

**Pediatric Intraoperative Nerve Monitoring During Thyroid Surgery**  
**A Consensus Statement from the**  
**American Head and Neck Society Endocrine Surgery Section**

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**Introduction**

Surgical thyroid disease is uncommon in children. Surgery is indicated for thyroid cancer, nodule, goiter, or medically uncontrolled hyperthyroidism. Graves' disease, the most common cause of hyperthyroidism in children and adolescents, occurs in 1 per 10,000 children<sup>1</sup>. Differentiated Thyroid Carcinoma (DTC) is the most common form of pediatric thyroid malignancy<sup>2</sup>. The age-adjusted annual incidence for pediatric patients diagnosed with DTC in the US is 0.54 per 100,000 persons<sup>3</sup>. The Center for Disease Control (CDC) reported that pediatric thyroid malignancy represents 1.8% of total thyroid malignancy cases diagnosed in 2017<sup>4</sup>. The annual DTC incidence is gradually increasing by around 1.1%. In a nationwide study in the Netherlands of pediatric patients diagnosed with DTC between 1970 and 2013, overall survival was 99.4% after a median follow-up duration of 13.5 years<sup>5</sup>. Tumor recurrence remains a central concern even after achieving a radiological and biochemical complete response. In some cases, revision surgery may be indicated. Recurrent laryngeal nerve identification may be challenging especially in cases of exthyroidal extension of malignancy, autoimmune thyroid disease, and recurrent or bulky neck disease. In hostile surgical fields, there is increased risk for laryngeal nerve injury<sup>6,7,8</sup>. Even with such aggressive disease, the pediatric population is known to have excellent survival outcomes and therefore may be subjected to the morbidity of recurrent laryngeal nerve (RLN) paralysis for many years<sup>9</sup>.

An analysis published in 2008 reports that children are more likely to experience RLN injury or hypoparathyroidism after thyroid surgery compared to an adult population (9.1 vs. 6.3%)<sup>7</sup>. Rates of transient and permanent vocal cord paralysis (VCP) in published retrospective reviews, as well as national database studies, range from 0 - 9.6%<sup>6,7; 10-12</sup>, including up to a 1.5% risk of bilateral vocal cord injury<sup>12</sup> and a 0.5 - 0.8% risk of tracheotomy<sup>6,10</sup>. Up to 50% of children with bilateral vocal cord injury require tracheotomy<sup>6</sup>. Rates of injury to the external branch of superior laryngeal nerve (EBSLN) and associated voice outcomes in pediatric population have not been reported.

Intraoperative neural monitoring (IONM) of the RLN has become an increasingly common practice during adult thyroid and parathyroid surgery internationally<sup>13</sup>. Stimulation of the RLN during thyroid surgery can facilitate identification and mapping of the nerve, particularly in difficult or revision cases, as well as provide prognostic information about postoperative neural function<sup>14</sup>. In adult patients, IONM demonstrates a 99% negative predictive value and 75% positive predictive value of postoperative VCP<sup>15</sup>. IONM provides real-time data of RLN functional status to optimize surgical decision-making to reduce bilateral VCP risk. This prognostic application of IONM is particularly strategic given higher rates of paralysis, need for bilateral surgery, and prolonged survival unique to the pediatric population. A simulation study has demonstrated that IONM use in the setting of loss of signal is a cost-effective approach, allowing for second-stage completion thyroidectomy after the neural function has recovered<sup>16</sup>.

Given the relatively small sample size of the affected population, performing prospective clinical trials for IONM specific to the pediatric population is extremely difficult. Several retrospective studies have described neural mapping techniques and outcomes in the pediatric population. These limited data may explain why there is no consensus regarding the utility of IONM in children<sup>17</sup>.

The focus of this consensus paper is on IONM in the pediatric population encompassing the following areas:

1. Pediatric IONM in Published Literature
2. Possible Nerve Monitoring Techniques in Pediatric Population
3. Consensus Statement-List of Recommendation
4. External Branch of Superior Laryngeal Nerve (EBSLN): injury and monitoring
5. Conclusion

### **1. Pediatric IONM in published literature**

In 2002, Brauckhoff et al. published the first retrospective IONM study of the RLN in children and adolescents aged between 3 and 16 years who were undergoing thyroid surgery. The IONM method included stimulating the RLN using a stimulation electrode while recording the electromyographic response through bipolar needle electrodes placed through the cricothyroid ligament into the intrinsic laryngeal muscles. The study compared nerve outcomes in a group of 98 monitored nerves at risk to a group of 84 unmonitored nerves at risk. No nerves were permanently injured in the IONM group compared to 1 nerve in the non-monitored group (1.19%)<sup>18</sup>. Meyer et al. published a retrospective study involving 11 to 16 year old children undergoing thyroid surgery, with 16 nerves at risk. They performed IONM using the same intralaryngeal technique used by Brauckhoff et al. Postoperative temporary paresis occurred in one case despite a normal intraoperative electromyogram and that nerve recovered later<sup>19</sup>.

White et al conducted a small retrospective study involving 5 pediatric patients (ages 11 through 17 years) where RLN was monitored using an endotracheal tube (ETT) equipped with integrated surface electrodes contacting the inner side of the true vocal cords<sup>20</sup>. These electrodes allowed both passive and stimulation-based monitoring of the thyroarytenoid muscle. Diminished electromyogram (EMG) amplitude after RLN dissection in an adolescent with papillary thyroid cancer was predictive of a transient VCP, and maintenance of baseline EMG signals was predictive of normal postoperative function for the remaining nerves dissected. The authors acknowledged that limited sizes of ETT with integrated surface electrodes are available for pediatric monitoring.

As an alternative to commercially available ETT with integrated surface electrodes, adhesive electrodes can be manually placed onto any desired-size ETT above the tube cuff, to monitor the vocalis muscle<sup>20-22</sup>. A series utilizing ETT with manually attached adhesive surface electrodes for IONM, involving 167 nerves at risk in the adult population, demonstrated a 100% correlation between intraoperative findings and 72-hour postoperative laryngeal examination<sup>21</sup>. Propst et al. published a retrospective series evaluating IONM in 25 children between the age of 4 and 17 years undergoing thyroid surgery; 46% of cases used adhesive surface electrodes applied to ETT as well as a grounding electrode and the remainder used ETT with integrated electrodes<sup>22</sup>. The authors used adhesive pads applied to ETT as small as size 4.0 and for children as young as 4.5 years of age. Responses were obtained for all but one nerve at risk (2.3%). Before surgery, electrodes were applied to patient foreheads after dermabrasion and using an alcohol wipe to remove grease to obtain low impedance recordings. However, this led to a rare complication in 2 patients who experienced superficial scarring from dermabrasion<sup>22</sup>. The authors recommended placing grounding electrodes over the mastoid to mitigate this risk.

Endolaryngeal electrode placement for EMG monitoring in pediatric thyroid surgeries has been described previously<sup>23-26</sup>. In 2013, Cheng and Kazahaya reported placing endolaryngeal hookwire electrodes directly into the vocalis muscle through laryngoscopy after intubation in 17 consecutive pediatric patients (4 - 15 years old) undergoing thyroid surgery mainly for thyroid malignancy in the US. One temporary paresis amounting to 3.1% of surgeries was noted<sup>23</sup>. Cheng and Kazahaya mention that this method provides enhanced reliability and sensitivity<sup>23,27,28</sup>. However, drawbacks of hookwire electrodes include an increase in the operative time, as attaching the electrodes through laryngoscopy is a separate procedure, and a risk of electrode dislocation.

Akkari et al. published a single-center retrospective study in the French pediatric population. The authors reported using IONM to monitor 93 nerves of 64 pediatric patients. ETT with integrated electrodes were used for children 8 years and older. In

children younger than 8 years, one of the 3 different techniques was used: (1) hookwire electrode placement; (2) electrode placement in the vocal cords through thyroid cartilage dissection and; and (3) direct visualization via nasal endoscopy. The authors did not report how many patients were included under each of the 3 techniques. Only one patient, who was monitored via the integrated ETT, had permanent RLN injury<sup>29</sup>.

Schneider et al.'s study on pediatric IONM is the largest to date<sup>17</sup>. The authors reported a single-center experience in pediatric IONM between 1998 and 2016 in Germany. This retrospective study included 504 children undergoing thyroidectomy procedures. The authors reported 2 techniques of IONM: Intermittent IONM (IIONM) using needle electrodes and handheld stimulation probes during the first half of the study, and continuous IONM (CIONM) using ETT with integrated or adhesive EMG surface electrodes and circumferential clip electrodes placed on the vagus nerve during the latter half of the study. Loss of EMG signal (LOS) was defined as loss of audio tone and/or nerve amplitude < 100  $\mu$ V at 1-2 mA stimulation. In cases of LOS or failure to recover at least 50% of baseline amplitude after a 20-minute pause after LOS, the contralateral lobectomy was not pursued, and surgery was staged. Transient and permanent VCP incidence was 1.3% and 0.4% respectively. LOS was predictive of VCP in 8 out of 10 children.

Using CIONM, both baseline signal amplitude and latency increased with age, to a greater extent on the left side as compared to the right side, consistent with increasing length of vagus-RLN axis. In children 13-18 years of age, compared with IIONM, baseline amplitudes were increased, and latencies were decreased when CIONM technique was employed; this was not observed in younger children, likely due to a better fit between the electrode cuff and vagus nerve in older children. The authors suggested that fit was particularly problematic for children under 6 years of age and that a moist gauze pad can help to stabilize the nerve against electrode clips. The authors ultimately concluded that, for children 6 years of age and older, CIONM was the preferred method for monitoring given the high-quality signals generated<sup>17</sup>.

For younger children who need ETT with smaller sizes, additional monitoring methods have been described. White et al. have used extraluminal posterior-cricoarytenoid electrode pads placed into hypopharynx by direct visualization after endotracheal intubation in younger children to document posterior cricoarytenoid (PCA) EMG. The authors acknowledge that accuracy and predictive value of this method is not well established in children<sup>20</sup>. Liddy et al. reported a series of 20 adult patients, in whom PCA muscle EMG was compared to vocalis muscle EMG in adults, and documented that PCA posterior cricoarytenoid EMG waveform parameters showed no statistically significant differences in mean latency values with vagal, RLN, and external branch superior laryngeal nerve stimulation compared with ETT recording<sup>30</sup>. PCA monitoring has also been critically studied in a canine model, and has been found to demonstrate electrophysiologic sensitivity comparable to ETT EMG monitoring. In this model, PCA monitoring demonstrated increased latency and decreased amplitude of EMG signal after compression injury corresponding to VCP<sup>31</sup>.

Anterior laryngeal monitoring using either surface or needle electrodes is another IONM technique, and its use in adults is reported in two recent papers. Chiang et al. reported inserting subdermal needle electrodes into perichondrium of the thyroid cartilage in adult patients<sup>32</sup>. Meanwhile, Liddy et al. described the results of placing adhesive electrode pads over the thyroid cartilage in adult patients<sup>33</sup>. This technique has the advantage of being visualized within the surgical field. However, use of this technique in pediatric population is not yet reported to the best of our knowledge.

## **2. Possible IONM Techniques in Pediatric Population**

Based upon the experiences of various authors in this consensus paper and review of the published literature in the last 20 years, we provide detailed recommendations regarding IONM techniques and indicate which monitoring techniques may be considered for each age group (Figure 8). Please be advised that techniques and equipment mentioned below are examples to make it easier for future clinicians and researchers to choose the appropriate technique based upon their internal environment. There is no financial influence on our decision to mention this equipment or our failure

to mention other equipment that may provide a similar experience as equipment described below:

### 2.1 Endotracheal Tube with Integrated Surface Electrodes

This technique detects vocalis muscles EMG. If an age/size appropriate commercially available ETT with integrated EMG electrodes is available, it should be used (Figure 1) [examples: NIM monitoring tube (Medtronic, Jacksonville, Florida); or Cobra EMG Monitoring ETT (Neurovision Medical, Ventura, California)]. It is recommended to keep a back-up, smaller sized tube ready at time of intubation, should the selected tube be too large for child's airway (see Table 1). It should also be advised that a suitable size for infants, toddlers, or younger children may not be available in this category of electrodes.

The smallest commercially available ETT with integrated electrodes is the NIM TriVantage™ EMG Endotracheal tube (ID 5.0mm, OD 6.5mm). Depending on the size of the child and outer diameter of an age appropriate standard endotracheal tube, in some cases a size 5.0 tube with integrated surface electrodes may still be appropriate for younger children; an alternative method for IONM should also be available as a back-up. The surgeon and anesthesia team should review tube outer diameter to ensure it is comparable to an age appropriate standard endotracheal tube and evaluate for a leak prior to cuff inflation to ensure the tube fit is not excessively snug. ETT position should be verified once patient positioning is finalized, including after placement of a shoulder roll with the neck extended, and prior to preparing the surgical field.

### 2.2 Endotracheal Tube with Adhesive Surface Electrodes

This technique detects vocalis muscles EMG. If a correct-size ETT with integrated electrodes is not commercially available, one can be manually created using an age-appropriate standard ETT and adhesive electrode pads added to it above the tube cuff. However, be advised that intraoperative displacement of adhesive electrodes has been reported in 7% of cases<sup>20</sup>. For children under the age of 10, the surgeon should be prepared to either create a monitoring ETT using adhesive electrodes on a standard ETT or should plan to use a different method for IONM if a commercially available ETT with integrated surface electrodes cannot be used.

Examples of adhesive electrodes that can be used to create a monitoring tube include: Dragonfly electrode (Neurovision Medical, Ventura, California), (Figure 2); or laryngeal surface electrodes (Invotec International, Jacksonville, FL)]. The ETT should be straightened, adhesive electrode should be wrapped around ETT with electrode midline near to the posterior aspect of ETT, and the free ends of electrode padding are wrapped around ETT. Care must be taken to trim the electrode sufficiently such that ends do not overlap after they are wrapped around an ETT and to avoid trauma to electrode wires. The central portion of the electrode pad may also need to be removed in smaller children to allow for slightly posterior positioning of electrode pads (Figure 3). Electrode wires can be taped along the length of the ETT to reinforce positioning and prevent displacement during intubation. The monitoring ETT should be positioned to ensure that the vocal cords are in contact with the middle of electrode array (Figure 4). Tube position should be confirmed after patient positioning through direct visualization (direct laryngoscopy or video laryngoscopy) or EMG recording variation with respiratory movements<sup>34</sup>.

### 2.3 Anterior Laryngeal Electrode Technique

Anterior laryngeal monitoring emerged as a trial to overcome false positive Loss of Signal (LOS) of vocalis muscle EMG. This LOS can occur intraoperatively when ETT with integrated or adhesive surface electrodes shift position. The reported LOS ranges from 3.8% to 23% in studies of monitored surgeries in adults using ETT electrodes. Given that the thyroarytenoid muscle is attached anteriorly into the inner surface of thyroid cartilage, anterior laryngeal monitoring technique aims to detect thyroarytenoid muscle EMG. Two possible approaches have been reported: (1) using a single needle electrode [example: Medtronic, Jacksonville, FL, USA]. Needles can be obliquely inserted into the perichondrium of thyroid cartilage's lateral side. However, this technique is invasive; (2) using an adhesive bipolar electrode [example: Neurovision Medical, Inomed, Medtronic & Stryker]. The adhesive electrode is cut in half to create two recording surfaces. Electrodes are then positioned over thyroid cartilage on either side of the midline and secured by suture to perichondrium; care is taken not to violate



the underlying electrode wire and to ensure surfaces do not overlap (Figure 7)<sup>33</sup>. The adhesive electrode method for anterior laryngeal monitoring technique is non-invasive. Anterior laryngeal monitoring technique -either needle or adhesive electrode- in children is not yet reported, to the best of our knowledge.

#### 2.4 Postcricoid Electrode Technique

This technique aims to detect posterior cricoarytenoid (PCA) muscle EMG. Unlike other techniques of monitoring that focus on vocalis muscle EMG (adductor muscle), the PCA is the only abductor muscle of the vocal cords. In this technique, an adhesive bipolar electrode [example: Neurovision Medical, Inomed, Medtronic & Stryker] is placed against the postcricoid region through direct laryngoscopy after endotracheal intubation<sup>19</sup> (Figure 6A). Alternatively, a nasogastric tube with adhesive electrodes sutured on the tube can be positioned in the hypopharynx such that electrodes are abutting posterior cricoarytenoid muscle after intubation (Figure 6B)<sup>30</sup>. This second method of PCA monitoring facilitates subtle repositioning of electrode pad more readily.

Postcricoid technique allows for monitoring of both adductor and abductor responses, therefore -when combined with ETT electrode monitoring- has the potential to be a more reliable method for predicting a patent airway postoperatively<sup>30,31</sup>. Another good use of PCA monitoring is in cases of extra-laryngeal RLN branching. Although RLN classically branches in the larynx, RLN extra-laryngeal branching is not uncommon and branches are more prone to injury. In event of extra-laryngeal branching, motor nerve fibers of RLN are reported to descend via the anterior branch of the extra-laryngeal branched RLN. However, in the minority of cases, motor nerves might be found in the posterior as well as anterior branches of the nerve. In a study by Barczynski et al., in 2500 RLNs at risk from 1230 patients, 613 branched RLNs were reported, among which 8 nerves had posterior branch motor nerves<sup>35</sup>. PCA monitoring can detect an abductor response. We did not find any reports of this technique being used in pediatric population to date.

#### 2.5 Hookwire Electrode Technique

Under direct visualization via suspension laryngoscopy, the surgeon can insert hookwire electrodes into vocalis muscles, both anteriorly and posteriorly, on each side (Figure 5). Hookwire electrode placement is confirmed by checking impedances or assessing for respiratory variation in EMG signal. After the surgical procedure, hookwire electrodes are withdrawn while taking care that each wire is intact. Although the use of this technique is reported in children, the technique may be less favorable compared to other techniques for some surgeons because (1) it requires a separate laryngoscopy procedure and equipment for electrode placement; (2) requires surgeon experience with suspension microlaryngoscopy; and (3) even for the skilled laryngoscopist may add up to 20 minutes of surgical time. Because it is an invasive procedure that requires the placement of electrodes into the vocalis muscle, there is a potential for complications which should be discussed prior to the procedure. Furthermore, similar to the risk of an ETT shifting during a case and losing contact, there is risk of the electrodes dislodging from the vocalis muscle.

### **3. Consensus Statement List of Statements**

**Statement 1:** (1a) IONM should be considered in all pediatric thyroid surgeries; (1b) IONM is highly recommended when performing pediatric total thyroidectomy or in hemithyroidectomy where the contralateral vocal cord is paralyzed to mitigate the risk of bilateral VCP and tracheotomy; (1c) IONM is highly recommended in re-operative surgery as it facilitates nerve identification and can provide information about neural functioning in this setting.

Available data suggest that regardless of technique used, pediatric IONM is safe. Applications of IONM in pediatric population are similar to those in adults. IONM expedites identification and aids in RLN mapping<sup>36,37</sup>. IONM can be particularly useful in the setting of central neck nodal disease, inflammation, or thyroid malignancy with extrathyroidal extension. IONM can also provide information about postoperative prognosis and whether to proceed to second side surgery or to stage a total thyroidectomy procedure, particularly in young children, in whom there is a higher risk of postoperative RLN paralysis and need for tracheotomy.

**Statement 2:** When IONM is planned, the surgeon should discuss IONM as part of the informed consent process and should describe how data will be utilized for surgical decision-making.

When IONM is used, patients and their families should be informed that IONM will be performed, and also be prepared for the possibility of a staged surgical procedure if LOS occurs during total thyroidectomy procedures. This allows for shared decision-making<sup>38</sup>. Surgeons wishing to utilize IONM in children should be familiar with the different methods available for IONM in pediatric population and be prepared to utilize more than one method if needed. Families should understand which methods will be employed, particularly if laryngoscopy and needle electrode placement will be attempted.

**Statement 3:** All children undergoing thyroid surgery should undergo preoperative and postoperative laryngeal examinations.

All patients undergoing thyroid surgery should have a documented baseline assessment of their voice, which at a minimum should include either self-reporting of changes to vocal pitch, quality, loudness, and endurance or the examiner's perceptual assessment of patient's voice<sup>36</sup>. The intraoperative neural monitoring study group (INMSG) guidelines recommend preoperative and postoperative laryngoscopy as part of the standard RLN monitoring protocol<sup>39</sup>. In adults, the American Head and Neck Society (AHNS) recommends a preoperative laryngeal examination for patients undergoing surgery who are at high risk for injury, based upon the preoperative voice quality, prior chest or neck surgery, or malignancy and nodal status<sup>40-43</sup>. Intraoperatively, when a RLN is found to be invaded by a tumor, knowledge of preoperative function of both ipsilateral and contralateral vocal cord is very valuable in guiding surgical management of the affected nerve<sup>42</sup>. A recent consensus statement published by the American Association of Clinical Endocrinologists and the American Head and Neck Society Endocrine Surgery Section recommended preoperative laryngeal examination for all children undergoing thyroid procedures<sup>8</sup>.

We recommend that all children undergoing thyroid surgery have a preoperative laryngeal examination. With higher rates of malignancy in children presenting with

thyroid nodules, and increased risk of multifocal and bilateral disease, total thyroidectomy is often indicated. There are reports of increased risk of postoperative vocal cord paresis in the pediatric population. Therefore, in addition to preoperative voice assessment, an evaluation of vocal cord function should be performed prior to thyroid surgery, regardless of suspected underlying pathology or perceived changes to voice quality before surgery. This is particularly important when bilateral or completion thyroid procedure is planned or in children with symptoms of vocal cord dysfunction, such as dysphonia, aspiration, and stridor.

To foster further research regarding predictive value of IONM techniques in pediatric population, we also recommend that postoperative laryngeal examination be considered for all children after thyroid surgery. Similar recommendations have been made for adult patients with thyroid cancer<sup>41</sup> or in adults reporting voice change following surgery<sup>40</sup>; even in adults without malignancy or voice concerns, postoperative laryngeal examination is supported for surgical quality assessment since postoperative laryngoscopy is the only way to document postoperative quality outcome<sup>40</sup>.

In children, laryngeal examination is best achieved using transnasal flexible fiberoptic laryngoscopy and can be done quickly using pediatric laryngoscopes in office setting. Laryngeal function can also be assessed through transcutaneous laryngeal ultrasound. In children, ultrasound assessment of laryngeal function is facilitated by limited calcification of the thyroid and cricoid cartilages. When ossification has occurred, ultrasound can also be performed through cricothyroid membrane in some cases<sup>44</sup>.

When postoperative laryngeal dysfunction is identified, the child should be referred to an otolaryngologist. Similar recommendations are made in adults diagnosed with vocal cord immobility or dysphonia after thyroid surgery<sup>40</sup>. This referral facilitates coordination of care with voice and speech pathologists and enables early treatment, including surgical interventions, to optimize voice and swallowing outcomes<sup>40</sup>.

**Statement 4:** When IONM is planned, this should be communicated to the anesthesia team to allow for intubation and appropriate anesthetic selection.

When IONM is used, good communication between surgical and anesthesia teams is essential. The anesthetist should not use long-acting paralytics regardless of the IONM technique selected, as these may depress EMG responses during intraoperative monitoring. Based on published evidence and their clinical experience, Macias et al. have published an interdisciplinary collaborative anesthesia protocol for monitored neck surgery<sup>45</sup>. When ETT with surface electrodes is used, correct positioning of ETT with optimal contact between the electrodes and both vocal cords should be verified<sup>45</sup>. Video-assisted intubation equipment, such as with a video laryngoscope [example: McGRATH by Medtronic, King Vision by Ambu & Glide Scope by Verathon] can be helpful so that both teams can visualize airway and tube position during intubation. Lubricants should not be applied to the ETT to ensure that tube remains optimally positioned. Because neck extension may also impact tube position, we recommend that ETT is visually inspected or that respiratory variation of the EMG signal be confirmed after the patient is positioned with neck extended for surgery<sup>37</sup>.

**Statement 5:** Surgeons planning to use IONM should be familiar with International Neural Monitoring Study Group (INMSG) guidelines and understand how monitoring data can be utilized for surgical decision-making.

We recommend that surgeons be familiar with INMSG guidelines for RLN and EBSLN monitoring, these guidelines provide methods for proper equipment set-up and intraoperative problem-solving algorithms for the interpretation of changes in amplitude and latency of the EMG signal<sup>38,46-48</sup>. Further research is needed on IONM in the pediatric patient to establish normative data on amplitude and latency and to establish parameters for what constitutes the loss of signal, however, adult data can serve as a model for how changes in baseline latency and amplitude can be used to change intraoperative management.

RLN IONM can facilitate identification of the RLN during dissection and help to identify anatomic variants of RLN<sup>38</sup>. Additionally, IONM can help localize the site of

injury, which in adults is often related to traction at the ligament of Berry<sup>38</sup>. Frequently, injured nerves appear intact visually, but are associated with change in EMG signals<sup>49</sup>.

There was no consensus about the pediatric definitions of IONM standards, such as the adequate initial baseline amplitudes, latency, and LOS definitions. However, Schneider et al. -who reported the data from 504 pediatric children- used similar definitions to the proposed INSMG guideline recommendations for IONM in adults. Additionally, Schneider et al. reported that there was a nonstatistically significant difference between multiple age groups  $\leq 3$ ; 4-6; 7-12; 13-18 years on either the right or the left RLNs when using IIONM. That non-statistically significant difference was present in both IIONM with needle electrodes and IIONM with tube electrodes. The only difference was detected when using the CIONM. Based on the fact that Schneider et al successfully applied adult definitions of IONM parameters in pediatric population and showed that the median IIONM values remained the same across all age groups in pediatric population, we think that adult IIONM INMSG guideline definitions may be used for pediatric IIONM<sup>17</sup>.

To appreciate a change in signal, surgeons must have an adequate initial baseline measurement; for adults, INMSG recommends an initial waveform amplitude of 500 $\mu$ V with a stimulation current of 1-2mA. The INMSG recommends immediate cessation of surgical maneuvers when a combined amplitude decrease  $> 50\%$  and latency increase  $> 10\%$  from baseline occurs, as these EMG signal changes precede LOS in adult patients when changes are persistent for 40-60 seconds. Once response amplitudes are  $< 100 \mu$ V, which serves as the threshold for loss of signal (LOS), likelihood of intraoperative recoverability decreases, and the risk of subsequent VCP increases. EMG recovery is defined as recovery of signal to  $> 50\%$  baseline measurement, with a minimum amplitude of 250  $\mu$ V, after LOS; when this is not achieved 20 minutes after LOS occurs, there is an up to 80% risk of VCP postoperatively in adult patients<sup>38,50</sup>.

Adult studies demonstrate an increased risk of bilateral VCP -up to 17%- when second side surgery is pursued despite LOS on the first side; these injuries could be avoided by aborting or staging second side surgery<sup>38</sup>. Staging completion surgery has not been shown to negatively impact oncologic outcomes<sup>51</sup>. While staging surgical procedure has not been well studied in the pediatric population, we feel this is a viable option in many cases to reduce the risk of surgical morbidity.

INMSG guidelines have also described how IONM can augment surgical decision making for invasive thyroid disease. In adults, RLN invasion has not been shown to negatively impact overall survival<sup>52</sup>, though it is associated with higher locoregional recurrence<sup>48</sup>. Neural invasion in differentiated thyroid cancer is a slow process; thus, often RLN function may be preserved despite malignant invasion<sup>53</sup>. The INMSG recommends that nerve preservation should be considered and attempted in patients who demonstrate maintenance of some glottic function on preoperative laryngeal examination or who maintain proximal stimulability on EMG, taking degree of invasion, underlying pathology, availability, and patient's ability to tolerate adjuvant therapies, and degree of invasion into other structures into account<sup>48</sup>. When proximal RLN is stimutable to some degree using IONM, even when gross laryngeal dysfunction is noted, the INMSG recommends consideration of nerve preservation because some functional activity may be imparted by remaining nerve fibers; the INMSG notes that resecting these remaining axons could lead to worsening voice outcomes and dysphagia<sup>48,54</sup>, negatively impacting postoperative quality of life. When ipsilateral dissection reveals an invaded nerve with maintenance of proximal signal, ipsilateral dissection should be halted, and the second side explored. If LOS is noted during contralateral dissection, and recovery is not noted after 20 minutes, return to the ipsilateral procedure and nerve dissection should be staged.

It is important to note that long term data on nerve preservation in the setting of preserved glottic function or EMG signal is not available in adults, and there is no body of literature on pediatric nerve-sparing techniques or algorithms. However, these techniques may aid in surgical decision making to optimize patient functional outcomes

after surgery, particularly given the excellent overall survival enjoyed by pediatric thyroid cancer patients, even in its advanced stages.

#### **4. External Branch of Superior Laryngeal Nerve (EBSLN) injury and monitoring**

In children, current literature on postoperative neural function focuses on transient or permanent VCP related to RLN injury. Rates of SLN injury and resulting dysphonia in the pediatric population after thyroid surgery are unknown. Even in adults, the incidence of EBSLN injury is poorly understood due to heterogeneous study methods and the variability of postoperative voice outcomes. EBSLN Injury leads to cricothyroid muscle dysfunction and thus affects vocal projection and the ability to produce higher registers of the voice. Although subtle, these voice changes can affect singing voice significantly. Rates of EBSLN injury in the adult literature range from 0-58%<sup>47</sup>. The EBSLN is at high risk during superior pole dissection and ligation of superior thyroid vessels. Up to 20% of EBSLNs are covered by fascia and thus are not visually identified intraoperatively<sup>55</sup>. IONM of EBSLN allows for stimulation and identification of all EBSLNs including the subfascial EBSLNs<sup>56</sup>. Additionally, IONM can be used to exclude the presence of the EBSLN in tissue that would be divided to release the superior pole of the thyroid gland<sup>40</sup>. INMSG has published a guideline on EBSLN monitoring that delineates its utility and application<sup>47</sup>. Currently, there is paucity of literature on EBSLN monitoring in pediatric surgeries.

#### **5. Conclusion**

IONM of the RLN is commonly used during adult thyroid surgery to facilitate nerve identification, mapping, and for prognostication of postoperative neural function. IONM in the pediatric population is less studied and understood, however, this technology may be useful, particularly in young children or in cases where there is extensive inflammation, extrathyroidal extension, or nodal disease. Surgeons wishing to use IONM in children must be prepared to evaluate preoperative and postoperative laryngeal function, be familiar with neural monitoring methods, and be knowledgeable about proper techniques and standards to optimally use this technology. The surgeons should also be able to interpret the IONM data correctly and use this information to



guide surgical decision-making. Further research is needed to establish normative pediatric EMG values, establish thresholds for intraoperative signal change, and understand how these changes correlate with postoperative function and prognosis in pediatric population.

## Tables

Table 1: Endotracheal tube sizes with suggestive appropriate age ranges

<b>Tube size (ID), mm</b>	<b>OD, mm (NIM TriVantage<sup>®</sup>, NIM Standard<sup>®</sup>, NIM Contact<sup>®</sup>)*</b>	<b>Age Range, years</b>
5.0	6.5, N/A, N/A	10-12**
6.0	8.2, 8.8, 9.0	13-15
7.0	9.5, 10.2, 10.5	16-18, female
8.0	10.7, 11.3, 11.5	16-18, male
* Tubes manufactured by Medtronic, Jacksonville, Florida		
** 5.0 tube may be appropriate for some children under 10 years of age.		

## Figures

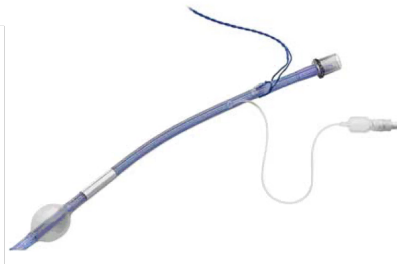


Figure 1: NIM endotracheal tube electrode

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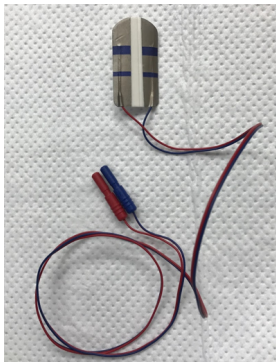


Figure 2: Adhesive electrode -Electrode (Neurovision Medical, Ventura, California)

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Figure 3: Adhesive electrode positioning on an age appropriate endotracheal tube

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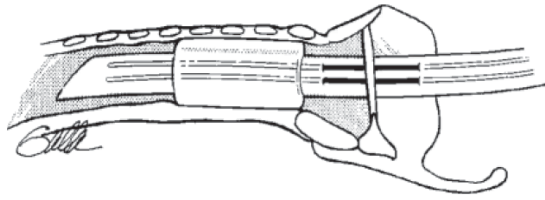


Figure 4: Proper intraluminal positioning of endotracheal tube electrodes

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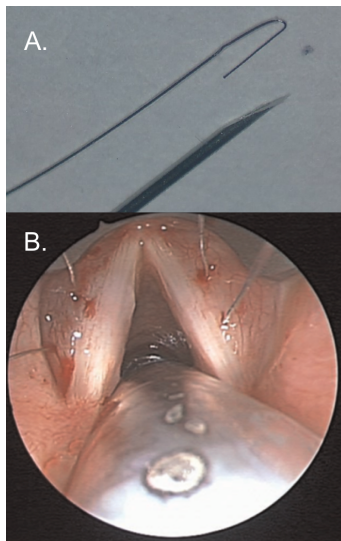


Figure 5: A. Hookwire electrode bent before placement. B. Endoscopic view of endolaryngeal hookwire electrode placement, anteriorly and posteriorly.

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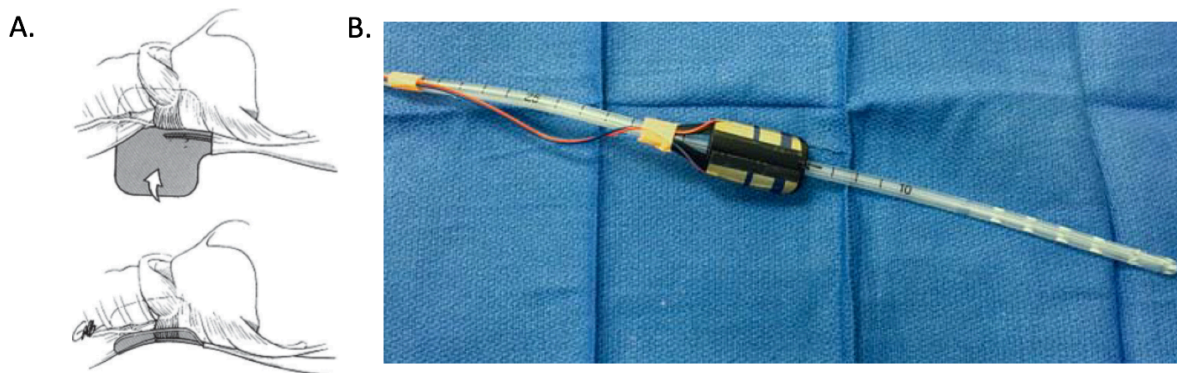


Figure 6: Electrode pad measuring posterior cricoarytenoid muscle activity applied to the postcricoid region. This can be applied directly (A) or positioned onto a nasogastric tube which is then positioned in the postcricoid area (B) after intubation.

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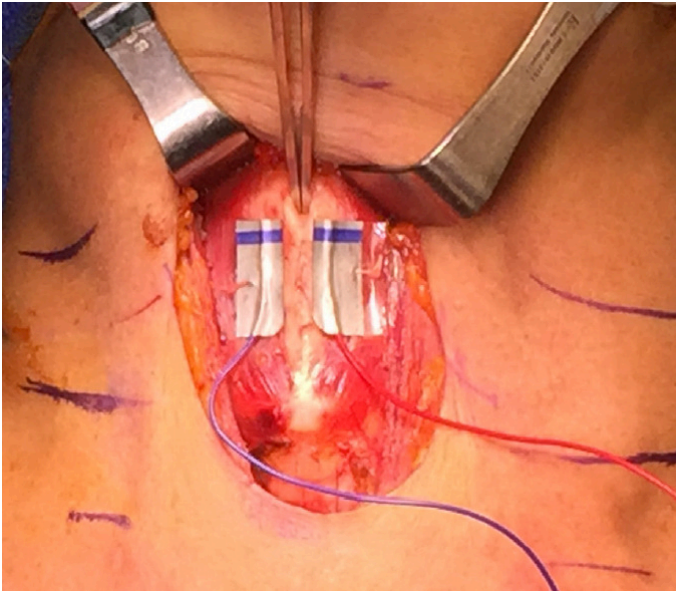


Figure 7: Electrode pad configuration for anterior laryngeal monitoring.

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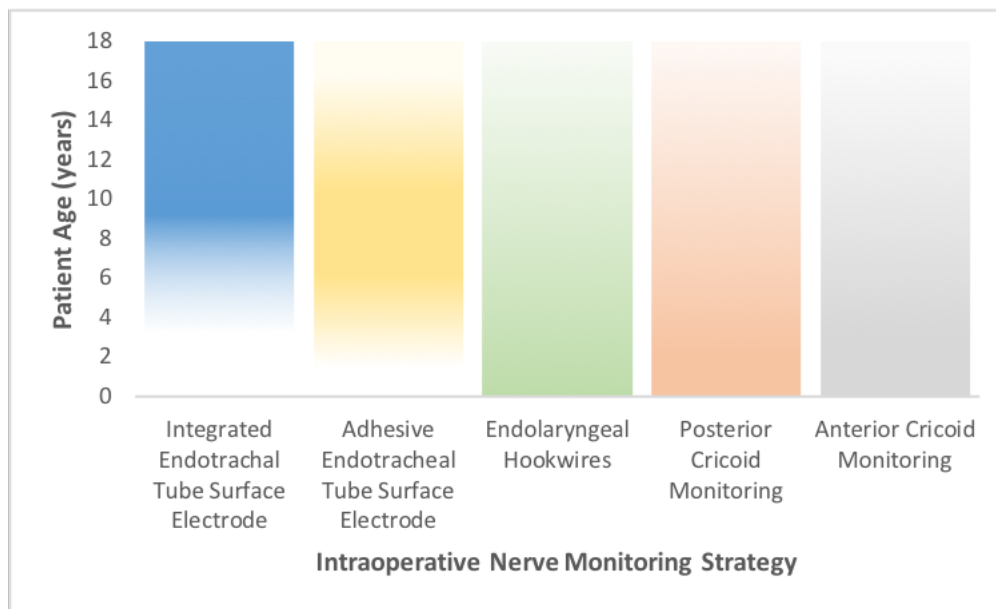


Figure 8: Intraoperative neuromonitoring options stratified by age

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