The Laryngoscope

Contemporary Review

External Branch of the Superior Laryngeal Nerve Monitoring During Thyroid and Parathyroid Surgery: International Neural Monitoring Study Group Standards Guideline Statement

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Intraoperative neural monitoring (IONM) during thyroid surgery has gained widespread acceptance as an adjunct to the gold standard of visual identification of the recurrent laryngeal nerve (RLN). Contrary to routine dissection of the RLN, most surgeons tend to avoid rather than routinely expose and identify the external branch of the superior laryngeal nerve (EBSLN) during thyroidectomy or parathyroidectomy. IONM has the potential to be utilized for identification of the EBSLN and functional assessment of its integrity; therefore, IONM might contribute to voice preservation following thyroidectomy or parathyroidectomy. We reviewed the literature and the cumulative experience of the multidisciplinary International Neural Monitoring Study Group (INMSG) with IONM of the EBSLN. A systematic search of the MEDLINE database (from 1950 to the present) with predefined search terms (EBSLN, superior laryngeal nerve, stimulation, neuromonitoring, identification) was undertaken and supplemented by personal communication between members of the INMSG to identify relevant publications in the field. The hypothesis explored in this review is that the use of a standardized approach to the functional preservation of the EBSLN can be facilitated by application of IONM resulting in improved preservation of voice following thyroidectomy or parathyroidectomy. These guidelines are intended to improve the practice of neural monitoring of the EBSLN during thyroidectomy or parathyroidectomy and to optimize clinical utility of this technique based on available evidence and consensus of experts.

Key Words: Superior laryngeal nerve; external branch of the superior laryngeal nerve; nerve identification; nerve stimulation; nerve monitoring; thyroid and parathyroid surgery.

Level of Evidence: 5

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INTRODUCTION

The purpose of this report is to provide a review of published data and clinical experience of the International Neural Monitoring Study Group (INMSG) with respect to standards in electrophysiologic intraoperative neural monitoring (IONM) of the external branch of the superior laryngeal nerve (EBSLN) during thyroid surgery. The INMSG is a multidisciplinary international

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group of surgeons and researchers selected based on clinical experience and expertise in thyroid and parathyroid surgery, neural monitoring, and related fields. This group includes surgeons (otolaryngologists, general surgeons, and endocrine surgeons), laryngologists, voice and laryngeal electromyography (EMG) specialists, and anesthesiologists, and has recently published guidelines on recurrent laryngeal nerve (RLN) IONM standards.[1]

The most common complications discussed with patients who undergo thyroid surgery are RLN paralysis and hypoparathyroidism. However, injury of the EBSLN can occur during the dissection and ligation of the superior thyroid vessels in up to 58% of patients, and its detection postoperatively is hampered by the varying and subtle symptoms and changes on postoperative laryngoscopy.[2–4] EBSLN injury results in dysfunction of the cricothyroid muscle, which results in altered fundamental frequency of the voice, a deterioration in voice performance in producing high-frequency sounds, and reduced vocal projection. This can be particularly significant for those using their voice professionally. EBSLN injury can be difficult to identify intraoperatively and is difficult to detect during routine postoperative laryngoscopy.[5]

In recent years, IONM has gained widespread acceptance as an adjunct to the gold standard of visual nerve identification, and this technique can be used to identify both the RLN and the EBSLN.[1] In contrast to RLN monitoring, EBSLN monitoring is based on two distinct outcome measures following the stimulation of the EBSLN: 1) evaluation of cricothyroid twitch (present in all patients), and 2) electromyographic glottis response of vocal cord depolarization identified on surface endotracheal tube electrode arrays in approximately 70% to 80% of patients. Glottic response after EBSLN is felt to be mediated through the EBSLN's distal/terminal fibers, which extend through the two heads of the cricothyroid muscle to the anterior glottis and are termed the human communicating nerve. Current available data suggest such glottis response with current endotracheal tube electrode arrays may be identified in 70% to 80% of patients during EBSLN stimulation. Newer electrode arrays and methods of monitoring may allow improvement in the percent of patients in whom this glottis response with EBSLN stimulation can be identified. Armed with thorough knowledge of the surgical anatomy of the EBSLN within the superior thyroid pole area and IONM technique, one may expect improved anatomic and functional identification and optimal preservation of the EBSLN.

These guidelines are intended to improve the practice of neural monitoring of the EBSLN during thyroidectomy or parathyroidectomy, to optimize clinical utility of this technique based on available evidence and consensus of experts, and to expand the recently published international standards guideline statement focused exclusively on RLN monitoring during thyroid and parathyroid surgery.[1]

SURGICAL ANATOMY AND CLASSIFICATION OF EBSLN ANATOMIC VARIATION

The superior laryngeal nerve is one of the first branches of the vagus after skull base exit. It typically originates from the vagus at the nodose ganglion at the level of C2, about 4 cm cranially to the carotid artery bifurcation.[6] About 1.5 cm caudally, the superior laryngeal nerve (SLN) divides into an internal and external branch. The EBSLN descends dorsal to the carotid sheath, and then crosses medially, extending to the larynx. In its course, the EBSLN is usually located dorsal to the superior thyroid artery and superficial to the inferior pharyngeal constrictor muscle as it descends and travels medially to innervate the cricothyroid muscle on the anterolateral aspect of the lower portion of the cricoid cartilage of the larynx.

Moosman and DeWeese found the EBSLN in 200 human cadaver dissections study to be approaching the larynx within the so-called sternothyroid–laryngeal triangle (also known as Jolles space), formed as the progressively dissected superior pole is retracted laterally and inferiorly. This sternothyroid–laryngeal triangle is defined medially by the inferior pharyngeal constrictor and cricothyroid muscle, anteriorly by the sternothyroid muscle, and laterally by the laterally retracted superior thyroid pole.[7] After the EBSLN travels down the lateral surface of the larynx on the inferior pharyngeal constrictor muscle, the EBSLN typically bifurcates into two branches at the level of the cricoid, entering separately at the pars recta and pars obliqua of the cricothyroid muscle bellies (Fig. 1). The EBSLN is usually about 0.8 mm wide, and its total length varies between 8 and 8.9 cm.[8,9]

Wu et al. processed 27 human hemilarynges with Sihler's stain, a technique that clears soft tissue and counterstains nerve. In this study, in 44% of the 27 specimens, a neural connection was found that exited the medial surface of the cricothyroid muscle (on the outside of the larynx) and then entered into the larynx extending through the cricothyroid membrane and ramifying the anterior third the ipsilateral thyroarytenoid muscle (also known as the vocalis muscle in the endolarynx).[10] Similar observations were made in the canine by Nasri et al., who identified cross-innervation of the thyroarytenoid muscle by the EBSLN in 42.9% of subjects.

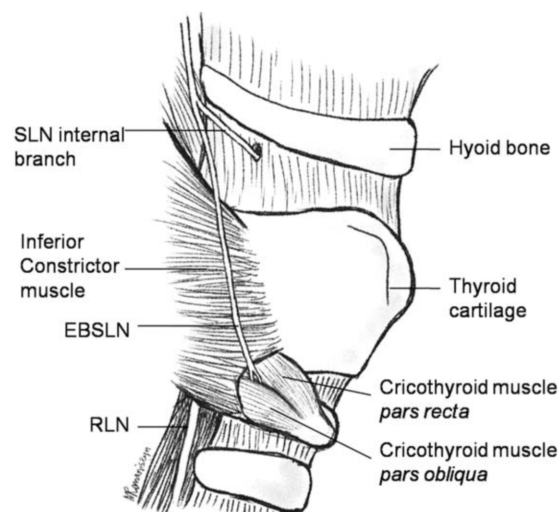

Fig. 1. An outline of the surgical anatomy of the external branch of the superior laryngeal nerve (EBSLN). RLN = recurrent laryngeal nerve; SLN = superior laryngeal nerve.

This was confirmed by EMG recordings from thyroarytenoid muscle following the electrical stimulation applied to the EBSLN.[11] Sanudo et al. found that in 68% of 90 human microdissected specimens, the EBSLN continues on after innervating the cricothyroid muscle, extending through the cricothyroid membrane to innervate the anterior thyroarytenoid muscle region.[12] Maranillo et al. studied the existence of a neural connection between the external laryngeal nerve and the RLN using a microdissection technique in 103 human larynges obtained from necropsies. The human communicating nerve was identified in 85% of cases in this study (bilaterally in 44% and unilaterally in 41%).[13]

Thus, the human communicating nerve provides documented connection to the vocal fold in 41% to 85% of patients.[10–15] The variability of this neural connection, variability in recording the small and early glottic waveform associated with EBSLN stimulation, and variability in endotracheal tube position are all likely responsible for defined waveforms being recordable in <100% of patients during EBSLN stimulation with currently available monitoring technology.

The surgical importance of the EBSLN is due to the close anatomical relationship between the nerve and the superior thyroid vessels. In most circumstances, the EBSLN extends medially to the larynx, well above the superior thyroid pole, and would therefore be at minimal risk of surgical injury during capsular dissection and individual ligation of branches of the superior thyroid vessels. However, there is variability in the caudal extent of the nerve relative to the superior pole region (see classification systems discussed below). In those with a large goiter, a thyroid tumor localized within the upper thyroid pole, or in patients with a short neck, the anatomical relationship between the nerve and the superior thyroid pole vessel can be much more intimate, exposing the EBSLN to a higher risk of inadvertent injury.[16]

Unfortunately, visual identification of the EBSLN is usually not possible in approximately 20% of patients in whom the nerve is located deep to the fascia of the inferior constrictor muscle, unless there is intramuscular dissection.[17] In the remaining 70% to 80% of patients, the nerve is located superficial to the inferior constrictor fascia and therefore is able to be visualized. With IONM stimulation, all EBSLNs should be able to be stimulated and identified, even those that are subfascial in location and not able to be directly visualized.

The most widely recognized surgical classification of the EBSLN was proposed in 1992 by Cernea et al.[16] This classification is based on the potential risk of injury to the nerve during thyroid surgery. It categorizes the nerve in relation to superior thyroid vessels and the upper edge of the superior thyroid pole.

THE CERNEA EBSLN CLASSIFICATION SCHEME IS AS FOLLOWS:

- The type 1 nerve crosses the superior thyroid vessels more than 1 cm above the upper edge of the thyroid superior pole and occurs in 68% of patients with a small goiter and in 23% of patients with a large goiter.
- The type 2A nerve crosses the vessels <1 cm above the upper edge of the superior pole and occurs in 18% of patients with a small goiter and 15% of patients with a large goiter.
- The type 2B nerve crosses the superior thyroid pedicle below the upper border of the superior thyroid pole and occurs in 14% of patients with a small goiter and 54% of patients with a large goiter.

Types 2A and 2B are particularly prone to injury during dissection and ligation of the superior thyroid vessels due to their low-lying course.[5,16]

In 1998, Kierner et al. published a similar classification to the Cernea system, adding a fourth category of the EBSLN running dorsally to the superior thyroid pedicle, which was observed in 13% of their dissection studies and was considered more difficult to visually identify.[6]

Another classification system of the EBSLN was proposed by Friedman et al.[18] It is focused on the anatomy of the EBSLN before its insertion into the cricothyroid muscle. Friedman's classification system was not intended to replace the classification system proposed by Cernea et al. In contrast, it should be considered as a complementary classification system, useful for intraoperative identification of the nerve. Three variations have been described by Friedman et al. for the main trunk of the EBSLN before its terminal branching.

FRIEDMAN'S EBSLN CLASSIFICATION SCHEME IS AS FOLLOWS:

- In the type 1 variation, the nerve runs its whole course superficially or laterally to the inferior constrictor, descending with the superior thyroid vessels until it terminates in the cricothyroid muscle.
- In the type 2 variation, the EBSLN penetrates the inferior constrictor in the lower portion of the muscle. In this case, it is only partially protected by the inferior constrictor.
- In the type 3 variation, the nerve dives under the superior fibers of the inferior constrictor, remaining covered by this muscle throughout its course to the cricothyroid muscle.

In 2009, Selvan et al. proposed a new clinical typing of the EBSLN based on a prospective, descriptive dissection study of 70 nerves in 35 patients. In this report, using EMG, the cricothyroid compound muscle action potential was recorded to identify the EBSLN and classified them according to clinical variation during routine thyroid operations.[19] It categorizes the nerve in relation to superior thyroid vessels and the cricoid cartilage.

SELVAN'S EBSLN CLASSIFICATION SCHEME IS AS FOLLOWS:

- The type 1a nerve was located within 1 cm of the entry of the vessels into the gland either anterior or between the branches of the superior thyroid vessels and within 3 cm from the cricoid cartilage (9% of patients).
- The type 1b nerve was located posterior to the vessels but within 1 cm of the entry of the superior thyroid vessel into

the gland. This entry point is close to the anterior insertion line of the cricothyroid muscle onto cricoid cartilage (present in 3% of patients).

- The type 2 nerve was located within 1 to 3 cm of the entry of the vessels into the gland or within 3 to 5 cm from the cricoid cartilage (present in 68% of patients).
- The type 3 nerve was located between 3 and 5 cm of the entry of the vessels into the gland or more than 5 cm from the cricoid cartilage (present in 20% of patients).

Different classification schemes of the EBSLN are presented in Figure 2.

PHYSIOLOGY AND PATHOPHYSIOLOGY OF THE EBSLN

The EBSLN carries the only motor fibers to the cricothyroid muscle, which functions to tilt the thyroid cartilage relative to the cricoid cartilage, thereby increasing the distance between the anterior commissure and the posterior commissure of the larynx. This increased the length and tension of the vocal fold. The cricothyroid muscle has two bellies, the pars recta and the pars obliqua. The combined action of these two subunits allows adjustment of vocal fold length and tension.[20] The frequency of vocal fold vibration and resultant timbre of the voice is influenced by the vocal fold tension and thickness, which are determined by the action of the cricothyroid muscle and the vocalis portion of the thyroarytenoid muscle. The vocalis muscle shortens the vocal fold and increases its thickness.

Injury to the EBSLN results in changes in voice quality, voice projection,[21] and the production of high-pitched sounds.[22] Clinically, a patient with EBSLN palsy may have a hoarse or weak voice.[23] Voice symptoms may be more noticeable with professional speakers, especially singers.[24] Women with the EBSLN injury may tend to be more aware of modified voice quality and may feel unable to recognize their voices, as pitch is lowered and associated with a profound lack of power, making voice projection and shouting difficult. Cricothyroid muscle weakness does not typically result in aspiration. This can occur with internal SLN injury, but the cricothyroid muscle does not directly affect glottis closure.

METHODS FOR DIAGNOSIS AND TREATMENT OF THE EBSLN INJURY

The diagnosis of the EBSLN dysfunction is difficult to confirm based solely on clinical or endoscopic findings. Voice changes are subtle and variable. Injury of the EBSLN can cause weakness or complete paralysis of the ipsilateral cricothyroid muscle. Patients may report a deeper voice or an inability to produce high pitched sounds. Singing voice may be significantly impaired. Patients may also complain of weakness, tightness of the voice, and require extra effort to speak.[2,25–27] Depending upon the intensity, these symptoms may have a significant impact on voice performance, and consequently on quality of life. The opera singer Amelita Galla Curci is said to have sustained injury to her EBSLN during thyroidectomy, despite having had her surgery performed under local anesthesia specifically to protect her recurrent laryngeal nerves. Her marvelous voice never fully recovered and she never performed on stage again.[28,29]

On functional voice assessment, shortening of the maximum phonation time (especially concerning the sounds /s/, /z/, and /e/; personal communication with Dr. Claudio R. Cernea) as well as lowering of the high tones and reduction of the vocal range can be detected.

The effect of cricothyroid muscle dysfunction on the appearance of the larynx is controversial. Some authors have claimed that the anterior commissure rotates to the side of EBSLN injury, whereas others report rotation to the opposite side. Some have observed a difference in level of the vocal folds. Asymmetric vibration of the vocal folds has also been reported as a videostroboscopic finding.[4,30,31] However, the cricoid and thyroid cartilages articulate in a visor apparatus, like a bucket handle, with little or no translational motion in the joints. Studies of motion in cadaver larynges indicate that the action of either cricothyroid muscle is to move the anterior commissure, which is attached to both vocal folds. Thus, unilateral cricothyroid contraction affects both vocal folds equally.[32]

Aerodynamic measures have shown increased subglottic pressures and decreased airflow rates when the cricothyroid muscle is paralytic.[7] The most reliable clinical sign of bilateral cricothyroid paralysis is the failure of the glottis to elongate when the patient attempts to glide from modal to high register phonation. Observation of this length change does not require stroboscopy. With unilateral paralysis or bilateral paresis, glottic elongation is weakened, but not abolished and therefore difficult to detect on examination.

Given that the clinical manifestations are often subtle and the laryngeal findings are inconclusive and sometimes controversial, EMG of the cricothyroid muscle is the most objective means of documenting EBSLN dysfunction. Using the inferior border of the thyroid cartilage and the superior aspect of the cricoid cartilage as external anatomical landmarks, an electrode is placed percutaneously into the muscle. An effective approach is to introduce the needle near the midline over the superior surface of the cricoid cartilage, and then glide the tip laterally over the surface of the cricoid entering the cricothyroid muscle from its deep surface. To exclude the possibility that the electrodes are in the sternothyroid muscles, the patient should be instructed to flex the neck or elevate the head, action that should activate cervical strap muscles, but not the cricothyroid muscle. To activate the cricothyroid muscle the patient is asked to produce a high-tone /e/, or to glide from midrange to a high pitch. The cricothyroid muscle is also activated by a sniff. An EBSLN injury may be manifest by decreased recruitment, polyphasic action potentials, or electrical silence.[5] Unfortunately, it is not possible to conclusively differentiate electrical silence of the cricothyroid muscle from failure to place the electrode in this small muscle.[33] Spontaneous improvement of voice quality can be expected in cases of temporary EBSLN injury, and voice therapy can be effective for patients with paresis or unilateral paralysis, as residual muscle function can be amplified by exercise. Unfortunately, there is currently

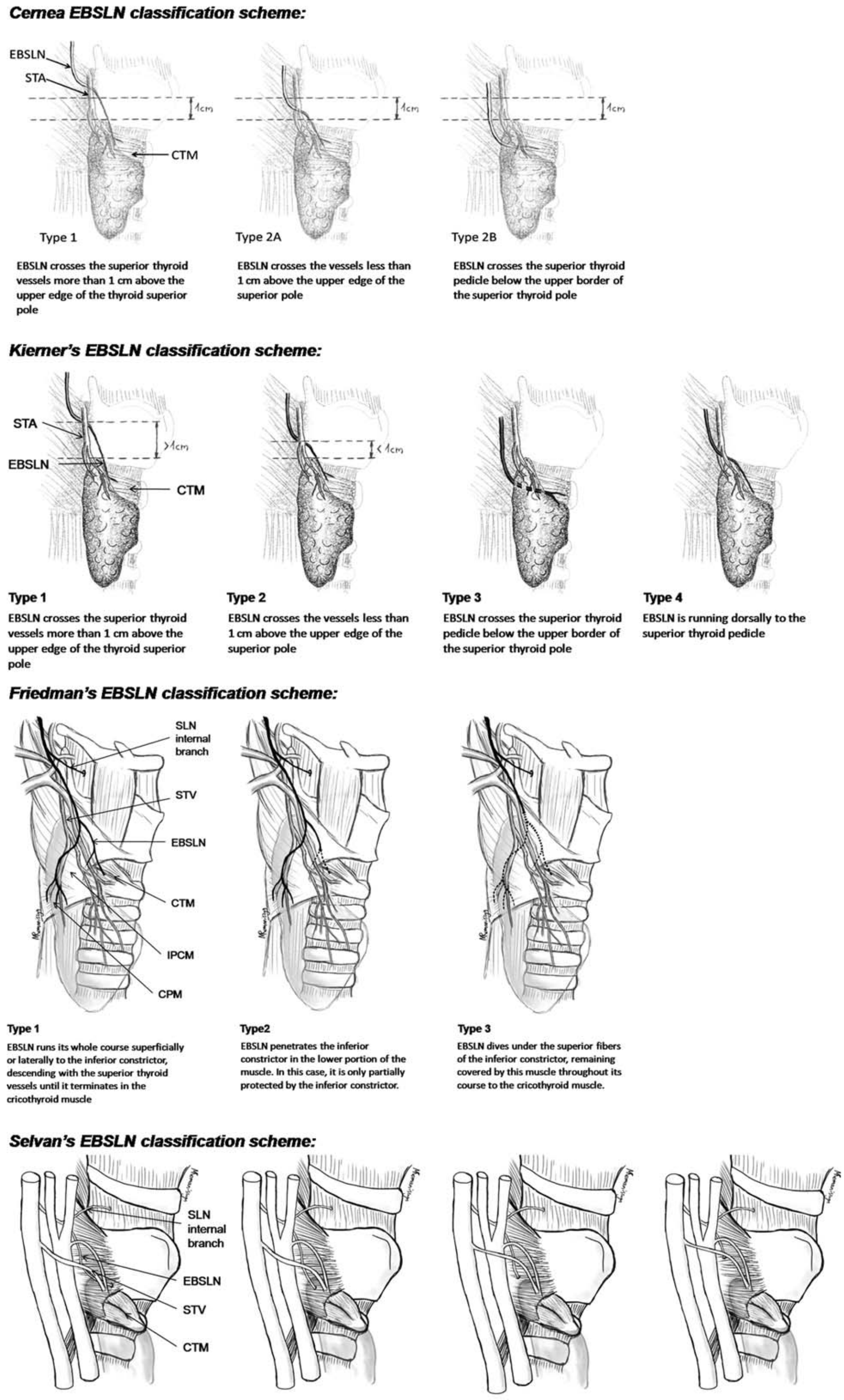

Fig. 2. Classifications of the external branch of the superior laryngeal nerve (EBSLN), which were modified from different studies.[5,6,15,17,18] CPM = cricopharyngeus muscle; CTM = cricothyroid muscle; IPCM = inferior pharyngeal constrictor muscle; SLN = superior laryngeal nerve; STA = superior thyroid artery; STV = superior thyroid vessels.

no effective means of restoring dynamic pitch range when cricothyroid paralysis is bilateral and complete. Isshiki type IV operation (cricothyroid approximation) or an inverse type III operation with the advancement of the anterior commissure can produce static elevation of pitch, but will not restore dynamic voice range. Promising data, based however on a very limited number of patients, were published in 2001 by El-Kashlan et al., who successfully performed selective cricothyroid muscle reinnervation using a muscle-nerve-muscle neurotization technique in three patients with high vagal lesions. All of these patients showed electromyographic evidence of cricothyroid muscle reinnervation and improvement in voice quality after this reconstruction.[34]

From a practical point of view, intraoperative electrical EBSLN testing at the end of the operation can serve for postoperative prognostication of the EBSLN function and has a potential to become a new standard of care in thyroid surgery. A positive cricothyroid twitch after stimulation of the EBSLN at the end of the operation can be regarded as a sign of good functional preservation of the nerve, denoting an extremely low risk of intraoperative nerve injury. It is of course important to test the most cranial portion of the nerve, stimulating a segment above the region of the nerve dissected during superior pole management so that the nerve can be adequately tested during this maneuver. It is essential that all thyroid surgeons be extremely familiar with normal laryngeal and cricothyroid muscle anatomy to accurately observe this cricothyroid muscle twitch (see Supporting Information, Video 1,* in the online version of this article).

SURGICAL DISSECTION TECHNIQUE OF THE EBSLN

Several techniques have been described to minimize the potential risk of injury to the EBSLN during superior thyroid vessels dissection and ligation:

1. Ligation of the individual branches of the superior thyroid vessels under direct vision on the thyroid capsule without attempts to visually identify the nerve[35]
2. Visual identification of the nerve before ligation of the superior thyroid pole vessels[30]
3. The use of either a nerve stimulator or intraoperative neuromonitoring for mapping and confirmation of the EBSLN identification[5,15,16,36–41]

The thyroid surgeon should use careful and meticulous surgical dissection techniques within the area of the superior thyroid pole to preserve both the EBSLN and the cricothyroid muscle. At the very least, the surgeon should ensure that the EBSLN is not injured at the time of dividing tissue at the superior pole by identification of its course or excluding its presence in the divided tissue visually or by nerve monitoring. To that end, the surgeon should be aware of the variations of EBSLN location by thorough knowledge of the anatomy in proximity

*Cricothyroid muscle twitch after stimulation of the EBSLN. Accessible in Supporting Information at: http://onlinelibrary.wiley.com/doi/10.1002/lary.24301/abstract Last accessed at 10th of July, 2013.

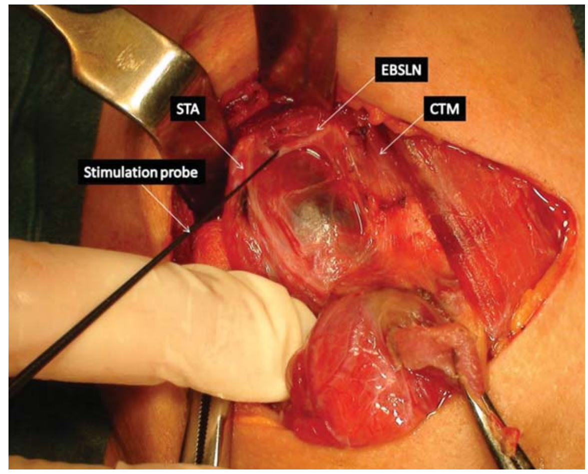

Fig. 3. Right-sided intraoperative view. Visual identification of the external branch of the superior laryngeal nerve (EBSLN) can be confirmed by applying the stimulation probe directly to the nerve. CTM = cricothyroid muscle; STA = superior thyroid artery.

to the superior pole of the thyroid (see surgical anatomy and classification of EBSLN anatomic variation section above). Initial blunt dissection of the superior pole of the thyroid lobe should be undertaken in the avascular space located between the medial aspect of the superior pole and cricothyroid muscle to obtain good exposure of the sternothyroid–laryngeal triangle harboring the EBSLN (Fig. 3). In most cases of a normal size or only slightly enlarged gland, there is no need for transverse division of the strap muscles. However, in cases of large masses within the superior portion of the thyroid lobe or in a patient with a short neck, a partial division of the sternothyroid muscle with cautery may improve access to the superior thyroid pedicle (Fig. 4). Gentle traction of

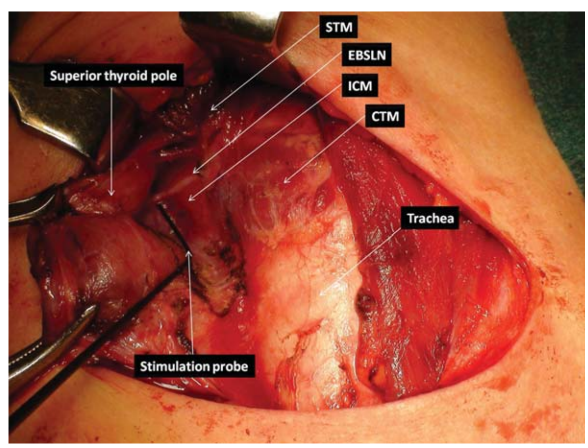

Fig. 4. The right-sided intraoperative view. Transverse division of the superior edge of sternothyroid muscle and gentle traction of the superior thyroid pole into lateral and caudal direction followed by blunt dissection within the avascular plane of sternothyroid–laryngeal triangle allows for improving exposure of the external branch of the superior laryngeal nerve (EBSLN), which is usually descending parallel to the superior thyroid artery and is lying on the inferior constrictor muscle before its termination within the cricothyroid muscle. CTM = cricothyroid muscle; ICM = inferior constrictor muscle; STM = sternothyroid muscle.

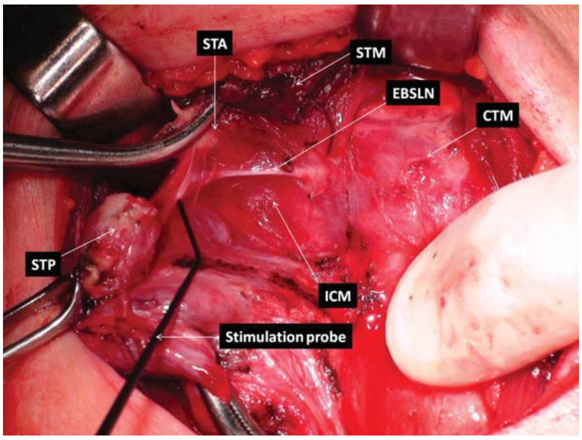

Fig. 5. Right-sided intraoperative view. Step-by-step ligation of individual branches of the superior thyroid artery (STA) can be undertaken under both visual control and stimulation of the external branch of the superior laryngeal nerve (EBSLN) to assure not only anatomical but also functional preservation of the nerve, which can be documented as a positive cricothyroid twitch. CTM = cricothyroid muscle; ICM = inferior constrictor muscle; STM = sternothyroid muscle; STP = superior thyroid pole.

the thyroid lobe in a latero-caudal direction may be helpful in obtaining good exposure of the sternothyroid–laryngeal triangle. The superior thyroid vessels should be isolated by meticulous blunt dissection, and individual branches of the superior thyroid artery should be exposed at their penetration point of the thyroid capsule (Fig. 5). It is worth emphasizing that transverse division of the superior edge of sternothyroid muscle and gentle traction of the superior thyroid pole into a lateral and caudal direction, followed by blunt dissection within the avascular plane of sternothyroid–laryngeal triangle, enables improved exposure of the EBSLN, which is usually descending parallel to the superior thyroid artery and is lying on the inferior constrictor muscle before its termination within the cricothyroid muscle (Fig. 4).

The INMSG notes that it is important to visually search for the nerve in all cases. Also, we appreciate that based on the above-noted excellent work of both Lennquist et al. and Freidman et al, nearly 20% of EBSLNs cannot be visually identified due to their subfascial/intramuscular course.[17,18] We also appreciate that the work of Selvan et al. has shown that in many cases, non-neural fibers or tendinous fibers of regional musculature can be mistaken for the EBSLN.[19]

It is therefore the recommendation of the INMSG that in all patients attempts be made to visually identify the EBSLN, but that in addition, neural stimulation with assessment be made of both cricothyroid muscle (CTM) twitch and glottis endotracheal EMG monitoring (see IONM of the EBSLN technique I and II sections below).

Dissection of the superior thyroid pole is much more difficult and potentially dangerous for the EBSLN in operations on large goiters or in patients with a short neck. In such cases, the upper border of the superior pole is markedly elevated, resulting in adherence of the nerve to the thyroid. Cernea et al. have documented that the incidence of type 2B nerve, which is particularly prone to injury, in patients with goiters above 100 g, may rise to 54%.[5,16] The increased number of type 2B nerves may be due to the upward enlargement of the superior pole of the thyroid rather than the low descending course of the EBSLN. Similar conclusions were drawn by Furlan et al., who evaluated some intrinsic risk factors for a surgical injury of the EBSLN based on its anatomic relationship with the thyroid gland. Based on 72 neck dissections of fresh human adult cadavers, they found that individual stature (a short neck) and a large volume of the hemithyroid gland were the risk factors for the EBSLN injury. In this study among large goiters, where the thyroid gland weight was at least 240 g, the incidence of type 1 nerve was 41%, type 2a nerve was 25%, and type 2b nerve was 24%.[42] Thus, the technique of mass ligation should be avoided at all cost, because it is unsafe and inevitably may jeopardize the EBSLN in the process.

It is crucial to keep in mind that in operations employing an energy-based device (EBD) for sealing of vessels of the superior thyroid pole, there is a high risk of collateral iatrogenic heat injury to the adjacent structures including the EBSLN, the RLN, and parathyroid glands.[37] Thus, any use of an EBD should be preceded by either visual identification or nerve mapping of the EBSLN to ensure its presence away from the danger zone of possible heat injury.[17] For this reason, traditional suture ligation for securing the upper thyroid pole vessels remains a valuable alternative to the EBD. Moreover, if a suture ligation or a vascular clip is identified near the EBSLN, and IONM suggests dysfunction of the nerve, both sutures or clips can be removed, limiting the risk of permanent nerve injury at this level.

The mnemotechnic formula of EBSLN can facilitate recall of the important steps necessary for safe dissection and identification of the EBSL during thyroidectomy (Table I).

IONM OF THE EBSLN TECHNIQUE I: STIMULATION–CTM TWITCH TECHNIQUE

The principles of electrophysiologic RLN monitoring during thyroid surgery described in detail in a recently published International Standards Guideline Statement can be applied to the EBSLN stimulation and monitoring with few important differences outlined below.[1]

Attempts to directly visualize the EBSLN as outlined above should be made. In addition, the INMSG feels that, based on its experience and the existing literature, ideal management of the superior pole and EBSLN preservation involves two maneuvers available only with neural monitoring/stimulation, and that with these maneuvers EBSLN preservation is maximally assured: 1) The EBSLN needs to be stimulated as clearly present (through CTM visual twitch assessment or endotracheal glottic waveform if observable) cranially and medial to the evolving superior pole pedicle. This response serves as a true positive stimulation. 2) Stimulation of the pedicle that is to be divided is stimulated as negative for EBSLN (i.e., no CTM visual twitch or endotracheal glottic waveform). This serves a true negative for absence of neural tissue in the pedicle (as

TABLE I.
The Mnemotechnic Formula of EBSLN Facilitates Recall of the Steps Necessary for Safe Dissection and Identification of the EBSLN.

Acronym	Description	Aims
E	Expose of the space harboring the EBSLN	Exposure of the EBSLN can be improved by transverse division of the laryngeal head of the sternothyroid muscle and gentle traction of the superior thyroid lobe towards the lateral and caudal direction.
B	Bluntly dissect tissues	Blunt dissection within the avascular space between the cricothyroid muscle and medial aspect of the superior thyroid pole allows for visual identification of the EBSLN lying on the inferior constrictor muscle before its termination within the cricothyroid muscle.
S	Stimulate tissues during dissection	Stimulation of tissues during blunt dissection should be undertaken in order to facilitate visual identification of the nerve.
L	Look for cricothyroid twitch	Looking for a positive cricothyroid twitch is recommended during gentle dissection of tissues with the tip of the stimulation probe rather than expecting a positive EMG response on the monitor.
N	Navigate your dissection using the technique of nerve mapping	Navigation of the dissection should be continued once the nerve is identified to assure functional nerve preservation. In cases when the nerve is not seen but mapped out in the operative field, this navigation should allow for optimizing the level of the superior thyroid artery ligation to ensure intact functional integrity of the EBSLN provided by electrical nerve testing. One obtains positive stimulation medially and then only divides tissue in the superior pole dissection, which stimulates negatively.

EBSLN = external branch of the superior laryngeal nerve; EMG = electromyography.

long as there has been true positive stimulation as noted in the first maneuver).

The INMSG feels strongly that this sequence of neural monitoring data optimizes preservation of the EBSLN. The rationale for this algorithm is supported by several recently published studies confirming that the use of IONM can improve the identification rate of the EBSLN, limiting the risk of inadvertent nerve injury.[15,16,36–41] Through this sequence of stimulation maneuvers, the presence of the EBSLN is effectively excluded in the tissues being surgically treated at the superior pole.

In a prospective study on video-assisted thyroidectomies, Dionigi et al. randomized 72 patients to two groups and found that the identification rate of EBSLN in the group in which IONM was used was 84% compared to 42% in the non-IONM group.[37] Lifante el al. also found, in a study of 47 patients with 69 nerves at risk, a greater rate of EBSLN identification during thyroidectomies under regional anesthesia, 65% with neuromonitoring versus 33% without it.[38]

Neuromonitoring of EBSLN is well documented in Barczyński et al.'s randomized controlled prospective trial of visualization versus neuromonitoring of the EBSLN, who found in 210 patients that the rate of EBSLN identification was improved when IONM was used to obtain EMG response and an audible signal from the monitor. They documented an identification rate of 34% without IONM versus 84% ($P<.001$) when IONM was used. IONM also reduced the prevalence of transient but not permanent EBSLN injury in a monitored versus nonmonitored group (1.0% vs. 5.0%, respectively; $P=.02$) and reduced the risk of early but not permanent phonation changes following thyroidectomy.[15] Results of this study seem to be encouraging enough to popularize the technique of the EBSLN monitoring during thyroidectomy.

Aina et al. used a nerve stimulator for identification of the EBSLN in 151 consecutive patients and 218 nerves at risk. The identification rate of the EBSLN was very high in this study and equal to 92.7%. In primary thyroid surgery, the successful identification of the nerve was possible in 95.5%; however, in secondary thyroid surgery only 65.0% of the nerves were identified.[39]

In Selvan et al.'s study, 100% of EBSLNs were found using nerve stimulation and EMG of the cricothyroid muscle in 35 patients and 70 nerves at risk. In this study, a considerable number of false positives were seen when visual identification alone was used prior to electrical stimulation.[19] In many cases, non-neural fibers or tendinous fibers of the cricothyroid or inferior constrictor muscles were wrongly assumed to be EBSLN but were unmasked by the lack of an action potential when stimulated. This finding suggests that visual identification of the EBSLN without EMG confirmation may likely be flawed. It is our belief that adding quantitative data to this technique could make the process of nerve identification and preservation more definitive and precise.

Nerve stimulation technique has a substantial advantage in identifying all nerve types, including Cernea type 1, which is found at a higher position and sometimes is crowded under the laryngeal head of the sternothyroid muscle, as well as descending types 2A and 2B, which are most vulnerable to surgical manipulation injury.[15]

We recommend using the IONM (with the current of stimulation set at 1 mA) at this stage of the dissection to rule out entrapment of the EBSLN during each portion of superior pole dissection by togging the stimulator probe between the tissue and the cricothyroid muscle. Visual identification of the EBSLN can be confirmed by applying the stimulation probe directly to the nerve (if seen) above the entry point into the cricothyroid muscle (Figs. 3, 4, and 5). To facilitate localization of the EBSLN, it is recommended to stimulate tissues parallel and underneath the laryngeal head of the sternothyroid muscle, which can be regarded as a highly reliable landmark for the identification of the EBSLN in its distal course before termination within the cricothyroid muscle (Fig. 6).[43]

It should be noted that one of the significant advantages of neural monitoring for the EBSLN is that even

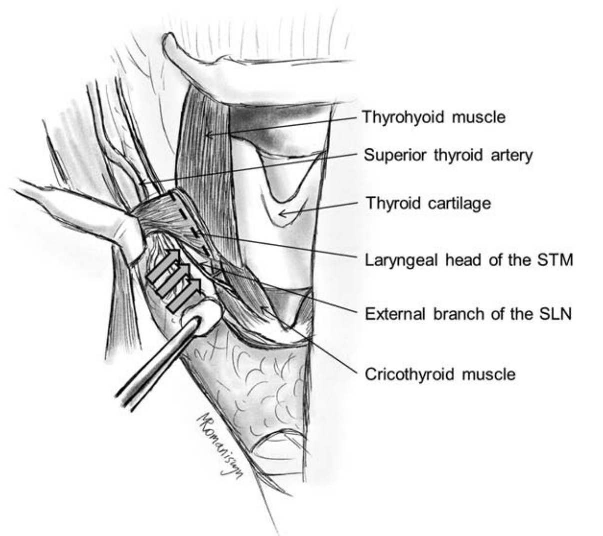

Fig. 6. To facilitate localization of the external branch of the superior laryngeal nerve (EBSLN), it is recommended to stimulate tissues parallel and underneath the laryngeal head of the sternothyroid muscle (STM) (marked with the dashed line), which can be regarded as a highly reliable landmark for the identification of the EBSLN in its distal course before termination within the cricothyroid muscle.[43] SLN = superior laryngeal nerve.

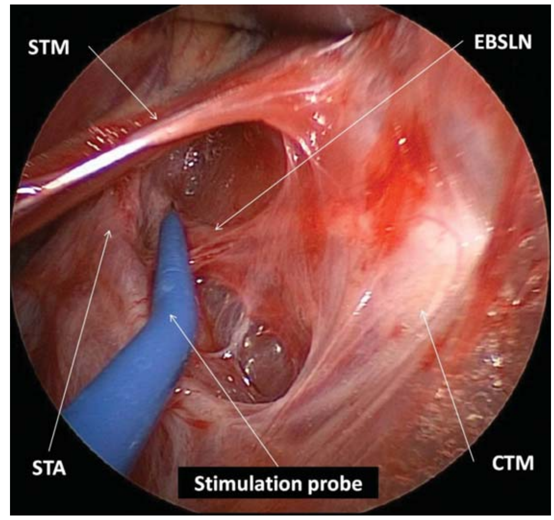

Fig. 7. Anatomical preservation of the right external branch of the superior laryngeal nerve (EBSLN) during minimally invasive video-assisted thyroidectomy. Right lobectomy is facilitated by magnification of the endoscope, whereas stimulation of the EBSLN allows for additional electrical nerve testing to assure functional nerve preservation. CTM = cricothyroid muscle; STA = superior thyroid artery; STM = sternothyroid muscle.

in those cases where the EBSLN is not able to be identified visually, due to its deep course into the inferior pharyngeal constrictor muscle fascia, through the technique of nerve mapping (the current of stimulation can be increased from 1 mA to 2 mA) the EBSLN and be definitively identified.[1] As already mentioned, the laryngeal head of the sternothyroid muscle is an excellent landmark for the linear oblique path of the EBSLN as it traverses down along the inferior constrictor toward the cricothyroid muscle. Within 1 to 2 mm of this obliquely oriented laryngeal line (the laryngeal head of the sternothyroid muscle, which inserts onto the thyroid cartilage lamina) the EBSLN can be found with a high degree of certainty where the nerve's course parallels the course of the sternothyroid muscles insertion on the larynx (Fig. 6). Blind stimulation in this area with the neural stimulator uniformly results in the identification of a linear path that sent stimulated results in discrete cricothyroid muscle contraction. In this way, neural stimulation of the external branch should be able to identify this nerve in 100% of cases. A positive identification of the nerve should be confirmed by observing contractions of the cricothyroid muscle (CTM twitch), which in some cases can be also accompanied by hearing an auditory signal and an EMG response on the monitor (see discussion IONM of the EBSLN technique II: stimulation-glottic EMG technique section below). After completion of the superior thyroid pole dissection, the functional integrity of the nerve may be documented through electrical stimulation and a positive cricothyroid twitch response (Fig. 5). This is the most reliable outcome measure following the EBSLN stimulation (present in 100% of cases). This technique is recommended not only for open thyroidectomy but also for minimally invasive video-assisted thyroidectomy, which can also be monitored in this way (Fig. 7).[37]

The CTM must be clearly localized visually as a triangular muscle profile on the anterolateral aspect of the cricoid cartilage. Its twitch is unmistakable and is quite easy to recognize as long as one is appropriately oriented to the basic laryngeal anatomy available during all thyroid and parathyroid surgery (see Supporting Information, Video 1, in the online version of this article; Fig. 1, Fig. 4).

With neural monitoring and assessment of the CTM twitch during EBSLN stimulation we can therefore identify 100% of EBSLNs, even those not able to be visually assessed. At the end of superior pole management, by stimulation the EBSLN proximally (i.e., superior, cranially) to the region of superior pole vessel dissection, this technique can prove the ongoing function postoperatively of the EBSLN.

IONM OF THE EBSLN TECHNIQUE II: STIMULATION–GLOTTIC EMG TECHNIQUE

In contrast to RLN monitoring, EBSLN monitoring is based on two distinct outcome measures following the stimulation of the EBSLN: evaluation of cricothyroid twitch (present in all patients) and electromyographic response recorded by the monitor via surface tube electrode within the vocal folds present in 70% to 80% of patients. During EBSLN stimulation in approximately 70% to 80% of cases, the EMG waveform can be detected on the monitor by endotracheal tube electrodes (Fig. 8). However, this is a much more variable outcome measure following the stimulation of the EBSLN and occurs due to the external human communicating nerve, a nerve that represents and extension of the EBSLN, ramifying the two heads of the CTM and extending into the larynx to innervate the anterior half of the ipsilateral vocal cord. This depolarization is then measured on glottic

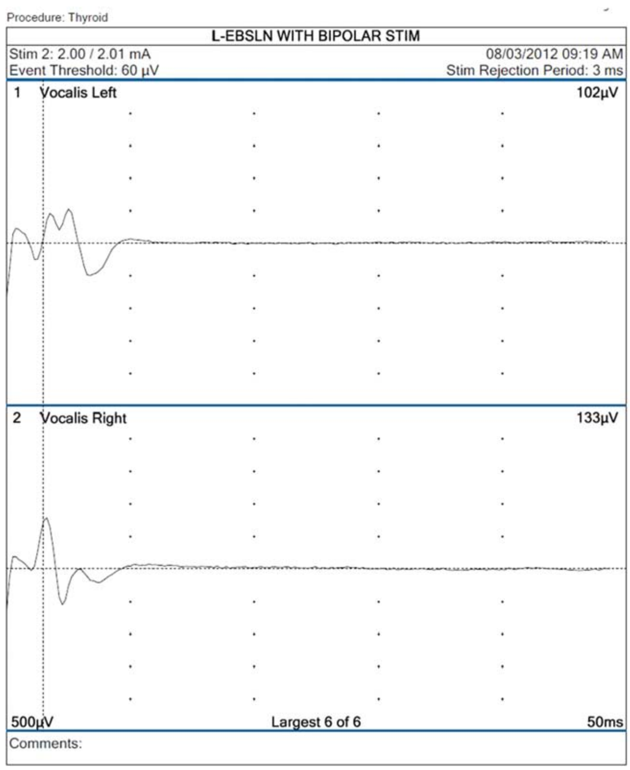

Fig. 8. Electromyography waveform detected by endotracheal tube electrodes after bipolar stimulation of the left external branch of the superior laryngeal nerve (EBSLN). This recording is not thought to be an artifact of field effect, because there is a clear waveform with defined but short latency from the stimulation artifact that is biphasic following probe stimulation, and is identified at the time of cricothyroid muscle twitch activation with a small but clear-cut recognizable amplitude. Adjacent stimulation of inferior constrictor musculature without direct EBSLN stimulation results in regional inferior constrictor twitch but no cricothyroid muscle twitch and no glottic waveform. The latency of response also is inconsistent with a central affect SLN to vagus reflex response.

surface endotracheal tube electrodes. The human communicating nerve has been described in up to 85% of anatomical dissection studies.[13,23,24]

The reason why EBSLN results in glottis identifiable waveform in only 70% to 80% is unclear, and this time and is likely due to equipment-related measurement issues. It is of note that sampling epoch timeframes available during EBSLN stimulation and glottis waveform recording are too fast for the EBSLN EMG activity to result from afferent SLN stimulation caused by centrally mediated, reflex vagal glottic activity. Such activity would have a much greater latency than observed with EBSLN-evoked glottis EMG activity. The waveform generated is of small amplitude and therefore may not be noted by monitoring software as a significant and recognizable waveform. This may be controlled to some degree by lowering the monitor amplitude threshold setting to lower than the typical threshold of 100 mV to 150 mV used for RLN monitoring. The waveform is also of very short latency given the short distance to the larynx, and therefore may be silenced by monitoring software that intentionally suppresses very early responses, which could be the tail of EMG activity related to the stimulation artifact of the current delivered. This may be controlled to some extent by shortening the preset stimulation suppression artifact period on the monitor. The variability in obtaining glottic EMG with EBSLN stimulation is also likely due to the fact that the EBSLN innervates primarily the anterior one-third of the cord, and therefore its measurement may be especially sensitive to endotracheal tube positioning. This variability may also conceivably relate to variability in anatomic presence of the human communicating nerve, though such anatomic variability seems unintuitive; preliminary studies with improved glottic measuring electrodes suggests that in time, newer monitoring systems will evolve to be able to record EMG in all patients during EBSLN stimulation.

Equipment

Many different nerve-monitoring formats have been studied, including laryngeal palpation, glottic observation, glottic pressure monitoring, endoscopically placed intramuscular vocal cord electrodes, intramuscular electrodes placed through the cricothyroid membrane, endotracheal tube-based surface electrodes, and postcricoid surface electrodes. For a variety of reasons including safety, utility, and simplicity, systems that rely on endotracheal tube-based surface electrodes have proliferated and represent the most common monitoring equipment format to date.[1]

The study group believes endotracheal tube-based systems that include graphic monitor documentation of waveform are preferred for neural monitoring of both the RLN and EBSLN. Audio-only systems are problematic in that the EMG response to both RLN and EBSLN stimulation cannot be quantified (waveform morphology, amplitude, threshold, and latency).[1] Stimulating electrodes may be monopolar or bipolar. Bipolar stimulating electrodes may offer the potential advantage of greater sensitivity through focal nerve stimulation and perhaps less stimulation artifact.

Technique

Certain standards of anesthesia, equipment set up, endotracheal tube placement, and verification tests of correct tube positioning are the same for the EBSLN as for the RLN monitoring.[1] The monitor should be set for an appropriate event threshold at 100 μV (or lower as noted above), and a stimulator probe should be set on a value of 1 to 2 mA. For confirmation of visually identified EBSLN, a current of 1 mA should be used. However, for EBSLN mapping, a higher values of up to 2 mA should be used. Pulsatile stimulus with 100 μs duration at 4 Hz can be applied through a flexible stimulator probe (which can be monopolar or bipolar). One must be aware that if a bipolar array is used for nerve stimulation, the exact orientation of the positive (anode) and negative (cathode) stimulating electrodes, as they are placed on the nerve, is of extreme importance in efficient nerve stimulation. In addition, the bipolar probe may not be optimal for mapping of the nerve because the stimulation is more focal at the point of contact as compared with the monopolar probe, which provides more diffuse current spread, which may facilitate mapping of a larger area.

Normative Data of the EBSLN Monitoring

Barczyński et al. recently found in a group of 210 EBSLNs at risk, that following 1 mA stimulation of the EBSLN, the mean amplitude of evoked potential recorded by surface electromyography electrodes on the endotracheal tube was present in 73.9% of patients and was equal to 249.5 ± 144.3 μV. It is important to note that the mean amplitude after EBSLN stimulation was significantly lower than the mean amplitude of evoked potential observed during stimulation of the RLN, which was equal to 638.5 ± 568.4 μV ($P < .001$).[15]

Similar observations were made recently by Randolph et al., who reviewed data of 72 consecutive patients undergoing thyroid surgery. Ninety-three RLNs were stimulated and 73 EBSLNs were found and stimulated with either 1 or 2 mA. A clear EMG waveform following EBSLN stimulation was obtained in 57 (78.1%) of the cases. The mean amplitude of response for the EBSLN was 269.9 ± 178.6 μV. The mean RLN amplitude was 782.2 ± 178.6 μV. For the EBSLN, the mean amplitude of EMG response obtained initially was 270.7 ± 190.7 μV, and the mean postdissection response was 260.3 ± 177.9 μV. There was no significant difference between the initial and final amplitudes of response ($P = .469$). There was no significant difference between the EBSLNs stimulated with 1 mA (280.8 ± 216.9 μV) and those stimulated with 2 mA (261.8 ± 142.4 μV) ($P = .704$). The mean amplitude of the EBSLN action potential was significantly lower than the mean RLN amplitude, which was about one-third of the RLN amplitude in comparison.[44]

Because there is great variability in amplitude values, and because there may be an influence of tube position in the size of the action potentials, looking at the EBSLN amplitude values as a percentage of those values obtained for the RLN and vagal nerve in each individual case may be a useful tool to determine which are the normal parameters of EBSLN neuromonitoring other than using only an absolute value or a range as reference. The amplitudes of response are similar among both genders. There was no difference between amplitudes of response on either side for the RLN as well, but amplitudes of response on the left EBSLN were higher than on the right. The explanation for this finding is still unclear.

Definitions

True positive result of the stimulation implying correct identification of the EBSLN is confirmed when CTM twitch is present following the stimulation of the ipsilateral nerve with the current of 1 mA (with or without corresponding EMG response). True negative result of the stimulation is defined as no CTM twitch following the stimulation of the non-EBSLN tissue. False positive stimulation implying incorrect identification of the EBSLN is defined as a positive CTM twitch (with or without corresponding EMG response) in the case of non-neural shunt stimulation. Such a scenario is sometimes seen during nerve mapping with the current of 2 mA. To rule out the non-neural shunt stimulations, it is best to turn down the stimulation current to a level where false positive stimulation is silenced (usually between 0.8 and 1 mA). False negative result of the stimulation implying misidentification of the EBSLN as non-neural structure is defined as no CTM twitch (and no corresponding EMG response) following the stimulation of the EBSLN. The most common reasons for this scenario include various equipment problems on the stimulation side, blood or fascia covering the stimulated nerve segment, insufficient stimulation current, neuromuscular blockage, and transient neuropraxia of the EBSLN.

INCIDENCE OF EBSLN INJURY

The actual prevalence of EBSLN injury is difficult to assess due to limited data and heterogeneous methods used in different studies (Table II). Given the variability of vocal symptoms and subtle and variable findings at laryngeal exam postoperatively, the only definitive way to diagnose EBSLN injury is with CTM EMG. The reported prevalence of this event varies widely from 0% to 58%; therefore, EBSLN injury is believed to be the most commonly underestimated morbidity following thyroid surgery.[3,28,45–48] Nonetheless, there is growing evidence in the published literature that the higher surgical attention is paid to the EBSLN during the dissection of the superior thyroid vessels, the lower prevalence of the nerve dysfunction may be expected. In addition, increasing use of nerve stimulation or IONM techniques in recent years has resulted in improved identification and functional preservation rate of the nerve.[5,15,34,40] Jansson et al. examined with EMG of the cricothyroid muscles in 26 patients after thyroidectomy with no EBSLN identification intraoperatively, and they found temporary EBSLN injury in 58% and permanent injury in 3.8% of the patients.[3] Cernea et al. found between 12% and 28% incidence of injury when the EBSLN was not identified intraoperatively, and some of these injuries were permanent as confirmed by long-term EMG evaluation.[5,16] On the other hand, Bellantone et al. demonstrated in a randomized study that accurate distal ligation of the branches of the superior thyroid vessels without attempts to visually identify the nerve is a safe technique in expert hands with similar prevalence of EBSLN injury as routine nerve identification (0.5% vs. 0.8% for temporary lesions), but the study did not include EMG definition of CTM function.[35]

SUMMARY

Our guideline statement summary is as follows:

- The EBSLN is believed to be the most commonly underestimated morbidity following thyroid surgery and is at a high risk of injury during dissection of the superior thyroid pole

TABLE II.
Reported EBSLN Identification and Injury Rates.

Author	Year of Publication	Study Design	Number of EBSLNs at Risk	Method of EBSLN Identification	EBSLN Identification Rate, %	EBSLN Injury, %	Evaluation Method
Barczyński[15]	2012	RCT	210 vs. 210	Visual vs. IONM	34.3 vs. 83.8	6 vs. 1.5 (temporary)	VSL, voice evaluation
Dionigi[37]	2009	RCT	57 vs. 55	Video-assisted vs. IONM	42 vs. 83.6	Not reported	Laryngoscopy
Lifante[38]	2009	RCT	33 vs. 35	Visual vs. IONM	21 vs. 66	Not reported	Laryngoscopy, voice evaluation
Bellantone[35]	2001	RCT	215 vs. 244	Visual vs. no nerve search	88.4	0.5 vs. 0.8 (temporary)	VSL, voice evaluation
Cernea[5]	1992	RCT	90	Nerve stimulator vs. no nerve search by consultant vs. no nerve search by resident	93	0 (with nerve stimulation), 12 (no nerve search, consultant),28 (no nerve search, resident)	EMG, voice evaluation
Selvan[19]	2009	PNR	70	IONM	100	0	EMG
Inabnet[41]	2009	PNR	15	IONM	53	Not reported	Laryngoscopy, voice evaluation
Dackiw[21]	2002	PNR	152	Nerve stimulator	8.9 (only Cernea type 2b)	Not reported	Voice evaluation
Aina[39]	2001	PNR	218	Visual (n = 169), nerve stimulator (n = 33)	92.7	Not reported	Not reported
Aluffi[46]	2001	PNR	35	No nerve search	0	14	EMG, VSL, voice evaluation
Teitelbaum[4]	1995	PNR	20	No nerve search	0	5	EMG, VSL
Jansson[3]	1988	PNR	26	No nerve search	0	58 (temporary), 3.8 (permanent)	EMG, laryngoscopy, voice evaluation
Lennquist[17]	1987	PNR	50	Visual	72	2.0 (permanent)	Laryngoscopy, voice evaluation
Kark[28]	1984	PNR	56	Visual	84	5	Laryngoscopy, voice evaluation
Moosman[7]	1968	PNR	400	Visual	100	Not reported	Not reported
Friedman[18]	2009	RC	2357	Mainly visual, nerve stimulator in recent years	85.1	Not reported	Not reported
Jonas[40]	2000	RC	190	IONM	37.2	4.6 (temporary)	Laryngoscopy, voice evaluation
Lore[47]	1998	RC	934	Visual	10	13.6 (temporary), 7.6 (permanent)	Laryngoscopy, voice evaluation
Reeve[48]	1969	RC	157	Visual	59	1.9	Laryngoscopy, voice evaluation

EBSLN = external branch of the superior laryngeal nerve; EMG = electromyography; IONM = intraoperative nerve monitoring; PNR = prospective non-randomized study; RC = retrospective cohort study; RCT = randomized controlled trial; VSL = videostrobolaryngoscope.

in the course of thyroidectomy in approximately one-third of patients (Cernea type 2A and 2B nerves).

- The laryngeal head of the sternothyroid muscle is a robust landmark for the course of the EBSLN as it descends along the inferior constrictor to the CTM.
- In up to 20% of cases, the nerve may not be able to be visualized due to a subfascial course along the inferior constrictor muscle.
- Nerve stimulation can objectively identify the EBSLN, leading to a visible cricothyroid muscle twitch in all (100%) cases.
- The use of IONM can significantly improve the identification rate of the EBSLN during thyroidectomy. CTM twitch and glottis EMG recordings are both methods of IONM that are recommended in all cases of thyroid and parathyroid surgeon that might jeopardize the EBSLN.
- A technique of togging the stimulator probe between the tissue of the superior thyroid pole vessels (with negative stimulation) and the region of the laryngeal head of the sternothyroid muscle (with positive stimulation) is recommended to assure preservation of the EBSLN.
- Transverse division of the superior edge of the sternothyroid muscle and gentle traction of the superior thyroid pole into a lateral and caudal direction, followed by blunt dissection within the avascular plane of sternothyroid–laryngeal triangle, allows for improving exposure of the EBSLN, which is usually descending parallel to superior thyroid artery and is lying on the fascia or between the fibers of the inferior constrictor muscle before its termination within the cricothyroid muscle.
- Application of IONM should not be limited to the RLN only but should be also expanded for EBSLN mapping, identification, and functional testing during thyroidectomy.
- EMG activity can currently be quantified in nearly 80% of cases. The role of measuring the waveform amplitude in prognostication of EBSLN function is yet to be determined.
- EBSLN nerve injury occurs frequently, is difficult to diagnose through laryngeal exam, and results in significant and irrevocable vocational changes for the voice professional.

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