Pitfalls in intraoperative nerve monitoring during vestibular schwannoma surgery

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Despite the widespread acceptance of intraoperative neurophysiological monitoring in skull base surgery over the last 2 decades, surgeon training in the technical and interpretive aspects of nerve monitoring has been conspicuously lacking. Inadequate fundamental knowledge of neurophysiological monitoring may lead to misinterpretations and an inability to troubleshoot system errors. Some surgeons perform both the technical and interpretive aspects of monitoring themselves while others enjoin coworkers (surgical residents, nurses, anesthetists, or a separate monitoring service) to perform the technical portion. Regardless, the surgeon must have a thorough understanding to avoid potential medical and legal pitfalls because poor monitoring is worse than no monitoring. A structured curriculum and protocol in both the technical and interpretive aspects of monitoring is recommended for all personnel involved in the monitoring process. This paper details the technical, interpretive, and surgical correlates necessary for optimal intraoperative nerve monitoring during vestibular schwannoma surgery with an emphasis on electromyographic monitoring for facial and recurrent laryngeal nerves. Just as the American Society of Anesthesiologists’ 1986 “Standards for Basic Anesthetic Monitoring” became a useful tool for both patients and anesthesiologists, impending guidelines in intraoperative neurophysiological monitoring should likewise become an important instrument for optimizing intraoperative neurophysiological monitoring.

(http://thejns.org/doi/abs/10.3171/2012.7.FOCUS12196)

**Key Words** • acoustic neuroma • electromyography • facial paralysis • intraoperative neurophysiological monitoring • nerve monitor • vestibular schwannoma

**Abbreviations used in this paper:** CMAP = compound muscle action potential; EMG = electromyography; RLN = recurrent laryngeal nerve; VS = vestibular schwannoma.
surgical morbidity and mortality, it was the addition of intraoperative electromyographic facial nerve monitoring that resulted in dramatic reductions in postoperative facial palsy. Facial monitoring is helpful in localizing the nerve within a tumor distorted field and provides real-time neurophysiological status feedback. This feedback allows the surgeon to detect and avoid stretch or ischemic nerve injury that may not otherwise be apparent with a visualized intact facial nerve.

Many studies have demonstrated improved postoperative facial nerve outcomes with the use of intraoperative monitoring. This dramatic improvement has led to the routine use of monitoring during VS surgery and has also been advised by the NIH.

Neurophysiology

Electromyography is used intraoperatively to monitor for nerve injury during VS surgery. This test relies on measurements of the CMAP generated by the muscles of facial expression. Depolarization of the facial nerve leads to distal propagation of nerve action potential to the motor endplate, where it is translated into motor unit potentials emanating from the corresponding muscle fibers. These motor unit potentials when summed together result in the measured CMAP, which reflects the activity of the muscles of facial expression. Changes in CMAP reflect changes in the functional status of the facial nerve. Monitoring the CMAP allows an order of magnitude larger response than if a nerve action potential was recorded due to the amplifying effect of the muscle response.

An accurate assessment of nerve conduction with EMG requires stimulation proximal to the potential site of injury. When an electrical stimulus is applied distal to injury in the acute setting, a seemingly normal response may be obtained, because distal Wallerian axonal degeneration following severe nerve injury takes 48–72 hours to reach the motor endplate. Nerves suffering from mild to moderate trauma will exhibit reductions in amplitude and prolonged latency. Increasing injury requires an increasing amount of current to elicit a response. Often a combination of physiological conduction block (neuropaenia) and physically injured neural elements (axonotmesis or neurotmesis) will be evident after significant surgical trauma. These injuries will be variably represented on EMG by reduction in amplitude, increase in latency, and increase in threshold stimulation as the level of nerve trauma increases.

Intraoperative Facial Nerve Monitoring

Intraoperative facial nerve monitoring aids in localization of the nerve displaced by tumor distortion, detects nerve injury during dissection, and provides a means for assessing nerve function after dissection is complete. While many modality monitoring devices can be employed, when only EMG recording is required, many centers use dedicated EMG monitoring systems, which are simpler and typically provide direct auditory feedback of responses to the surgeon. Common systems we have employed include the Medtronic Nerve Integrity Monitor and the Neurosign system. The nerve monitoring system is an adjunct, not a replacement, for surgical skill and judgment in the assessment and preservation of neural structures. False-positive and false-negative errors can occur with monitoring; therefore, a knowledgeable surgeon and monitoring team are essential to troubleshoot system errors. If monitoring results contradict the surgeon’s assessment of anatomy, tumor, or status of the nerve, then the surgeon should proceed with caution and may choose to reject the monitoring information until proper functioning of the monitoring system can be assessed.

It is important to be aware that EMG monitoring is disabled during the use of electrocautery. Electrocautery generates high intensity electrical artifact that typically overpowers the ability of the monitor to record low amplitude EMG activity. In fact, to reduce the disruptive noise artifact through the loudspeaker, most monitors defeat the loudspeaker during electrocautery. Thus, thermal nerve injury due to electrocautery may not be detected until after the injury has occurred and then only if the nerve has been stimulated to assess its function. Baseline stimulation should be performed as early and often as feasible using moderate-level mapping currents prior to initiating tumor dissection. Stimulation is especially important before and after any particularly risky surgical maneuver to ensure appropriate function of the monitoring system and to detect nerve injury at the earliest time possible.

Training

The successful use of intraoperative facial nerve and RLN monitoring requires the surgeon’s interpretation of neurophysiological responses. Furthermore, if the surgeon also takes on the responsibility of the electrode and device setup, specific training in the technical aspects of monitoring is required. Meticulous attention to detail must be paid to anesthesia, the monitoring device, and the electrodes to ensure accurate results. At our institution, the surgeon performs intraoperative monitoring in conjunction with a technologist who has received special training and certification (Certification in Neurophysiological Intraoperative Monitoring).

At many institutions, however, surgeons performing the technical setup have had little or no formal training. At academic institutions, residents who have had only cursory instruction by a coresident may perform the monitoring setup. Many staff surgeons may have had only a brief introduction to the technology through a product representative. Alternatively, some centers contract monitoring to either a service company or an in-house department such as Neurology or Anesthesia. Ultimately, it is incumbent on the operating surgeon to learn the technical and interpretive aspects of monitoring and to incorporate this knowledge into real-time surgical modification. It is suggested that an intraoperative nerve monitoring protocol be established at each institution in conjunction with a core curriculum and competency testing. Many institutions have similar requirements for new or high-risk procedures, such as the use of lasers, endoscopy, and others.

Technical Factors During Setup

To reliably perform EMG-based facial nerve moni-
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toring, an intraoperative checklist is beneficial, similar to
the orderly stepwise process performed preflight by com-
cmercial airline pilots before takeoff. Established proto-
cols (Table 1) can diminish the chance for error by creat-
ing obligations that must be completed before progressing
to the next step. In this manner, intraoperative monitoring
errors may be promptly identified and remedied.

The first step is to ensure that the anesthesiologist
avoids the use of long-acting muscle relaxants. Short-acting
muscle relaxants such as succinylcholine are acceptable for
anesthesia induction, except in the rare patient with pseudo-
docholinesterase deficiency, in which prolonged paralysis
is experienced. When in doubt, train-of-four EMG testing
should be performed prior to the nerves being exposed.

The second step is the judicious use of local anesthe-
sic (such as lidocaine or bupivacaine), which can chemi-
cally induce temporary paresis, rendering monitoring
useless. Anesthetic injections near the stylomastoid fora-
men are to be avoided, especially in children for whom
the mastoid tip may be poorly developed. In addition,
local anesthetic may track into the middle ear with the
potential to come into contact with the tympanic segment
of the facial nerve, which may be dehiscent in approxi-
mately 20% of patients.¹

The third step is careful electrode placement. For
facial nerve monitoring, intramuscular needle electrodes
are inserted in a closely paired manner at the nasolabial
groove (orbicularis oris) and near the eyebrow (orbicu-
laris oculi) on the side to be monitored (Fig. 1). Care must
be taken to direct the electrodes away from the orbit to
avoid inadvertent trauma to the eye. Two additional elec-
drodes are placed subcutaneously over the sternum, one
serving as a ground for the recording channels and the
other as a return for the monopolar nerve stimulator. We
routinely color code electrodes: blue for eyes, red for lips,
green for ground, white for anode, and black for cathode.
A reliable mnemonic for this set-up is “blue eyes, red lips,
green ground.” These electrodes are then connected to
their corresponding nerve monitor headboards with the
cathode (typically colored black) used for stimulation
rather than the anode (white), because cathodal stimula-
tion is more effective.

The fourth step is to check the impedances of the
different electrode pairs. The independent electrode im-
pedance should be less than 5 kOhm, while interelectrode
impedance should be less than 2 kOhm. If impedance is
too high, this suggests poor needle position or faulty elec-
trodes; the electrodes should be repositioned or replaced
and then retested.

![Fig. 1. Illustration of the EMG recording sites used for 2-channel facial nerve monitoring. Paired electrodes are placed subcutaneously at the nasolabial groove (orbicularis oris) and near the eyebrow (orbicularis oculi) on the side to be monitored. Ground and anodal return electrodes can be placed high on the forehead as shown, or more com-
monly today, near the sternum (not shown). Reproduced with permis-

The fifth step is to perform a tap test to check the
integrity of the connection from the electrode to the re-
cording device. Tapping the skin over each pair of facial
recording electrodes generates an electrical artifact. Most
monitors will display this artifact as a visual signal on
the oscilloscope, as well as a concurrent acoustic signal
from the loudspeaker. This design allows those surgeons

<table>
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<th>TABLE 1: Facial nerve monitoring setup protocol</th>
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<td>1. Ensure the anesthesiologist avoids use of long-acting muscle relaxants</td>
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<td>2. Be wary of local anesthetic (lidocaine or bupivacaine), which can chemically induce a temporary facial paresis, rendering monitoring useless</td>
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<td>3. Place electrodes carefully</td>
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<td>4. After electrodes are connected to the nerve monitor, check impedances of different electrode pairs</td>
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<tr>
<td>5. Perform a tap test to check integrity from electrode to recording device</td>
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<td>6. After incision and soft tissue exposure, check for current flow using nerve stimulator</td>
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<td>7. Stimulate the nerve at an early point in surgery before any significant nerve manipulation is performed</td>
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who are monitoring without the help of a monitorist to receive real-time audio feedback. It must be remembered that the tap test only represents an intact connection from electrode to monitoring device. Performing a tap test on a paralyzed face will also create the same electrical artifact present in the case of a nonparalyzed facial nerve; a true CMAP is not obtained. Therefore, no information is obtained regarding the functional status of the facial nerve with the tap test.

Pairing of audio and visual feedback allows the monitoring team to be as vigilant as possible in regard to a change in nerve status. For example, for those surgeons relying on the technician watching the screen without audio feedback, an important response may be missed if the technician looks away for a moment. Conversely, devices that only have an audible response with no oscilloscope lose the opportunity to differentiate artifact response from true response. Multimodality monitoring including RNL monitoring, auditory brainstem recording, and somatosensory and transcranial motor evoked potentials increases the complexity of monitoring, which typically therefore mandates the need for a technical assistant.

The sixth step is to check for current flow using the nerve stimulator. After incision and soft tissue exposure, touching the stimulator to soft tissue or wet bone should result in near 100% conduction of current from the stimulator to the monitor. Most devices will display the returned current visually. Others may present an audible warble tone that is distinct from a true response beep tone. At this time, the volume of the nerve monitor should be adjusted to assure the surgeon can hear it over ambient operating room sounds (such as a drill or suction).

The seventh step is to obtain a baseline response by stimulating near the nerve at sufficient current to elicit a response. Doing so at an early point in the surgery before any significant nerve manipulation is performed establishes that all aspects of monitoring and anesthesia are optimized. The distance from the nerve and the amount of intervening tissue will determine the current setting needed to elicit nerve depolarization. A normal facial nerve will respond to as little as 0.05-mA stimulation when the probe is placed directly on the nerve in the cerebellopontine angle. However, with increasing distance, as well as intervening soft tissue, bone, CSF, or blood, a current of 1–2 mA may be required to obtain a baseline “far-field” response by volume conduction of current through tissue. Once a confirmatory baseline response is obtained, current intensity is reduced to the lowest possible stimulating levels based on nerve proximity. In the senior author’s experience (J.M.K.), 30 years of using such mapping techniques with modern current settings (such as pulse durations of approximately 100 μsec at approximately 5 Hz) have resulted in no detrimental nerve effects.

The more difficult the tumor dissection, the more often electric stimulation should be performed to constantly assess both the location and integrity of the nerve. Using insulated stimulating surgical instruments such as Kartsch Stimulating Instruments (Neurosign) allows simultaneous surgical dissection with frequent electrical stimulation. Once the tumor has been resected, a final threshold response to stimulation should be obtained for comparison with the baseline amplitude.

**Intraoperative RNL Monitoring**

When VSS are large and extend significantly toward the jugular foramen, consideration should be given to monitoring the vagus nerve by way of its RNL. Similar to facial nerve monitoring, RNL monitoring is also based on EMG. Therefore, many of the principles and potential pitfalls discussed with respect to facial nerve monitoring also apply to RNL monitoring, with a few technical considerations. However, all monitoring modalities have their particular differences, which should be clearly understood to avoid error.

Today, the most commonly used method of intraoperative RNL monitoring utilizes surface electrodes along an endotracheal tube. Direct intramuscular needle placement can be effective but had practical challenges that limited its use, such as performing direct laryngoscopy to insert needles into the vocal cords. Consequently, while not ideal, RNL monitoring is most commonly performed today using laryngeal surface recording electrodes placed on endotracheal tubes. These may be premanufactured and attached to an endotracheal tube (the Medtronic Nerve Integrity Monitor EMG endotracheal tube), or they may be applied externally to the endotracheal tube using stick-on surface electrodes (Neurosign, IOM Solutions). This surface technique requires precise placement of the tube-electrode array during intubation such that electrodes directly contact the true vocal cords to allow recording of laryngeal musculature CMAP. By “hitchhiking” along with the endotracheal tube, the anesthesiologist becomes a key player in the procedure and must understand the proper method to optimize placement under direct laryngoscopic vision, often aided by devices such as the GlideScope (Verathon). Intraoperative head rotation or extension may displace the tube; therefore, consideration should be given to laryngoscopic reassessment of tube position if there is any doubt in tube-electrode positioning. Topical laryngeal anesthetic (such as viscous lidocaine) should be avoided during intubation as well, because this could temporally cause vocal cord paralysis preventing effective monitoring.

It must be remembered that laryngeal surface electrode contact must be precise with an optimal electrode-to-vocal cord fit. Endotracheal tube size must be considered. A tube with a small outer diameter will result in poor electrode contact, whereas too large of a tube may cause trauma during and following intubation. While the stick-on type laryngeal electrodes allow the anesthesiologist to choose whichever endotracheal tube he or she prefers, unfortunately, as of this writing, Medtronic only offers their Nerve Integrity Monitor endotracheal tubes in sizes 6, 7, and 8; there are no half sizes or pediatric sizes available in the US, which reduces options for glottic sizing. Stick-on electrodes should be taped 1–2 cm above the endotracheal cuff and can be used with any size endotracheal tube to optimize fit. Lubricants should be avoided. Additionally, with longer procedures, the moist environment of the airway can cause these adhesive electrodes to become displaced. New adhesives are being tested.

In regards to RNL stimulation, the surgeon should...
remember a few points when mapping for the lower cranial nerves in the posterior fossa. Vagal stimulation at the pars nervosa appears to be safe at stimulation levels of approximately 0.5–1 mA; in our experience, no bradycardia or other untoward vagal effect has been encountered at these levels. However, it is wise to avoid high-level stimulation of the nearby spinal accessory cranial nerve, as this can cause a sudden vigorous muscle contraction of the ipsilateral trapezius and sternocleidomastoid. This contraction can cause a sudden shift that can startle the surgeon; therefore, begin with 0.5 mA and increase amplitude slowly as needed.

Another caveat clinicians should be aware of concerns the Nerve Integrity Monitor EMG endotracheal tube wire reinforcement within the tube. While this reinforcement provides a generally desired increase in rigidity during intubation, the wire can become kinked or unraveled, leading to airway obstruction. To date, the reinforcement wires have been secured by a thin layer of silicone within the lumen of the endotracheal tube, rather than being integrated into the harder outer Silastic, as is common in other “reinforced” or “armored” tubes. Instrumentation of the tube (such as with a tube exchanger or catheter suctioning) can lead to unraveling of the wire within the tube, leading to buildup of clot/mucus with resultant airway obstruction (Fig. 2). Similarly, the patient may inadvertently bite on the tube, resulting in intraluminal wire kinking and obstruction of the endotracheal tube. Thus, to minimize these airway risks, surgeons, technologists, and anesthesiologists should be familiar with the Medtronic package insert caveats: a bite block should be used, and intraluminal manipulations of the Nerve Integrity Monitor tube should be avoided.

None of the described laryngeal electrodes/tubes are intended for use postoperatively, nor are they MRI compatible. When prolonged postoperative intubation is anticipated, the electrode-equipped endotracheal tube should be replaced with a standard endotracheal tube.

Monitoring Interpretation

The prepared surgeon must have a clear understanding of the monitoring technology to interpret data received and adjust surgical manipulation accordingly. The team should be aware that EMG responses can result from many causes such as trauma, ischemia, electric stimulation, thermal changes, patient movement, artifact, and others. Responses may be detected during continuous free-running EMG or during intended electrical stimulation. Prass and Lüders described 2 types of CMAP activity depending on the type of nerve irritation. The first type is the “burst” potential, which consists of a single polyphasic response due to near simultaneous activation of multiple motor units (Fig. 3A). Burst potentials are observed after direct contact of the nerve with surgical instrumentation and are fatiguable with repeated nerve contact. To provide real-time surgeon feedback, these responses will also be represented by a synchronous EMG “click” or “beep” sound produced by the neuromonitor loudspeaker.

The second type of continuous free-running CMAP is a “train” potential. This potential lasts seconds to minutes and is generated by multiple asynchronous responses from different motor units (Fig. 3B). This potential will be represented by a sound from the loudspeaker described as that of popping corn or an airplane engine. The train potential may be caused by mechanical injury (pressure or stretch) or thermal changes to the nerve. With increasing nerve injury, a greater intensity and longer duration of nerve potential will be evident. These findings should prompt the surgeon to adjust or suspend dissection to minimize nerve trauma. With nerve irritation, train potentials may last for several minutes and occasionally, with facial monitoring, 1 channel has prolonged train activity and the other channel does not. Some devices allow 1 channel to be silenced under these circumstances, but one should frequently return to check the silenced channel and unmute as soon as possible to avoid missing relevant feedback.

Thermal nerve injury after the use of laser or electrocautery deserves a special note because this injury may only become evident on EMG in a delayed manner. It may be represented as a gradual increase in baseline, but may also be associated with electrical silence. This finding is important, particularly with electrocautery, because the monitor is disabled during electrical artifact silencing. In this situation, electrocautery nerve injury may result under electrical silence without train EMG potentials. Therefore, if electrocautery injury is suspected, the nerve should be electrically stimulated as soon as possible to determine whether the nerve has been injured and where the injury may have occurred along the nerve’s course.

Other nontraumatic causes of train potentials to consider include drill vibration energy transmission to the nerve, temperature irritation from hot or cold irrigation, irritation from osmotic hypertonic saline irrigation, and lightening of general anesthesia resulting in facial muscle fasciculations. Simply aspirating CSF in the cerebellopontine angle may result in a sudden drop in temperature immediately adjacent to the nerve, triggering a train potential. Therefore, some train potentials are not indicative of trauma, but instead represent a transient change in nerve physiology homeostasis and must be kept in mind when interpreting monitor feedback.

Fig. 2. Photographs showing airway issues of the Nerve Integrity Monitor EMG endotracheal tube. **Left:** Use of instrumentation (such as a suction catheter) can lead to unraveling of the wires within the endotracheal tube and potential airway compromise. Reproduced with permission from Evanina and Hanisak: AANA J 73:111–113, 2005. **Right:** A second example of airway obstruction with the Nerve Integrity Monitor endotracheal tube, secondary to fibrin clot/mucus buildup on the exposed wires within the lumen of the tube.
The second manner in which intraoperative nerve monitoring is used is via nerve stimulator–generated EMG. A stimulating probe instrument is touched to or near the nerve, which generates a true stimulus-triggered EMG response. This potential is represented by a “machine gun” sound on the loudspeaker composed of precisely timed potentials coincident with the stimulus frequency, typically set to 3–5 Hz. Stimulating current levels, ranging from 0.05 to 2 mA, are adjusted accordingly in mapping out the rough location of the nerve.

There are numerous commercially available monopolar and bipolar stimulating probes, each with their own distinct advantages. Bipolar stimulators are superior when discrete differentiation of nerve from adjacent tissue is required (such as when differentiating the facial from the vestibular nerve), whereas monopolar stimulation is optimal when mapping the general location of the nerve. However, monopolar stimulators can be made to be quite selective by progressively decreasing the current intensity as the nerve is approached. As noted, the Kartush Stimulating Instruments have added function in that they allow the surgeon to stimulate and dissect concurrently, because they are shaped liked conventional microsurgical instruments. Conventional probes can be used intermittently to stimulate the nerve but sharp transection of the nerve with cold instrumentation may not elicit an EMG response until after the transection has already occurred. Stimulating instruments, on the other hand, will elicit an electrically evoked CMAP during the dissection to provide the surgeon ongoing feedback on nerve location and integrity.

False-positive errors can occur with stimulus-triggered EMG by a phenomenon known as “current jump.” This happens when volume conduction of current through nearby tissues leads to stimulation of the nerve (Fig. 4 upper). An inexperienced surgeon may incorrectly identify the stimulated structure as the nerve of interest, leading to surgical error. This error can be minimized by using bipolar stimulating instruments and/or the lowest monopolar current mapping levels possible to obtain a response.

False-negative errors can also occur with stimulated EMG. Due to the presence of CSF and blood in the field, electrical insulation along the stimulator’s shaft is required to reduce “current shunting” away from the nerve of interest (Fig. 4 lower). Also, high quality insulation is needed to avoid insulation cracking and inadvertent loss of fragments intracranially. Due to this occurrence being precipitated by repeated autoclaving of reusable probes, there is now a trend to single use probes, including Kartush Stimulating Instruments.

In regard to RLN monitoring interpretation, there are several limitations to consider. First, laryngeal surface electrodes lack the sensitivity and stability of intramuscular needle electrodes. Second, suboptimal positioning of surface electrodes may markedly impair the ability to detect laryngeal responses (false-negative error), and may also lead to erroneous recording of EMG activity from the adjacent pharyngeal musculature (false-positives), particularly at high levels of stimulation.

Last, failure to respond to stimulation can be due to an anatomically disrupted nerve, but can also be due to lesser levels of trauma. Other possibilities, such as anesthetic paralysis of the nerve and incorrect setup of the nerve monitor, must always be considered. Thus, failure to respond to stimulation cannot, by itself, be used as a determinant to resect and graft an unresponsive nerve segment. Instead, this measure is typically only taken with apparent physical disruption of the nerve.
Facial Nerve Outcomes

The use of intraoperative monitoring for VS surgery has resulted in improved facial nerve outcomes.9 A number of studies have specifically examined the correlation between intraoperative facial nerve monitoring findings and postoperative facial nerve outcomes. Lower final stimulus thresholds, higher CMAP response amplitudes, and lower ratios of proximal to distal stimulation thresholds have been correlated with better postoperative facial nerve outcomes.12,18 Recently, Prell et al.15 found that a real-time CMAP measure of train potential time (the A train) is relevant to facial nerve outcomes. Specifically, they found that if the total accumulated A train potential time was greater than 2.5 seconds, consideration should be given to limiting further dissection, because postoperative facial nerve weakness was more likely.

Vagal EMG monitoring has also been shown to reduce nerve morbidity following skull base surgery.17 Authors in this study found that intraoperative monitoring allowed for improved nerve localization in situations of severely distorted anatomy and that the immediate intraoperative feedback affected the extent and manner of surgical manipulation. These authors concluded that these factors facilitated gross-total tumor resection with cranial nerve preservation.

The real-time neurophysiological feedback provided by intraoperative nerve monitoring benefits the surgeon in always knowing the functional status of the nerve. Monitoring has shown the benefits of sharp over blunt dissection when the nerve is clearly delineated visually or by electric stimulation. Past surgical techniques of “rough and rapid” debulking have been modified due to the neurophysiological feedback provided to surgeons, such as EMG train potentials associated with overzealous blunt debulking and retraction.

Implementation of Intraoperative Checklist

To improve the quality of nerve monitoring, there has been a national movement to establish standards in monitoring techniques and to offer credentialing to those who complete this training. In fact, future malpractice claims are likely to be based on these evolving standards. As a corollary, in 1986, there was great controversy among anesthesiologists as to whether a document titled “Standards for Basic Anesthetic Monitoring” (http://www.asahq.org/For-Members/Standards-Guidelines-and-Statements.aspx) should be adopted by the American Society of Anesthesiologists. Fortunately, it became a useful tool for both patients and anesthesiologists. Likewise, we suggest that impending national guidelines already being developed by the American Society of Neurophysiological Monitoring be adopted and followed by surgeons and their teams to optimize intraoperative neurophysiological monitoring.

Conclusions

Surgeons and their ancillary personnel must be cognizant of the potential limitations and pitfalls of intraoperative neurophysiological monitoring. Ultimately, it is incumbent upon the surgeon to understand both the technical and interpretive aspects of intraoperative nerve monitoring to minimize errors and optimize patient safety.

Disclosure

Dr. Kartush is a consultant to Magstim, a manufacturer of intraoperative monitoring devices. He was a past consultant to Medtronic and was the founding president of the American Society of Neurophysiologic Monitoring.
Author contributions to the study and manuscript preparation include the following. Conception and design: Kartush. Analysis and interpretation of data: Kircher. Drafting the article: both authors. Critically revising the article: both authors. Reviewed submitted version of manuscript: both authors. Approved the final version of the manuscript on behalf of both authors: Kartush.

References
12. Marin P, Pouliot D, Fradet G: Facial nerve outcome with a peroperational stimulation threshold under 0.05 mA. Laryngoscope 121:2295–2298, 2011

Manuscript submitted May 15, 2012. Accepted July 13, 2012. Please include this information when citing this paper: DOI: 10.3171/2012.7.FOCUS12196. Address correspondence to: Jack M. Kartush, M.D., Michigan Ear Institute, 30055 Northwestern Highway, Suite 101, Farmington Hills, Michigan 48334. email: jkartush@comcast.net.