Arch Neurosci. 2023 October; 10(4):e141608. https://doi.org/10.5812/ans-141608.
Published online 2023 October 29. **Research Article**

# Facial and Cochlear Nerves Outcomes in the Surgical Resection of Giant Vestibular Schwannoma: Is There Any Predictive Value for Intraoperative Neuromonitoring of the Facial Nerve?

Miftau Fuseini [1], Marcarious Moorkereh Tantuoyir [1], Mohammad Mirahmadi Eraghi [2, 3] and Seyed Amir Hossein Javadi [4, *]

[1]School of Medicine, Tehran University of Medical Sciences, Tehran, Iran
[2]Brain and Spinal Cord Injury Research Center, Neuroscience Institute, Tehran University of Medical Sciences, Tehran, Iran
[3]Student Research Committee, School of Medicine, Islamic Azad University, Qeshm International Branch, Qeshm, Iran
[4]Department of Neurosurgery, Imam Khomeini Hospital Complex, Tehran University of Medical Sciences, Tehran, Iran

[*]*Corresponding author*: Department of Neurosurgery, Imam Khomeini Hospital Complex, Tehran University of Medical Sciences, Tehran, Iran. Email: javadi1978@yahoo.com

**Received** 2023 October 01; **Revised** 2023 October 08; **Accepted** 2023 October 10.

## Abstract

**Background:** Giant vestibular schwannoma (VS) represents one of the most challenging interventions in skull base surgery. Preserving facial and cochlear nerves requires effective surgical planning and nuanced techniques.
**Objectives:** The present study evaluates the role of intraoperative neuromonitoring (IONM) in predicting the outcome of facial and cochlear nerves.
**Methods:** This retrospective cohort comprised 34 patients with a giant (Samii IV/IVb grade) VS during 2016 - 2019. The retrosigmoid approach was used for tumor resection. Pre- and postoperative facial exams were graded according to the House-Brackmann Scale. Hearing ability was also classified according to the Hannover Hearing Classification. Intraoperative findings included the location of the nerve complex, tumor consistency, the surgical plane of the tumor from the facial nerve/ brainstem, and the level of internal auditory canal (IAC) decompression. Intraoperative neuromonitoring was used for all surgeries. The amplitude required for a positive response was recorded during the facial nerve's direct electrical stimulation (DES). All patients were followed 6 and 12 months postoperative.
**Results:** The preoperative facial nerve function was normal in 91.2% of patients, and 8.8% had slight facial nerve impairment (FNI). Considering preoperative hearing status, 9 cases (26.5%) had moderate hearing loss or impairment, while 25 patients (73.5%) complained of severe hearing impairment. The mean intraoperative direct facial nerve stimulation threshold was 1.38 ± 0.89. Hearing impairment was moderately severe in 7 (20.6%) and severe in 25 patients (73.5%) postoperation. In addition, postoperative assessment revealed 13 (38.2%) cases with moderate FNI and 12 (35.2%) with moderately severe FNI. The tumor size did not affect the postoperative hearing loss, and the postoperative hearing loss did not improve significantly ($P = 0.32$). There was no statistically significant correlation between the intensity of intraoperative DES and postoperative facial nerve function ($P > 0.05$). No significant correlation was observed between tumor consistency and postoperative hearing status ($P > 0.05$).
**Conclusions:** The retrosigmoid approach combined with IONM appears to be associated with favorable facial and cochlear nerve outcomes in giant VS. The postoperative facial nerve function may improve, but sensorineural hearing status may not improve significantly. Moreover, the intensity of intraoperative DES may not predict the postoperative facial function. Therefore, the findings of IONM should be interpreted carefully.

*Keywords:* Facial Nerve, Cochlear Nerve, Vestibular Schwannoma, Acoustic Neuroma, Intraoperative Neuromonitoring

## 1. Background

Vestibular schwannoma (VS), acoustic neuroma, or neurinoma accounts for 6 - 8% of all brain tumors and represents one of the most challenging lesions in skull base surgery (1). The course of VS is progressive with sensorineural hearing loss (SNHL), progressive ataxia, and lower cranial involvement causing dysphagia (2), which may warrant surgical resection. The main surgical challenge is the early detection of the facial nerve. The course of the facial nerve is undetectable in giant VS (3) due to the severe compression, which makes facial and cochlear nerves undifferentiated from arachnoid bands. Facial nerve damage may result from manipulation, traction, direct damage, or thermal injury (4). In this regard, intraoperative visualization and neuromonitoring have dramatically improved outcomes (4).

## 2. Objectives

Intraoperative neuromonitoring (IONM) provides a functional map of cranial nerves and helps in the early localization of facial nerves before being visualized microscopically. Facial nerve damage would increase the required stimulation amplitude threshold (mA). Generally, a positive response is achieved in direct facial nerve stimulation (DES) of the facial nerve at 0.5 - 1 mA. It is assumed that increased thresholds may have a predictive value for poor facial nerve outcomes. We aimed to evaluate the role of IONM in predicting the outcome of facial and cochlear nerves.

## 3. Methods

A single-center retrospective cohort of 34 adult patients (25 females) with giant VS from 2016 to 2019 was performed. The inclusion criteria were adult patients with giant VS (diameter > 4 cm). Patients with neurofibromatosis type 2 or prior treatment (recurrent cases) were excluded. All eligible patients completed initial and subsequent imaging, audiometric function testings, initial measurable hearing ipsilateral side, and stability in audiometric function (pure-tone average, speech discrimination score) in the opposite ear on serial audiometric function testing. All surgeries were performed by a senior neurosurgeon (corresponding author). IONM was provided by the same team at all operations applying the INOMED ® brain system. Brainstem auditory evoked response (BAER) was also used for all surgeries.

Demographic data, clinical presentation, physical examination, preoperative multi-slice computerized tomography (CT) scan, magnetic resonance imaging (MRI), intraoperative surgical findings, IONM records, and postoperative neurological examination were assessed from the tumor registry forms and patient's medical records. The preoperative and postoperative hearing were graded on a scale from A to D according to a classification scheme published by the American Academy of Otolaryngology-Head and Neck Surgery (5) and Hannover Hearing Classification. Tumor consistency and amplitude of the stimulation threshold were determined intraoperatively (6). The patients underwent general anesthesia and surgery at a lateral position (Ojemann). Short-acting muscle relaxant was only used during induction due to IONM. Bilateral cranial nerves, motor-evoked potential, and somatosensory-evoked potential were monitored during surgery. Electromyography (EMG) monitoring for orbicularis oculi and the orbicularis oris muscles innervated by the facial nerve was also applied. DES of the facial nerve was provided by monopolar and concentric bipolar stimulators. Direct stimulation was started at the amplitude of 0.1 mA and increased gradually to 2 mA. BAER was used for cochlear nerve monitoring. The suboccipital retrosigmoid approach was used for tumor resection in all patients.

The correlations of intraoperative stimulation threshold and tumor size were assessed with postoperative facial nerve outcome and hearing outcome, respectively. Analysis of variance was used for correlation analysis. Cross tabulation was performed for intraoperative facial nerve DES and perioperatively changes in facial nerve function. The Chi-square and Fischer's exact tests were used for further categorical analyses.

## 4. Results

### *4.1. Demographic Characteristics*

A total of 34 patients were eventually included in the study, 73.5% of whom were female (Table 1). The mean age at diagnosis and tumor diameter were 44.03 ± 15.08 years and 4.53 ± 0.615 cm, respectively. Regarding comorbidities, 2.9% of patients had hypertension, 8.8% high blood pressure, 14.7% hyperlipidemia, and 5.9% ischemic heart disease.

**Table 1.** Gender Distribution Among Study Participants

| | Frequency (%) | Valid Percent |
|---|---|---|
| **Male** | 9 (26.5) | 26.5 |
| **Female** | 25 (73.5) | 73.5 |
| **Total** | 34 (100.0) | 100.0 |

### *4.2. Preoperative Parameters*

Fifteen patients (44%) had right-sided lesions, and 19 (56%) had left-sided lesions. Furthermore, 9 (26.5%) subjects had moderate hearing loss or impairment, while 25 (73.5%) complained of severe hearing impairment. The location of the facial nerve was anterosuperior in 18 (52%), anterior in 9 (26%), inferior in 4 (11%), and posterior in 3 patients (9%). All locations were detected using intraoperative direct stimulation during surgery. Inferior and especially posterior locations were unusual and needed experience. Concerning preoperative facial nerve function, 31 (91.2%) patients had normal nerve function, and 3 (8.8%) had slight FNI.

### 4.3. Intraoperative and Surgery-associated Parameters

Suboccipital retrosigmoid craniotomy was performed in all patients. Moreover, canal drilling was placed in all patients during surgery. Regarding tumor consistency, 31 (91.2%) were soft, and 3 (8.8%) had adhesive capsules. The mean duration of surgery was 6.8 ± 2.0 hours, and the mean intraoperative direct facial nerve stimulation threshold was 1.38 ± 0.89.

### 4.4. Early Postoperative Outcomes

Postoperatively, hearing impairment was found to be moderate in 2 (5.9%), moderately severe in 7 (20.6%), and severe in 25 patients (73.5%). In addition, the postoperative assessment revealed 3 (8.8%) patients with slight facial nerve impairment, 13 (38.2%) with moderate FNI, 12 (35.2%) with moderately severe FNI, and 5 (14.7%) with severe FNI.

No patient was returned to the operating room, and we faced no postoperative significant hematoma requiring surgery. However, pseudo-meningocele [i.e., cerebrospinal fluid (CSF) collection) was encountered in three patients, which was managed conservatively in two cases, and one patient required V-P shunt insertion. No wound infection or significant dehiscence was detected. Herpes zoster was detected in one patient postoperatively and was managed with Acyclovir without complications. Nimodipine was used in 8 cases with significant manipulation of large arteries, especially the posterior inferior cerebellar artery at the margin of the tumor. These Schwannomas were invasive (penetrating) lobulated subtypes.

### 4.5. Follow-up

Approximately 82% of the patients improved after 6 months of follow-up. Facial nerve function enhanced from severe to moderately severe in 4 cases (80%), and 1 patient (20%) improved from severe to moderate facial nerve function. However, less than 10% of the patients (6%) had no changes in the facial nerve function. A one-year follow-up revealed similar results.

### 4.6. Statistical Analysis

The facial nerve function of patients with giant VS was measured before and after tumor resection to help determine the possible outcomes for each patient. Using the House-Brackmann Scale (HBS) (7), facial nerve functions are classified in Table 2.

Out of 31 patients who presented with normal preoperative facial function, 2 (6.5%), 12 (38.7%), 11 (35.5%), 5 (16.1%), and 1 (3.2%) cases developed slight, moderate, moderate to severe, severe, and total FNI, respectively. Therefore, 45% of patients had acceptable facial outcomes as mild to moderate FNI. Considering stimulation thresholds, patients with HB scale 2 had a mean of 1.67 ± 1.16 mA, HBS 3 had a mean of 1.31 ± 0.95, HBS 4 had a mean of 1.33 ± 0.89, HBS 5 had a mean of 1.60 ± 0.90, and HBS 6 had a mean of 1. There was no statistically significant correlation between intraoperative stimulation threshold and postoperative facial nerve outcome ($P > 0.05$).

Cross tabulation was performed for intraoperative facial nerve DES and perioperative changes in facial nerve function. The perioperative facial nerve function changes were categorized as 'no change,' 'moderate to severe prognosis, and 'worse prognosis.' Among the four patients presented with normal facial nerve DES, none had a change in prognosis, 2 (12.5%) developed a moderate to severe prognosis, and 2 (12.5%) sustained a worse prognosis.

Furthermore, out of 18 patients presented with mild intraoperative direct facial nerve stimulation threshold, 1 person had no change, 9 (56.3%) had a moderate to severe prognosis, and 8 (47.1%) had a worse prognosis. We observed that out of 7 patients who presented with moderate intraoperative direct facial nerve stimulation threshold, none had any change in prognosis, 2 (12.5%) had a moderate to severe prognosis, and 5 (29.4%) developed a worse prognosis. Out of 5 patients who presented with severe intraoperative direct facial nerve stimulation threshold, none had any change, 3 (18.8%) had moderate to severe prognosis, and 2 (11.8%) developed a worse prognosis. The hearing status of patients with different tumor sizes undergoing VS resection did not improve; therefore, tumor size does not affect postoperative hearing loss.

### 4.7. Hearing Loss

Among 9 patients who preoperatively had moderate hearing loss, 1 (11.1%) had no change, 2 (22.2%) had moderate to severe, and 6 (66.7%) had severe postoperative hearing loss. Similarly, out of 25 cases with severe hearing loss preoperatively, 1 (11.1%) had no change, 5 (20%) had moderate to severe, and 19 (76%) had severe postoperative hearing loss. No significant difference was found in hearing loss at preoperative and postoperative hearing status using the chi-square analysis. Fischer's exact test showed a p-value of 0.34. All patients with giant VS had poor outcomes in terms of hearing, and all patients presented with severe SNHL. There was no change

**Table 2.** House-Brackmann Facial Scale

| Grading | Description | Measurement | Function % | Estimated Function % | Postop Values (N) |
|---|---|---|---|---|---|
| I | Normal | 8/8 | 100 | 100 | 3 |
| II | Slight | 7/8 | 76 - 99 | 80 | 2 |
| III | Moderate | 5/8 - 6/8 | 51 – 75 | 60 | 12 |
| IV | Moderately severe | 3/8 - 4/8 | 26 - 50 | 40 | 11 |
| V | Severe | 1/8 - 2/8 | 1 - 25 | 20 | 5 |
| VI | Complete palsy | 0/8 | 0 | 0 | 1 |

in the patient's hearing status since the preoperative and postoperative hearing status remained as severe sensorineural loss.

### *4.8. Tumor Consistency and Postoperative Hearing Status*

Among the patients who underwent surgery, 31 presented with soft tumor consistency and 3 with adhesive capsule tumor consistency. Out of 31 cases with soft tumor consistency, 7 (100%) had a better prognosis, 18 had no changes, and 6 had an unfavorable prognosis. Among the 3 subjects with adhesive capsules, none had an improved prognosis, 2 had no changes, and 1 had an unfavorable prognosis. No significant correlation was found between tumor consistency and postoperative hearing status ($P > 0.05$). In addition, comparing preoperative and postoperative hearing status with canal drilling during the giant VS resections demonstrates no change in the outcome. Canal drilling may not positively affect the hearing status of giant VS cases.

## 5. Discussion

A retrospective cohort including 34 patients with giant (Samii IV/IVb grade) VS is reported in the current paper. About 45% of patients had acceptable facial outcomes as mild to moderate FNI. The tumor size did not affect postoperative hearing loss. There was no statistically significant improvement in the postoperative hearing status compared to preoperative values. The postoperative facial nerve function may improve; however, the intensity of intraoperative DES may not predict the postoperative facial function.

Preservation of facial nerve function is a critical consideration in VS surgeries since facial paresis is associated with significant social implications. With the growing technology in the surgery field, more uncomplicated, consistent, and safe surgical methods have emerged. However, methods that predict nerve function after surgery have yet to be well developed. This research assessed the facial and cochlear nerve outcomes following a retrosigmoid suboccipital surgical resection of a giant VS. In our investigation, the preoperative facial nerve function was normal (HBS 1) in 31 (91.2%) patients and slight (HBS 2) in 3 (8.8%) cases.

All patients were operated on with a retrosigmoid approach at the lateral position (Ojemann), which is the standard of surgery in such lesions by neurosurgeons. Middle cranial fossa and trans-petrosal approaches are more familiar to otolaryngologist surgeons and have limited indications by neurosurgeons. Such approaches are more indicated in patients with unserviceable hearing, and limited access to the posterior fossa is provided. Most of the cranial nerves in the posterior fossa (5th to 12th cranial nerve) could be reached and preserved by the retrosigmoid approach. Our results fall within the normal range of previous studies mentioned above. Anatomically, all facial nerves were preserved. Consequently, following surgical tumor resection, VS patients seemed to have improved facial nerve function in long-term follow-up.

The introduction of IONM, which can directly stimulate the facial nerve, allows the surgeon to monitor the nerve's structural and functional integrity in real time, allowing for early detection and the potential to prevent an intraoperative injury. It is worth noting that once the signals are abnormal, neuromonitoring cannot predict the extent of recovery. Furthermore, the introduction of IONM for facial nerve EMG is widely practiced in microsurgery to aid in the identification and dissection of the facial nerve (8). Using optimal monitoring techniques and correctly interpreting and troubleshooting intraoperative signal changes is critical for maximizing neural preservation (9). As a standard practice, IONM protects patients at risk during surgery by continuously observing the central nervous system (the brain, spinal cord, and nerves) (10). The EMG monitors orbicularis oculi and the orbicularis oris muscles innervated by the facial nerve at risk during surgery (11). Although some studies have indicated the predictive ability of IONM, including DES, somatosensory-evoked potentials, and acoustic-evoked potentials, in the microsurgery of VS, none expanded their predictive outcomes to the giant VS patients.

In a recent survey by Arlt et al. (12), the predictive ability of IONM, including direct nerve stimulation, somatosensory-evoked potentials, and acoustic-evoked potentials, in the microsurgery of 79 VSs with a diameter range of 10 - 57 mm was assessed. A significant correlation was observed between the postoperative facial nerve function and the amplitude of the corresponding DES in the orbicularis oris muscle (P = 0.03). The HBS was not found to be affected by the extent of tumor resection. The authors declared that repeated direct nerve stimulation and a detected decreased amplitude would predict the facial nerve function deterioration. Similarly, in a recent systematic review and meta-analysis, Quimby et al. (13) sought to assess the predictive ability of any of DES parameters on postoperative facial nerve function in patients undergoing VS surgeries. The authors concluded that minimum stimulation threshold values of 0.05 and 0.10 mA provided sensitive and specific values in a long-term follow-up, respectively.

The tumor size has no relationship with postoperative hearing status. All the subjects presented different tumor sizes with a range of 4 - 6 cm. After surgical resection, severe SNHL was seen in all patients. The natural history of tumor growth is variable; whereas some lesions demonstrate continuous development, others grow to a specific size and stagnate or shrink. In a review of the literature by Sughrue et al. (14), among 982 patients, the mean initial tumor size was 11.3 mm, and the mean growth rate was 1.2 mm/year. The authors found that a growth rate greater than 2.5 mm/year better predicts hearing loss than initial tumor size for patients with VS less than 25 mm in the largest dimension. The same findings were noted in a prospectively followed group of 59 patients managed conservatively by the same group. A similar conclusion from Hoa et al. (15) also presented that 50% of patients may maintain hearing during a 5-year observation period, and initial hearing loss (even small degrees) may predict a greater chance of loss of good hearing over time. Therefore, this may indicate that tumor size has no direct effect on the postoperative hearing status. Previous investigations support the findings of the current study, suggesting that patients with giant VS may have a poor outcome in terms of hearing. The primary variable predicting hearing outcome is preoperative hearing status.

All patients presented with severe SNHL both in preoperative and postoperative hearing status. There was no change in the patient's hearing status because the preoperative and postoperative hearing status remained as severe sensorineural loss. Moreover, this study found no significant difference in the preoperative and postoperative hearing status of patients with giant VS. In all cases, the preoperative and postoperative hearing status remained severe SNHL, implying that preoperative and postoperative procedures do not directly influence hearing.

Conversely, Philips et al. suggested that serviceable hearing was preserved in 57.5% of their study population (16), warranting further studies to ascertain the impact of surgical resection on sensorineural hearing in VS patients. This study found no correlation between tumor consistency and hearing loss in a similar trajectory as SNHL. The same hearing status was noticed in soft tumors and adhesive capsules, suggesting that operative procedures do not affect the hearing status of patients with severe SNHL. However, this study has enrolled patients with small-sized VS and has included both retrosigmoid and middle-fossa approaches.

The standard approach used by most neurosurgeons for VS surgeries remains as retrosigmoid approach. Drilling the posterior wall of the internal auditory meatus (IAM) is vital for removing vestibular schwannoma. During IAM drilling, 3 anatomical structures can be accessed, including the posterior semicircular canal, vestibular aqueduct, and jugular bulb (17). Any of these can be injured during drilling, primarily if the jugular bulb lies above the inferior edge of the IAM. This study sought to determine whether canal drilling directly affected hearing loss. There appears to be no change in the hearing status of patients who presented to the hospital and underwent the canal drilling procedure. These results indicate that no possible complications could be associated with canal drilling with a resultant impact on hearing loss.

Contrary to this study, Hummel et al. (18) reported that canal drilling affects postoperative hearing status compared to preoperative hearing. Approximately hearing status improved in 46% and 76% of their study subjects preoperatively and postoperatively, respectively. Further investigations are suggested to come to a common platform.

The reported rates of CSF leakage following VS surgeries range widely from 8.1 to 30% (19). The CSF leaks increase the length of hospitalization, the rate of hospital readmission, and potentially the rate of return to the operating room. It is worth bearing in mind that the segment of the facial nerve proximal to the geniculate ganglion lacks epineurium and is supplied mainly by a single artery, making it especially prone to surgical and ischemic injury (20).

### 5.1. Limitations and Recommendations

The current study had a relatively small sample size limited to a single medical center, with a retrospective nature, and may have some sources of bias. Moreover, IONM carries several false positive and negative results. Multicenter studies with longer considerable follow-up time are warranted with a larger sample size to ensure comprehensive applications of the findings in this study. More investigations on DES parameters, such as acoustic- and somatosensory-evoked potentials, may enable the accurate prediction of both short- and long-term postoperative facial function.

### 5.2. Conclusions

Administration of retrosigmoid approach coupled with intraoperative neuromonitoring is associated with facial and cochlear nerve preservation after the surgical resection of a giant VS. Postoperative facial nerve function is likely to improve; however, the sensorineural hearing status may not improve after surgical tumor resection. Moreover, the intensity of intraoperative direct facial nerve stimulation may not predict the postoperative facial function. Therefore, the findings of IONM should be interpreted carefully.

## Footnotes

**Authors' Contribution:** MF: Conceptualization and design of the study, analysis, and interpretation of data; MMT: Analysis and interpretation of data, draft, and revision of content; SAHJ: Conceptualization and design of the study, revision, and approval of the final version; MME: Final proofreading and providing the final editing.

**Conflict of Interests:** The authors did not have any conflict of interest.

**Data Reproducibility:** The datasets used and/or analyzed during the current study are available from the corresponding author upon reasonable request.

**Ethical Approval:** The research protocol was approved by the Ethics Committee of Tehran University of Medical Sciences with the ethics code IR.TUMS.NI.REC.1401.096.

**Funding/Support:** The authors did not receive support from any organization for the submitted work. No funding was received for preparing this manuscript. No funding was received for conducting this study.

**Informed Consent:** Written informed permission was obtained from the patients to publish this report per the journal's patient consent policy.

## References


1. Lanser MJ, Sussman SA, Frazer K. Epidemiology, pathogenesis, and genetics of acoustic tumors. *Otolaryngol Clin North Am*. 1992;**25**(3):499–520. [PubMed ID: 1625863].
2. Pinna MH, Bento RF, Neto RV. Vestibular schwannoma: 825 cases from a 25-year experience. *Int Arch Otorhinolaryngol*. 2012;**16**(4):466–75. [PubMed ID: 25991975]. [PubMed Central ID: PMC4435437]. https://doi.org/10.7162/S1809-97772012000400007.
3. Falcioni M, Fois P, Taibah A, Sanna M. Facial nerve function after vestibular schwannoma surgery. *J Neurosurg*. 2011;**115**(4):820–6. [PubMed ID: 21682562]. https://doi.org/10.3171/2011.5.JNS101597.
4. Nakatomi H, Miyazaki H, Tanaka M, Kin T, Yoshino M, Oyama H, et al. Improved preservation of function during acoustic neuroma surgery. *J Neurosurg*. 2015;**122**(1):24–33. [PubMed ID: 25343177]. https://doi.org/10.3171/2014.8.JNS132525.
5. Wang AC, Chinn SB, Than KD, Arts HA, Telian SA, El-Kashlan HK, et al. Durability of hearing preservation after microsurgical treatment of vestibular schwannoma using the middle cranial fossa approach. *J Neurosurg*. 2013;**119**(1):131–8. [PubMed ID: 23413947]. https://doi.org/10.3171/2013.1.JNS1297.
6. Weiss NM. Rare Diseases of the Middle Ear and Lateral Skull Base. *Laryngorhinootologie*. 2021;**100**(S 01):S1–S30. [PubMed ID: 34352901]. [PubMed Central ID: PMC8354576]. https://doi.org/10.1055/a-1347-4171.
7. Ilea A, Vâjâean C, Hurubeanu L, Boşca B, Ţărmure V. The Use of Digital Imaging in the Evaluation of Perception in Facial Asymmetry Caused by Facial Nerve Disorders. *International Conference on Advancements of Medicine and Health Care through Technology*. 2014.
8. Liu SW, Jiang W, Zhang HQ, Li XP, Wan XY, Emmanuel B, et al. Intraoperative neuromonitoring for removal of large vestibular schwannoma: Facial nerve outcome and predictive factors. *Clin Neurol Neurosurg*. 2015;**133**:83–9. [PubMed ID: 25867236]. https://doi.org/10.1016/j.clineuro.2015.03.016.
9. Kircher ML, Kartush JM. Pitfalls in intraoperative nerve monitoring during vestibular schwannoma surgery. *Neurosurg Focus*. 2012;**33**(3). E5. [PubMed ID: 22937856]. https://doi.org/10.3171/2012.7.FOCUS12196.
10. Ghatol D, Widrich J. *Intraoperative neurophysiological monitoring*. StatPearls; 2020.
11. Isaacson B, Kileny PR, El-Kashlan H, Gadre AK. Intraoperative monitoring and facial nerve outcomes after vestibular schwannoma resection. *Otol Neurotol*. 2003;**24**(5):812–7. [PubMed ID: 14501461]. https://doi.org/10.1097/00129492-200309000-00020.
12. Arlt F, Kasper J, Winkler D, Jahne K, Fehrenbach MK, Meixensberger J, et al. Facial Nerve Function After Microsurgical Resection in Vestibular Schwannoma Under Neurophysiological Monitoring. *Front Neurol*. 2022;**13**:850326. [PubMed ID: 35685739]. [PubMed Central ID: PMC9170892]. https://doi.org/10.3389/fneur.2022.850326.
13. Quimby AE, Lui J, Chen J. Predictive Ability of Direct Electrical Stimulation on Facial Nerve Function Following Vestibular Schwannoma Surgery: A Systematic Review and Meta-analysis. *Otol Neurotol*. 2021;**42**(4):493–504. [PubMed ID: 33394939]. https://doi.org/10.1097/MAO.0000000000003007.
14. Sughrue ME, Yang I, Aranda D, Lobo K, Pitts LH, Cheung SW, et al. The natural history of untreated sporadic vestibular schwannomas: a comprehensive review of hearing outcomes. *J Neurosurg*. 2010;**112**(1):163–7. [PubMed ID: 19538047]. https://doi.org/10.3171/2009.4.JNS08895.
15. Hoa M, Drazin D, Hanna G, Schwartz MS, Lekovic GP. The approach to the patient with incidentally diagnosed vestibular schwannoma. *Neurosurg Focus*. 2012;**33**(3). E2. [PubMed ID: 22937853]. https://doi.org/10.3171/2012.6.FOCUS12209.
16. Phillips DJ, Kobylarz EJ, De Peralta ET, Stieg PE, Selesnick SH. Predictive factors of hearing preservation after surgical resection of small vestibular schwannomas. *Otol Neurotol*. 2010;**31**(9):1463–8. [PubMed ID: 21113983].

17. Muhammad S, Lehecka M, Sinkkonen ST, Niemela M. Management of jugular bulb injury during drilling of the internal auditory canal (ICA) for vestibular schwannoma surgery. *Am J Otolaryngol*. 2019;**40**(2):341. [PubMed ID: 30704809]. https://doi.org/10.1016/j.amjoto.2019.01.004.
18. Hummel M, Perez J, Hagen R, Gelbrich G, Ernestus RI, Matthies C. Auditory Monitoring in Vestibular Schwannoma Surgery: Intraoperative Development and Outcome. *World Neurosurg*. 2016;**96**:444–53. [PubMed ID: 27647030]. https://doi.org/10.1016/j.wneu.2016.09.026.
19. Fishman AJ, Marrinan MS, Golfinos JG, Cohen NL, Roland JJ. Prevention and management of cerebrospinal fluid leak following vestibular schwannoma surgery. *Laryngoscope*. 2004;**114**(3):501–5. [PubMed ID: 15091225]. https://doi.org/10.1097/00005537-200403000-00022.
20. Sun MZ, Oh MC, Safaee M, Kaur G, Parsa AT. Neuroanatomical correlation of the House-Brackmann grading system in the microsurgical treatment of vestibular schwannoma. *Neurosurg Focus*. 2012;**33**(3). E7. [PubMed ID: 22937858]. https://doi.org/10.3171/2012.6.FOCUS12198.