ORIGINAL ARTICLE

Utility of Intraoperative Neurophysiological Monitoring in Thyroid Surgeries

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ABSTRACT

With the ultimate objective of reducing nerve injury, considering the uniqueness of each surgery to accommodate the patient best relies heavily on the intricacies presented within the surgery coupled with an understanding of when and how to implement monitoring. Thyroid and parathyroid surgeries present significant risks to patient outcomes, with the most frequent postoperative deficits resulting from injury to the vagal nerve and the recurrent laryngeal nerve (RLN). While visual identification has historically been used, the potential of permanent vocal cord damage necessitates new methods. As these nerves are particularly susceptible to insult during these procedures, we sought to establish the connection between IONM and analyze the role it plays in the reduction of these deficits.

Advantages alongside limitations of IONM were considered as we compared the success rates of nerve function retention and instances in which it was reported that monitoring did not produce ideal outcomes. The implications of these findings suggest that IONM aids in the early determination of damage, allowing clinicians the opportunity to make revisions that prevent loss and best preserve the integrity of nerves following procedures. Proper application of developing protocols should influence physicians' decisions of utilizing IONM techniques in the most advantageous way to the case, amending surgical strategy when needed.

INTRODUCTION

The thyroid gland is one of the largest endocrine glands located in the anterior compartment of the neck, inferior to the thyroid cartilage. The thyroid is a butterfly-shaped gland consisting of left and right lobes connected by an isthmus and posteriorly attached to the cricoid and tracheal cartilage. Hormones released by the gland travel through the bloodstream and affect almost every body part, from the heart and brain to the muscles and skin. The thyroid controls how the body's cells use energy from food in a process called metabolism. Normal thyroid lobe dimensions change from birth into adulthood: the length (L or craniocaudal) diameter is 1.8 to 2.0 cm in newborns and 4.0 to 6.0 cm in adults. In comparison, the A-P dimension measures 0.8 to 0.9 cm in newborns and 1.3 to 1.8 cm in adults. [1].

The thyroid gland uses iodine from food to make two thyroid hormones: triiodothyronine (T3) and thyroxine (T4). It also stores these thyroid hormones and releases them as they are necessary. Two areas in the brain, the hypothalamus and the pituitary gland, help control the thyroid gland. The hypothalamus releases thyrotropin-releasing hormone (TRH), which stimulates the pituitary gland to release thyroid-stimulating hormone (TSH). When low thyroid hormone levels, they secrete more TRH and TSH, stimulating the thyroid to make more hormones. When thyroid hormone levels are too high, they secrete less TRH and TSH, which reduces hormone production by the thyroid. (Michigan Medicine, 2020). Posteriorly to the thyroid, four parathyroid glands maintain serum calcium levels.

Thyroid and parathyroid surgery (TPTS) is associated with a high risk of injury to the recurrent laryngeal nerve (RLN), superior laryngeal nerve (SLN), and voice changes. The RLN is a branch of the vagus nerve (Cranial Nerve X) that supplies motor function and sensation to the larynx, and the SLN innervates the intrinsic muscles of the larynx, except for the cricothyroid muscle. The RLN branches in front of the Vagus nerve at the subclavian artery on the right and the aortic arch on the left. The RLN then loops under the artery and ascends along the tracheoesophageal groove. The association between a pre-operative RLN palsy and thyroid disease is usually suggestive of locally advanced malignant thyroid disease by nerve invasion. The risk of benign thyroid disease causing paralysis to the RLN is extremely rare and has been scarcely reported.

Intraoperative neuromonitoring (IONM) in thyroid surgery facilitates the identification of anatomical structures within the surgical field to aid the surgeon in reducing the frequency of vocal cord paralysis [2]. IONM of the RLN during the surgery provides feedback about any activity that may cause harm and provides the surgeon with a prognostic indicator of postoperative nerve function by assessing the nerve stimulation threshold at the end of the procedure.

IONM, intermittent or continuous, evaluates the functional state of the nerves and is being increasingly used [3]. The use of IONM during thyroidectomy confirms the functional integrity of the RLN and facilitates identification of the RLN before visualization during operations, especially for high-risk situations. IONM contributes to RLN protection in several ways. IONM application in thyroidectomy can facilitate nerve identification, which is associated with a higher chance of nerve identification and shorter operation time [4].

METHODS

A retrospective evaluation of patients who had undergone thyroid surgery with intraoperative neuromonitoring. Thyroid surgery was previously conducted by traditional visual identification of the recurrent laryngeal nerve to prevent lesions or harm. IONM in thyroid surgery allows for accurate RLN identification to prevent complications.

Continuous IONM detects the possibility of a lesion before it occurs. Reduces incidence of nerve palsy/anatomic integrity but not functionality. Direct visualization of the RLN nerve is sometimes impossible due to scar tissue or anatomic variation due to a goiter or thyroid cancer nodule.

Patient selection:

Raw data from 50 surgeries performed by one neuromonitoring team from November 2018 to February 2021 showcase a thyroid surgery performed with IONM. The surgeries included 11 parathyroidectomies, 20 hemi-thyroidectomies, and 19 total thyroidectomies. The typical criteria for thyroid surgery were determined to be either due to a goiter, hyperthyroidism, or cancerous mass. The IONM modalities performed in each case included Train-of-Four and Cranial EMG (Table 1).

Diagnosis	Surgery Performed
Parathyroid adenoma	Parathyroidectomy
Hyperthyroidism	Parathyroidectomy
Hyperparathyroidism	Parathyroidectomy
Left Neoplasm of endocrine gland	Thyroid lobectomy – left
Left Substernal Thyroid Goiter	Thyroidectomy – Hemi left
Right Thyroid Goiter	Thyroidectomy - Hemi right
Thyroid papillary Carcinoma	Thyroidectomy - Total
Graves' Disease	Thyroidectomy - Total
Thyroid Multinodular	Thyroidectomy - Total

Table 1. Table showing the surgeries performed for each diagnosis of the thyroid.

Anesthesia

Total Intravenous Anesthesia (TIVA) was induced to enable continuous monitoring. A short-acting paralytic, such as succinylcholine, was used only at intubation to properly place the intubation tube with the IONM strip electrodes on it. Lidocaine on the tube was avoided to prevent numbing of the vocalis muscles. Anesthesia intubation places the endotracheal tube with pre-attached electrodes (Medtronic Xomed - Jacksonville, Florida, USA) after positioning the patient supine. It plays a key role in placement due to hyperextension of the neck. Placement of the tube must be maintained if the patient is moved, as it can change the connection of the surface electrodes to the vocal cords.

The Train of Four (TOF) was obtained from a subdermal needle electrode placed in the bilateral abductor pollicis brevis, the abductor digiti minimi, and the abductor hallucis performed by stimulating from the median and posterior tibial nerves. Train of Four was monitored for the remainder of the cases.

Intraoperative Neurophysiological Monitoring (IONM)

For Electromyography (EMG) to be properly recorded, electrodes were placed on the intubation tube with the contact strips resting upon the vocal cords. The type of tube electrode varied per procedure and included types such as the NIM's tube, Xomed tube, or Medtronic ENT tube with the DragonFly electrode. Or electrodes were placed in the body of the vocalis muscle.

A stimulator probe was placed on the recurrent laryngeal nerve (RLN) or Vagus nerve and transmitted current to the nerve and a grounding electrode. The repetition rate for thyroid procedures is determined to be 2.39-3.79 Hz with a pulse width of 200 µs and stimulation intensity of 0.05-4 mA. The nerve stimulation probe can be monopolar or bipolar, and continuous monitoring electrodes can be monopolar or bipolar. The cathode and anode were placed according to the hemisphere stimulated for Transcranial Motor Evoked Potentials (MEP). Two channels for the left and right vocal cords are sufficient for thyroid surgery. After the correct positioning of electrodes has occurred, the impedance must be verified to be less than 5.0 kΩ. A value above 5.0 kΩ would indicate incorrect positioning or lack of contact with the patient's vocal cords. ISI is set to 2-4 ms (250-500 Hz), and pulse width is set to 50 or 70 µs. The cut-off for the high-pass and the low-pass filter for MEP are typically 10-5000 Hz but can be refined more, depending on the surgery (ACNS, 2015).

Corticobulbar MEP (CoMEP) of laryngeal muscles in thyroid surgeries has been determined to effectively predict the postoperative function of the RLN and vagal nerves. CoMEPs are recorded from the vocal cords using electrodes on the EMG tube. A reliable CoMEP was typically defined as an onset latency of vagal MEP between 10 to 13 ms and an amplitude equal to or greater than 200 µV from baseline. A combination of a 70-80 decrease of amplitude or an increase in the threshold of more than 100 volts of MEP and a change in morphology or absence of response is considered alarm criteria. The presence of a train or charge is considered alarm criteria for T-EMG and S-EMG not specific to surgery. The most common cause of an

RLN lesion is tractional trauma, and IONM has been useful in preventing trauma by promptly detecting changes in EMG and MEP amplitude and latency. In the 50 cases reviewed, most alerts occurred during dissection and were viewed in the EMG recording. Though intermittent intraoperative nerve monitoring of the RLN by EMG is valuable for nerve identification during thyroid surgery, continuous intraoperative nerve monitoring allows closer monitoring of the RLN function during dissection and removal, as intermittent monitoring will only catch RLN malfunction after the damage. [5].

Signal loss occurs when the original signal obtained from the vagus nerve and/or RLN nerve is no longer occurring. This could lead to a possible vocal cord palsy. However, it has been seen that the signal may improve over the course of the operation, as the most common cause of malfunction is due to intubation tube electrode malpositioning or displacement of electrodes.

RESULTS

Intraoperative neuromonitoring (IONM) provides protection to the recurrent laryngeal nerve (RLN) that cannot be guaranteed by the surgeon's eyesight alone. Of the 50 surgeries performed under Axis Neuro Technicians from November 2018 to February 2021, only five cases resulted in an alert. Of these cases, any alert occurred during dissection of a thyroid gland or irritation of the recurrent laryngeal nerve and returned to baseline once the surgeon was notified. IONM allowed for definite localization and confirmation of the RLN, preventing unnecessary traction and damage.

Although the results among the studies were mixed, several of them found that using IONM during thyroid surgery effectively reduced complications and postoperative deficit. Studies by numerous researchers found that the functional integrity of the recurrent laryngeal nerve was better preserved, and injuries were more often prevented in operations in which IONM was utilized, as well as allowed for procedure modification by the surgeons based on the nerve integrity. Other benefits of IONM being utilized during thyroid procedures included a reduction in the likelihood of vocal cord paralysis and other vocal cord dysfunctions, injury to the external branch of the superior laryngeal nerve, which would also affect vocal integrity postoperatively, as well as vocal fold paralysis and paresis. For example, one prospective study found “significant potential for reduction of temporary palsy” of the RLN using IONM [6]. Another significant result was the documented rates of transient and permanent paralysis of 2.6% and 1.4%, respectively, in patients who received IONM compared to 6.3% and 2.4% in patients without IONM [7]. Other results included a decrease in the duration of the procedures by 37 minutes when using IONM [8], and the use of continuous IONM was found to help hone surgical skills with constant feedback of nerve function during operation and reduce permanent vocal cord palsy rate to 0% in experienced hands [5]. These studies implicated IONM utilization in thyroid, nerve, and vocal cord integrity and risk minimization.

A few studies found no conclusive and significant difference in the incidence of injury between IONM utilization and non-IONM utilization. One study found no significant difference between IONM and visual nerve identification [9], and another found no statistical difference between the outcomes of IONM and non-IONM surgeries [10]. However, one study reported a decreasing overall incidence trend after introducing IONM despite finding no difference between individual procedures [11]. Several studies concluded mixed results of using IONM and/or discussed limitations of IONM. They found that aspects of using IONM, like varying amplitudes and high sensitivity, yielded accuracy concerns or had mixed results regarding nerve identification rates using IONM, for example, and recommended utilizing IONM during procedures with caution. One example, however, stated that IONM is underutilized during procedures regarding identifying the external branch of the superior laryngeal nerve [12].

DISCUSSION

Causes of RLN injury can occur due to transaction, clamping, traction, electrothermal injury, mechanical trauma, and ischemia, of which traction injury is the most common mechanism. The ability to definitively recognize nerve injury or evaluate severity solely by visualization can be difficult. Surgeons increasingly use IONM to assist in RLN identification to reduce the risk of injury [13]. Although most common complications experienced by patients undergoing thyroid surgeries are associated with injuries to the RLN, injuries to the external branch of the superior laryngeal nerve (EBSLN) can also occur in up to 58% of patients [5]. Visualization of the nerve remains the gold standard for nerve protection and is recommended in the American Academy of Otolaryngology Clinical Practice Guidelines [14]. IONM is a common practice in identifying the nerve anatomical structure and continuous or spontaneous monitoring of nerve activity throughout the surgery.

The EMG IONM modality contributes to early and definite mapping and confirmation of the RLN. This allows surgeons to avoid excessive traction and perceive the identification of extra-laryngeal branches, distorted RLN, and other anatomical variations through direct nerve stimulation [15]. It is generally assumed that normal EMG configuration represents the integrity of neural function in neurosurgeries involving head and neck surgeries. Goretzki and colleagues reported that IONM had a high positive predictive value for abnormal signals. Additionally, they report that the sensitivity of IONM in detecting temporary nerve injuries in macroscopically normal-appearing nerve was 93%, with the specificity of the first and second side dissection at 75-83% and 55-67%, respectively, with an overall specificity of 77% [16]. Multiple aberrant wave morphology and abnormal wave activity are used to indicate differences in nerve insults, including the following: spike trains, associated with nerve stretching, compression, or heating; complex train waves, associated with the activation of multiple groups of motor units at the same time; burst activity, associated with bumping into a nerve and brief mechanically induced activation of many motor units simultaneously or transection of a nerve; and neurotonic discharge, which is highly associated with postoperative deficits, and is correlated with nerve injury. Other additional activities, such as hot or cold irrigation, may also trigger continuous EMG artifacts, requiring stimulation of the subject nerves to ensure no nerve injury has occurred. Although 15% of nerve injuries can be detected physically, 100% of RLN injuries can be identified with IONM intraoperatively [17]. Indirect neurostimulation of the RLN is a better predictor of postoperative RLN dysfunction than direct RLN stimulation. It should be performed to monitor the mechanical intactness of the RLN throughout the surgery. Due to the increased false positive signal rate in direct RLN stimulation compared to indirect IONM, it is advised that direct RLN stimulation be used exclusively to detect RLN anatomy [8]. Monitoring using continuous IONM uses automatic periodic stimulation of the vagal nerve with an automatic software-based assessment of changes in the amplitude of EMG signals. C-IONM allows the surgeon to react promptly to RLN stress, reversing the RLN injury. The vagal nerve electrode from C-IONM can be placed in multiple locations relative to the common carotid artery and the internal jugular vein. This will allow for more efficient nerve propagation signals relative to these vascular components' location [15].

EMG IONM is used on the EBSLN by monitoring the electromyographic glottis response of vocal cord depolarization identified on surface tube electrode arrays placed behind the thyroid muscle. The glottic response is mediated by the two heads of the cricothyroid muscles, known as the human communication nerve. This human communication nerve is known to provide connection to the vocal fold in 41-85% of patients. Thus, the importance of this nerve is underlined not only by its involvement in the use of the vocal cords in the patient but also anatomically in close relationship with the thyroid vessels.

Visual identification of the EBSLN is usually not possible in approximately 20% of patients due to its location deep in the fascia of the inferior constrictor muscle. This highlights the importance of using IONM as stimulation to monitor and identify the nerve properly [6]. EMG can also be used to assess injury to the vagus nerve during brainstem tumor removals, which can also lead to injury of the vocal cords, leading to transient swallowing and speech dysfunction. As the vocal cords are supplied by the RLN branch of the vagus nerve, surface electrodes attached to the endotracheal tube are used during IONM of the cricothyroid muscle during brain stem tumor removal surgeries [17].

Although the use of EMG-IONM provides critical information to surgeons throughout the thyroid surgery, there are limitations to the modality and still a lack of high-quality evidence to justify a change in surgical strategy due to an aberrant loss of EMG signals. An inquiry of German thyroid surgeons showed that 90% of surgical teams surveyed would be willing to change surgical strategy by discontinuing surgery (85%) or taking a less extensive contralateral procedure (9%). However, the positive predictive value of the loss of EMG signal for vocal cord palsy was 30-80% with an experienced surgical team. Most patients retained normal vocal cord function despite the signal loss and thus would undergo unnecessary delayed surgery, increasing further surgical risks. Chiang et al. reported that 42% of patients with pathologic IONM signals regained normal nerve activity during surgery, and Sitges-Serra et al. reported that patients with an initial loss of EMG signal had a 90% chance of recovery before the end of the operation [13]. RLN injury rates are also low in the hands of experienced surgeons (<1%), adding to the difficulty of statistically determining the true benefit of IONM during these surgeries [14].

Additionally, vocal cord injury could be associated with improper intubation procedures, resulting in a malpositioned tracheal tube. This could also present a false IONM signal, further complicating the monitoring throughout the surgery. Further reports and data are still being compiled to review recording parameters and side effects presented after thyroid surgeries. Approximately 40% to 90% of thyroid surgery procedures in the United States and Germany utilize IONM. Among surgeons trained in the era of IONM, the value of the information provided depended on familiarity with the technology.

However, IONM is found to be more common among young fellowship-trained surgeons exposed to IONM throughout their training [12]. Further information about the specific anesthetics and pharmacological approach during these thyroid surgeries is of interest, along with standardization of established guidelines for managing loss of EMG signals during thyroidectomy surgeries. As with all IONM practices and modalities, the experience of the neurophysiology and the surgical team is paramount to ensure the best patient care during thyroid surgery procedures. Experienced IONM surgical teams, including CNIM-certified team members, have less than 50% post-neurological deficits compared to teams with less experience.

CONCLUSION

The standard practice of IONM can help surgeons accurately locate the laryngeal nerves and provide proper and immediate indicators of nerve function when dealing with the complicated neuroanatomy of the thyroid. IONM maintains high success rates of accurately predicting both transient and permanent damage of nerves following thyroid surgeries when used continuously and appropriately. With the practical guidelines provided by the American Clinical Neurophysiology Society, IONM aids in the early determination of damage, allowing surgeons the opportunity to make revisions that prevent the loss and best preserve the integrity of nerves following procedures to further ensure the safety of the patient. Further research is required to determine whether there is enough statistical evidence that IONM causes a reduction in nerve injury or if the reduction is due to the surgical team's experience.

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