



Contribution of intraoperative neuromonitoring to the identification of the external branch of superior laryngeal nerve

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ABSTRACT

Objective: We evaluated the contribution of intraoperative neuromonitoring to the visual and functional identification of the external branch of the superior laryngeal nerve.

Material and Methods: The prospectively collected data of patients who underwent thyroid surgery with intraoperative neuromonitoring for external branch of the superior laryngeal nerve exploration were assessed retrospectively. The surface endotracheal tube-based Medtronic NIM3 intraoperative neuromonitoring device was used. The external branch of the superior laryngeal nerve function was evaluated by the cricothyroid muscle twitch. In addition, contribution of external branch of the superior laryngeal nerve to the vocal cord adduction was evaluated using electromyographic records.

Results: The study included data of 126 (female, 103; male, 23) patients undergoing thyroid surgery, with a mean age of 46.2 ± 12.2 years (range, 18-75 years), and 215 neck sides were assessed. Two hundred and one (93.5%) of 215 external branch of the superior laryngeal nerves were identified, of which 60 (27.9%) were identified visually before being stimulated with a monopolar stimulator probe. Eighty-nine (41.4%) external branch of the superior laryngeal nerves were identified visually after being identified with a probe. Although 52 (24.1%) external branch of the superior laryngeal nerves were identified with a probe, they were not visualized. Intraoperative neuromonitoring provided a significant contribution to visual ($p < 0.001$) and functional ($p < 0.001$) identification of external branch of the superior laryngeal nerves. Additionally, positive electromyographic responses were recorded from 160 external branch of the superior laryngeal nerves (74.4%).

Conclusion: Intraoperative neuromonitoring provides an important contribution to visual and functional identification of external branch of the superior laryngeal nerves. We believe that it can not be predicted whether the external branch of the superior laryngeal nerve is at risk or not and the nerve is often invisible; thus, intraoperative neuromonitoring may routinely be used in superior pole dissection. Glottic electromyography response obtained via external branch of the superior laryngeal nerve stimulation provides quantifiable information in addition to the simple visualization of the cricothyroid muscle twitch.

Keywords: Thyroidectomy, intraoperative neuromonitoring, external branch of the superior laryngeal nerve, nerve identification, cricothyroid muscle twitch

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INTRODUCTION

Voice impairments are common complaints after thyroidectomy. They are considered to be multifactorial in origin and can occur due to the trauma of neural or other laryngotracheal structures (1). The preservation of both the recurrent laryngeal nerve (RLN) and external branch of the superior laryngeal nerve (EBSLN) is necessary to maintain vocal cord function (2).

The superior laryngeal nerve is a branch of the vagus nerve near its exit from the jugular foramen of the skull base. It usually arises from the nodose ganglion of the vagus at the level of C2, about 4 cm cranially to the carotid artery bifurcation. In addition, it receives a branch from the superior cervical sympathetic ganglion.

About 1.5 cm caudally, the superior laryngeal nerve divides into a larger internal branch and a smaller external branch. The EBSLN descends dorsally to the carotid sheath and then crosses medially towards the larynx. The EBSLN has a course dorsal to the superior thyroid artery and superficial to the inferior pharyngeal constrictor muscle as it descends and runs medially to innervate the cricothyroid muscle (CTM) (3-5).

The CTM maintains the tension of the vocal folds during the production of high-pitched sounds (3). The position of EBSLN exposes it to the risk of injury during dissection of the superior thyroid pole. CTM paralysis caused by EBSLN injury does not enable the pitch elevation, which is particularly a great problem for women and voice professionals (4, 5).

Current prevalence of intraoperative injury of EBSLN has not been established in the literature so far because of the postoperative variability in voice symptoms and the difficulty of identifying the injury via the direct laryngoscopy and videostrobolaryngoscopy, compared with RLN injury (5). EBSLN injury rates have been reported to be approximately 58% (6). Thus, EBSLN injury is the most underestimated complication after thyroid surgery (5).

Several surgical techniques have been described to preserve EBSLN during the dissection of the superior thyroid pole, but none of them has been determined to be superior enough to decrease the potential risk of EBSLN injury (5). Intraoperative neuromonitoring (IONM) has gained widespread acceptance as an adjunct to the gold standard of visual identification of RLN (7). Routine identification of EBSLN was thought to be almost impossible and harmful to the nerve previously. However, IONM has recently been reported to be helpful and less invasive for identifying EBSLN (8-11). As these findings increased the surgical interest in using neuromonitoring for the identification of EBSLN, the rate of neuromonitoring use has increased over time. On an international survey in surgeons with known interest in thyroid surgery, the International Neural Monitoring Study Group in Thyroid and Parathyroid Surgery reported that IONM was used for the identification of the EBSLN by 26.3% of low-volume versus 68.4% of high-volume surgeons ($p=0.004$) worldwide, and 93% of respondents believed that EBSLN identification with IONM is necessary for voice professionals (12). We have been using IONM for EBSLN exploration since July 2012. In the current study, we aimed to evaluate the contribution of IONM to visual and functional identification of EBSLN.

MATERIAL AND METHODS

The prospectively collected data of 126 (female, 103; male, 23) patients undergoing thyroid surgery via IONM for the EBSLN exploration from January to December 2015 were assessed retrospectively. Each side of the neck was accepted as a separate entity, and 215 neck sides were assessed.

Patients were informed of the intent of using a monitoring system to potentially aid in avoiding any possible injury to RLN and EBSLN and assessing their functions during the operation. The patients provided written informed consent for the surgical procedure as well as the study and publication of the stored results according to the institutional review board. This study was approved by the hospital's Ethics Committee.

The exclusion criteria were revision surgery, thyroid cancer with massive extrathyroidal extension, intentional nerve transection because of cancer invasion, and failure to assess EBSLN function because of technical issues.

Medical records were collected and stored within a prospective database. The collected information included demographic features, indications for thyroid surgery, operative details (such as type of surgery and the IONM data) and postoperative period details.

Intraoperative Neuromonitoring Technique

The NIM-3.0 Neuro Monitoring System (Medtronic Xomed; Jacksonville, FL, USA) with endotracheal surface electrodes was adopted to test the nerve intraoperatively. The patient

was under general anesthesia with a low-dose short-acting neuromuscular blockade (rocuronium 0.3 mg/kg) and intubated with Medtronic Xomed Nerve Integrity Monitor Standard Reinforced Electromyography Endotracheal Tube (size 6.0, 7.0, or 8.0 Fr). A sterile, single-use, pulse-generated monopolar stimulator probe (Medtronic Xomed; Jacksonville, FL, USA) was applied for nerve stimulation in the operative field with an interrupted stimulation technique, where in the probe was set to a value of 1 mA, impulse duration at 100 μ s, frequency at 4 Hz, and the monitor was set for an event threshold of 100 μ V. IONM setup, applications, and data interpretation were consistent with the International Neural Monitoring Guidelines (5, 7). The electromyographic waveform amplitude defined the vocal cord adductor function. Standard IONM was carried out as a 4-step procedure for RLN (V1, R1, R2, and V2). EBSLN function was evaluated via CTM twitch. An auditory signal and obvious glottis electromyographic waveform with EBSLN stimulation were also obtained in some cases and these electromyographic responses were recorded. Positive stimulation was defined as both the audible alarm of the monitoring system and achievement of a recognizable electromyographic waveform amplitude that was $>100 \mu$ V, for both RLN and EBSLN.

Surgical Technique

Thyroidectomy and/or central neck dissection was performed by a 4-6-cm collar transverse incision. Subplatysmal flaps were raised, strap muscles were divided along the midline, the thyroid lobe was medialized, and middle thyroid vein was divided. A previously described systematic approach is used consistently for monitoring and identification of RLNs (13).

Superior thyroid pole dissection: Superior pole dissection was performed before or after lateral gland mobilization. The upper pole of the lobe was retracted laterally and caudally to expand the sternothyroid-laryngeal triangle (SLT). In cases of enlarged gland or short neck, the strap muscles were transected with ligasure (Covidien, Mansfield, MA) at one-third of superior edge with care to preserve the ansa cervicalis to provide a better exposure and dissection of the superior thyroid pedicle (5, 14). The avascular space between the superior pole and CTM was dissected bluntly for a better exposure of the SLT where the EBSLN lies. After the visual identification of EBSLN in the SLT, confirmation analysis with a monopolar stimulator probe via CTM twitch assessment was performed. If the EBSLN was not identified visually, it was searched with a stimulator probe under the laryngeal head of the sternothyroid muscle, which is a good landmark for the EBSLN's course, and followed over the inferior pharyngeal constrictor (IPC) muscle down towards the CTM (15). When EBSLN was not able to be identified using a probe, the fibers of IPC muscle were not dissected through to identify the nerve visually.

While managing the superior pole dissection, each portion of the pedicle tissue was stimulated with a probe to make sure that EBSLN is not trapped during the manipulations of the surgeon. After dividing the superior thyroid vessels, we stimulated EBSLN with a probe cranially to the division point of the vessels to confirm the integrity of EBSLN.

Evaluation of Vocal Cord Function

Patients underwent a routine pre- and postoperative (within 2 days) direct laryngoscopy, directed by an independent laryngol-

Table 1. Demographic profile, indications, and types of surgery

Variable	n
Gender (Female/Male)	103/23
Mean age (year±SD)	46.2±12.2
Range	(18-75)
Preoperative diagnosis	
Benign thyroid disease	83
euthyroid	65
hyperthyroid	18
Suspicious malignancy	21
Malignant	22
Procedure	
Bilateral approach	
TT	70
TT+CLND	15
TT+CLND+LND	4
Unilateral approach	
Lobectomy	37
EBSLNs at risk	215
RLNs at risk	215
SD: standard deviation; TT: total thyroidectomy; CLND: central lymph node dissection; LD: lateral dissection; RLN: recurrent laryngeal nerve; EBSLN: external branch of the superior laryngeal nerve	

Table 2. The distribution of EBSLN identification methods

EBSLN identification methods	n (%)
Visual identification	
Direct visual identification	60 (27.9)
Visualization after identification with probe	89 (41.4)
Not visualized	
Identification with probe, (functional identification)	52 (24.1)
Total identification	201 (93.5)
Not identified	14 (6.5)
Total EBSLN at risk	(93.5)
EBSLN paresis (temporary)	3 (1.5)
EBSLN: external branch of the superior laryngeal nerve	

ogist. RLN palsy was determined to be permanent when there was no evidence of recovery within 6 months after the surgery.

The visual identification rate of EBSLN and IONM's contribution to the visual and functional identification of EBSLN were evaluated.

Statistical Analyses

The incidence of nerve events was calculated based on the number of nerves at risk. Differences between continuous and categorical variables were assessed by the Mann-Whitney U

test and Fisher's exact test or chi-square test, respectively. A value of $p < 0.05$ was considered to be statistically significant.

RESULTS

The study includes the data of 126 patients. Demographic characteristics, indication for surgery, and types of surgical procedures performed are presented in Table 1.

The methods used for EBSLN identification are described in Table 2. Two hundred and one (93.5%) of 215 EBSLNs were identified, but 14 (6.5%) EBSLNs were not able to be identified with IONM. Sixty (27.9%) EBSLNs were visually identified before being stimulated with a monopolar stimulator probe. Eighty-nine (41.4%) EBSLNs were visually identified after being stimulated with a probe. Although 52 (24.1%) EBSLNs were identified with a probe, they were not visualized. The IONM provided a significant contribution to visual ($p < 0.001$) and functional ($p < 0.001$) identification of EBSLN.

Additionally, positive electromyographic responses were recorded from 160 EBSLNs (74.4%). The amplitudes of the electromyographic waveforms obtained from RLNs and EBSLNs were $865 \pm 607 \mu\text{V}$ (range, 311-2770) (Figure 1a) and $181 \pm 92 \mu\text{V}$ (range, 100-392) (Figure 1b), respectively, with a significant difference when compared with each other ($p < 0.001$). However, no CTM twitch was observed via stimulating the proximal parts of the three (1.5%) of 201 EBSLNs, although they were visually intact at the end of the surgery (Table 2). Voice changes were detected in three patients with identified EBSLNs, who had loss of signal on the proximal parts of EBSLNs at the end of their operations. Voice complaints of these three patients, such as inability to produce high-pitched sounds and vocal fatigue at the end of the day, improved within 4 months. There was no vocal cord paralysis in these patients.

All the vocal cord paralyse detected were unilateral. 11 (5.1%) temporary and 1 (0.5%) permanent RLN paralyse (RLNP) were detected.

DISCUSSION

External branch of the superior laryngeal nerve is in close relation with the superior thyroid vessels, causing it to be at risk during thyroid surgery. Various anatomical classification systems for EBSLN have been proposed including the Cernea, Friedman, and Kierner classifications (5). Cernea classification describes EBSLN to have three types with regard to its relation with superior thyroid vessels and superior thyroid pole. Type 1 EBSLN crosses the superior thyroid vessels more than 1 cm from the upper edge of the superior pole, while Type 2A nerve crosses the vessels less than 1 cm above the upper edge of the superior pole. Type 2B nerve crosses the superior thyroid vessels below the upper edge of the superior thyroid pole. This classification is the most widely accepted one that is based on the potential risk of injury to EBSLN during thyroid surgery (16). The rate of EBSLNs according to the Cernea classification has been reported in studies with results varying from 17% to 60% for Type 1, 17% to 59% for Type 2A, and 10% to 56% for Type 2B (4, 8, 9, 17, 18). The different results may be due to various factors such as, the race of the individual, height of the individual, weight of the thyroid gland, identification type of EBSLN (visually or with the use of IONM), and the extension of the study. Both Type 2A and 2B, but mostly Type 2B, EBSLNs

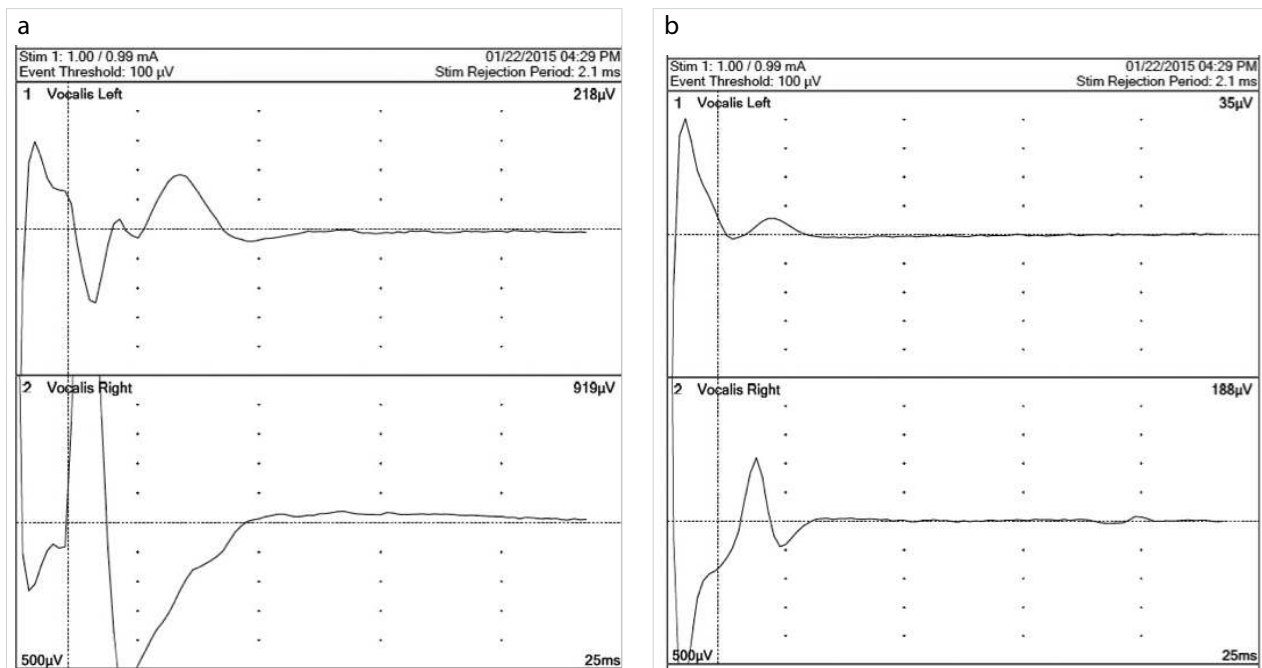


Figure 1. a, b. (a) The electromyographic waveform, with an amplitude of 919 µV, recorded from the right vocal cord via right RLN stimulation at the end of lobectomy. (b) The electromyographic waveform, with an amplitude of 188 µV, recorded from the right vocal cord via right EBSLN stimulation in the same patient

are at an increased risk of injury due to their close course to the superior thyroid vessels (4, 5).

Physical and functional preservation of EBSLN is as important as that of RLN and parathyroid glands for a safe thyroid surgery. Although the visual identification of RLN is accepted to be the gold standard to avoid injury, there is still no standard technique to preserve EBSLN and no consensus on the surgical protocol for EBSLN identification (19). Three techniques have been described to avoid EBSLN injury during the superior pole dissection. The first technique is the peripheral ligation of the individual branches of the superior thyroid vessels just on the thyroid capsule. The second technique is the visual nerve identification before ligating the vessels. The last one is the identification of the nerve with either a nerve stimulator or IONM before ligating the superior thyroid pole vessels (4, 5, 10, 20).

Some surgeons' expression that "I avoid injuring EBSLN by presuming where it should be, but I have never seen it" is not an appropriate approach for modern surgical principles. The fundamental principle of any surgery is the identification of a structure to avoid injuring it (21). Although nearly all RLNs can be visually identified, approximately 20% of the EBSLNs can not be visually identified due to their subfascial/intramuscular course into inferior constrictor muscle, which makes it necessary to conduct a microdissection for the identification of the nerve (22). Similarly, 25.2% of all the EBSLNs were identified with IONM, but all of them were not able to be visualized in the present study. In the present study, the visual identification rate of EBSLNs before being stimulated with a probe was only 27.9%, which was lower than the rate of 33%-93% reported in other studies (2, 10, 11, 17, 20). In our opinion, the reason for this low rate is that we did not divide the strap muscles to expose the sternothyroid-laryngeal triangle, except only in the patients with enlarged thyroid lobes

and a short neck. EBSLN identification rate was 34.1% in another study similar to ours in which the sternothyroid muscles were not divided, but the rate was high as 80%-88% in other studies where the sternothyroid muscles were divided to improve visual control of EBSLN (8-10, 17). However, the visual identification rate of EBSLN increased to 68.3% with the aid of IONM, which is close to the rates reported in the studies that included the routine division of strap muscles during superior pole dissection. In this study, the functional identification rate of EBSLN with IONM was noted to be 93.5%, which is threefold of the visual identification rate and in accordance with the rate of 83%-100% reported in other studies (2, 8, 10, 11, 15, 23). We demonstrated that IONM provided a meaningful contribution to visual ($p<0.001$) and functional ($p<0.001$) identification of EBSLN. Additionally, it is also important to verify the visually identified structure by IONM because non-neural fibers or tendinous fibers of regional muscles can be confused for EBSLN (23). It is not always possible to identify EBSLN even for experienced thyroid surgeons. EBSLN is very fine, about 0.8 mm in diameter, and often invisible because of its course through the pharyngeal constrictor muscle (2). In cases in which surgeons cannot identify EBSLN, they can only assume that it is not injured with ligation of small portions of superior thyroid vessels (2). The widespread use of thermal sealing devices is another threatening factor for the preservation of the nerve (24). EBSLN's course can be only affirmed with the use of IONM (5, 10, 22).

The amplitude of the electromyographic waveform defined the adductor motor function of the vocal cords, whose main adductor is the thyroarytenoid muscle. In addition to the observed CTM twitch, electromyographic data could be achieved with EBSLN stimulation via the use of standard monitoring tubes in 70%-80% of cases (10, 25, 26). The distant most fibers of EBSLN penetrate the two heads of CTM extend-

ing to the anterior portion of the thyroarytenoid muscle and connect with RLN. This connection has been described as the “human communicating nerve” and is known to contribute to the motor innervation of the thyroarytenoid muscle (25, 27). The mean amplitude of EBSLN stimulation was significantly lower than that of RLN (10, 15, 25). Similar to these previous studies, we also achieved electromyographic responses from 74.4% of EBSLNs identified by IONM and the mean amplitude was $181 \pm 92 \mu\text{V}$, which is lower than that of RLN ($865 \pm 607 \mu\text{V}$). Darr et al. (15) could find all EBSLNs and obtained recognizable electromyographic responses in 100% of cases via the use of a novel endotracheal tube having electrodes with an extended surface area, in their prospective study. They found that the electromyographic responses from the vocal cords had a great variability and tube position might influence the electromyographic waveform amplitudes. The mean electromyographic amplitudes were found to be similar between genders. Multiple nerve stimulations and extensive dissection did not affect EBSLN amplitude (15).

The reported prevalence of EBSLN injury alters widely from 0% to 58% (4, 6, 8, 10, 28). It is difficult to evaluate the actual prevalence due to the limited data, difficulty of quantifying EBSLN function, and differences in diagnostic techniques in various studies. CTM electromyography is the only definitive way to detect EBSLN injury because of the variability in vocal symptoms and findings at the postoperative laryngeal examination (5). Electromyography of CTM is too invasive to perform routinely and can be difficult to comment on secondary to variability in electromyographic needle placement. It is, therefore, very important to confirm that EBSLN is preserved during thyroidectomy by IONM (2).

Limitations of the Study

The present study has several limitations. First, the study is a retrospective one, although the data were collected prospectively. The patients without vocal cord paralysis and loss of signal in EBSLNs did not have voice change complaints. All three patients with identified EBSLNs via IONM had loss of signal on the proximal parts of EBSLNs after the dissection, supporting the fact that the voice change complaints were due to EBSLN injury. The voice change complaints of the patients were all temporary. However, one of the major limitations is that we could not evaluate the exact prevalence of EBSLN injuries in the patients postoperatively by electromyography. It is not a practical method to apply to all the patients who undergo thyroidectomies.

CONCLUSION

As a conclusion, IONM provides a significant contribution to the preservation of EBSLN by improving both the visual and functional identification of it. We think that EBSLN risk is unpredictable and IONM should be used in the superior pole dissection routinely. Although EBSLN's main function is to innervate CTM, it also contributes to the vocal cord's adductor function due to the presence of communicating nerves between RLN and EBSLN. Thus, glottis electromyographic response obtained with EBSLN stimulation provides quantifiable information in addition to the simple visualization of CTM twitch.

Ethics Committee Approval: Ethics committee approval was received for this study from the ethics committee of Şişli Hamidiye Etfal Training and Research Hospital.

Informed Consent: Written informed consent was obtained from patients who participated in this study.

Peer-review: Externally peer-reviewed.

Author Contributions: Concept - N.A., M.U.; Design - N.A.; Supervision - M.U., A.İ.; Resource - N.A., M.U.; Materials - N.A.; Data Collection and/or Processing - N.A.; Analysis and/or Interpretation - N.A., M.U.; Literature Search - N.A., M.U.; Writing Manuscript - N.A., M.U.; Critical Reviews - M.U., A.İ.;

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