HHS Public Access

Author manuscript

*JAMA Otolaryngol Head Neck Surg*. Author manuscript; available in PMC 2015 October 08.

Published in final edited form as:

*JAMA Otolaryngol Head Neck Surg*. 2014 February ; 140(2): 124–128. doi:10.1001/jamaoto.2013.6139.

# Correlation of Final Evoked Potential Amplitudes on Intraoperative Electromyography of the Recurrent Laryngeal Nerve With Immediate Postoperative Vocal Fold Function After Thyroid and Parathyroid Surgery

**Dane J. Genther, MD**, **Emad H. Kandil, MD**, **Salem I. Noureldine, MD**, and **Ralph P. Tufano, MD, MBA**

Department of Otolaryngology–Head and Neck Surgery, Johns Hopkins University School of Medicine, Baltimore, Maryland (Genther, Noureldine, Tufano); Department of Surgery, Tulane University School of Medicine, New Orleans, Louisiana (Kandil)

## Abstract

**IMPORTANCE—**Thyroid and parathyroid surgery are among the most common operations in the United States. Recurrent laryngeal nerve (RLN) injury is an infrequent but potentially detrimental complication.

**OBJECTIVE—**To correlate the final evoked potential amplitudes on intraoperative electromyography (EMG) after stimulation of the RLN with immediate postoperative vocal fold function after thyroid and parathyroid surgery.

**DESIGN, SETTING, AND PARTICIPANTS—**Retrospective observational study at a tertiary academic medical center. We included 674 patients (with 1000 nerves at risk) undergoing thyroid or parathyroid surgery from July 1, 2008, through June 30, 2012.

**INTERVENTIONS—**Thyroid and parathyroid surgery.

**MAIN OUTCOMES AND MEASURES—**The association of final evoked potential amplitudes on EMG after thyroid and parathyroid surgery with vocal fold function as determined by postoperative fiberoptic laryngoscopy.

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**Corresponding Author:** Ralph P. Tufano, MD, MBA, Department of Otolaryngology–Head and Neck Surgery, Johns Hopkins University School of Medicine, 601 N Caroline St, Ste 6242, Baltimore, MD 21287 (rtufano@jhmi.edu).

**Author Contributions:** Drs Genther and Tufano had full access to all the data in the study and take responsibility for the integrity of the data and the accuracy of the data analysis.
*Study concept and design*: Genther, Kandil, Tufano.
*Acquisition of data*: Genther, Noureldine, Tufano.
*Analysis and interpretation of data*: Genther, Kandil, Tufano.
*Drafting of the manuscript*: Genther, Tufano.
*Critical revision of the manuscript for important intellectual content*: All authors.
*Statistical analysis*: Genther.
*Administrative, technical, and material support*: Tufano.
*Study supervision*: Kandil, Tufano.

**Conflict of Interest Disclosures:** No other disclosures were reported.

**Previous Presentation:** This study was presented orally at the Eighth International Conference on Head and Neck Cancer; July 24, 2012; Toronto, Ontario, Canada.

**RESULTS—**Three patients experienced permanent vocal fold paresis (VFP) secondary to intraoperative RLN transection. Of the remaining 997 RLNs at risk, 22 (2.2%) in 20 patients exhibited temporary VFP on fiberoptic laryngoscopy after extubation. Eighteen patients experienced unilateral temporary VFP, and 2 experienced bilateral VFP without the need for tracheostomy or reintubation. Of the 22 RLNs, postdissection EMG amplitudes were less than 200 μV (true-positive findings) in 21 and at least 200 μV (false-negative finding) in 1. Of the 975 RLNs (97.5%) with normal function, postdissection EMG amplitudes were at least 200 μV (true-negative findings) in 967 and less than 200 μV (false-positive findings) in 8. In regard to immediate postoperative VFP, sensitivity, specificity, positive and negative predictive values, and accuracy of postdissection EMG amplitudes of less than 200 μV were 95.5%, 99.2%, 72.4%, 99.9%, and 99.1%, respectively.

**CONCLUSIONS AND RELEVANCE—**Intraoperative nerve monitoring of the RLN with EMG provides real-time information regarding neurophysiologic function of the RLN and can predict immediate postoperative VFP reliably when a cutoff of 200 μV is used. The high negative predictive value means that the surgeon can presume with confidence that the RLN has not been injured in the presence of a potential of at least 200 μV. This information would be useful in patients for whom bilateral thyroid surgery is being considered.

Recurrent laryngeal nerve (RLN) injury resulting in vocal fold paresis (VFP) is an infrequent but potentially detrimental complication of thyroid and parathyroid surgery. This complication can be particularly devastating in the case of bilateral VFP, which can cause significant airway compromise, possibly requiring tracheostomy or reintubation. A recently published systematic review reported mean incidences of temporary VFP of 9.8% and permanent VFP of 2.3% after thyroid surgery, with reported values of VFP (temporary or permanent) ranging from 2.3% to 26%.[1] The current criterion standard for RLN identification and protection intraoperatively is direct visualization because this method has been shown to result in a lower rate of RLN injury compared with neural avoidance alone.[2,3] In recent years, intraoperative monitoring of the RLN has gained acceptance as a useful adjunct during thyroid and parathyroid surgery, with approximately 40% to 45% of endocrine surgeons using this technology in all or some cases.[4,5] However, the ability of intraoperative nerve monitoring (IONM) to reduce RLN injury compared with direct visualization alone lacks sufficient evidence because reports have demonstrated inconsistent findings.[2]

The true incidence of temporary and permanent postoperative VFP may be underestimated if a routine laryngeal examination is not performed. Studies have demonstrated that symptomatic voice assessment alone is insufficient to identify vocal fold dysfunction.[6,7] In accordance with these findings, a preoperative laryngeal examination is necessary to determine the presence of preexisting VFP.[2,6] However, intraoperative examination of the larynx as a mechanism to determine RLN function is typically not possible owing to the presence of the endotracheal tube between the vocal folds and the condition of general anesthesia. A reliable modality to detect RLN injury intraoperatively would afford the surgeon real-time information that could help to guide surgical technique and planning, particularly in the case of bilateral thyroid surgery, when a risk of bilateral VFP exists. One potential IONM modality is electromyography (EMG), which has the potential to offer real-time neurophysiologic information regarding function of the RLN and ipsilateral vocal fold at the conclusion of the ipsilateral procedure. Therefore, we undertook the present study to correlate the final evoked potential on EMG with immediate postoperative vocal fold function as determined by postoperative flexible fiberoptic laryngoscopy after thyroid and parathyroid surgery.

## Methods

We retrospectively collected data from a series of consecutive patients who underwent total thyroidectomy, thyroid lobectomy, parathyroidectomy, and/or central neck reoperation in which an RLN was at risk. All operations were performed by one of us (R.P.T.) from July 1, 2008, through June 30, 2012, at a tertiary academic medical center. Some parathyroid surgical procedures that involved only removal of an inferior parathyroid adenoma and did not involve identification of the RLN were excluded from this study. Each patient underwent preoperative and postoperative flexible fiberoptic laryngoscopy to evaluate vocal fold function. Patients with preoperative vocal fold dysfunction were excluded from the study. Approval for this study was obtained from the institutional review board of Johns Hopkins University School of Medicine, and informed consent was waived.

Intraoperative monitoring of the RLN was performed in all cases using a commercially available nerve monitoring system (NIM 2.0 or 3.0; Medtronic Inc). The patient underwent intubation using an endotracheal tube (part of the monitoring system) by the anesthesia provider with placement of the surface electrodes between the vocal cords under direct visualization. No long-acting muscle relaxants were used during the intubation, and no muscle relaxants of any kind were used at any other time during the procedure. The ground leads were placed on the patient's shoulder. After patient positioning, tube position was verified by the surgical team through evaluation of the impedances of the paired electrodes, with a difference of no greater than 0.3 kilohms being acceptable. On the nerve monitor, the stimulation current was set to 1 mA, and the EMG threshold was set to 100 μV.

The RLN was identified by direct visualization. On completion of the dissection on the side of the nerve at risk, the RLN was stimulated at 1 mA, and the EMG amplitude was recorded as an integer value in microvolts. If the surgery was bilateral, the same protocol was followed on the second side. The patient was then extubated, and flexible fiberoptic laryngoscopy was performed in the operating room by the surgical team to evaluate vocal fold function. Any vocal fold weakness or asymmetry of motion was considered an abnormal (positive) finding. Patients with postoperative weakness were followed up regularly in the outpatient clinic to evaluate for recovery of function.

Preanalysis data exploration revealed a natural break in the data at 200 μV regarding VFP. Therefore, this value was used as the cutoff for evaluating IONM as a test of intraoperative vocal fold function. On IONM, a postdissection evoked potential of at least 200 μV was considered normal (negative test result), and a value of less than 200μV was considered abnormal (positive test result). Prevalence and test statistics with 95% confidence intervals were calculated using commercially available software (STATA, version 11; StataCorp).

## Results

The study group consisted of 674 patients with a total of 1000 nerves at risk. Ages ranged from 18 to 94 years, with a mean age of 51.2 years. Female patients constituted 72.0% of the study population. A summary of the operations and corresponding RLNs at risk is shown in the Table. Of the 1000 RLNs at risk, 3 (0.3%) were transected intraoperatively and repaired with primary anastomosis. The remaining 997 RLNs were visually intact intraoperatively and were included in the statistical analysis.

Of these 997 RLNs at risk, 22 (2.2% [95% CI, 1.4%–3.3%]) in 20 patients exhibited temporary VFP on flexible fiberoptic laryngoscopy performed after extubation. Eighteen of the 20 patients experienced unilateral temporary VFP, and 2, bilateral VFP. The 2 patients with bilateral vocal fold weakness did not require tracheostomy or reintubation. Of the 22 nerves in these patients, postdissection EMG amplitudes were less than 200 μV (true-positive findings) in 21 and at least 200 μV (false-negative finding) in 1. Of the 975 RLNs with normal postoperative function (97.5%), postdissection EMG amplitudes were at least 200 μV (true-negative findings) in 967 and less than 200 μV (false-positive findings) in 8. In total, 29 of 997 RLNs had abnormal EMG amplitudes, and 968 of 997, normal amplitudes. The sensitivity, specificity, positive predictive value (PPV), negative predictive value (NPV), and accuracy for postdissection EMG amplitude of less than 200 μV regarding prediction of VFP were 95.5% (95% CI, 77.2%–99.9%), 99.2% (98.4%–99.6%), 72.4% (52.8%–87.3%), 99.9% (99.4% to >99.9%), and 99.1% (98.3%–99.6%), respectively.

For those patients with temporary VFP, time to recovery of vocal fold function ranged from 2 to 67 days and was confirmed by in-office flexible fiberoptic laryngoscopy. The operations for the 20 patients with temporary VFP included 1 reoperative parathyroidectomy, 1 central neck reoperation, and 18 total thyroidectomies (14 for differentiated thyroid carcinoma) (Table). In the temporary VFP group, 16 RLNs were at risk during operations for malignant neoplasms, and 6 RLNs were at risk during operations for benign disease. No significant difference was found between the VFP group and the group with normal postoperative vocal fold function with regard to the proportion of malignant neoplasms ($P$ = .18). Therefore, in our study population, malignant disease did not appear to be associated with temporary postoperative VFP. The patient with temporary VFP and a normal postdissection EMG amplitude (600 μV) underwent a central neck reoperation, with the primary operation being performed at an outside hospital.

Three patients had permanent postoperative unilateral VFP as a result of RLN transection (not included in the statistical analysis). Their operations included 1 total thyroidectomy for a substernal goiter, 1 total thyroidectomy for papillary thyroid carcinoma with severe Hashimoto thyroiditis, and 1 thyroid lobectomy for a cytologically indeterminate nodule (postoperative pathological findings were benign).

## Discussion

Intraoperative nerve monitoring with EMG can afford the surgeon real-time information regarding neurophysiologic function of the RLN and a reliable prediction of immediate postoperative VFP, as demonstrated in the present study by an accuracy of 99.1% when a cutoff of 200 μV was used. The high NPV of 99.9% means that the surgeon can be confident that RLN injury has not occurred in the presence of a signal of at least 200 μV given that only 1 of the 968 patients with postdissection EMG amplitudes of at least 200 μV experienced temporary VFP. This information would be especially useful for cases in which bilateral thyroid surgery is being considered.

In the case of an abnormal EMG signal, the ability of IONM to predict postoperative VFP is less robust, with a PPV of 72.4%. Unfortunately, without a truly perfect test, a higher PPV is nearly unattainable given the very low incidence of temporary VFP (2.2%) in our population. However, if an abnormal signal is attained after dissection of the RLN, the chance of some degree of VFP is greater than 7 of 10 procedures. In this situation, the surgeon can reevaluate the extent of surgery on the second side and consider electing for a 2-stage procedure, depending of the nature of the operation.

We identified 7 previous peer-reviewed reports in the literature[3,8–13] examining the utility of IONM as a predictor of postoperative VFP and compared their results with ours. These studies used the following 2 intraoperative methods to test the integrity of the RLN: (1) manual palpation of posterior cricoarytenoid muscle contraction on RLN stimulation, and (2) vocal fold electrodes (surface electrodes on the endotracheal tube or needle electrodes placed into the vocalis muscle through the cricothyroid membrane). The vocal fold electrodes used audio response, visual EMG response, or both.[9–13] All 7 studies routinely examined patients by laryngoscopy within 1 week of surgery and reported rates of temporary VFP of 1.5% to 8.9%, with a mean of 5.0%. The 2 studies evaluating the RLN through intraoperative posterior cricoarytenoid muscle palpation[3,8] reported ranges for sensitivity of 69% to 75%, specificity of 92% to 99%, PPV of 33% to 92%, and NPV of 98%. The 5 studies using vocal fold electrodes[9–13] reported ranges for sensitivity of 40% to 100%, specificity of 94% to 98%, PPV of 11% to 62%, and NPV of 97% to 100%. These results are comparable to those of our study; however, direct comparison is difficult owing to the inconsistent methods across the studies. To our knowledge, our study is the first to examine the prognostic ability of IONM with regard to a specific EMG amplitude, which was 200 μV in the present study.

Our results demonstrate that IONM can predict immediate postoperative vocal fold function reliably when performed by an experienced and protocol-driven surgical team. A protocol must be followed to minimize technical issues that can lead to false-positive EMG signals. Our IONM protocol pays particular attention to optimal endotracheal tube and patient positioning to ensure adequate contact of the surface electrodes with the vocal cords bilaterally, careful anchoring of the endotracheal tube at the lips to prevent movement of the tube, definitive assurance of equipment function before commencement of the operation, and clear communication between the surgical team and anesthesia providers to eliminate any medications that may interfere with the EMG signal. The various mechanisms of technical failures are beyond the scope of this report, but a comprehensive review of this topic by Randolph et al[2] is available.

In our experience, this prognostic information afforded by IONM can be used in 3 significant ways. Intraoperatively, repeated stimulation of the RLN during dissection can provide real-time feedback on surgical technique.[14] This finding is particularly true when retracting the thyroid, which can lead to stretch injury, or when dissecting near the insertion of the RLN into the larynx, which is a common site of injury.[15] A second intraoperative use is guidance of the extent of surgery on the second side. Given the high NPV (99.9%) of IONM in the present study, if a normal signal (≥200 μV) is obtained after dissection of the RLN on the first side, the surgeon can presume with confidence that the nerve is functioning normally, and surgery on the second side can proceed as planned in the case of a bilateral operation. In the case of an abnormal signal (<200 μV) after dissection of the RLN on the first side, the chance that the patient will experience ipsilateral VFP exceeds 70%. In this case, the surgeon can scale back the extent of surgery on the second side or elect for a 2-stage operation to minimize the chance of bilateral VFP.[16] In addition, the prognostic information can be used to counsel patients and family members regarding recovery of vocal fold function.

A key limitation of the present study is the retrospective collection of the data; therefore, the study lacks the methodological rigor of a prospective analysis. Also, our IONM protocol, although consistent, was not formally standardized, and there was no formal algorithm for how to proceed with the operation in response to an abnormal EMG amplitude (<200 μV) after RLN dissection. In addition, our evaluation of postoperative vocal fold function occurred immediately after extubation; therefore, we were unable to reliably monitor for delayed weakness that may have occurred in the hours to days after surgery. However, the present study also has multiple strengths that support our findings. All operations were performed by a single experienced surgeon who followed a protocol for setup and use of the IONM system that did not deviate during the study period. Also, all data on EMG amplitudes and vocal fold function were personally recorded in the medical record by the surgeon (R.P.T.) at the time of the operation. Furthermore, the series of patients included in the present study is consecutive, limiting possible selection bias, and the patient population included all surgical patients in whom an RLN was at risk during the specified period regardless of the disease process or previous operations, making our findings generalizable to a population treated at a tertiary medical center.

## Conclusions

Postdissection evoked EMG amplitudes on intraoperative monitoring of the RLN can reliably predict immediate postoperative vocal fold function in patients undergoing thyroid and parathyroid surgery. However, a protocol to minimize false readings must be developed and followed. The information regarding neurophysiologic function of the RLN afforded by IONM can give real-time feedback on surgical technique, provide the surgeon with additional information to guide the extent of surgery on the second side, and aid in the postoperative counseling of patients. To our knowledge, this report is the first to demonstrate the prognostic value of a specific postdissection EMG amplitude (200 μV) in the determination of postoperative VFP.

## Acknowledgments

Dr Tufano serves as a consultant for Ethicon Endosurgery and Medtronic.

**Funding/Support:** This study was supported by grant T32DC000027-24 from the National Institutes of Health.

**Role of the Sponsor:** The funding source had no role in the design and conduct of the study; collection, management, analysis, or interpretation of the data; preparation, review, or approval of the manuscript; and decision to submit the manuscript for publication.

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## Table

Procedures Performed and Corresponding Number of RLNs at Risk

| Procedure | No. of Procedures | No. of RLNs at Risk |
|---|---|---|
| Total thyroidectomy | 323[a] | 639 |
| Thyroid lobectomy | 193 | 193 |
| Parathyroidectomy | 90 | 90 |
| Central neck reoperation | 68 | 78 |
| **All** | **674** | **1000** |

Abbreviation: RLNs, recurrent laryngeal nerves.

[a]Includes 143 operations for differentiated thyroid carcinoma or medullary thyroid cancer.