Optimal Stimulation During Monitored Thyroid Surgery: EMG Response Characteristics in a Porcine Model

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**Objectives:** To compare electromyography (EMG) characteristics of the external branch of superior laryngeal nerve (EBSLN), recurrent laryngeal nerve (RLN), and vagus nerve (VN) evoked with different stimulation probes/dissectors during monitored thyroid surgery.

**Study Design:** Experimental porcine model.

**Methods:** In five piglets (10 EBSLN/RLNs/VNs), laryngeal EMG was recorded by endotracheal tube surface electrodes with stimulation using five monopolar probes (group I), three bipolar probes (group II), and two stimulation dissectors (group III). The detectable EMG response (DER) was defined as > 100 μV and was obtained with these different probes/dissectors. Electromyography parameters, stimulus-response curve, and distance-sensitivity results were compared.

**Results:** All stimulation probes/dissectors evoked typical EMG waveforms from the EBSLN/RLN/VN with 1 mA current. A stimulus-response curve with increasing EMG amplitude with increase in stimulating current was noted, with the maximum EMG elicited by group I/III probes/dissectors at < 1 mA and at a higher current for group II probes. All groups recorded lower evoked EMG amplitudes when the nerve was stimulated with overlying fascia or when probe/dissector to nerve distance was greater. The mean amplitude decreased by 11%/33%/13% in group I/II/III probes/dissectors when stimulating nerves covered by fascia versus nerves dissected free of overlying fascia. The rate of obtaining DER at 1- or 2-mm distance was significantly higher in group I than in group II/III probes/dissectors (P < 0.001). Latency did not change with any of the stimulation probes/dissectors or trials.

**Conclusion:** Monopolar, bipolar probes, and newer stimulation dissectors all provided valid evoked VN/RLN/EBSLN waveforms. They have different functional sensitivity profiles and vary when stimulating with fascia and at a distance from the nerve. Selection of a stimulation probe/dissector for nerve monitoring can be based on the stimulation characteristics, the intended nerve monitoring application, and the surgeon’s preference.

**Key Words:** Intraoperative neural monitoring (IONM), thyroid and parathyroid surgery, external branch of superior laryngeal nerve (EBSLN), recurrent laryngeal nerve (RLN), vagus nerve (VN), monopolar probes, bipolar probes, stimulation dissectors.

**Level of Evidence:** N/A.

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**INTRODUCTION**

Injury to recurrent laryngeal nerve (RLN) remains a significant source of morbidity during thyroid operations. Thyroidectomy is not without its laryngeal consequences; a recent analysis of 27 articles reviewing over 25,000 patients undergoing thyroidectomy found that the average postoperative vocal cord paralysis (VCP) rate was 9.8% (range 0–18.6%).

Intraoperative neural monitoring (IONM) during thyroid and parathyroid surgery has gained widespread acceptance as an adjunct to the gold standard of visual nerve identification of RLN. It facilitates functional preservation of external branch superior laryngeal nerve (EBSLN), detects anatomic variations and nerve injury, elucidates mechanism of injury, and is also helpful in intraoperative prediction of the postoperative vocal cord function. Recent surveys suggest that 53% of general surgeons and up to 65% of otalaryngologists in the United States are currently employing neural monitoring (IONM) in some or all of their cases. German surgical departments report that more than 92% of surgeons routinely utilize IONM during thyroidectomy.
Organizational support for IONM is gradually increasing.\textsuperscript{2,14} The American Head and Neck Society, American Thyroid Association, and many other organizations recommend IONM in selective circumstances.\textsuperscript{15–17}

During IONM, a stimulation probe is needed to depolarize the nerve to evoke the laryngeal electromyographic (EMG) response.\textsuperscript{9} The EMG magnitude may be correlated with the number of muscle fibers participating in the depolarization, which in turn relates to RLN function.\textsuperscript{2,18} If evoked EMG response at the end of surgery is similar to the initial EMG, normal RLN function and postoperative normal vocal cord function may be predicted. If intraoperatively RLN is severely injured, nerve fibers would not transmit action potentials, and partial or complete loss of the EMG signal (LOS) would occur. True complete LOS at the end of operation is highly related to postoperative VCP. Staged thyroidectomy has been recommended in patients with LOS during planned bilateral thyroid operation to avoid bilateral VCP.\textsuperscript{2,19,20} Several studies have reported that vagus nerve (VN) stimulation improves the accuracy of IONM results and have recommended it as a routine procedure during monitored thyroid surgery.\textsuperscript{2,7,10,21,22}

Several stimulation probes have been are available for EBSLN, RLN, and VN stimulation. Recently, some prototypes of stimulation dissectors\textsuperscript{23} have been designed to provide dissection and stimulation in one instrument intraoperatively. There is little data on EMG comparisons of different stimulation probes/dissectors and their relative strengths or shortcomings. To optimize IONM utilization for prevention of VCP and EBSLN injury, a clear appreciation of normative electrophysiology parameters is required. Toward this end, an established porcine model and IONM system\textsuperscript{19,24–26} are used in this study to compare laryngeal EMG potentials evoked by stimulation of the EBSLN, RLNs, and VNPs with 10 different stimulation probes/dissectors.

**MATERIALS AND METHODS**

**Animal Preparation, Anesthesia, and Operation**

A porcine model was used to study the evoked EMG recorded from the laryngeal lumen, where the endotracheal tube surface electrodes lie in contact with the true and false vocal folds.\textsuperscript{18,24–26} Five Duroc–Landrace male pigs (weight 20–25 kg) were studied with approval from the Animal Care and Use Committee of Kaohsiung Medical University (Institutional Animal Care and Use Committee Approval No. 104106). The piglets were anesthetized with intravenous thiopental (15 mg/kg), and then a nerve integrity monitor (NIM) side by side (Fig. 2). Attention was paid to place the cathode (−) and anode (+) linearly oriented along the long axis of the nerve with the cathode distal (i.e., closer to the larynx and vocal cord) relative to the anode when applying these two bipolar probes. This does not apply to the Concentric bipolar probe (Medtronic Xomed, Inc Jacksonville FL) in which the cathode is the central electrode element and the anode is the outer electrode element. In this concentric bipolar design, the cathode is both distal and proximal to the anode element.

**Neural Stimulation Electrophysiologic Stimulus–Response Curves: Minimal and Maximal Stimulus Level.**

The EBSLN, RLN, and VN were initially stimulated with 0.1 mA current, which was increased by 0.1 mA increments until a detectable EMG response (DER) was recorded and defined as an evoked response with amplitude > 100 μV. The current was further increased until a maximal EMG response was obtained. The amplitude, latency, and waveform of the EMG response were recorded. The pulsed stimuli of 100 μs duration were repeated at 4 pulses/second (4 Hz). The current that first evoked a DER was defined as minimal stimulus level (mA), whereas the current that evoked maximal EMG response was defined as the maximal stimulus level (mA).

**Neural Distance Sensitivity and Fascia Testing With 1 mA.** Usually IONM is performed with 1 mA current; hence, we further tested and compared the 1 mA-evoked EMG responses for the EBSLN, RLN, and VN elicited by all of the study stimulation probes/dissectors under the following situations:

1. **Stimulation without overlaying fascia on nerve.** This situation mimics direct stimulation of more completely dissected nerves during the operation (Fig. 1C, D);
2. **Stimulation with overlaying fascia on nerve.** We first identified the path of the nerve and then performed the fascia-interposed tests when the nerves were visible through the fascia. Fascia was < 1-mm thick and did not preclude neural visual identification (Fig. 1B).
3. **Stimulation at distance away from nerve.** The distance was measured using a flexible plastic ruler marked in millimeters (Fig. 3). The tests began with direct nerve stimulation, and then the stimulator probes/dissectors were moved away at 1-mm increments until DER was not obtainable.

A bloodless surgical field was maintained, and use of electrocautery around the nerve was avoided. Electromyography data of the EBSLN, RLN, and VN evoked by all study stimulation probes/dissectors were compiled in Excel (Microsoft Corp., Redmond, WA). Statistical analyses were performed with SPSS (SPSS Inc, Chicago, IL). One-way analysis of variance with Bonferroni posttest was used, data were expressed as mean ± standard deviation, and a probability of $P < 0.05$ was considered statistically significant.
RESULTS

Neural Stimulation Electrophysiologic Stimulus-Response Curves: Minimal and Maximal Stimulus Levels

A positive correlation between the stimulation current and the resultant EMG amplitude was observed when testing all study stimulation probes/dissectors on the EBSLN/RLN/VN. For group I and III stimulation probes/dissectors, the magnitude of the EMG amplitudes quickly reached a plateau as the stimulation current was increased over the minimal stimulus level, and maximal EMG response was elicited with a stimulation current (maximal stimulus level) of less than 1 mA. For group II stimulation probes, the slopes of curves were reduced, requiring significantly higher stimulation current to achieve maximal EMG amplitudes (Fig. 4).

![Surgical approach and identification of the EBSLN, RLN, and VN. (A) Subplatysmal flaps were raised, and the strap muscles were separated from midline to wide expose the lateral neck. (B) The left EBSLN (cover with overlying fascia), (C) the left RLN, and (D) the left VN were localized and identified using a stimulation probe. EBSLN = external branch of superior laryngeal nerve; RLN = recurrent laryngeal nerve; VN = vagus nerve. [Color figure can be viewed in the online issue, which is available at www.laryngoscope.com.]

![Stimulation probes/dissectors testing array. (No. 1–5) group I monopolar probes: (1) Prass Slim, (2) Prass Standard, (3) Ball tip 1.0 mm, (4) Ball tip 2.3 mm, (5) Yingling ball tip 1–5, (Medtronic Xomed, Inc Jacksonville FL). (No. 6–8) group II bipolar probes: (6) Side-by-Side, (7) Concentric, (8) Prass Bipolar 6–8, (Medtronic Xomed, Inc Jacksonville FL). (No. 9,10) group III stimulation dissectors: (9) Stimulus hemostat (Prototype, Medtronic Xomed, Inc Jacksonville FL), (10) FVC instrument (Prototype2).]
The pooled mean minimal stimulus levels in group I/II/III stimulation probes/dissectors were 0.46/0.69/0.60 mA \( (P = 0.084) \) for EBSLN, 0.25/0.45/0.41 mA \( (P < 0.001) \) for RLN, and 0.26/0.51/0.43 mA \( (P < 0.001) \) for VN, respectively. The mean maximal stimulus levels in group I/II/III stimulation probes/dissectors were 0.78/1.22/0.81 mA \( (P = 0.078) \) for EBSLN, 0.56/2.02/0.79 mA \( (P < 0.001) \) for RLN, and 0.65/2.57/0.95 mA \( (P < 0.001) \) for VN, respectively. There is no significant difference between the mean maximum amplitude responses in group I/II/III stimulation probes/dissectors.

**Neural Distance Sensitivity and Fascia Testing With 1 mA**

**Stimulation Without Overlying Fascia on Nerve.** All 10 stimulation probes/dissectors evoked typical EMG waveforms with direct stimulation of the EBSLN, RLN, and VN with 1 mA current (Table I). The unique SLN, RLN, and VN latencies are characteristic of the individual nerve (Fig. 5). Mean latency was 2.87 ms \( (\pm 1.23) \) for the EBSLN, 2.90 ms \( (\pm 0.47) \) for the RLN, 4.71 ms \( (\pm 0.34) \) for the right VN, and 7.90 \( (\pm 0.91) \) for the left VN. Mean EBSLN latency was statistically significantly shorter than mean RLN latency \( (P < 0.001) \); mean RLN latency was statistically significantly shorter than pooled \( (\text{i.e., left and right}) \) mean VN latency \( (P < 0.001) \). The mean right VN latency was also statistically significantly shorter than mean left VN latency \( (P < 0.001) \). However, comparisons of latency between group I/II/III stimulation probes/dissectors were not statistically significant for both of the EBSLN, RLN, right VN, and left VN (Fig. 6A).

Pooled mean amplitude was 432 \( \mu \text{V} \) \( (\pm 344.6) \) for the EBSLN, 979.7 \( \mu \text{V} \) \( (\pm 271.6) \) for the RLN, and 869.9 \( \mu \text{V} \) \( (\pm 279.2) \) for the VN. The mean RLN amplitude was statistically significantly greater than VN and EBSLN amplitudes \( (P < 0.001) \). Contralateral comparisons of amplitude for the right versus left EBSLN/RLN/VN were not statistically significant. Comparisons of amplitude between group I/II/III stimulation probes/dissectors were not statistically significant for the EBSLN \( (P = 0.34) \) and RLN \( (P = 0.30) \), but statistically significant for the VN \( (P = 0.04) \). For group II stimulation probes, the amplitudes from VN \( (741 \mu \text{V}) \) with 1 mA were lower than the amplitudes from group I stimulation probes \( (934 \mu \text{V}, P = 0.04) \) and group III stimulation dissectors \( (899 \mu \text{V}, P = 0.26) \) (Fig. 6B).

**Stimulation With Overlying Fascia on Nerve.** All 10 stimulation probes/dissectors evoked typical EMG waveforms when stimulating the EBSLN, RLN, and VN with overlying fascia with 1 mA current (Table I). Pooled mean amplitude was 346.3 \( \mu \text{V} \) \( (\pm 295.7) \) for the EBSLN, 822.6 \( \mu \text{V} \) \( (\pm 301.4) \) for RLN, and 729.4 \( \mu \text{V} \) \( (\pm 278.7) \) for VN. Evoked EMG amplitude decreased significantly when stimulating the nerve with overlying fascia as compared to the nerve free of fascial covering. The mean amplitude decreased by 11\% in group I, 33\% in group II, and 13\% in group III stimulation probes/dissectors in comparison with the EMG response from nerve dissected free of fascia (Fig. 7). Latency did not vary in any of the stimulation probes/dissectors with neural testing with or without overlying fascia \( (P = 0.95) \).

**Stimulation at Distance Away From Nerve (stepwise by 1-mm distance increments).** The rate of obtaining DER on neural distance testing with 1 mA is shown in Table I. In nerve comparisons, the mean DER rate with all stimulation probes/dissectors at 1 mm was 48\% on the EBSLN, 71\% on the RLN, and 58\% on the
VN—and at 2 mm was 11% on the EBSLN, 31% on the RLN, and 15% on the VN.

In stimulation probes/dissectors comparisons, the mean DER rate on all nerves for 1-mm distance was 85% for group I, 24% for group II, and 47% for group III—and for 2-mm distance was 35% for group I, 0% for group II, and 8% for group III stimulation probes/dissectors. For group II, Concentric (no.7) and Prass Bipolar (no.8) probes, direct test on the EBSLN and VN is needed to evoke the EMG response (Table I). The distance-sensitivity of DER at 1-mm or 2-mm distance was significantly higher in group I than in group II ($P < 0.001$) and group III ($P < 0.001$) stimulation probes/dissectors.

### Table I.

The Distance–Sensitivity of DER without or with Overlying Fascia on Nerve or at 1- or 2-mm Distance With 1 mA Stimulation Current.

<table>
<thead>
<tr>
<th>Stimulator Type</th>
<th>EBSLN* (n = 10)</th>
<th>RLN† (n = 10)</th>
<th>VN‡ (n = 10)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Group I monopolar probes</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1. Prass Slim</td>
<td>10/10/8/6</td>
<td>10/10/10/8</td>
<td>10/10/3/6</td>
</tr>
<tr>
<td>2. Prass Standard</td>
<td>10/10/8/1</td>
<td>10/10/10/7</td>
<td>10/10/5/1</td>
</tr>
<tr>
<td>3. Ball tip 1.0 mm</td>
<td>10/10/6/2</td>
<td>10/10/10/6</td>
<td>10/10/3/2</td>
</tr>
<tr>
<td>4. Ball tip 2.3 mm</td>
<td>10/10/5/0</td>
<td>10/10/9/1</td>
<td>10/10/7/0</td>
</tr>
<tr>
<td>5. Yingling ball tip</td>
<td>10/10/6/2</td>
<td>10/10/9/5</td>
<td>10/10/9/2</td>
</tr>
<tr>
<td>DER (%), mean§</td>
<td>100/100/66/22%</td>
<td>100/100/96/54%</td>
<td>100/100/94/28%</td>
</tr>
<tr>
<td><strong>Group II bipolar probes</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>6. Side-by-Side</td>
<td>10/10/8/0</td>
<td>10/10/7/0</td>
<td>10/10/2/0</td>
</tr>
<tr>
<td>7. Concentric</td>
<td>10/10/0/0</td>
<td>10/10/2/0</td>
<td>10/10/0/0</td>
</tr>
<tr>
<td>8. Prass Bipolar</td>
<td>10/10/0/0</td>
<td>10/10/2/0</td>
<td>10/10/0/0</td>
</tr>
<tr>
<td>DER (%), mean§</td>
<td>100/100/27/0%</td>
<td>100/100/37/0%</td>
<td>100/100/7/0%</td>
</tr>
<tr>
<td><strong>Group III stimulation dissectors</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>9. Stimulus hemostat</td>
<td>10/10/3/0</td>
<td>10/10/6/1</td>
<td>10/10/4/0</td>
</tr>
<tr>
<td>10. FYC instrument</td>
<td>10/10/4/0</td>
<td>10/10/6/3</td>
<td>10/10/5/1</td>
</tr>
<tr>
<td>DER (%), mean§</td>
<td>100/100/35/0%</td>
<td>100/100/60/20%</td>
<td>100/100/45/5%</td>
</tr>
</tbody>
</table>

* EBSLN: None of the nerves showed detectable EMG response (DER, defined as an evoked EMG amplitude > 100 μV) at 3- or 4-mm distance with all of the study stimulation probes or dissectors No. 1-9 (Medtronic Xomed, Inc Jacksonville FL), and No. 10 (Prototype23).
† RLN: DER at 3 mm was only observed in two nerves with no. 1 probe, one nerve with no. 2 probe, and one nerve with no. 10 probe. None of the nerves showed DER at 4-mm distance.
‡ VN: DER at 3 mm was only observed in one nerve with no. 1 probe. None of the nerves showed DER at 4-mm distance.
§ Mean DER rate on all nerves was 85% (decreased 15%) for group I probes, 24% (decreased 76%) for group II probes, and 47% (decreased 53%) for group III dissectors at 1-mm distance.

DER = detectable EMG response; EBSLN = external branch of superior laryngeal nerve; EMG = electromyography; RLN = recurrent laryngeal nerve, VN = vagus nerve; μV = microvolt; mA = milliamp.
DISCUSSION

Intraoperative RLN injury is a significant source of morbidity from thyroid surgery and is a leading cause for medicolegal litigation. Unilateral injury can lead to mild hoarseness or predisposition to aspiration, but stridor and acute airway obstruction might occur in bilateral injury. Intraoperative neural monitoring during thyroid and parathyroid surgery has gained widespread acceptance, and several recent guidelines have proposed IONM as an option for patients undergoing thyroid surgery. Intraoperative neural monitoring does not replace knowledge of surgical anatomy or excellent surgical technique but adds a new functional dynamic to surgery, empowering the surgeon beyond what is available to through visual information alone. The utility of IONM in the determination of postoperative nerve prognosis lies in our ability to determine when true partial or complete LOS has occurred relative to the initial normative stimulation data. Several conventional monopolar or bipolar probes or newer stimulation dissectors can be employed during IONM. For optimal utilization of nerve monitoring, a surgeon must therefore be familiar with electrophysiologic characteristics and normative EMG waveform information elicited by different stimulation probes/dissectors under different stimulation scenarios. An understanding of EMG characteristics and normative data will also improve thyroid surgeons' ability to predict pathologic neural states.

There is little data in the literature related to the comparison of EMG response of EBSLN, RLN, and VN evoked with different types of the stimulation probes/dissectors. This porcine model study presents normative data for EBSLN, RLN, and VN without overlying fascia. The error bars represent the standard deviation of the EMG amplitudes.

Fig. 6. Column graph of different evoked EMG (A) latencies (ms) and (B) amplitudes (\(\mu V\)) when stimulating with the group I/II/III probes/dissectors with 1 mA on the dissected EBSLN, RLN, and VN without overlying fascia. The error bars represent the standard deviation of the EMG amplitudes.

EBSLN = external branch of superior laryngeal nerve; EMG = electromyography; RLN = recurrent laryngeal nerve; VN = vagus nerve; \(\mu V\) = microvolt; mA = milliamp; ms = milliseconds. [Color figure can be viewed in the online issue, which is available at www.laryngoscope.com.]

Fig. 7. Column graph of evoked EMG amplitudes (\(\mu V\)) of the EBSLN, RLN, and VN when using 1 mA stimulation with the group I/II/III stimulation probes/dissectors with and without overlying fascia on nerve. The error bars represent the standard deviation of the EMG amplitudes.

EBSLN = external branch of superior laryngeal nerve; EMG = electromyography; RLN = recurrent laryngeal nerve; VN = vagus nerve; \(\mu V\) = microvolt; mA = milliamp. [Color figure can be viewed in the online issue, which is available at www.laryngoscope.com.]
group III dissectors (Fig. 4). In addition, we noted the minimal and maximal stimulus levels vary with different stimulation probes/dissectors. For group II, Concentric (no. 7) and Prass Bipolar (no. 8) probes, the minimal and maximal stimulus levels are significantly higher than others. Our previous study reports that 1 mA is a safe and stable intensity to evoke the maximal EMG during IONM with the group I Prass Slim probe in a porcine model.\(^\text{15}\) A recently published data by Faden et al.\(^\text{30}\) also indicates that stimulation threshold greatly affects the predictive value and concluded that a stimulation level of 0.5 mA optimizes the predictive value of IONM; however, the type of stimulation probe used for neural testing is not mentioned. The current study shows that surgeons should appreciate that the minimal/maximal stimulus levels, and thus the optimal stimulation level, may vary with different types of the stimulation probes/dissectors. For group I monopolar probes or group III dissectors, the stimulation current between 0.5 mA to 1 mA can be selected as optimal level after nerve identification because it evokes a near-maximal or maximal, and therefore clear-cut, EMG response and is safely obtained. Stimulation at lower levels runs the risk of inadequate EMG response potentially misinforming the surgeon as to nerve identity. However, for Concentric and Prass Bipolar probes, the stimulation level higher than 1 mA is required to obtain a maximal EMG response, especially for RLN and VN stimulation (Fig. 4).

The present study also confirms that all stimulation probes/dissectors provide valid stimulation of the EBSLN, RLN, and VN with 1 mA stimulation current (Figs. 5 and 6). The EMG waveform, latency, and amplitude characteristics obtained by different stimulation probes/dissectors are comparable to the clinical normative electrophysiologic characteristics of the EBSLN, RLN, and VN data recently reported.\(^\text{31}\) Similarly, our study showed a statistically significant difference between the latency of left and right VN (Fig. 6A), which is likely due to their differing length.\(^\text{32}\) In ipsilateral comparisons, VN showed statistically significantly longer latency, allowing clear distinction from the RLN. In addition, our study also showed a decrease in EMG amplitude from vagal stimulation compared to RLN. This finding may be caused by longer travelling pathway and less synchrony in arrival of action potentials at the endplates from vagal stimulation.

The present study demonstrates the utility of IONM for identification of the EBSLN. These were successfully identified with detection of EMG response in 100% of cases with 1-mA stimulation current with all stimulation probes/dissectors (Table I). Our data verifies the data by Darr et al.\(^\text{33}\) that IONM can safely assist in 100% EBSLN identification, and the Tri-Vantage NIM tube (Medtronic-Xomed), with an increased circumferential electrode surface area, allows for 100% quantifiable EBSLN EMG activity. Analogous to the RLN waveform, the EBSLN exhibits a short latency after stimulation and is biphasic or triphasic in configuration (Figs. 5 and 6). Our normative amplitude data shows similar trends as previously reports.\(^\text{31,34}\) External branch of superior laryngeal nerve amplitudes are consistently smaller than ipsilateral VN and RLN amplitudes.

Our study shows that the neural stimulation resulted in decreased evoked EMG response during nerve stimulation with overlying fascia or with greater distance from the nerve for all stimulator groups. The mean amplitude decrease due to overlying fascia was more obvious with bipolar probes (33%) than the monopolar probes (11%) and stimulation dissectors (13%) (Fig. 7). Our study investigated a relatively thin layer of overlying fascia, which did not preclude visualization of the nerve. Future study is needed to investigate whether the reduced EMG may be more significant if the overlying fascia is thicker. Nerve depolarization was most readily achieved at a distance away from the nerve with monopolar probes followed by stimulation dissectors. The bipolar group was least capable of depolarizing the nerve at distance (Table I).

Given the above stimulating characteristics, certain strategies may be employed when choosing stimulation probes/dissectors for optimal stimulation during monitored thyroid surgery:

1. **Group I:** Monopolar probes are most sensitive in neural depolarization at a distance from the nerve and with overlying fascia, and so have greatest utility in nerve detection during initial phases (neural mapping) of monitored thyroid surgery.
2. **Group II:** Bipolar probes are most specific and may be helpful for reduction of false positive stimulation during IONM. However, they need to be close to the nerve and require higher stimulation current for maximal neural amplitude response. In addition, it is suggested that they be used with a correct probe–nerve orientation because the current flow is most effectively delivered when the cathode (−) electrode is distal (i.e., closer to the larynx) to the anode (+) electrode on the nerve. The correct orientation avoids anodal block which can elevate thresholds.
3. **Group III:** Stimulation dissectors shared many of the attributes of monopolar probes and thus represent a viable alternative for surgeons.

A limitation of this study is that it is based on an animal model, and thus the specific data of this study may not be totally applicable to humans. However, this model was previously proven as a useful and reliable model to evaluate the electrophysiologic correlates of EMG during IONM.\(^\text{18,54–56}\)

**CONCLUSION**

To our knowledge, this current study is the first to compare the EMG response characteristics of EBSLN, RLN, and VN evoked with different stimulation probes/dissectors. We confirmed that both conventional monopolar/bipolar probes and newly emerging stimulation dissectors can effectively evoke EBSLN, RLN, and VN waveforms that provide intraoperative nerve function documentation during thyroideotomy. Specific stimulation probes/dissectors can be employed for neurononitoring based on specific stimulation characteristics, the specific surgical monitoring application desired, and the surgeon’s preference.
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