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CLINICAL REVIEW

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Pediatric intraoperative nerve monitoring during thyroid surgery: A review from the American Head and Neck Society Endocrine Surgery Section and the International Neural Monitoring Study Group

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Abstract

Children are more likely to experience recurrent laryngeal nerve (RLN) injury during thyroid surgery. Intraoperative nerve monitoring (IONM) may assist in nerve identification and surgical decision making. A literature review of pediatric IONM was performed and used to inform a monitoring technique guide and expert opinion statements. Pediatric IONM is achieved using a variety of methods. When age-appropriate endotracheal tubes with integrated surface electrodes are not available, an alternative method should be used. Patient age and surgeon experience with laryngoscopy influence technique selection; four techniques are described in detail. Surgeons must be familiar with the nuances of monitoring technique and interpretation; opinion statements address optimizing this technology in children. Adult IONM guidelines may offer strategies for surgical decision making in children. In some cases, delay of second-sided surgery may reduce bilateral RLN injury risk.

KEYWORDS

intraoperative nerve monitoring, pediatric, recurrent laryngeal nerve, thyroid surgery, vocal cord paralysis

1 | INTRODUCTION

Surgical thyroid disease in children, performed for thyroid cancer, nodule, goiter, or medically uncontrolled hyperthyroidism, is uncommon. Graves' disease, the most common cause of hyperthyroidism in children and adolescents, occurs in one per 10 000 children.[1] The age-adjusted annual incidence for pediatric patients diagnosed with differentiated thyroid cancer (DTC) in the United States is 0.54 per 100 000 persons,[2] representing 1.8% of thyroid cancers diagnosed in 2017.[3] The annual incidence of DTC is rising by approximately 1.1% per year.

Recurrent laryngeal nerve (RLN) identification can be challenging in cases with underlying autoimmune thyroid disease, extrathyroidal extension of malignancy, bulky neck lymphadenopathy, and reoperative surgery.[4–6] Additionally, during pediatric thyroid surgery, identification of the RLN can be difficult due to the nerve's smaller size and presence of ectopic cervical thymic tissue. Children are more likely to experience RLN injury or hypoparathyroidism after thyroid surgery compared to adults (9.1 vs. 6.3%).[5] Rates of transient and permanent vocal cord paralysis (VCP) range from 0% to 9.6%,[4,5,7–9] including up to a 1.5% risk of bilateral RLN injury[9] and a 0.5%–0.8% risk of tracheotomy.[4,7] Even with extensive disease, the pediatric population is known to have excellent survival outcomes and therefore may be subject to the morbidity of RLN paralysis for many years.[10]

Intraoperative neural monitoring (IONM) of the RLN has become a common practice during adult thyroid and parathyroid surgery.[11] RLN stimulation can facilitate identification and mapping of the nerve, particularly in difficult or revision cases, as well as provide prognostic information about postoperative RLN function.[12] IONM demonstrates a 99% negative predictive value and 75% positive predictive value of postoperative VCP in adults.[13] This real-time data can be used to optimize surgical decision-making to reduce bilateral VCP risk; in cases of intraoperative loss of signal (LOS) during IONM, second-stage completion thyroidectomy after recovery of neural function is a cost-effective approach.[14]

In children, the prognostic application of IONM is particularly strategic given higher rates of paralysis, need for bilateral surgery, and prolonged survival unique to the pediatric population. This review focuses on the application of IONM technology in pediatric thyroid surgery, including what is known on the subject, with a special focus on monitoring technique and optimizing use of IONM in children.

2 | METHODS

This review is intended to present a summary of what is known about pediatric intraoperative recurrent laryngeal nerve monitoring, followed by a "how to" guide and expert opinion statements to implement and optimize use of this technology in children. The authors span a variety of disciplines relevant to the subject of pediatric IONM, including general surgery, endocrine surgery, pediatric surgery, and pediatric otolaryngology and members of the American Head and Neck Society Endocrine Surgery Section (AHNS-ES) as well as the International Nerve Monitoring Study Group (INMSG). An extensive literature review was conducted, including a PubMed literature search, to identify relevant and the most current information on the subject using the terms *thyroidectomy*, *thyroid surgery*, *pediatric*, *child*, *adolescent*, *laryngeal nerve*, *laryngeal nerve monitoring*, *paralysis*, *nerve injury*, both individually and in combination. Expert opinion statements were informed using the literature review as well as application of a recent consensus statement by the American Association of Clinical Endocrinologists (AACE) and the AHNS-ES on pediatric thyroid surgery as well as INMSG guidelines. Opinions were drafted by writing subcommittees then circulated to and agreed upon by the authors.

3 | DISCUSSION

3.1 | Pediatric IONM in the published literature

3.1.1 | Intermittent intraoperative nerve monitoring (IIONM)

Brauckhoff et al. published the first retrospective study of IONM in children 3–16 years of age in 2002.[15] Intermittent stimulation of the RLN was performed using a stimulation probe while recording the electromyographic (EMG) response through bipolar needle electrodes, which were placed through the cricothyroid membrane into the intrinsic laryngeal muscles. The study compared 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 unmonitored group (1.19%).[15] Meyer et al. subsequently published a smaller retrospective study of 16 nerves at risk during thyroid surgery using the same IOMN technique as Brauckhoff et al. involving children 11–16 years of age. Postoperative temporary VCP occurred in one case despite a normal intraoperative electromyogram.[16]

IONM through additional techniques in children has also been reported. White et al. conducted a small retrospective study involving five pediatric patients age 11–17 years in whom RLN monitoring was achieved using an endotracheal tube (ETT) with integrated surface electrodes, allowing both passive and stimulation-based monitoring of the thyroarytenoid muscle.[17] In this series, one adolescent with papillary thyroid cancer demonstrated diminished EMG amplitude after RLN dissection, which was predictive of a transient VCP; maintenance of baseline EMG signal was predictive of normal postoperative function for the remaining nerves at risk. The authors acknowledged that limited sizes of ETT with integrated surface electrodes are available for pediatric monitoring, however.

As an alternative to commercially available ETT with integrated surface electrodes, manual placement of adhesive electrodes onto a desired-size ETT has been described.[17–19] A series utilizing adhesive electrodes placed onto ETT for IONM of 167 adult nerves at risk during thyroid surgery demonstrated a 100% correlation between intraoperative findings and 72-h postoperative laryngeal examination.[18] Propst et al. published a retrospective series evaluating IONM in 25 children 4–17 years of age; 46% of cases used ETT with adhesive electrodes and the remainder used commercially available ETT with integrated electrodes.[19] Responses were obtained for all but one nerve at risk (2.3%). The authors noted that adhesive electrodes could be applied to ETT as small as size 4.0.

Endolaryngeal electrode placement for IONM in pediatric thyroid surgery has also been described.[20–23] In 2013, Cheng and Kazahaya reported their experience using hookwire electrodes, placed directly into the vocalis muscle through laryngoscopy after intubation. In 17 consecutive patients undergoing thyroid surgery, age 4–15 years, one transient VCP (3.1% of surgeries) was reported.[20] This method provides enhanced reliability and sensitivity.[20,24,25] However, drawbacks of hookwire electrodes include an increase in the operative time, need for experience with laryngoscopy, and risk of electrode dislocation.

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. However, the authors acknowledged that accuracy and predictive value of this method are not well established in children.[17] Liddy et al. reported a series of 20 adult patients, in whom PCA muscle EMG was compared to vocalis muscle EMG generated using ETT with integrated electrodes. They documented that PCA EMG waveform parameters showed no statistically significant differences in mean latency values during stimulation of the vagus, RLN, or EBSLN compared to ETT recordings.[26] 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.[27]

Other studies have used a combination of methods based on patient age but have not compared the results of each method. Akkari et al. published a single-center retrospective study of 64 pediatric patients with 93 nerves at risk. ETT with integrated electrodes were used for children 8 years and older. In children younger than 8 years, one of three different techniques was used: (1) hookwire electrode placement, (2) electrode placement in the vocal cords through thyroid cartilage dissection, and (3) direct visualization via nasal endoscopy. The authors did not report how many patients were included under each of the three techniques. Only one patient, who was monitored via an ETT with integrated surface electrodes, had permanent RLN injury.[28]

3.1.2 | Continuous nerve monitoring

The largest study of pediatric IONM to date is a single-center experience between 1998 and 2016, published in 2018.[29] This retrospective study included 504 children undergoing thyroidectomy procedures. Schneider et al. utilized intermittent IONM (IIONM) during the first half of the study, and continuous IONM (CIONM) during the latter half. IIONM was achieved using hand held stimulation probes and needle electrodes; CIONM was performed using circumferential clip electrodes placed around the vagus nerve and ETT with either integrated or adhesive surface electrodes. LOS was defined as loss of audio tone and/or nerve amplitude <100 μV at 1–2 mA stimulation. In cases of LOS or failure to recover at least 50% of baseline amplitude after a 20-min 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 eight out of 10 children.

The authors also studied EMG signal characteristics and compared IIONM to CIONM. 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 the 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 and improve contact with the 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.[29]

3.1.3 | External branch of the superior laryngeal nerve (EBSLN) injury and monitoring

The EBSLN is at high risk during superior pole dissection and ligation of the superior thyroid vessels.[30] 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 the singing voice significantly. Rates of EBSLN injury in the adult literature range from

0% to 58%.[31] In children, current literature on postoperative outcomes focuses on transient or permanent VCP related to RLN injury. There is no literature describing EBLSN monitoring in children, and rates of EBSLN injury and resulting dysphonia in the pediatric population after thyroid surgery are unknown. These represent an important area of future research.

3.2 | Pediatric intraoperative nerve monitoring techniques

Based upon the experiences of various authors in this expert panel 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 1). Please be advised that techniques and equipment mentioned below are examples to make it easier for 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 the equipment described below.

3.2.1 | Endotracheal tube with integrated surface electrodes

This technique detects vocalis muscle EMG. If an age/size appropriate commercially available ETT with integrated EMG electrodes is available, it should be used (Figure 2A) [e.g., 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 the time of intubation, should the selected tube be too large for the child's airway (see Table 1).

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 5.0 mm, OD 6.5 mm). 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

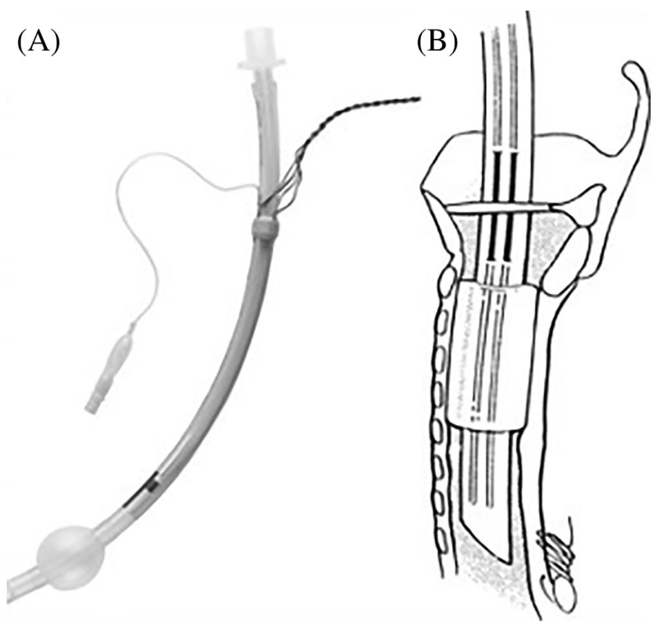

FIGURE 2 Intraoperative nerve monitoring using integrated endotracheal tube surface electrode technique. (A) A NIM TriVantage™ EMG Endotracheal Tube. (B) Proper intraluminal positioning of endotracheal tube electrodes

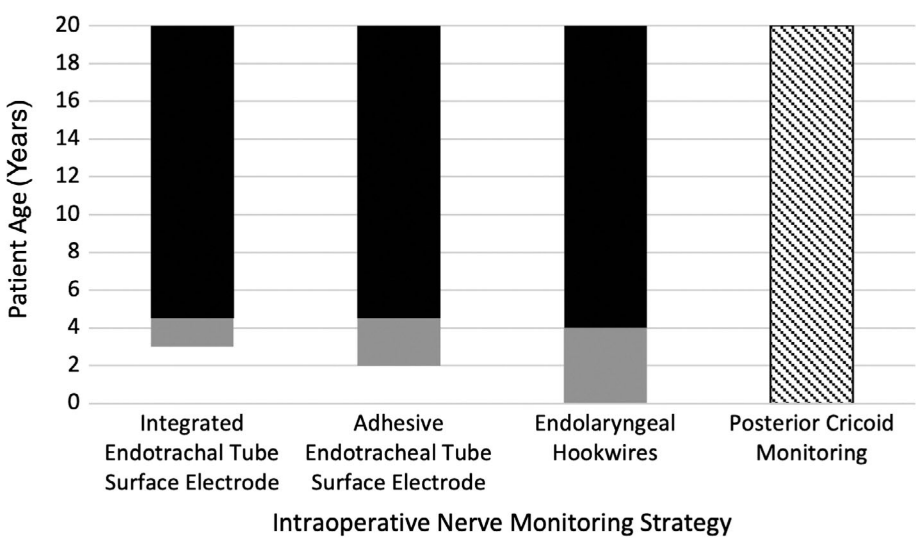

FIGURE 1 Intraoperative neuromonitoring options stratified by age. *Solid black*: technique is reported in the literature at this age; *Solid gray*: technique can be considered in this age based on author experience and patient size; *Pattern*: technique has been studied in adult patients and described for use in the pediatric population

younger children; an alternative method for IONM should also be available as a back-up (Table 2).

The surgeon and anesthesia team should review the ETT outer diameter to ensure that 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. When using an endotracheal ETT with integrated surface electrodes in younger children, tube length also needs to be considered; the ETT tip may be deep in the trachea when the tube electrodes are positioned optimally against the vocal folds. 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.

TABLE 1 Integrated electrode endotracheal tube sizes with suggested appropriate age ranges

Tube size (ID), mm	OD, mm (NIM TriVantage®, NIM Standard®, NIM Contact®)[a]	Age range, years
5.0	6.5, N/A, N/A	5–8[b]
6.0	8.2, 8.8, 9.0	9–12
7.0	9.5, 10.2, 10.5	13–18

[a]Tubes manufactured by Medtronic, Jacksonville, Florida.
[b]5.0 tube may be appropriate for some children younger than 5 years of age.

3.2.2 | Endotracheal tube with adhesive surface electrodes

This technique detects vocalis muscle EMG. If a correct-size ETT with integrated surface electrodes is not commercially available, one can be created by applying adhesive electrode pads to an age-appropriate standard ETT above the tube cuff. Examples of adhesive electrodes that can be used to create a monitoring tube include: Dragonfly electrode (Neurovision Medical, Ventura, California) (Figure 3A); or laryngeal surface electrodes (Invotec International, Jacksonville, FL).

The ETT should be straightened, the adhesive electrodes should be wrapped around the ETT with the electrode midline near to the posterior aspect of the ETT, and the free ends of the electrode padding should be wrapped around the ETT. Care must be taken to trim the electrodes sufficiently such that ends do not overlap after they are wrapped around the 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 a slight posterior positioning of the electrode pads (Figure 3B, Table 2). Electrode wires can be taped along the length of the ETT to reinforce positioning and prevent displacement during intubation, which has been described in up to 7% of cases.[17] The monitoring ETT should be positioned to ensure that the vocal cords are in contact with the middle of electrode array (Figure 2B). Tube position should be confirmed

TABLE 2 Comparison of IONM techniques

Technique	Technical considerations: Muscle monitored	Separate: laryngoscopy required after intubation	Adhesive electrode pad required	Intraoperative displacement risk increased	Considerations specific to children versus adults (> 18 years)
Endotracheal tube with integrated surface electrode	Vocalis	No	No	No	• Age appropriate tube may not be commercially available • For young children, tube length below electrode array may be too long
Endotracheal tube with adhesive electrode	Vocalis	No	Yes	Yes	• Electrode pad may need to be trimmed to prevent overlap when applied to smaller tube
Postcricoid adhesive electrode	Posterior cricoarytenoid	Yes	Yes	Yes	• No pediatric data available
Endolaryngeal Hookwire	Vocalis	Yes	No	Yes	

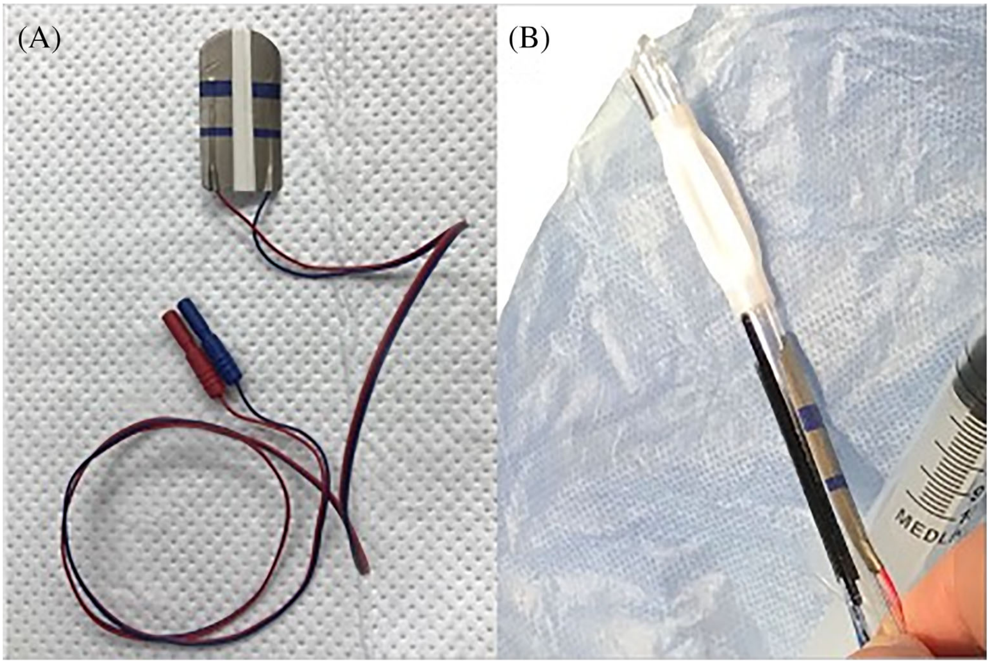

FIGURE 3 Intraoperative nerve monitoring using adhesive endotracheal tube electrode technique. (A) An adhesive electrode (Neurovision Medical, Ventura, California). (B) Positioning of an adhesive electrode on an age-appropriate endotracheal tube [Color figure can be viewed at wileyonlinelibrary.com]

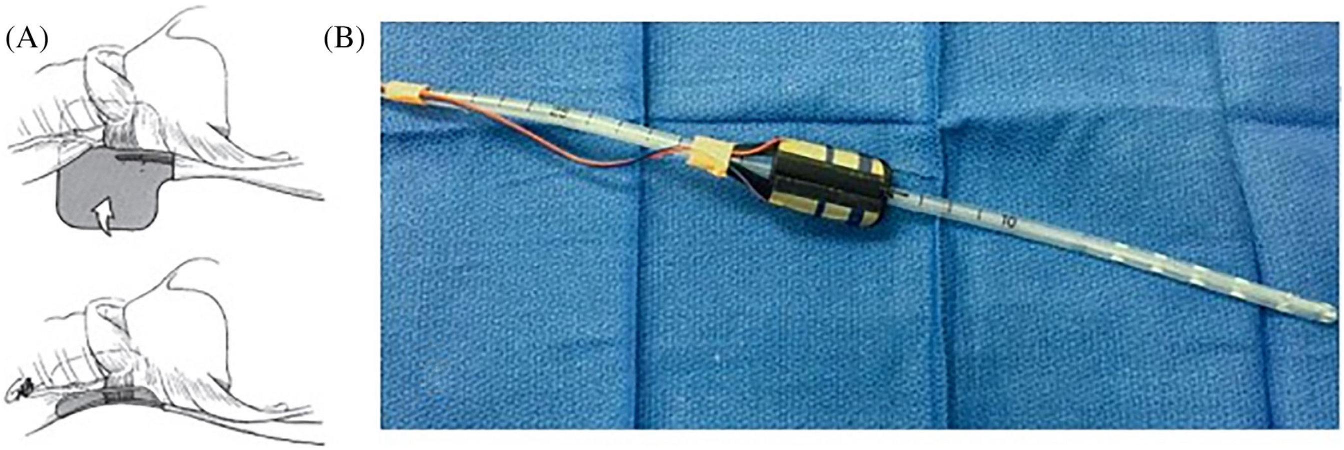

FIGURE 4 Intraoperative nerve monitoring using posterior cricoarytenoid monitoring technique. An electrode measuring posterior cricoarytenoid muscle activity can be applied to the postcricoid region directly (A), or positioned onto a nasogastric tube that is then positioned in the postcricoid area (B) after intubation [Color figure can be viewed at wileyonlinelibrary.com]

after patient positioning through direct visualization (direct laryngoscopy or video laryngoscopy) or EMG recording variation with respiratory movements.[32]

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.

3.2.3 | Postcricoid electrode technique

This technique detects 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 (e.g., Neurovision Medical, Inomed, Medtronic & Stryker) is placed against the postcricoid region through direct laryngoscopy after endotracheal intubation (Figure 4A).[17] Alternatively, adhesive electrodes can be secured to a nasogastric tube with sutures and the tube positioned in the hypopharynx after endotracheal intubation (Figure 4B).[26] This second method of PCA monitoring facilitates subtle repositioning of the electrode pad more readily (Table 2).

This technique allows for monitoring of both adductor and abductor responses; therefore, when combined with ETT electrode monitoring, it has the potential to be a more reliable method for predicting a patent airway postoperatively.[26,27] PCA monitoring may also be useful in cases of extra-laryngeal RLN branching, during which the nerve is more prone to injury, particularly when motor nerves are found in posterior as well as anterior branches of the nerve, which occurs in a minority of patients. In a study by Barczynski et al., in 2500 RLNs at risk from 1230 patients, 613 branched RLNs were reported, among which eight nerves had posterior branch motor nerves.[33] PCA monitoring can detect an abductor response in these cases.

We did not find any reports of this technique being used in pediatric population to date, though it has been described for use in children by White et al.[17]

3.2.4 | Hookwire electrode technique

This technique detects vocalis muscle EMG. After configuring hookwire electrodes into a bent shape (Figure 5A), the surgeon can insert hookwire electrodes into the vocalis muscles, both anteriorly and posteriorly, on each side under direct visualization via suspension laryngoscopy (Figure 5B). Hookwire electrode placement is confirmed by checking impedances or assessing for respiratory variation in the 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) it requires surgeon experience with suspension microlaryngoscopy; and (3) even for the skilled laryngoscopist, this may add up to 20 min 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, such as trauma to the vocal fold, which should be discussed prior to the procedure; a separate informed consent may be needed for this procedure. Similar to the risk of an ETT shifting and losing contact, there is risk of the electrodes dislodging from the vocalis muscle intraoperatively (Table 2).

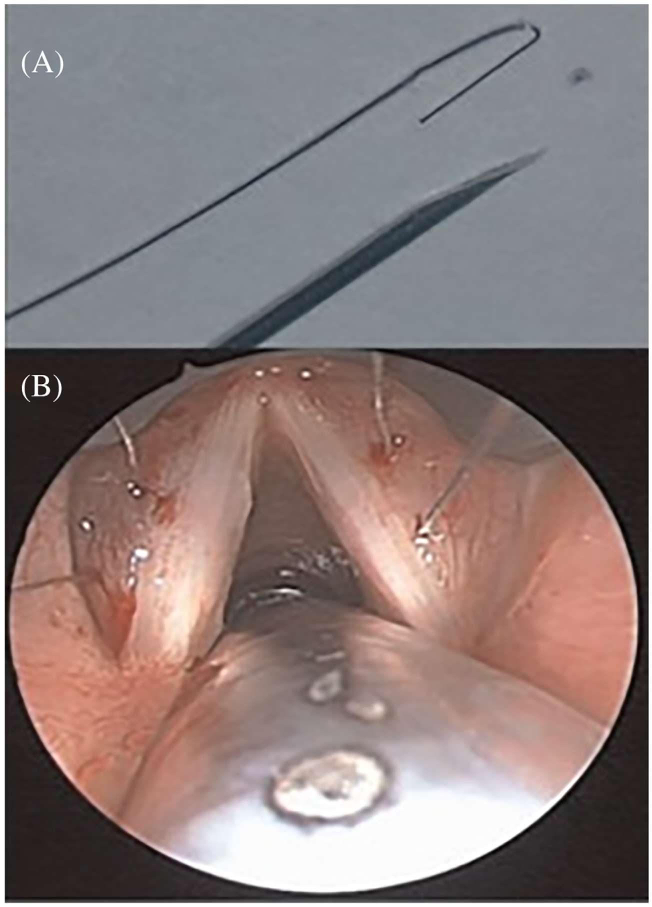

FIGURE 5 Intraoperative nerve monitoring using endolaryngeal hookwire technique. (A) A hookwire electrode bent before placement. (B) An endoscopic view of endolaryngeal hookwire electrode placement [Color figure can be viewed at wileyonlinelibrary.com]

3.3 | Considerations for nerve monitoring in pediatric thyroid surgery

These expert opinion statements on pediatric IONM during thyroid surgery are based on the writing committee's expert opinion, review of recent scientific literature, and application of a recent consensus statement by the AACE and AHNS-ES on pediatric thyroid surgery as well as INMSG guidelines. They are intended to help optimize the use of IONM during thyroid procedures in children.

> **Statement 1.** *(1a) IONM can be considered in all pediatric thyroid surgeries; (1b) IONM may be most beneficial when performing pediatric total thyroidectomy or in hemi-thyroidectomy where the contralateral vocal cord is paralyzed to mitigate the risk of bilateral VCP and tracheotomy; (1c) IONM may be most beneficial 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 the technique used, pediatric IONM is safe. Applications of IONM in the pediatric population are similar to those in adults. IONM expedites identification and aids in RLN mapping.[11,34] 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 VCP 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.*

Patients and their families should be informed when 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.[35] Surgeons wishing to utilize IONM in children should be familiar with the different methods available for IONM in this population and be prepared to utilize more than one method if needed (Figure 1). Families should understand which methods will be employed, particularly if laryngoscopy and needle electrode placement will be attempted.

> **Statement 3.** *(3a) All children undergoing thyroid surgery should undergo preoperative and postoperative voice evaluations. (3b) Preoperative laryngeal examination may be most beneficial for children with voice abnormalities, prior history of neck or chest surgery, or in whom there is a suspicion of thyroid malignancy or lymph node metastases. (3c) Postoperative laryngeal examination should be considered in cases of postoperative voice abnormality or intraoperative concern for nerve injury.*

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 and breathing.[34] The INMSG guidelines recommend preoperative and postoperative laryngoscopy as part of the standard RLN monitoring protocol in adults.[36] In adults, the 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.[37–40] Intraoperatively, when a RLN is found to be invaded by a tumor, knowledge of preoperative function of both ipsilateral and contralateral vocal folds is very valuable in guiding surgical management of the affected nerve.[39]

A recent consensus statement published by the AACE and AHNS-ES recommends preoperative laryngeal examination for all children undergoing thyroid procedures.[6] We encourage that children undergoing thyroid surgery have a preoperative laryngeal examination, particularly those at high risk for nerve injury. This preoperative evaluation is important when a bilateral or completion thyroid procedure is planned or in children with symptoms of vocal cord dysfunction, such as dysphonia, aspiration, or stridor to aid in surgical planning.

Postoperative laryngeal examination has been recommended for adult patients with thyroid cancer[38] or in adults reporting voice change following surgery[37]; 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.[37] Postoperative laryngeal examinations should be performed in children with postoperative voice change or in whom there is intraoperative concern for nerve injury, and can be considered for quality assessment. When postoperative laryngeal dysfunction is identified, the child can be referred to an otolaryngologist. This referral facilitates coordination of care with voice and speech pathologists and enables early treatment, including surgical interventions, to optimize voice and swallowing outcomes.[37]

In children, laryngeal examination is best achieved using transnasal flexible fiberoptic laryngoscopy, which can be performed quickly using pediatric laryngoscopes in an office setting. Laryngeal function can also be assessed through transcutaneous laryngeal ultrasound.[41]

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

Good communication between the surgical and anesthesia teams is essential when IONM is planned. The anesthetist should not use long-acting paralytics regardless of the IONM technique selected, as these may depress EMG responses. Based on published evidence and their clinical experience, Macias et al. have published an interdisciplinary collaborative anesthesia protocol for monitored neck surgery.[42] When an ETT with surface electrodes is used, correct positioning of the ETT with optimal contact between the electrodes and both vocal cords should be verified.[42] Video-assisted intubation equipment, such as with a video laryngoscope (e.g., McGRATH by Medtronic, King Vision by Ambu & Glide Scope by Verathon), can be helpful so that both teams can visualize the 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, the ETT should be visually inspected or respiratory variation of the EMG signal be confirmed after the patient is positioned with neck extended for surgery.[11]

> **Statement 5.** *Surgeons planning to use IONM should be familiar techniques and understand how IONM data can be utilized for surgical decision making.*

There are INMSG guidelines available to assist surgeons in understanding the use and interpretation of IONM in thyroid surgery and how it can assist surgical decision making. 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.[31,35,36,43] RLN IONM can facilitate identification of the RLN during dissection and help to identify anatomic variants of the RLN.[35] Additionally, IONM can help localize the site of RLN injury in cases of signal loss, which in adults is often related to traction at the ligament of Berry.[35] Frequently, injured nerves appear intact visually, but are associated with EMG signal change.[44]

There is no consensus about the pediatric definitions of IONM standards, such as adequate initial baseline amplitude, latency, and LOS. In their study of pediatric IONM, Schneider et al. used similar definitions to the INSMG guideline recommendations for adults. Based on the fact that Schneider et al. successfully applied adult definitions of IONM parameters in the pediatric population and showed that the median IIONM values remained the same across all age groups in a pediatric population, it may be possible to use adult IIONM INMSG guideline definitions for pediatric IIONM.[29] Adult data may serve as a model for how changes in baseline latency and amplitude can be used to change intraoperative management.

To appreciate a change in signal, surgeons must have an adequate initial baseline measurement. For adults, INMSG recommends an initial vagal waveform amplitude of 500 μV with a stimulation current of 1–2 mA. 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 s. Once response amplitudes are <100 μV, which serves as the threshold for LOS, the 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 μV, after LOS; when this is not achieved 20 min after LOS occurs, there is an up to 80% risk of VCP postoperatively in adult patients.[35,45]

Adult studies demonstrate the risk of bilateral VCP increases to 17% when contralateral surgery is pursued despite LOS on the first side; these injuries could be avoided by aborting or staging second side surgery.[35] Staging completion surgery has not been shown to negatively impact oncologic outcomes in adult patients.[46] While staging surgical procedures 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 aid in surgical decision making for invasive thyroid disease. In adults, RLN invasion has not been shown to negatively impact overall survival,[47] though it is associated with a higher rate of locoregional recurrence.[43] Neural invasion in DTC is a slow process; thus, often RLN function may be preserved despite malignant invasion.[48] The INMSG recommends that nerve preservation be considered in patients with maintenance of some glottic function on preoperative laryngeal examination or proximal stimulability on EMG, taking the degree of nerve invasion and invasion of other anatomic sites, underlying pathology, and availability of and patient's ability to tolerate adjuvant therapies into account.[43] When the proximal RLN is stimulable to some degree using IONM, even when gross laryngeal dysfunction is noted, some functional activity may be imparted by the remaining functional nerve fibers. The INMSG notes that resecting these remaining axons could lead to worsening of voice outcomes and dysphagia,[43,49] negatively impacting postoperative quality of life. The INSMG recommends that when ipsilateral dissection reveals an invaded nerve with maintenance of a 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 min, return to the ipsilateral procedure and nerve dissection should be staged.[43]

Long-term data on nerve preservation in the setting of preserved glottic function or EMG signal are 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 of patients with pediatric thyroid cancer, even in advanced stages.

4 | CONCLUSION

IONM of the RLN is commonly used during adult thyroid surgery to facilitate nerve identification, mapping, and prognosticate postoperative neural function. Though IONM in the pediatric population is less studied and understood, 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 should be prepared to perform laryngeal examinations, be familiar with neural monitoring methods, and be knowledgeable about proper techniques to optimally use this technology. 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 the pediatric population.

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DATA AVAILABILITY STATEMENT

Data sharing is not applicable to this article as no new data were created or analyzed in this study.

CONFLICT OF INTEREST

The authors declare that there is no conflict of interest.

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