Auditory and Vestibular Research

Audiological Signatures of Posterior Fossa Lesions: Insights from Hearing Thresholds and Brainstem Responses

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Highlights

PTA reveals significant differences in hearing threshold severity across lesion types
Higher thresholds are noted in schwannoma compared to vascular loop and meningioma
ABR testing complements PTA by providing objective auditory pathway measures

Abstract

Background and Aim: Posterior fossa lesions often present with slowly progressive hearing loss, making diagnosis challenging. Pure-tone audiometry (PTA) and the Auditory Brainstem Response (ABR) are essential tools for assessing retro-cochlear involvement and establishing hearing thresholds. This study aimed to assess the audiometric profiles of patients with posterior fossa lesions and ascertain whether they could distinguish between different types of lesions.

Methods: A cross-sectional study was conducted on 36 patients aged 10-65 years. Each participant underwent otoscopic examination, tympanometry, PTA, and ABR testing. The data were analyzed using the chi-square and Kruskal-Wallis tests in SPSS version 25, with Cohen's f and Cramer's V for effect size. A p-value of less than 0.05 was considered significant.

Results: Lesion types showed a strong correlation with clinical presentation. Vascular loops were associated with tinnitus, vestibular schwannomas with facial numbness and hearing loss, and meningiomas with vertigo and headache. Schwannoma cases exhibited significantly higher ipsilateral hearing thresholds, especially at high frequencies ($p < 0.05$). ABR results varied by lesion type: vascular loops mostly caused delayed wave III, meningiomas produced prolonged wave V and I–V intervals, while schwannomas showed the most severe abnormalities, including missing or delayed waves and interpeak intervals. Contralaterally, only schwannomas displayed ABR delays in wave V and I–V interval.

Conclusion: Lesion differentiation was aided by the clinical and audiological characteristics of posterior fossa lesions. ABR offers objective data on retro-cochlear involvement, while PTA identifies changes in hearing threshold. When used together, they improved diagnostic precision and patient care.

Keywords: Auditory brain stem response, hearing loss, posterior cranial fossa, pure-tone audiometry, vascular loops, vestibular schwannomas

Introduction

The brainstem, cerebellum, and cranial nerves III–XII are vital components of the posterior cranial fossa (PCF), making up only one-eighth of the entire brain volume. Because of this complex structure, even small lesions can

significantly affect neurological, vestibular, and auditory functions. Vestibular schwannomas (VS), meningiomas, and vascular anomalies such as vascular loops are common posterior fossa lesions that mostly affect cranial nerves VII and VIII [1]. The Schwann cells of the vestibular branch of the eighth cranial nerve are the source of benign, slowly developing tumors known as vestibular schwannomas. They often reach the cerebellopontine angle (CPA) cistern from the internal auditory canal (IAC) [2]. Unilateral sensorineural hearing loss (SNHL), tinnitus, imbalance, and, in cases of larger tumors, facial numbness or ataxia are common clinical manifestations of VS [3]. Meningiomas develop from arachnoid cells and have a slower growth rate. Their symptoms are more variable and milder than those of VS, and they often induce tinnitus, hearing loss, headaches, and sometimes cranial nerve impairments [4]. Vascular loops are an underrecognized potential cause of audio-vestibular complaints, especially when they include the anterior inferior cerebellar artery (AICA). Due to local demyelination and ephaptic transmission, recurrent nerve compression by these loops may result in episodic vertigo, tinnitus, or hearing loss [5]. For the early detection of these lesions, audiological examination is essential. The most reliable subjective technique for determining hearing sensitivity is pure-tone audiometry (PTA). Asymmetrical hearing thresholds are frequently observed in retro-cochlear lesions, which usually present as flat or sloping audiometric configurations [6]. The objective Auditory Brainstem Response (ABR) test evaluates the auditory pathway from the cochlea to the brainstem. When imaging is not available, ABR is very helpful in identifying retro-cochlear dysfunction [7]. ABR frequently exhibits extended interpeak intervals (I–III, I–V) and prolonged absolute latency of wave V in vestibular schwannoma [8]. Although numerous studies have characterized PTA and ABR findings in vestibular schwannomas, fewer have directly compared the audiological profiles of different posterior fossa lesions. In particular, the diagnostic contributions of PTA and ABR in differentiating vestibular schwannomas, meningiomas, and vascular loops remain underexplored. This study aimed to evaluate and compare audiometric and electrophysiological findings across these three lesion types, to identify distinctive diagnostic patterns that may enhance early detection and support interdisciplinary clinical management.

Methods

Ethical Approval and Study Design

The study was approved by the Ethical Committee of Mustansiriyah University's College of Medicine [Ethical code: 8038, dated 29/10/2024]. Informed consent was collected from each patient before data collection.
This prospective cross-sectional study was conducted from October 2024 to May 20٢5. Due to the uncommon nature of posterior fossa lesions, purposive sampling was used, and only clinically stable patients referred from the Neurosurgery Department at Ghazi Al-Hariri Hospital to the Otolaryngology and Audio-Vestibular Consultation Unit were included.

Participants

A total of 36 patients who met the inclusion criteria were enrolled. Males and females between 10 and 65 years who had MRI-confirmed posterior fossa lesions, normal middle ear function (type A tympanogram), and clinically stable were eligible. The age range was restricted to minimize the confounding effect of age-related hearing loss. Patients were excluded if they presented with conductive or mixed hearing loss, were exposed to confounding factors (chronic loud noise, cognitive impairment, ongoing use of ototoxic medications), or had a history of skull or ear surgery.

Assessments

The researcher and supervisory faculty created a detailed questionnaire that gathered comprehensive data, including demographic information (age, sex, and occupation), symptom history (hearing loss, tinnitus, vertigo, balance disorders, facial numbness, headaches, and neurological issues), medical history (neurological conditions, noise exposure, and ototoxic medications), and surgical history. Each participant subsequently underwent a complete audiological and imaging assessment, performed under standardized clinical conditions.
Otoscopic examination was first conducted to assess the external auditory canal and eardrum for color, position, and retraction. Tympanometry was then performed using the Otowave Model 102 tympanometer (Amplivox Ltd., Oxfordshire, UK), with a 226 Hz probe tone; tympanograms were categorized using Jerger's classification system [9]. The pure-tone audiometry was carried out using a clinical audiometer (Amplivox Ltd., Serial No. 323514,

manufactured in Oxfordshire, UK) in a sound booth compliant with ANSI standards. Bone conduction testing was done using B-71 bone vibrator (500 Hz–4 kHz), and air conduction testing was done using DD45 supra-aural headphones (250 Hz–8 kHz). Hearing thresholds were established using the modified Hughson-Westlake method, and Hearing degree classification was based on Goodman's standards [10].

The neurodiagnostic auditory brainstem response (ABR) was performed using the PathMedical SENTIERO Advanced system (Model SOH100360, Serial No. 303438, manufactured by PATH Medical GmbH, Landsberger Str. 65, 82110 Germering, Germany). Insert earphones (PIEP IP-05) were calibrated to ANSI standards, with a maximum stimulus level tested at 95 dB nHL. Stimuli consisted of 0.1 ms clicks presented at 80 dB nHL, alternating polarity, with a presentation rate of 19.9 Hz. Signals underwent band-pass filtering between 80 and 2000 Hz. An artifact rejection threshold of ±7 µV was implemented. Responses were documented within a 15 ms analysis window following stimulus onset. Disposable surface electrodes were positioned on the high forehead (non-inverting), ipsilateral mastoid (inverting), and cheek/ground, ensuring electrode impedance remained below 5 kΩ and inter-electrode differences were kept under 2 kΩ. Averaged data consisted of 2000 accepted sweeps per trial, with a minimum of two replications to confirm the reproducibility of waveforms. Contralateral masking was implemented by administering broadband white noise to the non-test ear at 40 dB SL. Absolute latencies (waves I, III, V) and inter-peak latencies (IPLs: I–III, III–V, I–V) were judged against published normative means and SDs [8]. Values > mean + 2 SD were classified as delayed. The cut-off limits applied were: Wave I > 1.99 ms, Wave III > 4.07 ms, Wave V > 5.93 ms, I–III > 2.40 ms, III–V > 2.22 ms, I–V > 4.44 ms. Cases where reproducible ABR waveforms were not obtained at the maximum stimulation level were classified as no waves.

Magnetic resonance imaging with contrast was utilized to confirm lesion type using specific sequences designed for posterior fossa imaging, including T1, T2, FLAIR, CISS, DWI, and post-gadolinium T1. At Ghazi Al-Hariri Hospital, experienced radiologists examined and analyzed the images to guarantee accurate assessment.

Data Analysis

The statistical analysis was conducted using IBM Corp.'s SPSS version 25. Descriptive data were shown as percentages, frequencies, and mean ± standard deviation. Data normality was evaluated using the Shapiro-Wilk test. Due to uneven group sizes and non-normal distributions, the Kruskal-Wallis test was employed to compare continuous variables (frequency-specific thresholds), while the Chi-square test was employed for categorical variables (symptoms, audiometric patterns, and ABR abnormalities). Effect sizes were calculated to complement p-values and quantify the strength of associations: Cramer's V was reported for Chi-square tests, with thresholds for interpretation as small ($V \approx 0.1$), medium ($V \approx 0.3$), and large ($V \geq 0.5$) while for the Kruskal–Wallis test the effect size was expressed as Cohen's f, with interpretation thresholds of small ($f \approx 0.10$), medium ($f \approx 0.25$), and large ($f \geq 0.40$) [11]. Statistical significance was defined as a p-value < 0.05.

Results

The study included 36 patients, with ages ranging from 23 to 64 years and a mean age of 42.61 ± 12.62 years. Approximately one-third of patients (12, 33.3%) were between 40 and 49 years. Regarding sex, 20 were male (55.6%) and 16 were female (44.4%), resulting in a male-to-female ratio of approximately 1.25:1. In terms of employment, employees were the predominant group (16 patients; 44.4%), followed by housewives (14 patients; 38.9%). The most common first noticed symptom was tinnitus, in 15 patients (41.6%), followed by hearing loss in 11 patients (30.6%).

The distribution of posterior fossa lesions in the study was as follows: 18 patients (50%) had vascular loops (13 unilateral and 5 bilateral), 10 patients (27.8%) had VS, and 8 patients (22.2%) had meningiomas. Significant correlation was found between lesion type and clinical presentation using a chi-square test, indicating that each lesion has a unique symptom profile. Vestibular schwannomas were substantially more likely to be associated with hearing loss and facial numbness, while vascular loop patients more frequently reported tinnitus. In contrast, meningioma patients experienced headache, vertigo, and dizziness significantly more often than the other two lesions. All lesions produced symptoms exclusively ipsilateral to the lesion. (**Table 1).**

Analysis of symptom distribution by lesion type revealed that vascular loops contributed nearly half of all hearing loss cases (46.2%) and over two-thirds of tinnitus cases (68.0%). Meningiomas were responsible for half of the dizziness cases (50.0%), whereas facial numbness was predominantly attributed to schwannoma (77.8%) **(Figure 1).**

According to chi-square analysis of audiograms in the ipsilateral ears, 60% of vestibular schwannomas exhibited a flat pattern, and 40% showed a sloping pattern. A sloping pattern was present in 56.5% of vascular loop cases, whereas meningiomas were distributed equally (50% flat, 50% sloping). All lesion types in the contralateral ears primarily showed a flat pattern (100%). There was no significant correlation between lesion type and the audiogram pattern in either ear (**Table 2).**
In the ipsilateral ears, frequency-specific air conduction thresholds exhibited significant differences across lesion types, as verified by the Kruskal-Wallis test. The average thresholds at all assessed frequencies were markedly elevated in schwannoma patients compared to meningiomas and vascular loops. The disparity was most evident at higher frequencies, with the maximum mean threshold seen at 8000 Hz. Conversely, thresholds in the contralateral ears exhibited no significant variation between lesion types and remained within normal (**Table 3)**.

ABR abnormalities differed by type of lesion in the ipsilateral ears. There were delayed wave III (69.6%) and V (60.9%) in vascular loops, with I–III and I–V interval prolonged in 52.2% and 43.5% of cases, respectively; 8.7% of responses were missing. Prolonged waves V and III were seen in 87.5% and 37.5% of meningiomas, respectively, along with inter-wave delays (III–V: 50% and I–V: 62.5%) and no missing responses. Schwannomas demonstrated absent responses in 40% of cases; inter-wave intervals (I–III and III–V: 40%), wave V (60%), wave III (40%), and I–V (60%) displayed delays. Except for wave I, there was a significant correlation between lesion type and ABR abnormalities.
Contralateral ear: ABR responses were mainly normal, except in schwannoma cases, which showed notable I–V interval and wave V delays (**Table 4–5)**.

Discussion
Meningiomas, vestibular schwannomas, and vascular loops are posterior fossa lesions affecting important neurological and auditory functions. This study evaluated their demographic, audiometric, symptomatic, and ABR profiles to identify diagnostic trends. The average age was 42.6 years with a slight male predominance (1.25:1), mostly between 40–49 years. This contrasts with a prior meningioma study that found a mean age of 44 years and female predominance [12]. While a study on vascular loops revealed varying demographics, with some pointing to male predominance [13], another reported balanced gender distribution and older average patient age, likely due to differences in lesion types and inclusion criteria [14]. The most frequent initial symptom was tinnitus, followed by hearing loss, consistent with research showing tinnitus as a precursor to cochlear nerve involvement in lesions of the posterior fossa [1]. In contrast, some research reported that hearing loss was the first symptom and that tinnitus appeared later, especially in cases of vestibular schwannoma, when tinnitus frequently follows hearing loss [15]. Variability in posterior fossa lesion symptoms likely reflects variations in patient demographics, lesion type, and diagnostic timing. Although vestibular schwannomas (75–85%), meningiomas (10–15%), and epidermoid cysts (7–8%) were identified as prevalent CPA tumors in earlier publications [16], our results differed since vascular loops were included. Vascular loops were the most common in our population (50%), followed by meningiomas (22.2%) and vestibular schwannomas (27.8%). Vascular loops may be incidental MRI findings in as many as 47.6% of patients [17]. Therefore, unilateral tinnitus should raise suspicion of posterior fossa pathology, particularly when accompanied by audio-vestibular symptoms. The symptomatic presentation in our study supports their potential causal role, consistent with earlier research that linked vascular loops to sensorineural hearing loss and tinnitus due to persistent nerve irritation [18]. Symptom profiles varied by lesion type. Due to compressive effects of vestibular schwannomas on cranial nerves VII and V, patients with VS mostly manifested with hearing loss, facial numbness, or sensory abnormalities [19]. Vascular loops, on the other hand, were associated with tinnitus without obvious neurological symptoms, confirming the theory of persistent nerve stimulation without significant structural harm [14]. Due to compression of central structures such as the brainstem and cerebellum, patients with meningiomas were more likely to experience headache, vertigo, and dizziness [20]. These distinctive patterns highlight the importance of comprehensive clinical evaluation for accurate lesion differentiation. Flat audiograms were most frequently linked to VS cases (60%) and are probably caused by broad auditory nerve compression that affects all frequencies [21]. Sloping audiograms, which are usually indicative of high-frequency hearing loss resulting from localized ischemia of the cochlear basal turn, were more common in vascular loops (56.5%) [22]. Our results imply that a small percentage of vascular loops might contribute to symptomatic SNHL, despite conflicting research on the relationship between vascular loop type and hearing loss pattern [23]. In line with earlier

researches that reported different presentations depending on tumor size and proximity to auditory channels [24,6], meningioma cases showed diverse audiometric configurations, with both flat and sloping patterns occurring equally (50%). The sample size in our investigation and the chronicity of the lesions likely contributed to the lack of a significant correlation between lesion type and audiogram pattern, indicating that audiogram configuration alone was not a valid marker for differentiating posterior fossa lesions. Clinically, audiogram shape alone is not useful and should be combined with symptom history, quantitative thresholds, and ABR results for better lesion classification.

Particularly in VS patients, who showed the largest threshold increases across all frequencies, frequency-specific hearing thresholds displayed the most severe impairments on the lesion side. Meningiomas followed in severity, followed by vascular loops. These lesions had a significant side-specific impact on hearing function, as seen by the relatively preserved contralateral ears [25]. The pattern seen in VS was consistent with a previous study that linked progressive auditory nerve compression, outer hair cell failure, and local inflammatory responses to high-frequency degradation [6]. On the other hand, the smaller increase in thresholds linked to vascular loops might be the result of sporadic irritation as opposed to widespread nerve injury [18]. Across lesion types, pure-tone thresholds in our study demonstrated a stepwise increase in severity, with vascular loops exhibiting the least elevation, meningiomas presenting intermediate losses, and vestibular schwannomas providing the most obvious impairments. This progression reflects the increasing extent of cochlear nerve involvement, ranging from isolated neurovascular irritation to ongoing tumor compression. Despite significant group-level variations, considerable overlap in the absolute threshold values was observed. For example, the mean thresholds for vascular loops, meningiomas, and schwannomas were 42 ± 19 dB, 49 ± 16 dB, and 75 ± 13 dB, respectively, at 8000 Hz; a patient with a meningioma threshold of 65 dB would fall within the schwannoma range. This overlap reduces PTA's diagnostic accuracy on a case-by-case basis [26].

The auditory brainstem response results revealed different electrophysiological patterns according to lesion type, providing information about the pathophysiology of posterior fossa involvement. Prolonged I–III and I–V interpeak intervals, delayed Wave V latencies, and missing waveforms were common characteristics of vestibular schwannomas. Axonal compression and localized demyelination are consistent with delayed conduction between the lower brainstem and the distal eighth cranial nerve, as indicated by the expansion of the I–III interval. There was a delay in the I–V interval, which includes the entire auditory brainstem pathway, indicating a more extensive effect of tumor mass on brainstem conduction. Greater loss of synchronous neural firing, a hallmark of advanced nerve impairment and mass displacement, is shown by the absence of repeatable waveforms in vestibular schwannomas [10]. An electrical signature distinctive to meningiomas was observed. There was no apparent increase in the I–III interval or prior waves, and the main anomaly was a delay in Wave V, accompanied by inter-wave prolongations (I–V and III–V). This suggests that whereas subsequent transmission at the lateral lemniscus and inferior colliculus was compromised, conduction from the cochlea via the auditory nerve and lower brainstem remained largely unaltered. This finding is consistent with meningiomas' dural-based genesis, which compresses central auditory pathways in the cerebellopontine angle rather than entering the cochlear nerve directly. The distinction between their influence and the more widespread conduction anomalies observed in schwannomas is highlighted by the preservation of earlier waves in meningiomas [6]. A unique auditory brainstem response profile was identified in vascular loops. While Wave I was preserved, the most common aberration found was delayed Wave III latency and, to a lesser degree, a delayed wave V. The cochlear nucleus and adjacent auditory brainstem circuits are primarily responsible for the production of Wave III. This finding supports the theory that vascular loops impair conduction in the proximal segment of the auditory nerve without causing widespread disruption but rather through localized irritation or pulsatile compression of the nerve at its root entrance zone via the anterior inferior cerebellar artery (AICA) or its branches, which often intersect the vestibulocochlear nerve at the cerebellopontine angle or internal auditory canal [5]. The presence of Wave V delay signifies that the disturbance often ascends to upper brainstem regions, resulting in delayed transmission throughout the lateral lemniscus–inferior colliculus route. In contrast to mass lesions, responses were nearly never absent, indicating maintained synchronization despite the latency shift [27]. This ABR pattern underscores the localized effects of vascular loops, confirming their possible contribution to tinnitus and minor auditory impairment. Interestingly, patients with schwannomas showed contralateral ABR abnormalities, which were not observed in cases of vascular loops, supporting the notion that vascular loops exert a more localized effect without significant brainstem compression or displacement [28]. In contrast, contralateral ABR abnormalities in schwannoma cases likely reflected brainstem displacement or mass effect extending beyond the tumor side and included delayed peak latencies,

reduced wave amplitudes, distorted waveforms, and poor response stability [29]. Several clinically significant connections were found between PTA and ABR results. ABR anomalies, such as prolonged I–III and I–V interpeak intervals, delayed Wave V latency, and absent waves in vestibular schwannoma, were frequently associated with higher PTA thresholds, reflecting progressive cochlear nerve compression [30]. In meningiomas, delays in Wave V and interpeak intervals were accompanied by mild to moderate threshold rise, indicating that central conduction timing does not always parallel functional hearing sensitivity [24]. ABR identified abnormalities not consistently anticipated by the extent of PTA loss, highlighting its significance as an adjunctive assessment. In vascular loops, PTA often showed minimal or no threshold elevation, yet ABR detected delayed Wave III latencies in about 70% of patients, revealing subclinical dysfunction missed by behavioral testing [5]. Overall, PTA reflected the degree of functional hearing loss, whereas ABR identified the site and severity of conduction impairment. Together, they enhance lesion characterization and interpretation of incidental MRI findings. Because of the cost and limited availability of MRI, audiological testing remains essential for screening and triage [7]. In our groups, various patterns were linked to MRI-validated lesions. Vestibular schwannomas exhibited significant ABR delays and a distinct side-specific threshold rise, which clearly suggested a cerebellopontine angle tumor and necessitated an emergency MRI. Vascular loops with delayed Wave III, mild high-frequency PTA changes, and isolated tinnitus suggested neurovascular interaction rather than a mass lesion. Patients with discrete Wave III delays and mild high-frequency loss may get conservative treatment or be referred selectively, but those with significant broad-frequency loss and long interpeak intervals should have imaging done to rule out schwannoma. It may be possible to reduce unnecessary MRI referrals while prioritizing high-risk cases for immediate evaluation by using audiological data in decision-making. Despite this, a drawback of our study was the lack of speech audiometry with extended high-frequency pure-tone audiometry, as these tools were not available at our institution. Additionally, small sample size, particularly for the meningioma and schwannoma groups, absence of tumor size stratification, and potential selection and verification bias (MRI-positive sample) limit generalizability. For these reasons, future research, such as larger multicenter studies and standardized ABR protocols, is warranted.

Conclusion

The PTA pattern did not change significantly, and the severity of hearing loss increased gradually from vascular loops to meningiomas to schwannomas. However, there was overlap in the threshold ranges, especially at higher frequencies. As a result, PTA alone was not a valid diagnostic approach. Furthermore, different lesion-related profiles were found in the ABR data. Vestibular schwannomas were connected to the most severe auditory impairment, vascular loops were linked to minor but noticeable ABR issues, and meningiomas may have contributed to a considerable ABR delay. Complementary information that supports early identification was produced by combining objective auditory brainstem response testing with subjective pure tone audiometry, especially when imaging is unavailable or unclear.

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Authors' contributions

NA: Conceptualization, data collection, interpretation of the results, and drafting the manuscript.
HW: study design, Statistical analysis, and manuscript review with editing.
MA: Conceptualization, data collection, and manuscript review and editing.

Conflict of interest

The authors declared no conflict of interest.

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Table 1: Clinical symptom distribution according to lesion types

Variable§	Type of lesion‡			P- Value†	Cramer's V¶
	Vascular loop (n=18)	Meningioma (n=8)	Schwannoma (n=10)		
Hearing loss	12 (66.7%) / 6 (33.3%)	4 (50.0%) / 4 (50.0%)	10 (100%) / 0 (0%	**0.016***	0.34
Tinnitus	17 (94.4%) / 1 (5.6%)	2 (25.0%) / 6 (75.0%)	6 (60.0%) / 4 (40.0%)	**0.011***	0.56
Dizziness	3 (16.7%) / 15 (83.3%)	8 (100%) / 0 (0%)	5 (50.0%) / 5 (50.0%)	**0.0003***	0.62
Vertigo	11 (61.1%) / 7 (38.9%)	6 (75.0%) / 2 (25.0%)	2 (20.0%) / 8 (80.0%)	**0.038***	0.35
Headache	6 (33.3%) / 12 (66.7%)	7 (87.5%) / 1 (12.5%)	6 (60.0%) / 4 (40.0%)	**0.025***	0.36
Facial numbness	0 (0%) / 18 (100%)	2 (25.0%) / 6 (75.0%)	7 (70.0%) / 3 (30.0%)	**0.0002***	0.64

*p<0.05 Statistical significance
†Chi-square test
‡Data are presented as n (%): Yes/No for each clinical symptom
§Patient-level analysis.
¶Effect size: small (V ≈ 0.1), medium (V ≈ 0.3), and large (V ≥ 0.5)

Table 2: Audiogram pattern distribution by lesion types

Audiogram pattern‡	Type of lesion†			P- Value*	Cramer's V§
	Vascular loop Ipsilateral (n=23) Contralateral (n=13)	Meningioma Ipsilateral (n=8) Contralateral (n=8)	Schwannoma Ipsilateral (n=10) Contralateral (n=10)		
Ipsilateral ear					
Flat	8 (34.8%)	4 (50.0%)	6 (60%)	0.552	0.19
Sloping	13 (56.5%)	4 (50.0%)	4 (40%)		
Rising	2 (8.7%)	0 (0)	0 (0)		
Contralateral ear					
Flat	**13 (100%)**	**8 (100%)**	**8 (80%)**	0.106	0.38
Sloping	0 (0)	0 (0)	2 (20.0%)		
Rising	0 (0)	0 (0)	0 (0)		

*Chi-square test
†Data are presented as n (%)
‡ Ear-level analysis
§Effect size: small (V ≈ 0.1), medium (V ≈ 0.3), and large (V ≥ 0.5

Table 3: Frequency-specific air conduction thresholds of the ipsilateral and contralateral ears according to lesion types

Frequency (Hz)	Air conduction (Ipsilateral ear) ‡			P- value†	Cohen's f ¶ (Effect size)
	Vascular loop Mean ± SD§	Meningioma Mean ± SD§	Schwannoma Mean ± SD§		
250	11.50 ± 7.68	16.87 ± 5.93	48.08 ± 24.40	**0.048***	0.458
500	14.31 ± 8.70	23.75 ± 7.44	59.42 ± 28.40	**0.045***	0.464
1000	20.18 ± 6.79	30.00 ± 7.07	64.08 ± 29.88	**0.043***	0.468
2000	23.50 ± 13.51	36.25 ± 9.16	70.06 ± 21.08	**0.017***	0.551
3000	31.06 ± 16.72	41.25 ± 10.32	71.09 ± 17.91	**0.015***	0.562
4000	33.06 ± 17.78	41.25 ± 14.07	71.51 ± 14.91	**0.036***	0.484
6000	41.25 ± 18.36	46.87 ± 14.37	74.03 ± 16.12	**0.034***	0.489
8000	42.01 ± 19.22	49.37 ± 15.68	75.50 ± 13.00	**0.009***	0.607
Frequency (Hz)	**Air conduction (Contralateral ear) ‡**			**P- value†**	**Cohen's f ¶ (Effect size)**
	Vascular loop Mean ± SD§	**Meningioma Mean ± SD§**	**Schwannoma Mean ± SD§**		
250	17.50 ± 7.93	13.75 ± 6.46	13.04 ± 7.33	0.815	0.109
500	17.44 ± 8.66	15.01 ± 7.98	16.26 ± 6.94	0.909	0.074
1000	10.01 ± 5.74	15.06 ± 8.42	15.03 ± 6.54	0.506	0.201
2000	18.50 ± 9.40	22.50 ± 7.07	16.25 ± 7.90	0.670	0.153
3000	17.49 ± 8.81	23.45 ± 5.97	24.02 ± 9.08	0.789	0.117
4000	17.50 ± 6.38	26.25 ± 9.04	24.14 ± 6.97	0.753	0.128
6000	17.32 ± 7.05	28.75 ± 11.04	29.04 ± 13.67	0.580	0.179
8000	20.01 ± 5.84	31.51 ± 10.45	35.05 ± 7.82	0.497	0.204

*p<0.05 Statistical significance
†Kruskal–Wallis test
‡Ear-level analysis
§SD; Standard deviation.
¶Effect size: small (f ≈ 0.10), medium (f ≈ 0.25), and large (f ≥ 0.40)

Table 4: Comparison between lesion types according to the assessment of the auditory brainstem response of the ipsilateral ears

ABR (Ipsilateral ear)‡	Type of lesion			P- Value†	Cramér's V¶
	Vascular loop (n=23)	Meningioma (n=8)	Schwannoma (n=10)		
Wave I					
NA§	2 (8.7%)	0 (0)	4 (40%)	0.057	0.334
Normal latency	17 (73.9%)	8 (100%)	6 (60%)		
Increased latency	4 (17.4%)	0 (0)	0 (0%)		
Wave III					
NA	2 (8.7%)	0 (0)	4 (40%)	**0.020***	0.377
Normal latency	5 (21.7%)	5 (62.5%)	2 (20%)		
Increased latency	16 (69.6%)	3 (37.5%)	4 (40%)		
Wave V					
NA	2 (8.7%)	0 (0)	4 (40%)	**0.034***	0.356
Normal latency	7 (30.4%)	1 (12.5%)	0 (0)		
Increased latency	14 (60.9%)	7 (87.5%)	6 (60%)		
Interpeak interval (I-III)					
NA	2 (8.7%)	0 (0)	4 (40%)	**0.033***	0.358
Normal latency	9 (39.1%)	6 (75%)	2 (20%)		
Increased latency	12 (52.2%)	2 (25%)	4 (40%)		
Interpeak interval (III-V)					
NA	2 (8.7%)	0 (0)	4 (40%)	**0.006***	0.420
Normal latency	17 (73.9%)	3 (37.5)	2 (20%)		
Increased latency	4 (17.4%)	5 (62.5)	4 (40%)		
Interpeak interval (I-V)					
NA	2 (8.7%)	0 (0)	4 (40%)	**0.022***	0.374
Normal latency	11 (47.8%)	3 (37.5%)	0 (0)		
Increased latency	10 (43.5%)	5 (62.5%)	6 (60%)		

*p<0.05 Statistical significance
†Chi-square test
‡Ear-level analysis
§NA; Not applicable
¶ Effect size: small (V ≈ 0.1), medium (V ≈ 0.3), and large (V ≥ 0.5)

Table 5: Comparison between lesion types according to the assessment of the auditory brainstem response of the contralateral ears

ABR (Contralateral ear)‡	Type of lesion			P- Value†	Cramér's V¶
	Vascular loop No. (%)	Meningioma No. (%)	Schwannoma No. (%)		
Wave I					
Normal latency	13 (100%)	8 (100%)	10 (100%)	-§	-
Increased latency	0 (0)	0 (0)	0 (0)		
Wave III					
Normal latency	13 (100%)	8 (100%)	10 (100%)	-	-
Increased latency	0 (0)	0 (0)	0 (0)		
Wave V					
Normal latency	13 (100%)	8 (100%)	4 (40%)	**0.001***	0.66
Increased latency	0 (0)	0 (0)	6 (60%)		
Interpeak latency (I-III)					
Normal latency	13 (100%)	8 (100%)	10 (100%)	-	-
Increased latency	0 (0)	0 (0)	0 (0)		
Interpeak latency (III-V)					
Normal latency	13 (100%)	8 (100%)	9 (90%)	0.338	0.265
Increased latency	0 (0)	0 (0)	1 (10%)		
Interpeak latency (I-V)					
Normal latency	13 (100%)	8 (100%)	7 (70%)	**0.031***	0.47
Increased latency	0 (0)	0 (0)	3 (30%)		

*p < 0.05 (statistical significance)
†Chi-square test

‡Ear-level analysis
§Missing p-values (-) indicate no variability among groups.
¶Effect size: small (V ≈ 0.1), medium (V ≈ 0.3), and large (V ≥ 0.5)

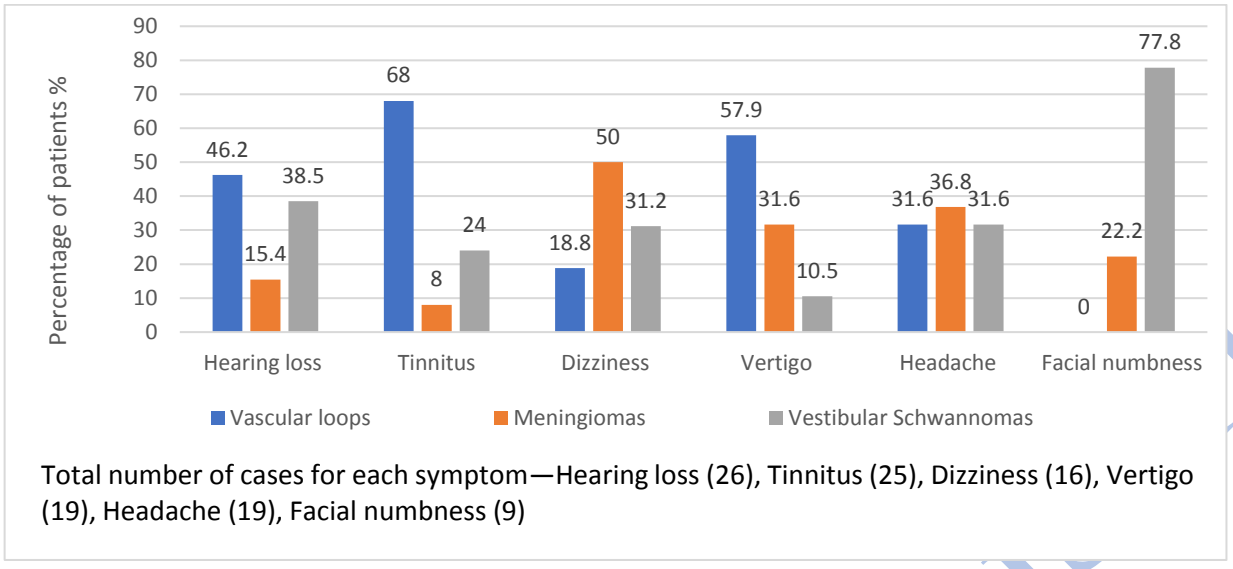
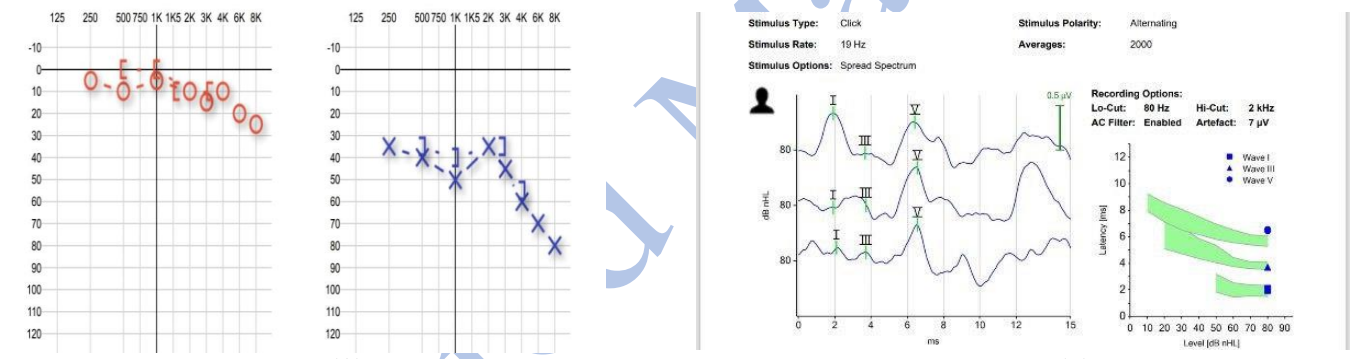
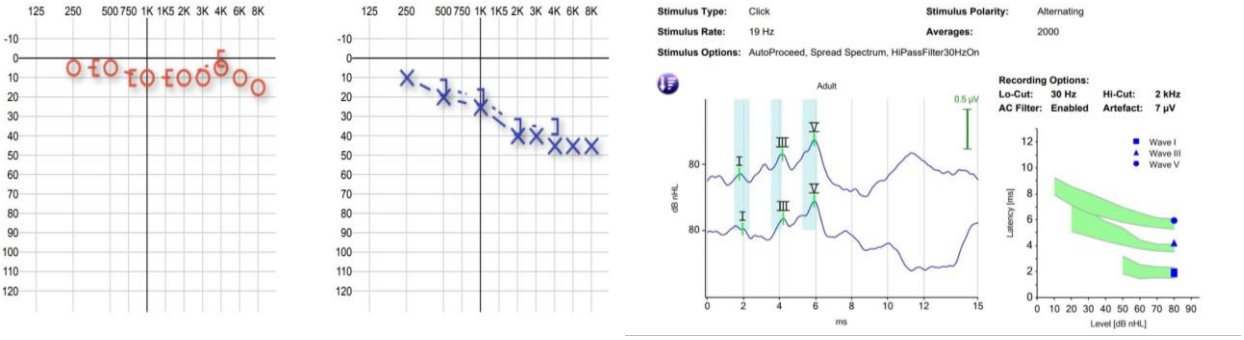


Figure 1: Distribution of clinical symptoms by lesion type and their contribution to total cases



(A) **(B)**

Figure 2: A. Pure-tone audiogram of a patient with unilateral vestibular schwannoma. The ipsilateral ear (Left, blue) shows moderate sloping sensorineural hearing loss, while the contralateral ear (Right, red) demonstrates normal hearing thresholds. **B.** ABR of the same patient's left ear, showing delayed wave V latency and prolonged I–V interpeak interval



(A) **(B)**

Figure 3: A. Pure-tone audiogram of a patient with a vascular loop. The ipsilateral ear (Left, blue) demonstrates a mild sloping sensorineural hearing loss, while the contralateral ear (Right, red) demonstrates normal hearing threshold. **B.** ABR of the same patient's ipsilateral ear, showing delayed wave III latency