [17]. Cortical spreading depression and transitory vascular hypoperfusion associated with migraine may further impair cochlear microcirculation, resulting in increased outer hair cell dysfunction [39]. These findings suggest that migraine may exert a cumulative effect on hearing function and highlight the necessity of detecting cochlear damage early in individuals with more severe disease.

Study Limitations

The present study has a relatively small sample size, and the assessment of cochlear function was limited to otoacoustic emissions without the inclusion of additional auditory measures, such as electrocochleography, due to limited availability. In addition, the current study made no distinction between participants assessed during migraine episodes and those evaluated during interictal periods. Furthermore, the possible influence of current migraine medications was not precisely controlled. These factors may have affected the auditory findings. Future studies with a larger sample size and more comprehensive auditory assessment, including stratification of patients based on attack state and treatment use, are recommended to further clarify these findings.

Conclusion

This study demonstrates that migraine is associated with subclinical cochlear dysfunction, as evidenced by altered otoacoustic emission responses. This cochlear involvement is more prominent in patients with migraine with aura and in those with greater disease severity and disability, suggesting a possible relationship between migraine severity and cochlear function. These findings highlight the clinical value of otoacoustic emissions as a sensitive and non-invasive tool for the evaluation and monitoring of migraine patients.

Conflict of interests

The authors declared no conflict of interest.

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Data sharing statement

The datasets generated and analyzed during the current study are available from the corresponding author upon reasonable request.

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