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Laryngeal Nerve Monitoring

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ABSTRACT. Intraoperative neurophysiological monitoring of the vagus and recurrent laryngeal nerves is increasingly used during thyroidectomy, parathyroidectomy, skull base surgery, and cervical discectomy with fusion. Monitoring can assist in nerve localization and in reducing the incidence of neural trauma. To be effective, however, monitoring must be correctly implemented and the results interpreted based on an in-depth understanding of technique and the surgical structures at risk. Because “poor monitoring is worse than no monitoring” all members of the surgical monitoring team must have training specific to laryngeal recording to maximize its benefit and minimize pitfalls. This publication will review pertinent anatomy and neurophysiology as well as technical and interpretative factors.

KEY WORDS. Cervical spine surgery, endotracheal electrodes, intraoperative neurophysiological monitoring, recurrent laryngeal nerve, superior laryngeal nerve, thyroidectomy, vagus nerve.

INTRODUCTION

Injury to the recurrent laryngeal nerve (RLN) has long been a concern during thyroidectomy and is the most common reason for malpractice litigation in endocrine surgery. Historically, the RLN was considered so fragile that surgeons were traditionally taught to avoid it. It was believed that simply dissecting in the nerve’s vicinity could lead to injury via direct trauma or disruption of its vascular supply. Surprisingly, a directive to do the opposite later countermanded this philosophy: routinely...
identify the nerve surgically. Management of the RLN has now reached a third stage: active identification in conjunction with intraoperative neurophysiological monitoring (IONM). Intraoperative monitoring has gained wide acceptance in many surgical procedures that place nerves, spinal cord, or brain at risk. Monitoring of the RLN is increasingly used during thyroidectomy, parathyroidectomy, skull base procedures, and cervical disectomy with fusion. It is of particular benefit in cases with difficult anatomy due to prior surgery, large volume tumor/goiter, or history of radiation therapy. Recently, monitoring of the external branch of the superior laryngeal nerve (SLN) has also been advised. To be effective, however, monitoring must be correctly implemented and the results interpreted based on an in-depth understanding of technique and the surgical structures at risk. Poor monitoring is worse than no monitoring (Kartush 1989, Kartush and Bouchard 1992). Therefore, the purpose of this publication will be to review pertinent anatomy, neurophysiology, and technical and interpretive factors to optimize the benefits of monitoring the laryngeal nerves.

MONITORING, TRAINING, AND COMPETENCY

Complex, multimodality monitoring often involves numerous individuals including the surgeon, anesthesiologist, technologist, and an interpreting neurophysiologist (either present in the operating room or in constant real-time communication at a remote site). Each individual has an important role to play. A poorly trained technologist or neurophysiologist who conveys inaccurate information can inadvertently mislead the surgeon. Similarly, a surgeon with inadequate training in neurophysiologic monitoring may not be able to assimilate and act upon correct neurophysiologic information. Expertise in one modality does not assure expertise in all modalities. One must understand the dissimilarities, for example, between monitoring the facial nerve and monitoring the recurrent laryngeal nerve (Kartush and Lee 2013). Furthermore, even within a single modality, there may be significant differences based upon the procedure. Experience, for example, in monitoring the facial nerve during parotidectomy would be helpful but not sufficient for monitoring the facial nerve during acoustic tumor resection where understanding the effects of cerebrospinal fluid current shunting and cerebellar retraction are essential for proper interpretation.

Simple, single modality procedures using devices specifically designed for direct surgeon feedback (e.g., electromyography [EMG]) are often performed by the surgeon with or without the assistance of a technologist. When monitoring alone, the surgeon is duty-bound to assure that he or she has had proper training for both the technical and interpretive aspects specific to the monitoring modality employed. Regrettably at this juncture, no standardized educational curriculum exists for training all individuals involved in monitoring but, fortunately, educational assessment exams have at least evolved on the technical side. For example, the American Board of Registration of Electroencephalographic and Evoked Potential Technologists
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(ABRET) credentials technologists via the Certification Examination in Neurophysiologic Intraoperative Monitoring (CNIM). ASET – The Neurodiagnostic Society has published National Competency Skill Standards for Performing Intraoperative Neurophysiologic Monitoring (ASET 2011). Neurophysiologists can be accredited on the interpretive aspects of monitoring by the American Board of Neurophysiologic Monitoring (ABNM). The American Society of Neurophysiologic Monitoring (ASNM) is a multidisciplinary society that promotes standards for all individuals involved in monitoring, including surgeons. The ASNM has published position statements on proper use of many IONM modalities (ASNM 2010) as well as practice guidelines for the IONM supervisor (Skinner et al. 2014).

Uniform monitoring training and certification have not yet evolved for surgeons but there is a clear need given that surgeons must always interpret the laryngeal monitoring data – and often perform the entire EMG technical set up, as well. Consequently, residency training programs must begin to formalize their IONM curriculum and develop departmental protocols in order to maximize the efficacy and safety of monitoring. There is a precedent for this in that many surgical departments already require special training and documentation should a surgeon wish to use new, complex, or higher risk procedures such as lasers or robotic assisted surgery. Publications such as those by International, German, and Taiwan Intraoperative Monitoring Study Groups have begun to bring key information to thyroid surgeons – and are likewise of value to all personnel monitoring laryngeal nerves (Dralle et al. 2008, Chiang et al. 2010, Randolph et al. 2011).

Historically, it was the facial nerve that was first monitored intraoperatively more than a century ago. Facial nerve monitoring has evolved to become a common procedure in many operations where the nerve is at risk. Given its demonstrated efficacy, the National Institutes of Health (NIH) in 1991 published a Consensus Statement recommending that the facial nerve be routinely monitored during acoustic tumor resection (NIH 1991, Hong and Kartush 2012, Kircher and Kartush 2012, Porter et al. 2013). In contrast to the facial nerve, the benefits of recurrent laryngeal nerve monitoring using current technologies are less convincing most likely due to: a) the monitoring techniques used to record the response (surface versus intramuscular recording), b) suboptimal methodologies employed by both technologist and surgeon (passive versus active evoked monitoring), and 3) the relatively low incidence of RLN injury (in the realm of 1%) requires a large sample size before studies can show the true benefits of IONM. These factors will all be examined. Table 1 summarizes some of the literature’s divergent conclusions on the present effectiveness of RLN monitoring during thyroid surgery.

Routine use of IONM can lead to behavior modification of the surgeon’s technique. Monitoring provides feedback that certain surgical maneuvers, traditionally considered proper in the past, may indeed be traumatic, e.g., blunt versus sharp dissection. If mechanically evoked potentials are elicited during dissection, the surgeon is
Table 1. Literature review of laryngeal monitoring efficacy.

<table>
<thead>
<tr>
<th>Paper</th>
<th>Nerves at Risk</th>
<th>Nerves at Risk (Monitored/Unmonitored)</th>
<th>Benefit of IONM</th>
</tr>
</thead>
<tbody>
<tr>
<td>Randolph et al. 2004</td>
<td>Prospective, observational Patricia and Medtronic ETT/NIM®</td>
<td>586</td>
<td>Yes</td>
</tr>
<tr>
<td>Ulmer et al. 2008</td>
<td>Prospective, observational EMG electrodes and surface stick on electrodes/vagal electrodes and Outcome</td>
<td>32</td>
<td>Yes</td>
</tr>
<tr>
<td>Petro et al. 2006</td>
<td>Prospective, observational No complications EMG electrodes/NIM®</td>
<td>60</td>
<td>Yes</td>
</tr>
<tr>
<td>Thomusch et al. 2004</td>
<td>Prospective, observational, multcenter Direct/indirect stimulation and Outcome EMG electrodes/NIM®</td>
<td>15,403</td>
<td>Yes</td>
</tr>
<tr>
<td>Chiang et al. 2008</td>
<td>Prospective, observational Medtronic ETT/NIM® and Outcome</td>
<td>173</td>
<td>No</td>
</tr>
<tr>
<td>Tomoda et al. 2006</td>
<td>Prospective, observational Palpation and Outcome</td>
<td>2197</td>
<td>No</td>
</tr>
<tr>
<td>Schneider et al. 2009</td>
<td>Prospective, observational Stick on electrode/vagus anchor No complications</td>
<td>78</td>
<td>Yes</td>
</tr>
<tr>
<td>Beldi et al. 2004</td>
<td>Prospective, observational Stick on electrode and Outcome</td>
<td>429</td>
<td>No</td>
</tr>
<tr>
<td>Chan et al. 2006</td>
<td>Prospective, observational Stick on electrodes and Outcome</td>
<td>271</td>
<td>No (but author recommends for high risk cases)</td>
</tr>
<tr>
<td>Hermann et al. 2004</td>
<td>Prospective, observational EMG electrodes and Outcome</td>
<td>502</td>
<td>No (helpful but does not predict postoperative outcome)</td>
</tr>
<tr>
<td>Robertson et al. 2004</td>
<td>Retrospective, cohort Palpation and Medtronic ETT/NIM® and Outcome</td>
<td>116</td>
<td>No</td>
</tr>
<tr>
<td>Thomusch et al. 2002</td>
<td>Prospective, multcenter EMG electrode</td>
<td>2483/4640</td>
<td>Yes</td>
</tr>
<tr>
<td>Dionigi et al. 2009</td>
<td>Prospective, randomized minimally-invasive ETT/NIM®</td>
<td>55/57</td>
<td>No</td>
</tr>
<tr>
<td>Barczynski et al. 2009</td>
<td>Prospective, randomized EMG electrodes</td>
<td>1000/1000</td>
<td>Yes</td>
</tr>
<tr>
<td>Shindo et al. 2007</td>
<td>Retrospective Palpation Medtronic ETT/NIM®</td>
<td>427/257</td>
<td>No</td>
</tr>
<tr>
<td>Loch-Wilkinson et al. 2007</td>
<td>Prospective Palpation</td>
<td>100/40</td>
<td>No</td>
</tr>
</tbody>
</table>
Table 1. Continued.

<table>
<thead>
<tr>
<th>Study</th>
<th>Nerves at Risk (Monitored/ Unmonitored)</th>
<th>Benefit of IONM</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chan et al. 2006</td>
<td>Prospective Stick on electrode</td>
<td>501/499</td>
</tr>
<tr>
<td>Yarbrough et al. 2004</td>
<td>Retrospective Hook-wire electrodes via direct laryngoscopy</td>
<td>52/59</td>
</tr>
<tr>
<td>Brauckhoff et al. 2002</td>
<td>Retrospective Children</td>
<td>91/78</td>
</tr>
</tbody>
</table>

ETT – endotracheal tube; NIM® (Medtronic, Minneapolis, Minnesota, USA); EMG – electromyography.

alerted to the fact that they may be causing microtrauma to the nerve and thus their technique can be immediately modified. In addition, the proper use of electrical stimulation can also modify the surgeon's dissection by actively "mapping" or confirming the location of nerves early during the surgical dissection even before nerves become visible to the surgeon.

Initially, RLN monitoring was performed by placing needle EMG electrodes into the vocal cords via direct laryngoscopy or transcutaneously. Difficulties in achieving this accurately and safely led to a search for alternative means. As discussed in detail in the historical section below, RLN monitoring is now typically performed by attaching surface recording electrodes to an endotracheal tube (ETT) due to its close proximity to the vocal cords. It is important to understand that while this commonly used technique has many practical advantages, the use of surface electrodes is a compromise that may increase the possibility of false-negative and false-positive errors. Furthermore, "hitchhiking" the laryngeal electrodes onto the endotracheal tube engenders potential risks to the airway. Consequently, it is important that surgeon, anesthetist, and monitorist all have training specific to laryngeal recording to maximize its benefit and minimize its disadvantages. There are significant differences in the recording modes of laryngeal versus facial EMG. Consequently, experience in facial nerve monitoring cannot be assumed to be sufficient to perform laryngeal nerve monitoring without additional training.

CRANIAL NERVE X ANATOMY AND PHYSIOLOGY

The vagus nerve, Latin for "the Wanderer", is the longest of the twelve cranial nerves and contains fibers that subserves many different functions. Its viscero-motor parasympathetic and viscero-sensory fibers supply the entire aero-digestive tract
while its somatosensory and somato-motor branches innervate the palate, pharynx, and larynx. End-organs below the neck have dual innervation by both ipsi- and contralateral nerves, making trauma to one nerve clinically insignificant. In contrast, because of its highly complex and strictly unilateral innervation of pharynx and larynx in the neck, unilateral injury typically causes considerable functional impairment of the larynx.

The recurrent laryngeal nerve branches off the vagus at the level of the thoracic inlet, loops in an anterior to posterior direction around the aortic arch on the left and the subclavian artery on the right to then ascend in the tracheoesophageal groove towards the larynx (Figure I). Its terminal branches enter the larynx between cricoid and thyroid cartilage at the cricothyroid joint before branching to supply the intrinsic laryngeal muscles. Anatomic variations along the RLN are common. Proximal bifurcation or even arborization along its course towards the laryngeal muscles has a reported incidence of 20 to 95% (Miller and Spiegel 2008). If dissection is carried along one branch assuming it is the main RLN, one or more branches or even the majority of the main motor trunk may be inadvertently sacrificed. This is of significant importance both clinically and specific to interpreting the results of RLN stimulation. Kandil et al. (2011) reported that 34% of their patients had extralaryngeal bifurcation of the RLN with the motor fibers routinely in the anterior branch while the posterior branch contained only sensory fibers. Such anomalies demonstrate the importance of frequent electrical stimulation which can neurophysiologically alert the surgeon that a nerve visible in the common trachea-esophageal location may not be a normal RLN but in fact be an aberrant sensory division. Under these circumstances, the enlightened surgeon-monitoring team who encounter what anatomically appears to clearly be the RLN but does not respond to stimulation will first exclude technical malfunction and then electrically map other more anterior and inferior areas for the branch that carries motor fibers to the vocal cords. In a similar way, “non-recurrent” recurrent laryngeal nerves can also be electrophysiologically identified. In these rare instances, the RLN does not originate inferiorly in the chest but takes a more direct path originating from the vagus nerve in the neck.

Histologically, peripheral laryngeal branches of the recurrent laryngeal nerve from healthy individuals contain small, medium, and large fibers. The large fibers with thick myelin represent efferent neurons for motor innervation of the intrinsic laryngeal musculature (Dahlqvist et al. 1986). Whereas the intracranial segment of the vagus lacks a protective sheath, the ultrastructure of the peripheral nerve has thick connective tissue (epineurium, perineurium, and endoneurium) shielding its nerve fibers. The unmyelinated intracranial portion of the nerve makes it exquisitely sensitive to both electrical and mechanical stimulation. In contrast, peripheral nerves like the RLN, with its motor thick fibers and the thick neural sheaths are much less sensitive. Contrasting facial and RLN responses during monitoring, a key difference is a reduced responsiveness of the RLN to mechanical stimulation. The proximal facial
nerve will readily elicit EMG signals with even minor surgical manipulation whereas it requires a much higher "strain" to mechanically depolarize the RLN. When the surgeon cannot rely on mechanical evoked potentials during dissection, electric stimulation of the nerve becomes even more critical in mapping the nerve's location and repeatedly re-assessing the nerve's function which can dynamically change due to
micro-trauma, traction, and de-vascularization. We refer to the use of frequent electrical stimulation as “active” monitoring, whereas “passive” monitoring relies only on detecting mechanically evoked trauma potentials.

The superior laryngeal nerve is composed of an internal and external branch. The internal branch innervates the sensory fibers of the larynx while the external branch (EBSLN) primarily innervates the cricothyroid muscle, which increases tension of the vocal folds allowing higher, sustained pitches. The SLN is a small nerve with quite a variable course which may increase the chance of inadvertent iatrogenic injury particularly when dissecting the superior thyroid vessels. It may be injured in up to 58% of patients but the incidence is likely underestimated due to the more subtle effects of SLN injury versus recurrent nerve injury (Teitelbaum and Wenig 1995). In 80% of patients, the SLN may lie in a sub-fascial plane of the inferior constrictor muscle making it difficult to visualize by conventional means. But fortunately for surgeons who use electric stimulation to actively monitor (versus only passively relying on mechanically evoked responses), the SLN can be readily identified neurophysiologically by stimulating at the superior pedicle even if the nerve cannot be seen, e.g., due to a sub-fascial location (Lennquist et al. 1987, Friedman et al. 2002).

Clinically, unilateral RLN trauma typically leads to hoarseness from a single paralyzed vocal cord – while bilateral trauma may lead to life-threatening airway obstruction (Figure 2). The paralyzed vocal cord will be in a paramedian position on laryngoscopy and will not move towards the center to close the glottis during phonation, nor move laterally with deep inhalation. With one functional vocal fold the airway is wide but the voice will be breathy (hoarse) because air will leak through the incompetent glottis. If both RLNs are injured, the laryngoscopic exam will show both folds in a paramedian position. Bilateral paralysis causes a raspy voice but, more importantly, due to lack of vocal fold abduction during deep inhalation, stridor is heard and the patient will have symptoms of shortness of breath with exertion. Furthermore, the combined sensory and motor paralysis can lead to aspiration of food and liquids resulting in pneumonia.

Injury of the SLN is frequently undiagnosed as clinical findings may be subtle. On laryngoscopy, the vocal fold of the injured SLN may be seen as slightly elevated compared to normal. Generally the voice is clear but the patient will be unable to maintain a high pitch tone due to loss of cricothyroid muscle function which acts to tense the vocal cords. Furthermore, the patient may experience coughing and choking when swallowing, particularly with thin liquids. This is because the SLN also provides sensation to the supraglottic region above the vocal folds. Liquids can enter the laryngeal inlet that is insensate due to the SLN trauma but then trigger a cough reflex when reaching the vocal folds and subglottis.

Injury of the vagal nerve will lead to more pronounced symptoms as several of the mechanisms to protect the airway are compromised by the combined loss of both RLN and SLN function. First, ipsilateral SLN causes the supraglottic region to be insensate
allowing food or liquids to trickle into the larynx without being noticed and, second, the RLN injury creates a paralyzed vocal cord which prevents closure of the vocal folds. This combination is further exacerbated by the simultaneous paralysis of other vagal nerves that innervate the pharyngeal musculature above the glottis. These normally lead the food bolus into the posteriorly located esophagus rather than the anteriorly positioned trachea. Vagal nerve paralysis leads to loss of pharyngeal nerve function resulting in pooling of foods that can "spill" into the larynx when the food bolus is not "squeezed" into the esophagus. The consequence of these multiple dysfunctions markedly increases the risk of aspiration of food and liquids into the trachea resulting in recurring aspiration pneumonia.

The incidence of avoidable vagus nerve injury is unknown but high, proximal vagal injuries (e.g., skull base), especially when associated with concomitant IXth nerve injury can result in severe dysphonia, dysphagia, and aspiration. And yet, in a large published case series of skull base procedures performed by experienced neurosurgeons, the author comments that the vagus was monitored infrequently "due to the demanding and complex nature of monitoring this nerve" (Topsakal et al.
Dysphonia is most commonly caused by RLN injury during neck surgery, particularly the thyroid. In 2009, almost 60,000 thyroidectomies were performed in the United States (Vashishta et al. 2012). The incidence of RLN injury during thyroid surgery lies between 1 to 6%. In revision surgery or surgery for malignant thyroid lesions RLN injury is known to be much higher, with 8% being reported as permanent. Fortunately, most RLN injuries are transient and recover within six months but even temporary vocal cord paralysis can lead to major complications such as aspiration pneumonia.

Accurate documentation of RLN function is imperative when collecting and analyzing data. The gold standard to assess vocal cord function is to perform preoperative and postoperative direct laryngoscopy, and when indicated, videostroboscopy and EMG. Simply relying on patients verbalizing a complaint after surgery may fail to detect partial injuries or those that are well compensated by movement of the contralateral vocal cord. Many past studies failed to obtain laryngoscopic documentation of vocal cord function and thus the true incidence of RLN injury has almost certainly been under-reported.

HISTORY OF LARYNGEAL MONITORING

Laryngeal recording methods have evolved over the last three decades. Initially, using principles from facial EMG, needles were placed into the true or false vocal cords by direct laryngoscopy or percutaneously through a transcricoid approach. The use of intramuscular needle electrodes had the advantage of robust EMG signals – but there were also significant disadvantages due to the specific microenvironment of the larynx. A critical factor leading away from intramuscular needle recording was the practical fact that, while direct laryngoscopy was a common procedure for Otolaryngologists, it was rarely in the armamentarium of General Surgeons (for thyroidectomies) or Neurosurgeons (for skull base procedures). Therefore, an initial alternative to laryngoscopic placement of vocal cord electrodes was transcricoid approaches to the larynx by placing long needle electrodes through either the skin or after through the cricothyroid membrane once it had been exposed surgically (Spahn et al. 1981, Lipton et al. 1988, Alon and Hinni 2009) (Figure 3). When correctly placed, excellent laryngeal EMG could be obtained – but disadvantages also prevented this method from becoming a standard. Most importantly, the transcricoid approach entails "blind" electrode placement by the surgeon who can only estimate the final location of the electrode tips after penetrating the cricothyroid membrane. Poor placement could result not only in false negative errors but there are reports of the needle electrodes penetrating through the vocal cords to then puncture the subglottic endotracheal tube balloon resulting in the need for urgent reintubation.
Straight needle electrodes placed via laryngoscopy were also problematic because they not uncommonly became displaced during the operation, for example, when the head was placed in hyperextension. This displacement was especially of concern because once the laryngoscope was removed, the larynx was no longer visible – thus unrecognized electrode displacement led to false negative monitoring errors. In an attempt to reduce electrode displacement, hooked tip electrodes were tried which did reduce displacement, but the barb-like hooks often traumatized the vocal cords when removed at the end of the procedure. Infection and bleeding into the vocal cords are yet other concerns of needle electrodes.

Nonetheless, apart from RLN monitoring, carefully placed needle electrodes may have value for improving specificity when monitoring the SLN’s target muscle, the cricothyroid (Inabnet et al. 2009). Once the surgical field is opened, needle electrodes can be placed under direct visualization into the cricothyroid muscle. This accurate recording technique readily allows detection of electrically evoked responses of the SLN when the surgeon is about to dissect the superior pole of the thyroid gland. Stim probes or stimulating dissection instruments can be used to map the location of the SLN prior to ligation of vessels in the area. This is of particular importance for the times when the SLN is in an invisible, sub-fascial plane.
In the past, maintaining a laryngoscope or video-equipped endoscope in place throughout the procedure has been attempted primarily to directly visualize movement of the vocal cords; secondarily as a means to assess the position of needle or surface electrodes. Such visualization can be of benefit to determine if there is a recording error (e.g., if a laryngeal twitch is visualized in response to electric stimulation despite no recorded EMG, a technical recording error is confirmed). The technique, however, is impractical as the principle means of continuous, ongoing observation of small vocal cord movements when procedures may last for hours.

Therefore, despite the acknowledged superiority of intramuscular needle electrodes for EMG recording in general, the multitude of practical problems specific to RLN monitoring has led most surgeons to settle on surface recording of the laryngeal response as an acceptable compromise. Ease of surface electrode placement has, at this time, trumped superior EMG needle electrode recording. While this compromise is understandable based on the foregoing history, the intraoperative monitoring clinician and surgeon must both keep the advantages and disadvantages of this compromise clearly in mind. Limitations and pitfalls of surface recording will be elaborated below.

ANESTHETIC CONSIDERATIONS

As with all EMG monitoring, long-acting paralytics must not be administered by anesthesia nor should topical viscous lidocaine be used during intubation. Neuromuscular blockade of 50% or more will obliterate mechanically evoked neurotonic discharges and markedly increase stimulation thresholds (Daube 1991). Low doses of neuromuscular blocking agents may allow recording of electrically evoked responses but abolition of the smaller mechanically evoked responses is too significant a disadvantage to allow their use except under extenuating circumstances.

Because surface laryngeal electrodes are attached to endotracheal tubes, it is essential that the anesthesia team be trained in the proper placement of the tube to avoid false negative and positive monitoring errors. As detailed later, surgeon, anesthesiologist, and monitorist all have an obligation to understand the proper use and precautions of the monitoring device they select. This is especially true for factory-adhered electrodes because the endotracheal tube selected by the factory may not have been the ideal choice of the anesthetist who may have to modify or compromise their technique in order to use this particular tube. According to the package insert of one of the most commonly used factory-installed laryngeal electrodes, anesthetists are prohibited from performing common airway maneuvers such as suctioning through these endotracheal tubes – nor may they use a tube exchanger. Furthermore, they may be required to use a bite guard to prevent the anesthetized patient from inadvertently collapsing the tube and compromising the airway. The package inserts are an important source of information that should be clearly understood by all the
stakeholders. Likewise, package inserts are an important source of information for user-installed electrodes that must be appropriately placed to optimize position on the tube as well as minimize the chance of electrode displacement.

SURGICAL DISSECTION OF THE RLN

Certain maneuvers and specific locations during thyroid or parathyroid surgery place the RLN at increased risk for injury. Suboptimal positioning, exposure, and visualization will make every surgery more challenging and error-prone. Safe dissection is maximized with adequate exposure, clear identification of landmarks, and a bloodless operating field. Classically, the surgeon maximizes exposure with a wide dissection around the thyroid gland, but minimally invasive techniques including use of endoscopes and robots are increasingly being used to minimize scar and postoperative pain. In so doing, intraoperative monitoring may become even more important in locating and preserving the laryngeal nerves.

Different surgical techniques are employed based on training and experience – some approach the gland starting superiorly while others choose an inferior approach. Nonetheless, the nerve is often at greatest risk at the thyrohyoid ligament (“Berry’s ligament”), a tight band stabilizing the thyroid. Dissection typically begins after ligation of the middle thyroid vein and separation of the superior pole, allowing the gland to roll medially. Identification of the RLN may be undertaken at this time or the RLN may be sought inferiorly within the “RLN triangle”, with its boundaries along the trachea, carotid sheath, and the undersurface of the retracted thyroid, as described by Lore et al. (1977). Dissecting parallel to the course of the nerve will minimize stretch injuries of the RLN. Once identified it is traced towards its entrance site into the larynx near Berry’s ligament. Meticulous dissection is required along this ligament as the nerve passes under or through a tight fascial band. Small vessels within the ligament will frequently cause minor bleeding but cautery should be avoided in this area to prevent thermal injury to the RLN. If this approach fails, the superior approach can be used identifying the RLN at its entry into the larynx, dissecting the nerve from medial to lateral.

RECORDING ELECTRODES

For monitoring the RLN, contact surface electrodes are attached to an endotracheal tube either by the user or at the factory – each method having its distinct advantages and disadvantages. Intubation technique is critical, not only to align the electrodes with the surface of the vocal cords, but to assure proper use in order to minimize risks to the airway. Because these electrodes are not intramuscular, slight malposition of the surface electrodes can result in missing the laryngeal EMG (a false negative error) – or inadvertently recording from other nearby muscles (e.g.,
inferior pharyngeal constrictors) which could result in a false positive error. It is possible to design pinpoint laryngeal electrodes (LE) to contact only the vocal cords, which would restrict recording predominately from the thyroarytenoid muscles within the cords. Such precision, however, would then miss recording the compound motor action potentials from many of the other important laryngeal muscles, especially the posterior cricoarytenoid muscles which are key abductors of the vocal cords. Consequently, most LEs are designed to be broad enough, or multiple in number, to contact a large portion of the laryngeal inlet. Some RLN’s “arborize” or split into multiple branches before entering the larynx near Berry’s ligament. Stimulating one such branch while only recording from the thyroarytenoid muscles might miss the fact that a branch to the posterior cricoarytenoid muscles has been encountered. Thus, as is true in other types of EMG intraoperative monitoring, recording should be selective enough to avoid inadvertent recording of non-target muscles – while sensitive enough to sample a sufficient population of muscles in the area of interest.

As noted, surface electrodes are of two basic types: either factory installed unto an endotracheal tube, or an adhesive type applied by the clinician to an endotracheal tube of the anesthetist’s choosing. A commonly used factory-installed LE, the NJM® EMG tube, is manufactured by Medtronic (Minneapolis, Minnesota, USA) (Figure 4). Factory installation provides a secure connection of the LE to the NJM® tube. Conversely, the anesthetist is restricted to using a wire reinforced tube selected by the factory with only three size choices: 6, 7, and 8 mm internal diameter (ID). Half sizes have not been made available in the United States.

These prefabricated Medtronic NJM® tubes were initially criticized for being too flexible. The company responded by stiffening the tube with a reinforcing wire on the inner lumen surface. The stiffening wire, however, has proven susceptible to rare collapsing or unraveling which may result in airway obstruction. Inadvertent biting on the tube by the patient can lead to collapse of the endotracheal tube lumen.

FIG. 4. Medtronic NJM® laryngeal monitoring endotracheal tube. (Reprinted with permission from Jack M. Kartush, M.D.)
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Therefore biting or common anesthesia maneuvers such as suctioning or using a tube exchanger must be avoided to prevent unraveling of the wire which may then extend beyond the tube which can then create an obstructive fibrin clot (Evanina and Hanisak 2005). Other special features of the NIM® tube such as its slightly longer length as well as the silicone elastomer cuff have also been reported to cause airway obstruction and pneumothorax (Leissner et al. 2007, Kim et al. 2010, Sundaram 2010, Capra et al. 2012). Additional problems with overinflated cuffs leading to similar airway emergencies have been described with this tube (Oysu and Demir 2011) (Figure 5A, B, C, D).

Thus, special precautions to avoid airway obstruction with the factory installed electrode include: 1) use of a bite block (Figure 6), 2) avoidance of suctioning through the endotracheal tube with a catheter, and 3) abstaining from use of a tube exchanger. Once again, it is strongly emphasized that users familiarize themselves with the manufacturer’s recommendations for use.

It is not widely known that the NIM® endotracheal tubes have a larger outer diameter than the average endotracheal tube of the same numbered size (which represents the ID, internal diameter). This fact in conjunction with the absence of half sizes, may lead the anesthetist to use a larger than expected diameter endotracheal tube which may increase the risk of laryngeal trauma. The NIM® tubes as well as all user applied LE devices are contraindicated for prolonged intubation. Consequently, if a patient must remain intubated after surgery, the endotracheal tube with attached LE should be replaced.

Other options for surface electrodes include taped-on designs, which are attached to conventional endotracheal tubes. Some examples include Rea’s design by Neurovision Medical Products (Ventura, California, USA) (Figure 7A) and those by Magstim Neurosign Surgical (Carmarthenshire, Wales, UK) (Figure 7B). They are of lower cost and there are no additional concerns about airway safety because the anesthetist selects whichever endotracheal tube they believe is best for their particular patient. These laryngeal electrodes accommodate full and half sized endotracheal tubes. There are no limitations to the anesthetist on suctioning through the tube or using a tube exchanger. The electrodes should be taped approximately 1 to 2 cm above the cuff. A water-based lubricant (e.g., K-Y® jelly, Johnson and Johnson, New Brunswick, New Jersey, USA) may be used after the electrodes have been applied, not before. As with factory-installed electrodes, surgeon, anesthesiologist, and monitorist must familiarize themselves with proper use of the stick-on electrodes. Figure 8 provides an example of the proper method to attach one such user-applied electrode. During very long cases (e.g., skull base tumors), it is possible for the adhesive to become less adherent resulting in slippage from the tube. While such electrode slippage has never caused any reported airway problems, the accuracy of EMG recording may be diminished if they slip inferior or superior to the glottis. Conversely, if the electrodes simply lateralize from the ET tube, their position may
FIG. 5. If not properly protected, the reinforcing wire within the Medtronic NIM® monitoring tube can unravel causing airway obstruction. A demonstrates wire unraveling beyond the endotracheal tube (ET) tip with formation of an obstructive fibrin clot. (Reprinted with permission from Jack M. Kartush, M.D.) B demonstrates wire unraveling within the endotracheal tube. (Reprinted with permission from the AANA Journal from Evanina and Hanisak 2005). In C the arrow indicates kinking of the Medtronic NIM® monitoring tube may cause airway obstruction. (Reprinted with permission from Lippincott Williams & Wilkins from Rengasamy and Ortega 2004.) In D, the left photo shows normal ET tube where balloon maintains patent lumen. The right photo shows how a prolapsing balloon of a NIM® tube can cause obstruction of the endotracheal tube by deflecting the tip onto the tracheal wall. (Reprinted with permission from the American Medical Association from Capra et al. 2012.)
FIG. 6. The risk of NiM® endotracheal tube obstruction can be reduced by proper placement of “bite guards” (such as these created out of gauze) to prevent the patient’s unconscious biting down onto the tube. (Reprinted with permission from Jack M. Kartush, M.D.)

FIG. 7. User-applied laryngeal electrodes: A) Neurovision™ Medical Products (Ventura, California, USA). B) Magstim Neurosign® Surgical (Carmarthenshire, Wales, UK).
actually move closer to the vocal cord muscles thereby improving recording of the adjacent EMG responses. Newer stick-on electrodes have overlapping adhesive to reduce the possibility of becoming detached.

In order to avoid missing important EMG responses, clinicians must assure that the laryngeal electrode is in as close proximity to the vocal cord muscles as possible. If the endotracheal tube is placed too shallow, too deep, or rotated, recording can be compromised.

As noted, a major concern of using surface electrodes to record EMG potentials is that poor contact of the electrodes to the vocal cords will adversely impact the accuracy resulting in difficult to measure low amplitude responses – or even completely missed responses. Furthermore, even a perfectly positioned endotracheal tube may not allow perfect apposition of the surface electrode to the vocal cords.
Laryngeal electrodes are traditionally flush against the endotracheal tube yielding a circular surface in the midst of the larger triangular glottic inlet. This geometric mismatch often leads to sub-optimal contact of the electrode to the vocal cords. A commonly recommended way of compensating for this is to use an overly large endotracheal tube to force the electrodes closer to the cords. However, an oversized endotracheal tube can cause trauma during intubation and place undue pressure on vocal cords and trachea. Balloons were considered long ago as a method to push the electrodes closer to the cords – but fear of glottic and sub-glottic trauma prevented that method from being accepted.

To solve this problem, a new self-optimizing laryngeal electrode has been designed to gently fill the triangular glottic space atraumatically: Lantern Laryngeal Electrode (Neurosign® Surgical, Carmarthenshire, Wales, UK) (Figures 9 and 10). Like the unfolding of a Chinese lantern, the Lantern Laryngeal Electrode gently fills the triangular glottic space to optimize vocal cord contact without having to rely on an over-sized endotracheal tube.

**SUPERIOR LARYNGEAL NERVE MONITORING**

In contrast to the RLN, paresis of the superior laryngeal nerve (SLN) may lead to more subtle symptoms that are more likely to be missed. Unlike the RLN, the SLN enters the thyroid from a superior branch of the vagus nerve. In addition to sensory function, it innervates the ipsilateral cricothyroid muscle which helps maintain and increase vocal fold tension. The incidence of SLN injury during thyroid surgery has been reported between 28% and 58% but the incidence is likely underestimated due to the more subtle effects of SLN injury versus recurrent nerve injury (Teitelbaum and Wenig 1995, Lifante et al. 2009) A slight elevation of the ipsilateral vocal fold and the inability to maintain a high pitch tone may be the only findings on exam and might only be noted by a professional voice user, such as a singer. As noted previously, sensory anesthesia resulting from SLN injury may lead to silent aspiration and pneumonia, especially in a patient with other morbidities. Recently, attention has
been focused on reducing the risk not only to the RLN but to the SLN (Barczynski 2013).

The most common method to measure recurrent laryngeal nerve responses uses a surface electrode on an endotracheal tube. Because the SLN primarily innervates the cricothyroid muscle which is not in contact with this electrode, responses may be missed. However, in 68 to 83% of patients of patients, there is a communicating nerve from the SLN that provides additional innervation to thyroarytenoid muscle within the vocal folds (Sañudo et al. 1999, Maramillo et al. 2003). Consequently, stimulation of the SLN may in fact register a response on an endotracheal tube electrode that has leads anteriorly in contact with the vocal folds by means of this secondary mechanism causing tensing of the vocal cords – rather than contraction of the cricothyroid muscle. Because this vocalis muscle contraction is not present in all patients, endotracheal tube electrodes alone cannot be relied upon to detect all SLN responses. Consequently, it is best to complement the endotracheal tube electrode either by a) visual inspection of the contraction or b) by placing a needle electrode into the muscle once the cricothyroid space has been surgically exposed.

**Technical Aspects – Electrode Position**

Close contact of the electrode to the vocal musculature is critical to maximize surface EMG recording. Positioning too deep, too shallow, malrotated, or too loose a contact will lead to recording errors. The endotracheal tube must be of the appropriate size. If the tube is too small, the surface electrodes will have insufficient contact
with the vocal fold resulting in inaccurate EMG recordings. During intubation the anesthesiologist places the endotracheal tube such that the color-coded location of the laryngeal electrodes is centered at the midline of the vocal cords. To assure optimal positioning, attention must be paid to tube depth, rotation, and diameter.

Unintended movement of the endotracheal tube may occur when the head is positioned; rotated for skull base procedures or hyper-extended for thyroid surgery. Such movement may displace the laryngeal electrodes therein compromising recording of the EMG response. If the head must be adjusted it may be helpful to re-visualize the glottis following re-positioning using a laryngoscope, flexible endoscope, or newer iterations such as the GlideScope® (Verathon Inc., Bothell, Washington, USA).

With commonly used laryngeal electrodes, there may be a 15% incidence of false negative responses. In a study of 173 nerves monitored during thyroid surgery malpositioning of the tube (and therefore the electrodes) was suspected to be the most common cause of failure to recognize a nerve injury (Chiang et al. 2008). With exposure of the larynx in the neck, Randolph et al. (2004) noted that suspected false negative errors can be cross-checked by stimulating the presumed nerve while directly palpating the laryngeal twitch response in the tracheo-esophageal groove. If a laryngeal twitch can be palpated despite absence of an EMG response, a technical problem is confirmed and must be corrected.

While it is important for electrode impedance to be low (typically below 5 kOhms), low impedance does not equate to proper electrode position; “good tissue contact” in an unwanted position (too deep in the trachea or within the esophagus) will also yield low impedance. Similarly, a “tap test”, commonly performed with intramuscular facial muscle electrodes, provides no information on whether laryngeal electrodes are in a proper position.

Nerve Stimulation

Stimulation can be performed with either bipolar or monopolar stimulators (Kartush et al. 1987). While bipolar stimulation is most specific, monopolar stimulators are superior for mapping the general location of a nerve especially when it is not clearly visible (Kartush et al. 1985). The stimulator can be a simple monopolar probe or an electrified instrument as has been advocated for years by Kartush (1989) and Silverstein (1991). By electrifying the instruments that surgeons already use, surgeons are more likely to actively (versus passively) monitor during critical dissection therein not only continuously mapping the location of the nerve but also re-assessing its integrity after potentially injurious maneuvers. It is possible for the surgeon and monitoring teams to electrify their own instruments but these should be a) insulated to prevent current from shunting away into adjacent tissue or fluid, and b) securely connected to the stimulator cord to prevent inadvertent detachment. The insulated
Kartush Stimulating Instruments (KSI) (Magstim Neurosign® Surgical, Carmarthenshire, Wales, UK) are disposable tools with which the surgeon can dissect and stimulate simultaneously. They are available in the form of both: a) micro-instruments and b) a fine stimulating hemostat optimized for thyroid and parotid surgery. (Reprinted with permission from Jack M. Kartush, M.D.)

The RLN and SLN nerves may respond to current intensities as low 0.3 mA – but when first mapping the location of the nerve, it is best to start at approximately 2.0 mA to assure an initial response before rapidly titrating the current level down as soon as the nerve has been identified. The stim level chosen at any given time is dependent upon distance from the nerve as well as the surrounding tissue. Like using a minesweeper, once the general location of the nerve is identified, progressively lowering of the stim level allows enhanced spatial resolution. Mapping, for example, with 3.0 mA when stimulating through a centimeter of soft tissue will pose no risk to the nerve. Conversely, an unjustified fear of “excessive stimulation” which might prompt a surgeon to only map at 0.5 mA markedly increases the chance of false negative errors.

Cautery should be avoided adjacent to nerves. When necessary, bipolar cautery is preferable to monopolar cautery due to its more focused electrical and thermal effects. At other times, alternative hemostatic options may be preferred including pressure and topical adrenaline or thrombin. Whenever a risky surgical maneuver has
been performed adjacent to a nerve, it is prudent to re-stimulate the nerve proximal to this area to assure the nerve has maintained neural integrity. Deferring neural integrity testing until the very end of surgery may prove that the nerve has been compromised – but by this time, the surgeon may no longer be aware of which maneuver, and at which location, the nerve may have been injured.

Brief, intermittent RLN and vagal nerve stimulation are well tolerated without any reported adverse effects (laryngeal, cardiovascular, or respiratory) when performed with commonly used pulsed stimulation below 4.0 mA (typically 1.5 mA). The quality of the recorded signal should be confirmed at the beginning of each procedure by obtaining a “baseline” EMG recording from vagal nerve stimulation and then from the RLN in the tracheo-esophageal groove. Such proximal baseline testing is essential to confirming proper system set up as well as the absence of complicating anesthetic factors (neuromuscular blockade or transient lidocaine-induced nerve paralysis). Furthermore, the amplitude of these initial responses can be used as a baseline to determine if later responses have deteriorated (increased stimulation needed for threshold or complete loss of signal).

The stimulus intensity should be titrated – i.e., an initial high stimulus level (e.g., 2.0 to 3.0 mA) can be helpful for initial nerve mapping but once the nerve is identified, lower levels of stimulation allow greater precision. The RLN typically has a threshold of approximately 0.3 to 0.5 mA. It is best, however, to stimulate at higher intensities because even small amounts of blood and soft tissue will cause enough current shunting that a false negative error may occur. Consequently, once the RLN is identified, stimulus levels of 1.0 to 2.0 mA are commonly used.

In addition to baseline proximal stimulation, the surgeon should map distally to exclude anomalies such as an arborized nerve or a “non-recurrent” recurrent laryngeal nerve. As discussed above, it is important to realize that an arborized RLN typically will have its motor division anteriorly rather than in the expected posterior trachea-esophageal location. Under these circumstances, electrical stimulation is critical in assisting the surgeon in recognizing these anomalies.

Continuous Vagal Evoked EMG

As noted, a stretched or bluntly traumatized recurrent laryngeal nerve is much less likely to display mechanically evoked EMG potentials compared to the proximal facial nerve. Consequently, frequent electrical stimulation is essential in maximizing the benefits of IONM during thyroid surgery. In addition, researchers have been exploring the possible benefits of continuous vagal stimulation while monitoring the ongoing vocal fold EMG. This is simply a variant of the long established principle behind somatosensory evoked potentials where stimulation of a peripheral sensory nerve evokes a cortical evoked response. Similarly, the monitorist obtains a baseline
response and looks for changes in amplitude and latency that may signal neural trauma.

Recently, stimulating electrodes have been developed which remain in contact with the vagus nerve in the carotid sheath throughout the procedure (Figure 12). A repetitive stimulus triggers an ongoing EMG response. Changes of the compound muscle action potential amplitude and latency can be followed (Ulmer et al. 2008, Schneider et al. 2009). Research is underway in many centers to determine if this technique may provide greater sensitivity and thus an earlier warning when the RLN has been traumatized directly or by de-vascularization. Numerous electrodes have been suggested to wrap around the vagus nerve in an attempt to assure that the stimulating electrode remains secure whilst the surgeon’s attention is elsewhere. Users should use great caution to secure these devices, however, because of the possibility of vagal nerve injury or even avulsion should the electrode wire become inadvertently pulled away. Furthermore, surgical dissection to expose the vagus nerve requires dissection of the carotid artery and jugular vein – while the risk of hemorrhage is very low in experienced hands, it should be kept clearly in mind. Consequently, we are evaluating alternate means of reliable vagal stimulation while ameliorating the risks of carotid sheath dissection.

We speculate that this technique of Continuous Vagal Evoked EMG (CV-EMG) may in fact have significant advantage if applied to RLN monitoring when used during cervical spine surgery (e.g., anterior cervical disectomy and fusion [ACDF]). Because of the aforementioned unreliability of detecting RLN trauma via mechanically evoked potentials, typical RLN techniques have not proved very effective in monitoring during ACDF (Dimopoulos et al. 2003). Under these circumstances, the greatest concern is typically the persistent pressure applied to the RLN between the surgical retractor and the endotracheal cuff. If this indirect trauma can be better
detected by CV-EMG, the operative team can be alerted to either relax the retractor or temporarily deflate the endotracheal cuff to minimize RLN ischemia.

**Direct or Indirect Nerve Injury**

During electrocautery, most dedicated nerve monitors temporarily deactivate the loudspeaker and the EMG oscilloscope. This is an important feature that prevents the surgeon from being startled by a raucous blast of artifact coming through the loudspeakers every time cautery is used. This feature is rarely available in multimodality monitoring equipment that, as a workaround, requires great attentiveness by the monitorist to “ride the volume knob”, i.e., to manually turn the volume up and down as needed.

When automatic muting is engaged, the monitor cannot detect nerve injury if it occurs from direct cauterization or thermal spread. Even complete electrosurgical ablation of the nerve would not elicit a signal and, therefore, it is important to use frequent electrical stimulation to confirm functionality after cautery adjacent to a nerve. In contrast, gradual thermal injury in the cerebellopontine angle from adjacent laser use can lead to a slow increase of the baseline. Electrocautery should never be used simultaneously with the nerve stimulator because current can travel back through the stimulator and into the monitoring device. If cautery is required during the dissection, the use of bipolar cautery or the use of modern alternatives such as the Harmonic scalpel (Ethicon Endo-Surgery, Inc., Cincinnati, Ohio, USA) may limit thermal spread.

**Pitfalls: False Positive and Negative Errors**

To minimize the risk of injury the surgeon and monitorist must be aware of interpretive errors. Besides a true positive response, where after nerve stimulation an expected EMG response is triggered, false positive and negative errors must be distinguished. Clear understanding and use of the correct terminology of false positive and negative errors in scientific publications is necessary. In the current literature these errors are described with various terms. It is crucial to use proper definitions to avoid confusion (Chan and Lo 2006).

A true positive response means that the nerve stimulator elicits a muscle response as a result of stimulation of its innervating nerve. A positive response should always be confirmed at the beginning of the case (i.e., baseline testing) prior to close neural dissection.

A false positive response is an EMG signal that was not triggered by the target nerve stimulation but caused by stimulating either a structure in proximity to the nerve (leading to cross activation) or direct muscle stimulation. A false positive error at the larynx may occur, for example, when the pharyngeal constrictors are inadvertently stimulated; the large muscle response may be carried to the laryngeal surface
electrodes and misinterpreted as an RLN response. This error appears to be increased if the endotracheal tube has been inserted deep into the trachea as well as when high levels of stimulation are used that create volume conducted responses or artifact.

An increased EMG baseline (i.e., trains of EMG activity) could represent neural trauma — but it is important to exclude other causes especially by correlating the responses to the ongoing surgical events. For example, in neurotologic surgery at the cerebellopontine angle, cool irrigation often results in trains of EMG activity that do not represent trauma. During RLN monitoring, periodic fluctuations of the baseline may in fact indicate a cuff leak (e.g., from 15 to 80 mV), particularly when there is a corresponding EMG response synchronized with ventilation. In contrast, if there is a large, irregular baseline shift, it may indicate that the patient’s anesthesia may be “light” and the patient’s vocal cords are contracting voluntarily. These causes of EMG baseline change need to be differentiated from mechanically evoked EMG due to neural trauma.

A false negative response has no EMG response despite stimulation of the target nerve. If muscle twitches along the larynx can be palpated when stimulating the vagus or RLN in the absence of an EMG response, a technical problem should be assumed. There appears to be an approximately 15% incidence of false negative responses with commonly used surface laryngeal electrodes. Randolph et al. (2004) have noted that suspected false-negative errors can be cross-checked by directly palpating the laryngeal twitch response in the tracheoesophageal junction. This false negative error should lead to a check of the entire system.

If monitor and probes appear to be functional, the impedance is suitably low and electrode position appears correct, an improper “stimulus ignore period” may be the cause (Figure 13). This intentional silencing of the monitor’s loudspeaker prevents the surgeon from hearing responses created by the stimulus artifact. It should be understood that this feature is similar to, but distinct from, automatic muting during cautery. However, the duration of intentional muting needs to be set appropriate to the anticipated conduction time based on the distance between where the nerve is stimulated and the muscle that is being recorded. Unpublished research by the senior author (JMK) in 1982 led to establishing the factory setting of the original NIM® monitor’s stimulus ignore period at 3.1 msec for monitoring the facial nerve during otologic surgery. However, in contrast to the facial nerve, given that the markedly shorter nerve length of the RLN is associated with a shorter conduction time, many users were not aware that the stimulus ignore period needs to be shortened for thyroid surgery (Kartush and Lee 2013). To prevent inadvertent filtering of a response rather than just stimulus artifacts during thyroid or parathyroid surgery, the stimulation suppression filter should be lowered from the default duration of 3.1 msec (e.g., otologic procedures) to approximately 2.35 msec. Each device and each situation may require different values that each team should assess and establish. Note, too, that the site of stimulation is another important factor: stimulating in
FIG. 13. Stimulation of the recurrent laryngeal nerve (RLN) nerve close to the larynx (e.g., Berry’s ligament) may result in a response with a very brief latency, for example, less than 3 msec. Stimulus filters are helpful in ignoring stimulus artifact but if not used judiciously, can result in masking of both stimulus and response, causing a false-negative error. In this case, the response peak occurred at 1.75 msec but was detected because the technologist shortened the stimulus filter’s time window from the factory default of 3.1 msec. (Reprinted with permission from Jack M. Kartush, M.D.) L-Voc – left vocal cord; R-Voc – right vocal cord.

the tracheo-esophageal groove will have a longer conduction time than stimulating distally at Berry’s ligament. Shortening the ignore period further can sometimes be helpful in avoiding inadvertent silencing of true responses especially for very distal stimulation – but too short of an ignore period will allow the stimulus artifact to be heard which can confuse or distract the surgeon and monitorist.

Anesthetic causes should also be excluded when troubleshooting monitoring. Avoiding long acting muscle relaxants typically allows normal mechanical and electrical evoked EMG recording – however, in some rare individuals with atypical pseudocholinesterase activity, they may have very prolonged muscle paralysis despite induction with short acting muscle relaxants e.g., succinylcholine (Bojanic et al.
A normal response to RLN stimulation during early baseline testing confirms appropriate nerve and muscle function. When this fails, troubleshooting should include a train of four (TOF) peripheral nerve stimulation test to determine if neuromuscular blockade has in fact been reversed. In thyroid surgery, lidocaine local anesthetics are rarely infiltrated near the RLN. However, during ear and parotid surgery, clinicians must be aware that lidocaine inadvertently affecting the facial nerve (e.g., through a tympanic membrane perforation), may temporarily paralyze the nerve rendering monitoring useless. In this instance, the false negative error occurs not due to failure of the muscles to contract but failure of the nerve to depolarize secondary to temporary chemical paralysis.

Increased thresholds to stimulation may be seen after micro-trauma, the presence of overlying tissue, liquids in the operative field, desiccation, or a malpositioned electrode within the larynx.

Assessment of the RLN’s integrity at the end of the procedure is best made by stimulating the vagus nerve or the most proximal location of the RLN in the tracheoesophageal groove. Should nerve injury be suspected, it is critical that the epicenter of neural trauma be localized by stimulating both proximal and distal to the lesion. Stimulating only distal to the site of a fresh injury will evoke a normal response – and if not cross-correlated to proximal stimulation (which would show loss of signal or a reduced response) will result in a false positive error.

As an illustration in thyroid surgery, if the nerve is injured in the mid tracheoesophageal groove, an assessment of nerve integrity requires stimulation at either the vagus nerve or the RLN in the proximal trachea-esophageal groove, not just distally at Berry’s ligament.

A recurrent nerve anomaly such as a bifurcation could lead clinicians to erroneously conclude that monitoring failed. For example, consider a bifurcated nerve wherein the motor fibers are typically in only the anterior branch. If the surgeon only stimulates the posterior branch in the expected location within the tracheal groove and has no response, they will mistakenly conclude that the RLN has been injured. When the patient awakes with normal RLN function, they will now mistakenly conclude that monitoring failed, whereas in fact, the anomaly led to user error. There are two important lessons to learn here. The first is that not every apparent monitoring failure is a failure of the recording electrodes or device – user error must also be considered. The second is that while anomalies may, by definition, be infrequent or rare, the surgeon and monitoring team must anticipate these by establishing a consistent protocol that reduces the chance that they may become ensnared in such a pitfall. In this instance, the clinical correlate is that while proximal stimulation of RLN and/or vagus is indeed critical, it is also essential that stimulation be used from proximal to distal along typical and atypical RLN paths to determine the nerve’s location as well as exclude anomalous anatomy.
### Table 2. Kartush laryngeal nerves monitoring protocol.

#### Kartush Laryngeal Nerves Monitoring Protocol

<table>
<thead>
<tr>
<th>Steps</th>
<th>Check Box</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 - Consult with anesthesia:</td>
<td>✓</td>
</tr>
<tr>
<td>• Avoid long acting muscle relaxants &amp; lidocaine on endotracheal tube</td>
<td>✓</td>
</tr>
<tr>
<td>• Proper placement of Laryngeal Electrodes</td>
<td>✓</td>
</tr>
<tr>
<td>2 - Demonstrate absence of neuromuscular blockade:</td>
<td>✓</td>
</tr>
<tr>
<td>• Train of four</td>
<td>✓</td>
</tr>
<tr>
<td>• RLN/SLN/Vagal nerve stimulation within the operative field</td>
<td>✓</td>
</tr>
<tr>
<td>3 - Assure the monitor’s loudspeaker is set at a volume sufficient to be heard over the operating room’s ambient noise</td>
<td>✓</td>
</tr>
<tr>
<td>4 - Check electrode impedance &amp; Stim Ignore setting</td>
<td>✓</td>
</tr>
<tr>
<td>5 - Check stimulus current flow through soft tissue</td>
<td>✓</td>
</tr>
<tr>
<td>6 - Obtain baseline RLN/SLN/Vagal nerve response to distal stim</td>
<td>✓</td>
</tr>
<tr>
<td>7 - Electrically map the location of target nerves within the operative field</td>
<td>✓</td>
</tr>
<tr>
<td>• RLN/SLN/Vagal nerve stimulation</td>
<td>✓</td>
</tr>
<tr>
<td>• Selectively use monopolar, bipolar or Stimulating Instruments</td>
<td>✓</td>
</tr>
<tr>
<td>• Titrate stim current based on nerve location and surrounding tissue (cartilage, soft tissue, blood)</td>
<td>✓</td>
</tr>
<tr>
<td>8 - Map location of SLN. Record response via LE or cricothyroid electrode</td>
<td>✓</td>
</tr>
<tr>
<td>9 - Consider monitoring continuous vagal evoked laryngeal responses</td>
<td>✓</td>
</tr>
<tr>
<td>• Establish repetitive stimulation of the Vagal nerve</td>
<td>✓</td>
</tr>
<tr>
<td>• Monitor the ongoing EMG responses for amplitude reduction and latency increases</td>
<td>✓</td>
</tr>
<tr>
<td>10 - Obtain a final proximal nerve response to stim prior to closure</td>
<td>✓</td>
</tr>
<tr>
<td>• Vagus</td>
<td>✓</td>
</tr>
<tr>
<td>• Proximal RLN</td>
<td>✓</td>
</tr>
<tr>
<td>11 - Generate a brief written report (can be within Operative Report):</td>
<td>✓</td>
</tr>
<tr>
<td>• Confirm adherence to protocol</td>
<td>✓</td>
</tr>
<tr>
<td>• Highlight key events</td>
<td>✓</td>
</tr>
</tbody>
</table>

### GUIDELINES AND CHECKLISTS

Over the last century, physicians have been reluctant to accept written clinical practice guidelines believing that they would result in “cookbook medicine”. These were believed to take away the “art and science” of Medicine and lead to fodder for plaintiff’s lawyers. However, the last two decades have shown a significant cultural shift. Sparked by reports of the Institute of Medicine and the World Health Organization, more than a thousand clinical guidelines have been published to improve patient safety. The airline industry has long learned that even experienced pilots benefit from protocols and checklists due to the complexity of their work environment – and the
dire consequences of errors. Consequently, the senior author (JMK) has long promul­
gated a Facial Nerve Monitoring Protocol with an associated Checklist to aid in
following the protocol. An analogous checklist has been created to assist clinicians in
monitoring laryngeal nerves (Table 2).

All checklists represent a balance between complexity versus simplicity. The latter
tends toward being comprehensive but difficult to use while the latter is incomplete
but much more likely to be used in clinical practice. The Laryngeal Nerves Monitor­
ing Protocol is not intended to be all encompassing but a “pre-flight” and “intra­
flight” checklist intended for the knowledgeable practitioner. It can also serve as
the basis for a hospital, department, or monitoring service company’s Policy and
Procedure Manual. Furthermore, for self-monitoring surgeons who in the past have
overlooked generating any type of IONM written report, such a checklist can serve
not only as a reminder to perform all the recommended steps but also as a rapid
means of establishing documentation of the monitoring procedure.

SUMMARY

Monitoring the laryngeal nerves during surgery can assist in nerve location and in
reducing the incidence of neural trauma. All members of the surgical monitoring
team must have training specific to laryngeal recording to maximize its benefit
and minimize pitfalls. Active monitoring entails frequent use of electric stimulation
rather than passively awaiting responses after trauma has occurred. Stimulating
dissection instruments are a useful adjunct to detect the location of nerves prior to a
mechanical insult. As improved methods are adopted, the efficacy of laryngeal nerve
monitoring will increase. For additional information, refer to the monitoring course

DISCLOSURES

Dr. Kartush was principal designer of the NIM® monitor, past consultant
to Medtronic, founding president of the American Society of Neurophysiologic
Monitoring, and is a consultant to Magstim Neurosign® Surgical, a manufacturer of
intraoperative monitoring products. Dr. Naumann indicates no disclosures.

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