NEW PLACEMENT OF RECORDING ELECTRODES ON THE THYROID CARTILAGE IN INTRA-OPERATIVE NEUROMONITORING DURING THYROID SURGERY.

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Abstract (word count: 286)

Objective: During thyroid surgery, extreme caution is needed not to harm the recurrent laryngeal nerve and to avoid vocal cord palsy. Intra-operative neuromonitoring became increasingly popular as an adjunct to the gold standard of visual identification of the recurrent laryngeal nerve (RLN). Electromyographic (EMG) responses are normally recorded by electrodes attached to the endotracheal tube. Alteration in position can lead to false loss of signal. We developed thyroid cartilage electrodes that can be fixed directly onto the thyroid cartilage.

Study Design: Prospective clinical cohort.

Methods: Thyroid surgery with intra-operative neuromonitoring using both endotracheal tube-based electrodes and thyroid cartilage electrodes was performed in 25 patients undergoing thyroid surgery. EMG data were collected and reported as median and interquartile ranges (IQR), and the results were compared with the x Wilcoxon signed-rank test for paired measurements.

Results: After stimulating vagal nerve (VN), recurrent laryngeal nerve (RLN) & external branch of the superior laryngeal nerve (EBSLN), significantly higher EMG amplitudes were measured before and after thyroid resection for the thyroid cartilage (TC) electrodes, in all comparisons except for the right VN. At the level of the left EBSLN, median amplitude of 560mV (IQR 190-1050) before and 785mV (IQR 405-3670) after resection was noted. At the level of the right EBSLN, median amplitude of 425μV (IQR 257-698) before and 668mV (IQR 310-1425) after resection was noted. Median amplitudes of 760mV (IQR 440-1180) and 830mV (IQR 480-1490) were noted at the left RLN, median amplitudes of 695mV (IQR 405-1592) and 1078mV (IQR 434-1895) were noted at the right RLN.

Conclusion: Thyroid cartilage electrodes appear to be a feasible and reliable alternative for endotracheal electrodes.

Keywords: intra-operative neuromonitoring, thyroid cartilage electrodes, thyroid surgery, recurrent laryngeal nerve, external branch of the superior laryngeal nerve

Introduction

During thyroid surgery, extreme caution is needed not to harm the recurrent laryngeal nerve, and to avoid vocal cord palsy. Vocal cord paralysis is a significant complication after thyroid and parathyroid surgery with a prevalence up to 20% in complicated cases, such as cancer, thyrotoxicosis and redo surgery[1]. A structurally intact nerve does not always guarantee normal postoperative vocal cord mobility, and therefore intra-operative neuromonitoring (IONM) has become increasingly popular in thyroid and parathyroid surgery[2,3,4,5]. It has been used to verify and document functional integrity of the recurrent laryngeal nerve since even the external branch of the superior laryngeal nerve can be assessed before and after surgery[6].

As an adjunct to the gold standard of visual identification, neuromonitoring has also proven to be a useful tool for identification of the nerve, assessment and prognostication of its postoperative function. Use of neuromonitoring has led to lower rates of vocal fold paralysis, especially in high-risk cases and has proven to be cost-effective in planned bilateral thyroid surgery[7].

Current neuromonitoring systems consist of a probe for continuous vagal stimulation and a hand-held stimulator for intermittent monitoring and nerve mapping. Recording electrodes are attached or integrated onto the endotracheal tube. Various different electrode placements have been tried: intramuscular, as well as endotracheal tube-based. Because of their ease of setup, their non-invasive nature and the larger areas that can be covered, endotracheal tube-based electrodes have gained popularity and are most widely used[1,8].

One of the most delicate acts before surgery with IONM is the placement of the recording electrodes, which are attached to the endotracheal tube. During surgery, this contact between recording electrodes and the vocal cords must be maintained because loss of signal may indicate imminent nerve damage. Selection of the appropriate size of the endotracheal tube is thus important. Tube electrodes attached to the surface of an endotracheal tube are put in place by the anesthesiologist at the level of the vocal cords. Both the surgeon and the anesthesiologist check the positioning of the endotracheal tube by laryngoscopy[3].

During surgery, maintaining a stable electromyographical (EMG) signal is sometimes difficult since rotation, upward or downward displacement of the tube may cause an unstable EMG signal or even a false loss of signal (LOS). The presence of mucus, blood or saliva in between the electrodes and the vocal cords can distort the EMG signal. A large Italian prospective series of 152 consecutive thyroid operations (with 304 nerves at risk) revealed an intra-operative adjustment of around 10% during surgery [9].

Adjustment or repositioning is troublesome and time-consuming. To detect clinically relevant EMG changes, it is absolutely crucial to calibrate the system at the start of the procedure in order to achieve the largest possible amplitude. Recent publications regarding the impact of positional changes investigated the impact on amplitude and latency in a porcine experiment. This study concluded that if there are amplitude changes without latency changes due to tube rotation and depth changes alone, this could still reflect a neurophysiologic event[8,10]. The relationship between tube displacement and amplitude and latency was investigated by Barber et al.[15], revealing especially amplitude changes with tube malpositioning. Latency is not reliable when the amplitude is low. The endotracheal tube electrodes seem to be the Achilles' heel of the IONM system.

Alternative electrode systems have been sought after and tried. As presented at the 1st world congress of intra-operative neuromonitoring we developed recording electrodes that can be placed directly onto the thyroid cartilage[11]. Since the thyro-arytenoid muscles are attached to the anterior part of the inner surface of this thyroid cartilage, recording trough these types of electrodes could be more stable[7,12]. The aim of this study is to evaluate and compare simultaneously recorded EMG signals using our thyroid cartilage electrodes and the standard endotracheal tube-based electrodes for IONM in thyroid surgery.

Materials & Methods

Study design and setting

This was a prospective clinical cohort in which the use of thyroid cartilage electrodes is assessed in comparison with the standard endotracheal tube-based electrodes. This single center study was conducted from August 2017 to February 2018.

In the Onze-Lieve-Vrouw (OLV) Hospital Aalst, thyroid and parathyroid surgery is routinely performed. Intra-operative neuromonitoring is used in all of our cases, consisting of an S-shaped probe for continuous vagal stimulation and a hand-held bipolar stimulator for intermittent stimulation. This bipolar S-shaped electrode stimulates the VN continuously with 0.8 mA at a frequency of 3 Hz[13]. International guidelines provided by the IONM study group are followed, in which laryngoscopy, vagal stimulation and recurrent nerve stimulation are the key elements[2]. Analysis of our first 960 thyroid surgery procedures showed that in 10% of our cases, neuromonitoring could not be used throughout the whole procedure due to several types of technical failure or dislocation of the tube[11]. We acknowledge this percentage to be quite high, but these displacement rates reflect our initial experience since 2005, when guidelines from the IONM study group were not yet available.

With approval of the ethics committee of the OLV Clinic, cartilage electrodes were developed and used in 25 cases in combination with the standard endotracheal tube electrodes. Neither financial nor any free electrodes were received from the industry.

Patients and exposure

Twenty-five non-consecutive patients who underwent either complete or partial thyroidectomy without lymph node clearance were invited to enroll, and all patients provided written informed consent. Only patients with benign pathology were selected.

All patients had normal preoperative laryngeal examination. Patient characteristics, demographic data, type and laterality of procedure, postoperative complications and EMG data from both electrodes were recorded and analyzed.

The Avalanche® SI (Dr. Langer Medical) neuromonitoring system was used for IONM. Endotracheal tube size 7.5 or 8 was chosen according to the patient's anatomy. Two Dragonfly® Laryngeal Surface Electrodes - 1 Channel, 6.0-7.0 mm bipolar electrodes were put onto the endotracheal tube. Two other dragonfly bipolar electrodes were cut into two separate smaller electrodes.

These adapted electrodes can be placed and fixed directly on the perichondrium of the laminae of the thyroid cartilage with two stitches Prolene® 5/0. No extra dissection is required. (Figure 1a & 1b). These electrodes are placed outside the operative field. After stimulation of the 3 nerves at 0.8 mA, the endotracheal tube-based electrodes and our thyroid cartilage electrodes were used to record the EMG amplitude of both vocalis muscles. All operations were performed by the same senior surgeon (SVS)[11].

Outcomes

Amplitude and latency recording was comprised of two channels. During stimulation: evoked EMG responses and latency times were registered for both recording electrodes at the same time (figure 3). Pre- and postoperative amplitudes (in millivolt, mV) were recorded for both sides. Demographic and clinical data were presented as n (%) or median values and interquartile ranges (IQR). Amplitude was expressed as median values and interquartile ranges (IQR). We registered EMG responses in every single case for both recording electrodes.

All statistical analyses were completed using STATA MP/14 (StataCorp LP). All p-values were two-sided and $p<0.05$ was considered statistically significant. Since the amplitude values were not normally distributed (skewed to the right), the non-parametric Wilcoxon signed-rank test for paired measurements was used to compare these paired measurements of both electrodes. Results are presented as boxplots. Because of the small number of patients, we did not perform a power calculation.

Results

Patients

This study analyzed 25 thyroid surgery procedures (7 unilateral total lobectomies and 18 total thyroidectomies, representing 43 nerves at risk) performed for various thyroid diseases (multinodular goiter (17) and Graves' disease (8)).

Demographic data of the study cohort are shown in table 1. Forty-three nerves at risk were enrolled in our study. Median age at time of surgery was 54 (37-78). Median BMI was 24.8 (18.13-36.76) kg/m^2. Only 4 male patients were included, mainly due to the higher number of women with thyroid disease. One temporary RLN lesion was seen. No permanent hypocalcemia was seen. Three patients (12%) developed a transient hypocalcemia. One transient RLN palsy was observed, due to a type 2 stretch lesion. This patient was included in our analysis.

ET-based versus TC electrodes

Median amplitudes for all nerves and the results of the Wilcoxon signed-rank test are shown in table 2.

Except for the right vagal nerve, the thyroid cartilage electrodes registered statistically significant higher amplitudes before and after dissection. Especially at the level of the EBSLN and the RLN, this difference was remarkable.

With left vagal stimulation, median EMG amplitude was significantly higher before (785mV (IQR 443-979) vs. 325mV (IQR 270-610)) and after thyroid resection (682mV (IQR 360-900) vs. 403mV (IQR 230-530)) with the TC electrodes (p=0.0058 and p=0.0017). No difference was found with right vagal stimulation. Median EMG amplitude was similar before (496mV (IQR 345-1043) vs. 476mV (IQR 317-675)) and after thyroid resection (500mV (IQR 290-904) vs. 370mV (IQR 185-558)). Boxplots for both sides are shown in figure 3.

The TC EMG waveform with RLN stimulation showed robust biphasic morphology with the same polarity of deflection compared to the ET electrodes. With left recurrent laryngeal nerve stimulation, median EMG amplitude was significantly higher before (760mV (IQR 440-1180) vs. 590mV (IQR 233-731)) and after (830mV (IQR 480-1490) vs. 460mV (IQR 270-750)) thyroid resection with the TC electrodes (p=0.0552 and p=0.0042). This statistically significant difference was also seen with right RLN stimulation (p=0.0419 and p=0.0196) before (695mV (IQR 405-1592) vs. 740mV (IQR 230-900)) and after (1078mV (IQR 434-1895) vs. 540mV (IQR 220-1076)) resection. Boxplots for both sides are shown in figure 4.

With left EBSLN stimulation, median EMG amplitude was significantly higher before (560mV (IQR 190-1050) vs. 179mV (IQR 50-250)) and after (785μV (IQR 405-3670) vs. 185mV (IQR 60-310)) thyroid resection with the TC electrodes ($p<0.0004$ and $p<0.0012$). This statistically significant difference was also seen with right EBSLN stimulation ($p=0.0010$ and $P=0.0029$) before (425mV (IQR 257-698) vs. 90mV (IQR 73-270)) and after (668mV (IQR 310-1425) vs. 180mV (IQR 65-265)) resection. Boxplots for both sides are shown in figure 5.

Discussion

This single-center study based on 25 individuals undergoing partial or total thyroidectomy (43 nerves at risk) showed that thyroid cartilage electrodes provide higher EMG waveforms after stimulation of all three nerves at risk during thyroid surgery. Our results show clear biphasic waveforms when stimulating the EBSLN, RLN and vagal nerve. When comparing with the EMG signals from the tube-based electrodes, there is statistically significant higher EMG amplitude. Especially at the level of the EBSLN, where the amplitude of the traditional electrodes only shows a small amplitude artificial response, the TC electrodes produce a strong biphasic waveform with large amplitude. Especially in professional voice users, these large amplitudes could lead to better assessment of postoperative function.

Possible explanation for the higher amplitudes could be the closer contact to the thyroarytenoid muscle, the absence of interference of blood, air or mucus in between the vocal cords and the electrodes or the larger shape of the vocal muscle at its insertion.

We have no reasonable explanation for the lack of difference on the right vagal nerve. Neither do we have a reasonable explanation for the fact that EMG amplitudes of the TC electrodes after resection are larger in comparison to EMG signal before resection. EMG amplitudes before resection are usually larger or equivalent to those after resection, as confirmed by results from the ET electrodes.

ET-Based electrodes have shown a high negative predictive value of (92-100%) but a low and variable positive predictive value (10-90%). It has been shown that a significant decrease or loss of signal has extremely unpredictable outcomes[14]. One of the possible explanations could be a loss of solid contact between the endotracheal tube electrodes and the vocal cords.

To avoid external factors that influence EMG signals, we developed electrodes that can be placed during surgery and which are completely surgeon-controlled. Our electrodes are placed above the upper edge of the cricothyroid muscle to avoid cover up. Our electrodes are smaller when compared to the tube electrodes.

Three published articles (needle electrodes under the thyroid cartilage perichondrium)[12], (anterior laryngeal electrodes)[7], (trans-cartilage surface recording electrodes)[16], have recently supported this technique by publishing preliminary and promising results.

Endotracheal tube movement does not affect thyroid cartilage electrodes and since the electrodes are present in the operative field, they can be easily manipulated if necessary. We have performed cases with thyroid cartilage electrodes when encountering technical problems with our tube electrodes before or during thyroid dissection. Use of TC electrodes may reduce the incidence of false LOS or amplitude drops to provide more stable and reliable IONM. There is no risk attached to the placement or the use of our electrodes. It is a bit more invasive in comparison with ET-based electrodes, but less invasive than needle electrodes. We did not encounter any displacement issues. Older patients with dens, more calcified cartilage could provide a fixation problem, but with the use of needles, initially developed for calcified coronary tissue, a superficial stitch could be placed easily.

Injury to the recurrent laryngeal nerve remains an important cause of morbidity after thyroid surgery. To date IONM guidelines are based upon the use of recording electrodes integrated or fixed on the endotracheal tube to capture EMG signals. The value of IONM as an adjunct to visual identification has been investigated thoroughly[1,12,14-16].

Our preliminary study investigates the use of electrodes placed directly on the thyroid cartilage.

With recording electrodes on the thyroid cartilage, influence of the positioning of the tube on the quality of the detection signal could be avoided. These electrodes are entirely surgeon-controlled. Further investigation is needed to confirm this statement.

Thyroid cartilage electrodes could be a feasible alternative for endotracheal electrodes. Our electrodes provide higher EMG waveforms and latencies for vagal, RLN and EBSLN. At baseline, TC electrodes obtained significantly higher EMG amplitudes. Whether this results in a more stable signal should be confirmed in another study.

When combined with the use of a laryngeal mask, postoperative coughing could be avoided. By using a laryngeal mask all non-surgical trauma to the vocal cords are excluded. More studies are necessary to investigate feasibility and validate our preliminary results. The accessibility of the electrodes in the surgical field is the most important advantage, eliminating any doubt on the correct endotracheal electrode position.

Tables & figures

Table 1. Study cohort demographics.

Study cohort demographics (n=25)		
Age at surgery (median)		54 (37-78)
Sex		
	Male	4 (16%)
	Female	21 (84%)
Body Mass Index (median)		24,8 (18,13-36,76)
Type of surgery		
	Total	18 (72%)
	Left hemi	3 (12%)
	Right hemi	4 (16%)
Indication		
	Goiter	17 (68%)
	Graves	8 (32%)
Nerves at risk		43
Device		
	Focus	6 (24%)
	Open Fine Jaw	19 (76%)
Duration of surgery (median)		90 (60-210)
Weight specimen (median) (grams)		42 (18-382)
Blood loss (median) (grams)		20 (3-145)
Parathyroid glands visualized (median)		3 (2-4)
Hypocalcemia		
	Transient	3 (12%)
	Permanent	0
Revision		0
Recurrent nerve lesion	*Transient*	1 (4%)

Table 2. Comparison of baseline electromyographic amplitudes from the tube-based electrodes and the thyroid cartilage electrodes (values in mV).

	Vagus			
		Larynx	**Tube**	
	N	**Median (IQR)**	**Median (IQR)**	***p***
Before Left	19	785 (443-979)	325 (270-610)	*0.0058*
After Left	18	682 (360-900)	403 (230-530)	*0.0017*
Before Right	19	496 (345-1043)	476 (317-675)	*0.1312*
After Right	19	500 (290-904)	370 (185-558)	*0.0641*
	Recurrens			
		Larynx	**Tube**	
	N	**Median (IQR)**	**Median (IQR)**	***p***
Before Left	17	760 (440-1180)	590 (233-731)	*0.0552*
After Left	17	830 (480-1490)	460 (270-750)	*0.0042*
Before Right	20	695 (405-1592)	740 (230-900)	*0.0419*
After Right	19	1078 (434-1895)	540 (220-1076)	*0.0196*
	EBSLN			
		Larynx	**Tube**	
	N	**Median (IQR)**	**Median (IQR)**	***p***
Before Left	16	560 (190-1050)	179 (50-250)	*0.0004*
After Left	14	785 (405-3670)	185 (60-310)	*0.0012*
Before Right	14	425 (257-698)	90 (73-270)	*0.0010*
After Right	12	668 (310-1425)	180 (65-265)	*0.0029*

Figure 1a. Fixation of the thyroid cartilage electrodes onto the thyroid cartilage with Prolene 5/0.

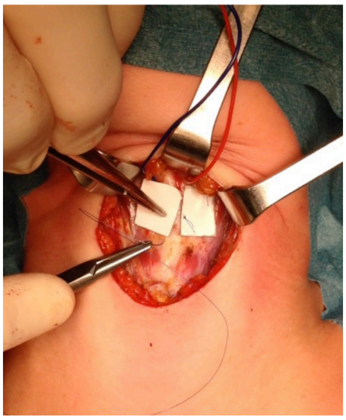


Figure 1b. Positioning of the thyroid cartilage electrodes completely outside the operative field.

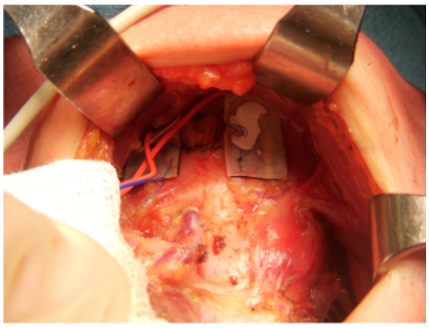


Figure 2. During stimulation evoked EMG responses and latency times were registered for both recording electrodes at the same time (in mV). For readability of the graphics, input EMG signals are decreased 1000 times by adjusting the software settings.

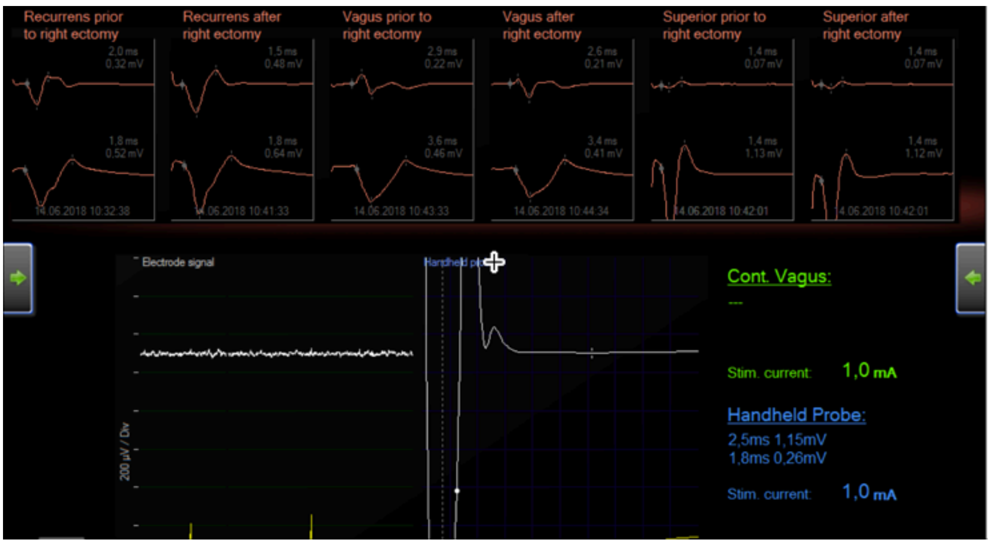


Figure 3. Boxplots of EMG amplitude results after stimulating the vagal nerve before and after resection of the thyroid.

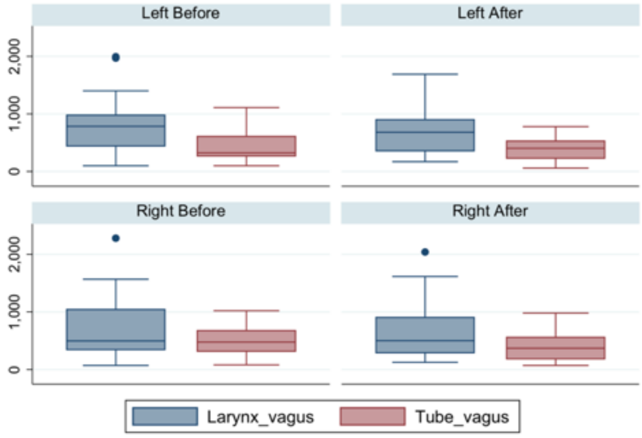


Figure 4. Boxplots of EMG amplitude results after stimulating the recurrent laryngeal nerve before and after resection of the thyroid.

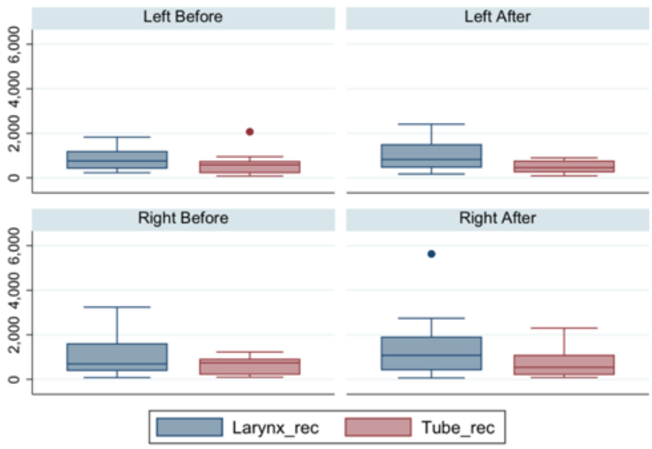
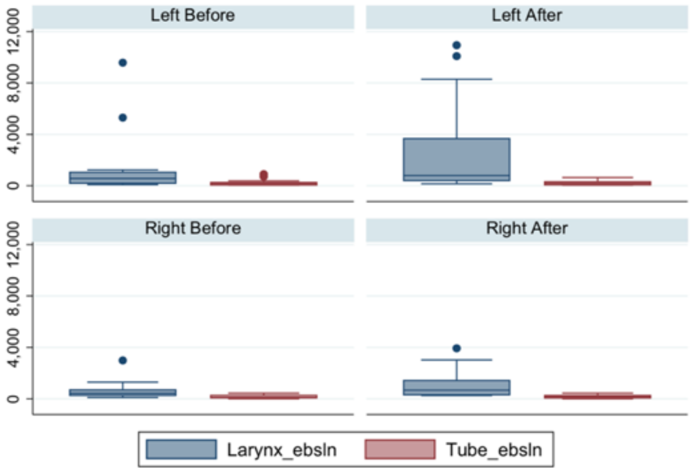


Figure 5. Boxplots of EMG amplitude results after stimulating the external branch of the superior laryngeal nerve before and after resection of the thyroid.



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