



Research

Combined Use of Intraoperative Neuromonitoring and Neuronavigation Techniques in Surgery for Vestibular Schwannoma in the Cerebellopontine Angle

Serebellopontin Açığı Yerleşimli Vestibüler Schwannoma Cerrahisinde İntraoperatif Nöromonitörizasyon ve Nöronavigasyon Tekniklerinin Kombine Kullanımı

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ABSTRACT

Objective: Surgery for vestibular schwannoma (VS), located in the cerebellopontine angle, presents a significant neurosurgical challenge due to the tumor's proximity to cranial nerves and critical neural and vascular structures. This study aimed to evaluate the efficacy and safety of combining intraoperative neuronavigation (NN) and neuromonitoring (NM) in the resection of VS tumors.

Methods: We retrospectively reviewed the medical records of patients who underwent VS tumor resection at our center between 2018 and 2023. Patients were divided into two groups: those who underwent surgery with NN and NM guidance (nVS group) and those who underwent surgery without these techniques (pVS group). The groups were compared with respect to cranial nerve identification, preservation of facial nerve function, advantages and limitations of NN and NM systems, and extent of tumor resection.

Results: In the pVS group, intraoperative visualization of the facial nerve was not achieved in seven patients (46.7%). Conversely, all patients in the nVS group had their facial nerves successfully identified intraoperatively ($p<0.001$). Postoperative evaluation revealed worsening facial nerve function, as measured by the House-Brackmann scale, in seven (46.7%) patients in the pVS group compared with two (16.7%) patients in the nVS group ($p<0.001$). The median time from anesthesia induction to surgery commencement was significantly shorter in the pVS group ($p<0.001$).

Conclusion: The combined use of NN and NM enhances tumor margin identification and adjacent structure visualization during surgery. Additionally, it facilitates real-time monitoring of neurological functions, contributing to improved surgical outcomes and reduced risk of postoperative complications.

Keywords: Vestibular schwannoma, neuromonitoring, neuronavigation, image guided surgery

ÖZ

Amaç: Vestibüler schwannoma (VS) tümörlerinin cerrahisi, tümörlerin kraniyal sinirlere ve önemli nöral ve vasküler yapılara yakınlığı nedeniyle nöroşirürjikal bir zorluk olmaya devam etmektedir. Çalışmamızda, VS tümörlerinin rezeksiyonunda birlikte kullanılan intraoperatif nöronavigasyon (NN) ve nöromonitörizasyonun (NM) etkinliğini ve güvenilirliğini araştırdık.

Gereç ve Yöntem: 2018-2023 yılları arasında merkezimizde VS tümörü nedeniyle ameliyat edilen hastalar retrospektif olarak analiz edildi. Çalışmaya NN ve NM kılavuzluğunda ameliyat edilen grup (nVS) ve kontrol grubu (pVS) dahil edildi. Gruplar, kraniyal sinirlerin tanımlanması, fasiyal sinirin fonksiyonel olarak korunması, kullanılan NN ve NM sistemlerinin avantaj ve dezavantajları ve rezeksiyon derecesine göre karşılaştırıldı.

Bulgular: pVS grubunda 7 (%46,7) hastada fasiyal sinir intraoperatif olarak görüntülenemedi. Ancak, nVS grubunda NN ve NM kullanımı ile tüm hastalarda fasiyal sinir lokalize edildi ($p<0,001$). Ameliyat sonrasında, pVS grubunda 7 hasta (%46,7) ve nVS grubunda 2 hasta (%16,7) House-Brackmann ölçeğinde ameliyat öncesi değerlendirmelere kıyasla kötüleşme gösterdi ($p<0,001$). Anestezi induksiyonu ile ameliyatın başlaması arasında geçen ortalama süre pVS grubundaki hastalarda anlamlı derecede kısaydı ($p<0,001$).

Sonuç: NN ve NM'nin birlikte kullanımı, cerrahi sırasında tümör sınırlarının ve komşu yapıların belirlenmesine ve hastaların nörolojik fonksiyonlarının gerçek zamanlı olarak izlenmesine olanak sağlar.

Anahtar Kelimeler: Vestibüler schwannoma, nöromonitörizasyon, nöronavigasyon, görüntü kılavuzluğunda cerrahi

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INTRODUCTION

The cerebellopontine angle (CPA) is a complex anatomical region that houses numerous critical neural and vascular structures (1-3). Vestibular schwannoma (VS) is the most common benign tumor in this region (4,5). Surgical treatment of VS poses significant challenges for neurosurgeons, as they must navigate narrow surgical corridors while avoiding damage to vital neurovascular structures. Such damage can result in severe neurological deficits or even mortality (6-9).

Image-guided neuronavigation (NN) systems, which are computer-assisted tools, enable neurosurgeons to plan surgical approaches by accurately visualizing anatomical details and localizing lesions. These systems also provide intraoperative orientation, facilitating precise identification of tumor margins (10,11). The application of NN to the surgical treatment of VS enables the precise intraoperative identification of lesions (2,5,11).

However, NN alone does not provide critical information about the functional integrity of neural tissues and cranial nerves. To achieve optimal surgical outcomes, methods that deliver continuous, real-time functional feedback to the surgical team are essential (2,5,12). Neuromonitoring (NM) systems fulfill this need by offering constant intraoperative assessment of the functional status of cranial nerves and neural tissues, thereby facilitating the early detection of hazardous conditions and critical neurophysiological changes (3,12-14). Such real-time monitoring allows for the timely modification of the surgical plan, reducing the risk of irreversible neurological damage.

This study aims to share our clinical experience with the combined use of NN and NM in the surgical management of VS located within the CPA. We specifically evaluated the effectiveness and safety of integrating these techniques to improve surgical precision and outcomes.

METHODS

This retrospective study was conducted following approval from the Medicana Bursa Hospital Ethics Committee (approval no: 2023/05-2, date: 27.12.2023). All procedures adhered to the ethical standards set forth by the institutional and national research committees and the principles of the 1964 Declaration of Helsinki and its subsequent amendments. Written informed consent was obtained from all participants.

Patients

Patient data were retrieved from the hospital's electronic database, which included outpatient follow-up records,

operative notes, NM and NN data, histopathological reports, neuroimaging studies, and surgical videos.

Patients were included if they had VSs exceeding 20-mm in diameter and had undergone surgical resection between 2018 and 2023. These patients were categorized into two groups. Patients who underwent surgery before the implementation of NN and NM systems (2018-2021) were classified as the pVS. Those who underwent surgery using NN and NM guidance (2021-2023) were designated as the nVS group. Patients with tumors whose histopathological diagnoses were other than VS, patients undergoing surgical interventions for non-tumor-related conditions, patients undergoing biopsy procedures, and patients with contraindications to magnetic resonance imaging (MRI) were excluded from the study.

Use of NN

In the nVS group, NN was facilitated by the Medtronic Stealth Station (Medtronic, Minnesota, USA). Axial T2-weighted and contrast-enhanced T1-weighted MRI scans, with a 1-mm slice interval, were acquired preoperatively and tailored for integration with the NN system. These images were transferred to the surgical NN workstation.

Patient positioning was achieved with a dynamic reference frame affixed to a Mayfield head holder. The NN system was registered using surface marking techniques and a freehand stereotactic navigation device. Image-patient registration (fusion) was performed to achieve precise alignment with three-dimensional imaging. Once the required accuracy level was verified, surgical procedures commenced (Figure 1).

Use of NM

In the nVS group, NM protocols were established using the nerve integrity monitor-eclipse system (Medtronic, Inc., Minneapolis, Minnesota). The NM protocol included transcranial motor-evoked potentials (MEPs) elicited in the median and tibial nerves, as well as in corticobulbar-innervated muscles of the head and face. Additionally, free-running muscle electromyography recordings were obtained from the orbicularis oculi, orbicularis oris, masseter, and genioglossus muscles.

Baseline MEP values were recorded preoperatively for each patient. An experienced neurophysiologist continuously monitored the intraoperative NM parameters (Figure 2). Significant NM events were defined as either a reduction of >50% in MEP amplitude or an increase of >20 mA in the current required to elicit MEP responses. If a significant change in MEP parameters was detected, the surgical procedure was suspended until normalization occurred.

At the surgeon's discretion, cranial nerve localization and functional status were assessed intermittently using a monopolar probe at the lowest amperage (0.05-0.5 mA).

Surgical Procedure

All surgeries were performed with patients positioned in a Mayfield three-pin head-holder in the park-bench position. In the pVS group, standard anesthesia protocols were implemented, whereas the nVS group received intravenous remifentanyl and propofol as the general anesthetic regimen, with neuromuscular blocking agents used only during induction.

Standard microsurgical techniques were employed in both groups, using a Leica OH6 surgical microscope

(Leica Microsystems, Wetzlar, Germany). Following a dural incision, the cerebellum was retracted using a narrow brain retractor. The cerebellomedullary cistern was then opened, and cerebrospinal fluid (CSF) was drained to relax the cerebellum, fully exposing the CPA. In the nVS group, the NN and NM systems guided localization of cranial nerves. In the pVS group, cranial nerve localization was based on the surgeon's preoperative MRI evaluation and intraoperative microscopic visualization of the surgical field. Tumor tissue was removed incrementally using an ultrasonic surgical aspirator (CUSA Clarity Console, Integra LifeSciences, France).

All patients underwent evaluations of facial nerve function and detailed neurological examinations at three time

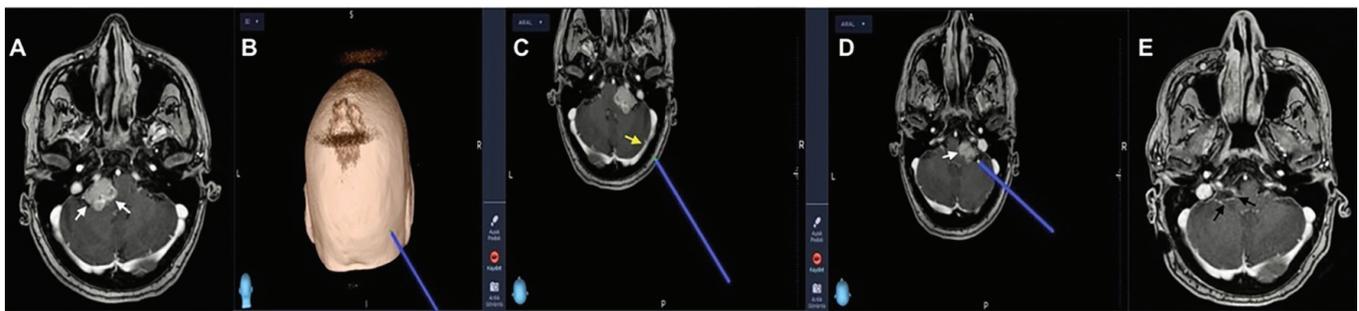


Figure 1. Intraoperative NN application in a patient undergoing surgery for vestibular schwannoma located in the right CPA. **A.** Preoperative contrast-enhanced MRI image showing the tumor in the right CPA (white arrow), **B.** determination of the skin incision site using intraoperative NN (blue arrow: NN probe image), **C.** intraoperative localization of the transverse sinus with intraoperative NN (yellow arrow: transverse sinus; blue arrow: NN probe image), **D.** intraoperative identification of tumor localization and surrounding structures with intraoperative NN (white arrow: tumor; blue arrow: NN probe image). **E.** Postoperative contrast-enhanced MRI image showing the excised tumor area (black arrow)
 NN: Neuronavigation, CPA: Cerebellopontine angle, MRI: Magnetic resonance imaging

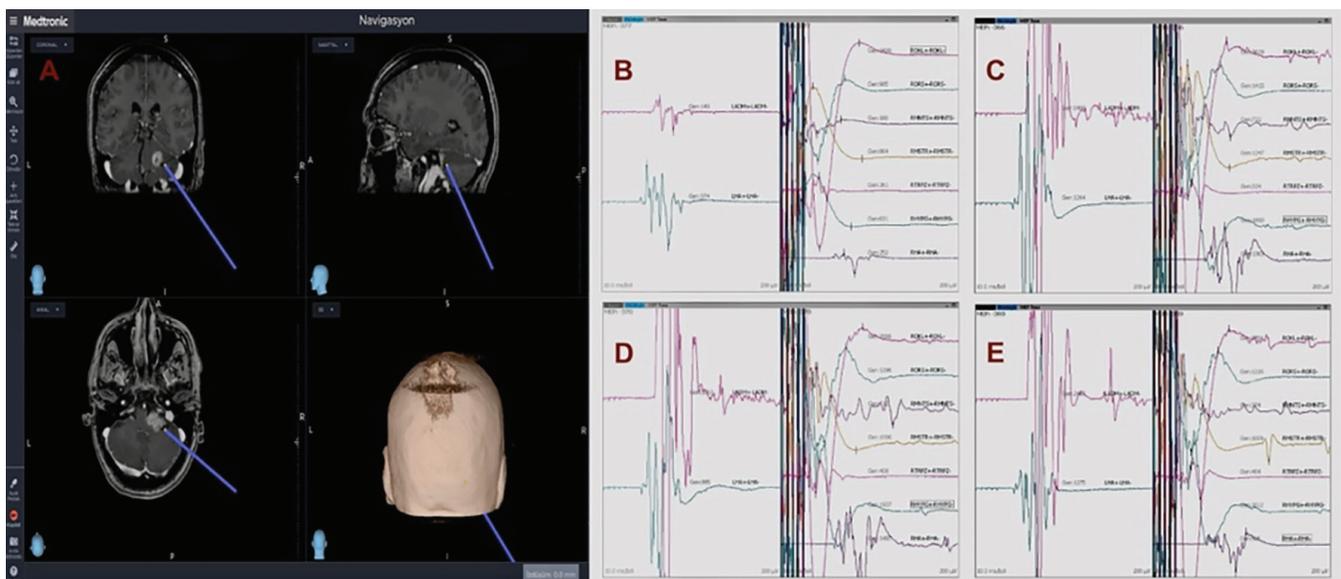


Figure 2. Combined intraoperative NN and NM application in a patient undergoing surgery for vestibular schwannoma located in the right CPA. For NM, MEP traces were recorded from the orbicularis oculi, orbicularis oris, masseter, mentalis, hypoglossus, trapezius, abductor digiti minimi, and tibialis muscles using cortical magnetic stimulation, corresponding to cranial nerves V, VII, X, XI, and XII. **A.** Intraoperative NN used for determining tumor localization and surrounding structures. **B.** Baseline MEP traces recorded before the operation. **C.** MEP traces recorded during tumor resection. **D.** MEP traces recorded after tumor resection. **E.** Final MEP traces recorded after the operation
 NN: Neuronavigation, NM: Neuromonitoring, CPA: Cerebellopontine angle, MEP: Motor-evoked potential

points: before discharge, 1-month postoperatively, and 6 months postoperatively. Facial nerve function was assessed using the House-Brackmann (HB) scale (15), with an increase in the HB score compared with preoperative values regarded as indicating a new neurological deficit.

All patients underwent preoperative brain MRI enhanced with 1-mm gadolinium, as well as early postoperative cranial computed tomography (within 24 hours) and follow-up MRI scans. Independent neuroradiologists and the study authors reviewed all neuroimaging scans for residual contrast-enhancing tumor tissue. Gross total resection (GTR) was defined as the absence of significant tumor tissue on postoperative MRI, whereas subtotal resection was defined as residual tumor volume exceeding 5% of the total tumor volume.

The groups were compared with respect to age, gender, anatomical structures, facial nerve identification, preservation of facial nerve function, operative time, the advantages and disadvantages of the NN and NM systems, and the extent of tumor resection.

Statistical Analysis

Descriptive statistics, including numbers, percentages, means, and standard deviations, were used to analyze clinical characteristics. The Mann-Whitney U test was used to compare the following variables between the nVS and pVS groups: age, time from anesthesia induction to surgery initiation, mean operation time, and preoperative and postoperative facial nerve HB scale scores. Changes in facial nerve function based on the HB scale were analyzed using the Friedman test, while the chi-square test was used to compare gender distributions. Analysis of covariance was used to assess the variables influencing postoperative 6-month facial nerve HB scores. Statistical significance was set at $p < 0.05$, and IBM SPSS 26.0 software was used for all statistical analyses.

RESULTS

Twenty-seven patients who underwent VS surgery in the CPA and met the inclusion criteria were enrolled in the study. The pVS group comprised 15 patients (6 males and 9 females), while the nVS group included 12 patients (5 males and 7 females; $p = 0.930$). The mean age was 55.9 ± 11.4 yr (range, 37-74 yr) in the pVS group and 51.7 ± 11.1 yr (range, 30-72 yr) in the nVS group ($p = 0.300$). Table 1 presents the demographic and clinical characteristics of the study population.

In the pVS group, dural sinus damage and mastoid air-cell openings were observed during craniotomy in three patients (20%) and four patients (26.7%), respectively. Additionally, facial nerves were not visualized intraoperatively in seven patients (46.7%). In the nVS group, no damage to the dural sinuses or mastoid bone was observed. An NM probe was used to stimulate the tumor capsule and surrounding tissues, facilitating localization of the facial nerve in all cases. The difference in facial nerve identification between the groups was statistically significant ($p = 0.006$; Table 1).

GTR was achieved in 53.3% (8/15) of the pVS group and 58.3% (7/12) of the nVS group; the difference was not statistically significant ($p = 0.795$; Table 1). The median operative times did not differ significantly between groups ($p = 0.139$). However, the median time from anesthesia induction to surgery initiation was significantly shorter in the pVS group than in the nVS group ($p < 0.001$). Setting up the NN system and placing NM electrodes required an additional 28.6 ± 6.6 min (Table 1).

Postoperatively, seven patients (46.7%) in the pVS group exhibited deterioration in facial nerve function based on HB scale scores. At the 6-month follow-up, two patients returned to their preoperative neurological status, and two patients showed partial improvement. In the nVS group, deterioration was observed in 2 (16.7%) patients, with one showing partial improvement at follow-up. Preoperative, first-month postoperative, and six-month postoperative HB scores did not differ significantly between groups ($p = 0.648$, $p = 0.373$, and $p = 0.792$; respectively). However, intra-group analysis revealed significant differences in the pVS group's HB scores over time ($p = 0.003$), whereas no significant differences were noted in the nVS group ($p = 0.156$) (Table 2).

When considering the effects of group, gender, GTR rates, and preoperative HB scores on 6-month postoperative HB scores, membership in the pVS group was a statistically significant factor associated with worsened outcomes ($p = 0.030$). Preoperative HB scores also significantly influenced postoperative deterioration ($p = 0.003$; Table 3, Figure 3). No complications related to NN or NM occurred, and there was no surgical mortality in the series.

Table 1. Demographic and clinical characteristics of the patients included in the study

Med (n)	nVS group		pVS group		P
	Q1-Q3 (%)	Med (n)	Q1-Q3 (%)		
Age, yr	50.50	45.50-59.50	54.00	47.00-65.00	0.300 ^a
Mean start of surgery time, min	57.50	52.50-65.00	20.00	20.00-30.00	<0.001 ^{a,*}
Mean operation time, min	190.00	180.00-210.00	180.00	150.00-200.00	0.139 ^a
Gender	Male	5 41.7	6 40.0		0.930 ^b
	Female	7 58.3	9 60.0		
Signs and symptoms	Headache	5 41.7	7 46.7		
	Hearing loss	6 50.0	8 53.3		
	Ataxia	4 33.3	3 20.0		
	Facial pain	1 8.3	1 6.7		
	Dysphagia disorders	3 25.0	1 6.7		
	Facial paralysis	2 16.7	1 6.7		
	Extent of the surgery	STR 7 58.3	7 46.7	8 53.3	
Intraoperative FN determination facial nerve localization	Yes	12 100.0	8 53.3		0.006 ^{b,*}
	No	0 0.0	7 46.7		
Dural venous sinus injury	Yes	12 100.0	12 80.0		0.100 ^b
	No	0 0.0	3 20.0		
Opening of the mastoid air cells	Yes	12 100.0	11 73.3		0.053 ^b
	No	0 0.0	4 26.7		

FN: Facial nerve, GTR: Gross total resection, Med: Median, STR: Subtotal resection, Min: Minute, *: Statistically significant, ^a: Mann-Whitney U test, ^b: Chi-square test

Table 2. Evaluation of facial nerve function in the postoperative follow-up of patients based on the HB scale

FN-HB grade	nVS group			pVS group			P ^a
	Med	Q1	Q3	Med	Q1	Q3	
Preoperative period	1.00	1.00	1.00	1.00	1.00	1.00	0.648
1-month follow-up	1.00	1.00	2.00	1.00	1.00	3.00	0.373
6-month follow-up	1.00	1.00	2.00	1.00	1.00	3.00	0.792
	0.156 ^b			0.003 ^{b,*}			

FN: Facial nerve, HB: House-Brackmann, Med: Median, *: Statistically significant, ^a: Mann-Whitney U test, ^b: Friedman test

DISCUSSION

In the present study, combined use of NN and NM techniques in VS surgery significantly improved the identification and preservation of anatomical and vascular structures.

One of the primary challenges in VS involving CPA tumors is intraoperative localization of displaced neurovascular structures and cranial nerves (2,3,14). Achieving anatomical orientation can facilitate tumor resection while minimizing patient harm. In conventional cranial surgery, surgeons use preoperative computed tomography or MRI imaging to construct a three-dimensional mental representation of lesions and surrounding anatomy to guide the procedure. This task is considerably more complex for CPA lesions (16-19).

NN systems offer a significant advantage in preoperative planning and intraoperative anatomical orientation (5,11,20). In a study involving 436 patients undergoing VS surgery via the retrosigmoid approach, Chen et al. (5) demonstrated that NN effectively identified sinus structures and the tumor's anatomical relationships with adjacent structures. Similarly, in our study, NN facilitated accurate localization of the sigmoid sinus, transverse sinus, brainstem, and tumor. In the nVS group, skin incisions were planned using NN to identify the sinuses, thereby avoiding sinus damage during craniotomy. Furthermore, the air cells in the petrosal and mastoid bones were identified using the NN system, enabling the planning of a personalized craniotomy. In the pVS group, the identification of anatomical

and neurovascular structures relied solely on the surgeon's expertise. Complications such as sinus rupture and opening of the mastoid air cells were noted, but their incidence did not differ significantly from that in the nVS group ($p < 0.1$), which was likely due to the small cohort size. Nevertheless, the NN system provided surgeons with greater ease and confidence when identifying anatomical structures. One of the key factors influencing surgical success in VS is the accurate determination of the anatomical relationship between the tumor and the facial nerve. The NN system offers a substantial advantage by enhancing intraoperative anatomical orientation.

Despite their potential, NN systems are infrequently employed during VS surgery, likely due to concerns about their accuracy. One major challenge is brain shift, which can disrupt surgical orientation (21,22). Addressing this issue is a critical area of ongoing research, as maintaining procedural accuracy is vital (20-22). However, existing literature indicates that brain shift is less common in infratentorial tumors, even with CSF drainage (20,23,24). The infratentorial space is characterized by a smaller volume, and despite CSF drainage and dislocation of surrounding tissues, displacement of the brainstem from the midline rarely occurs (20). This stability is attributed to the cranial nerves and major blood vessels, which are firmly positioned in this anatomical region. As a

Table 3. Variables affecting the postoperative 6-month facial nerve HB scores via ANCOVA analysis

	Type III sum of squares	df	Mean square	F	p	R ²
Corrected model	16.029	8	2.004	3.438	0.014	0.604
Intercept	0.019	1	0.019	0.033	0.857	0.002
Preoperative FN-HB grade	6.711	1	6.711	11.516	0.003*	0.390
pVS group	3.235	1	3.235	5.552	0.030*	0.236
Gender	1.147	1	1.147	1.968	0.178	0.099
GTR	0.100	1	0.100	0.172	0.683	0.009
pVS group and gender	0.737	1	0.737	1.265	0.275	0.066
pVS group and GTR	0.012	1	0.012	0.020	0.889	0.001
Gender and GTR	0.247	1	0.247	0.423	0.524	0.023
pVS group, gender, and GTR	0.496	1	0.496	0.851	0.369	0.045
Error	10.489	18	0.583			
Total	95.000	27				
Corrected total	26.519	26				

R²=0.556 (adjusted R²=0.463). *: Statistically significant, ANCOVA: Analysis of covariance, FN: Facial nerve, GTR: Gross total resection, HB: House-Brackmann

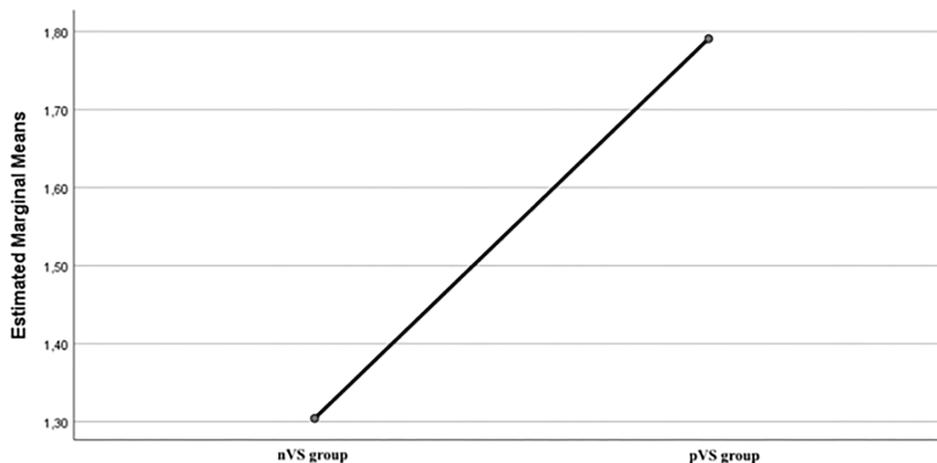


Figure 3. ANCOVA results associated with postoperative 6-month facial nerve function HB scores. ANCOVA analysis, which controlled for the effects of the pVS group, gender, GTR, and preoperative facial nerve HB scores, revealed that the pVS group exhibited significantly higher postoperative HB scores compared with the nVS group 6 months after surgery. The pVS group was identified as a highly significant factor in the worsening of facial nerve scores ($\chi^2=0.1236$, $p=0.03$)

ANCOVA: Analysis of covariance, HB: House-Brackmann, GTR: Gross total resection

result, brain shift in these cases is minimal and does not pose significant challenges (23,24). Consequently, NN data maintains its accuracy during surgical procedures. Sure et al. (24) reported that NN significantly improves the efficiency and safety of skull-base tumor surgery and that no notable intraoperative shift was observed. Similarly, Zhang et al. (20) reported that NN is a reliable tool for infratentorial tumor surgeries because spatial shifts in the brainstem are negligible.

Data from the patient records in our study corroborate these findings, showing no significant deviations in NN data for the nVS group and successful intraoperative identification of dural sinuses, tumor localization, adjacent brainstem structures, and vascular anatomy. However, NN alone was insufficient for the precise localization of cranial nerves, including the facial nerve, near tumor tissue. These structures were effectively identified by stimulation with the NM probe. The combined use of NN and NM facilitated accurate localization of tumor tissue, neurovascular structures, and displaced cranial nerves, including the facial nerve, in all patients in the nVS group.

Identification of anatomical structures is only one aspect of achieving surgical success during VS resection. Equally critical is the intraoperative monitoring of neuronal functions to prevent new neurological deficits. NM enables real-time monitoring of brainstem and cranial nerve functions during surgery. Della Pepa et al. (13) demonstrated, in a series of 83 patients, that NM reliably predicted early and late postoperative facial nerve function following CPA tumor resection. Furthermore, a meta-analysis by Staronni et al. (14), conducted on behalf of the European Association for Neurosurgical Societies Skull Base Committee, recommended the routine use of NM to preserve facial and cochlear nerve function during VS surgery.

In our study, intraoperative facial nerve monitoring was successful in all patients in the nVS group, indicating a statistically significant advantage over the pVS group ($p < 0.01$). Postoperative facial nerve outcomes aligned with intraoperative findings, with better results observed in the nVS group compared to the pVS group.

Brainstem auditory evoked potential (BAEP) measurements are another commonly used intraoperative NM technique in VS surgery (2,25), particularly for monitoring cochlear nerve function (25,26). BAEP has been shown to influence resection strategies to preserve hearing during VS surgery (25,27) and to predict postoperative hearing loss. In a meta-analysis, Gu et al. (26) found that changes in BAEP during VS surgery have a high sensitivity (0.95) in predicting postoperative hearing loss. Thus, intraoperative BAEP monitoring may provide

valuable insight into hearing function during surgery, allowing the neurosurgeon to decide whether to continue or halt tumor resection. However, the retrospective design of our study limits our ability to track BAEP values for every patient because the data are incomplete. The presence of different types of BAEP changes in some patients also hindered further analysis, which is a key limitation of this study. We believe that future research should prioritize the integration of advanced NM techniques that have improved sensitivity and specificity, particularly in larger patient populations, to address one of the most significant challenges in VS surgery: loss of cranial nerve function.

However, NM data can be influenced by factors such as the depth of anesthesia and cold-water irrigation during surgery (2,14,28,29). Additionally, the complex and redundant nature of cranial nerve pathways, including multiple corticobulbar branches that innervate cranial nerve nuclei, complicates the relationship between changes in MEP amplitude and clinical outcomes (28-30). Recent literature has examined various electrophysiological methods used in VS surgery (2,12,28-30). In our review, we found few studies combining NM with navigation (2,5). Our study aimed to evaluate the advantages and disadvantages of using NN alongside NM during intraoperative oncologic neurosurgical procedures targeting VS. We found that combining NN and NM significantly improved the identification of anatomical structures and the localization of the facial nerve during surgery. Furthermore, among patients who experienced worsening facial nerve HB scores at 6 months post-surgery, failure to use the NN-NM combination was a highly significant factor (Table 3, Figure 3). The use of NN and NM allows for real-time intraoperative monitoring, which aids in identifying the tumor mass, critical neurovascular structures, and safe entry points. Continuous monitoring of the facial nerve enables functional tracking, which significantly contributes to achieving maximal surgical safety. These findings highlight the two main advantages of combining NN and NM during surgery.

Nevertheless, there are some disadvantages. First, this method is costly and requires additional equipment that is not typically available in standard surgical centers. Preoperative data must be loaded onto the navigation workstation and registered to the patient's reference frame during surgery. Similarly, for NM, proper electrode placement and baseline recordings of the patient's functional status are necessary and can delay the initiation of surgery. In our study, the interval from anesthesia induction to surgical incision was significantly longer in the nVS group than in the other groups. Furthermore, the accuracy of these techniques depends on staff training, and the techniques

require a learning curve. To ensure success, experienced neurophysiologists must closely monitor and interpret the data during surgery.

Study Limitations

Our study has several limitations. First, it is a single-center retrospective study with a small sample size. Increasing the sample size may increase confidence in estimates or reduce the margin of error. Second, we did not assess the individual anesthetic doses (e.g., analgesics and muscle relaxants) or body temperatures, which may have influenced the measurements. However, all patients underwent surgery in a highly standardized surgical and anesthetic environment, as described in previous studies. Finally, although all tumors were large VS causing facial nerve compression, preoperative facial nerve involvement varied among patients and should be considered when interpreting clinical outcomes, particularly regarding facial nerve function. Moreover, BAEP data were incomplete for some patients, limiting our analysis. Therefore, larger, randomized trials with more objective criteria are needed to provide definitive answers.

CONCLUSION

Our study demonstrates that real-time intraoperative information is a significant advantage in the surgical management of VS. NM provides real-time monitoring of neurological function, while NN enables precise identification of anatomical and neurovascular structures adjacent to the tumor. When used together, these methods complement each other, enhancing patient safety and enabling safer resection. This synergy has the potential to significantly improve outcomes in VS surgery.

ETHICS

Ethics Committee Approval: This retrospective study was conducted following approval from the Medicana Bursa Hospital Ethics Committee (approval no: 2023/05-2, date: 27.12.2023).

Informed Consent: Written informed consent was obtained from all participants.

FOOTNOTES

Authorship Contributions

Surgical and Medical Practices: A.T., A.B., Concept: A.T., A.B., Design: A.T., A.B., Data Collection or Processing: A.T., A.B., Analysis or Interpretation: A.T., A.B., Literature Search: A.T., Writing: A.T.

Conflict of Interest: No conflict of interest was declared by the authors.

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