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An experimental study of needle recording electrodes placed on the thyroid cartilage for recurrent laryngeal nerve function monitoring during thyroid surgery

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ABSTRACT

Background: Needle electrodes placed on the thyroid cartilage (TC) are an alternative to endotracheal tube (ET) electrodes to assess the function of the recurrent laryngeal nerve (RLN) during thyroid surgery. This study assessed the use of needle electrodes on the TC to obtain an electromyography (EMG) signal profile of the RLN in an experimental porcine model.

Methods: Continuous intraoperative neuromonitoring (CIONM) was used to record the electromyogram. Each TC side was delineated into nine areas in order to find the optimal placement of the electrode. Needle electrode area, depth, and orientation were evaluated for optimal EMG amplitudes. RLN root locations were stimulated at four locations: vagus nerve distal to the CIONM electrode; and most proximal; middle; and laryngeal entry point of the RLN. A nerve retraction injury model was adapted to compare RLN monitoring by TC and ET electrodes.

Results: One of the nine areas was identified as the optimal site for placement of needle electrodes. The electromyograms obtained from the various needle insertion depths and orientations were similar. The latencies obtained from the TC and ET electrodes were similar. The amplitude profile of the TC electrodes responded earlier than did the ET electrodes to RLN injury (0.88 ± 1.25 s). Amplitude and drop to loss-of-signal were also registered earlier (3.88 ± 1.89 and 5.25 ± 1.98 s, respectively).

Conclusion: EMG amplitudes obtained through TC electrodes were higher, and recorded RLN injury earlier relative to ET electrodes.

Keywords: intraoperative neural monitoring; recurrent laryngeal nerve; thyroid cartilage; thyroid surgery; porcine model

Surgical relevance

Needle electrodes placed on the thyroid cartilage (TC) are an alternative to endotracheal tube (ET) electrodes when assessing the function of the recurrent laryngeal nerve (RLN) in thyroid surgery. This study used an experimental porcine model to evaluate the use of needle electrodes inserted in the TC, compared to ET electrodes, for producing an electromyography (EMG) profile of the RLN. Nine areas of the TC, with various needle insertion depths and orientations, were compared. Perichondral insertion into the avascular area of the TC was found safe.

The EMG amplitude and latency features via the TC and ET electrodes were compared, using both intermittent and continuous monitoring. Changes of EMG amplitudes in response to nerve traction injury were registered earlier with the TC electrodes compared with the ET electrodes, and the amplitudes were higher and more stable. Latencies via the TC and ET electrodes were similar. These results indicate that the development of a non-invasive monitoring electrode with improved function, easy placement and low cost is possible.

INTRODUCTION

Multiple methods for monitoring the recurrent laryngeal nerve (RLN) during thyroid and parathyroid surgery have been proposed. These include laryngeal palpation; glottic observation or pressure recording; intramuscular electrodes placed endoscopically on the vocal cord or through the cricothyroid membrane; postcricoid surface electrodes; or electromyographic (EMG) endotracheal tube (ET)-based surface electrodes [1]. For reasons of safety and simplicity, the most common intraoperative neuromonitoring (IONM) systems currently rely on ET surface electrodes [1-3]. ET surface electrodes are designed for placement at the level of the glottis, with the endotracheal cuff in its normal position in the subglottis. The electrodes then make contact with the medial surface of the vocal cords, for monitoring the summed depolarization of the bilateral vocalis portions of the thyroarytenoid muscles [3-5].

Despite the many advantages of ET electrodes, there are also problems in terms of verification, maintenance, stability, patient selection, and operative use (Supplemental table 1) [1-7]. The proper placement of the endotracheal tube with complete contact to the mucosa of the vocal cords is essential to minimize monitoring problems, specifically to obtain the best impedance, thus providing a precise EMG profile and exact determination of loss of signal (LOS), and allowing differentiation between signal and artefact [1-6]. A poor and unreliable signal can be due to improper outer diameter of tube, malposition, degree of rotation, depth of insertion, upward or downward displacement, salivary pooling, tube fixation, or change in head and tracheal position [8]. Furthermore, an error in intraoperative RLN stimulation is possible if there is interference due to transtracheal stimulation, in which current is shunted to the ET electrodes, especially in a situation when the RLN is adjacent to the trachea/ET electrodes [1].

Methods to assess the position of the endotracheal tube include repeat laryngoscopy, respiratory variation, checking impedance values, and a tap test [1, 2], but even with great attention to initial tube position, corrective manoeuvres are required in 5-7% of monitored thyroid surgeries. These methods necessitate additional procedures, and their accuracy for determining the proper position of the endotracheal tube have not been evaluated [1-6,8].

Obtaining EMG data via ET electrodes is especially challenging in the case of tracheal invasion, resection, tracheostomies, or giant goiters [1,2], and they also increase total costs [9]. Standard endotracheal tubes can be converted to monitoring tubes by attaching an adhesive pad with paired electrodes, so that the lower electrode is 7-10 mm above the upper edge of the tube cuff [1], but care must be taken that the adhesive pad electrode adheres closely to the endotracheal tube and does not overlap with itself [9].

Alternatively, the functions of the thyroarytenoid muscle and RLN may be assessed using needle electrodes placed into the thyroid cartilage (TC). Chiang et al. [2] and Van Slycke et al. [8] showed that TC electrodes are an alternative IONM format for recording laryngeal EMG signals during thyroidectomy.

This experimental study assessed the feasibility of using needle electrodes in the TC at various locations, depths, and orientations to obtain an EMG signal profile of the RLN, and evaluated TC electrodes relative to ET electrodes for EMG performance.

METHODS

Animals

Four female Meishan piglets were obtained from the Laboratory Animal Centre of Jilin University (age 1.5 ± 0.3 months; weight 24.1 ± 1.6 kg (range, 22.8-25.9 kg). The Animal Care and Use Committee of Jilin University approved this study, which was conducted in accordance with the ARRIVE guidelines[10].

Induction and maintenance of anaesthesia

Induction anaesthesia was given with the following: 0.5 mg atropine sulphate via subcutaneous injection, and intramuscularly 40 mg (2 mg/kg) each of tiletamine/zolazepam and xylazine hydrochloride. An EMG electrode surface ET (standard reinforced 7.0#, Medtronic, Jacksonville, FL, USA) was properly secured. The depth and angle of the contact between the ET electrode surface and the mucosa of the vocal cord were confirmed by video-laryngoscopy [1]. Muscle relaxants were avoided [1]. Isoflurane (2.0-3.0%) and oxygen (2.0 L/min) were used to maintain general anaesthesia [1].

Intraoperative neuralmonitoring equipment

NIM® Nerve Monitoring System 3.0 (Medtronic, Jacksonville, FL, USA) software was used to record the EMG. The event threshold was set at 100 μV [1]. Nerves were stimulated with a single-use, incrementing Prass® stimulating probe (no. 8225490; Medtronic, Jacksonville, FL, USA), with a 100-ms impulse duration and 4-Hz frequency. Real-time EMG data of parameters were obtained via continuous vagus nerve stimulation using a 2.0-mm Automatic Periodic Stimulation (APS®) electrode (Medtronic, Jacksonville, FL, USA) [11]. The amplitude and latency waveforms were displayed separately, and the upper limit threshold for the latency (+10%) and lower limit threshold for amplitude (–50%) were depicted as separate alarm lines [1,11]. Loss of signal was assumed in the event of signal failure or EMG signal <100 µV with a primary intact signal and adequate stimulation of 1-2 mA [1]. Needle recording electrodes (12 mm in length) were used (Medtronic Xomed, Jacksonville, FL, USA). The composite materials of the electrodes were stainless steel and a platinum/iridium alloy [12-15].

Experimental set-up and evaluations

To determine the TC areas that were suitable to insert a 2-mm long needle tip so that it would not penetrate through to the inner tissues of the larynx, the thickness of the TC was preoperatively measured using a portable colour Doppler ultrasonography (S8 Series, Sonoscape, Shenzhen, PRC) with the animal supine and the neck extended (Supplemental figure 1). The thickness of the TC was determined postoperatively with callipers (Sheffield®, Great Star, Hangzhou, PRC). The thickest and thinnest parts of the TC on both sides were in the lower lateral and the middle portions, respectively.

After surgical disinfection, an H-shaped incision was made in the middle of the neck to expose the thyroid, carotid sheet, and TC. The TC anatomy was outlined, length and width, on each side. Each side of the TC was then delineated and marked into nine areas by two transverse and two sagittal lines (Figure 1). The APS® electrodes were implanted bilaterally. The RLN root was stimulated at the following four locations: a. vagus nerve just distal to the APS® electrode position; b. most proximal segment of the RLN; c. middle portion of the RLN; d. and the RLN at the laryngeal point of entry (Figure 1B). The latencies of the EMG recordings via the TC and ET electrodes were compared.

Besides comparison of latencies the following general features of TC electrode placement and the resulting EMG profiles of the RLN were assessed: influence of the TC anatomy on the recording; associations between EMG values and area of needle insertion; associations between the EMG profile and depth of needle insertion; associations between the EMG signal and needle orientation; detection and confirmation of RLN monitoring by TC and ET electrodes via nerve retraction; and observation if the EMG amplitude and latency is influenced by manipulation of the trachea (described in detail below).

Associations between EMG values and area of needle insertion

The needle electrode tips were adjusted with rigid plastic tubing to ensure an insertion depth of 2 mm (Figure 1). The needle electrodes were inserted into the TC (Figure 1), sagittally and into the centre of the each of the nine delineated areas. The EMG parameter values from both the TC and ET electrodes were recorded simultaneously. The optimal TC electrode placement area was defined as the area with the highest EMG signals.

Associations between the EMG profile and depth of needle insertion

The optimal depth of insertion of the TC electrodes was defined as the depth in which the highest EMG signals were recorded. To determine this, the lengths of the exposed portion of the needle electrodes were adjusted to 2, 5, or 12 mm (entire length) with plastic tubing (Figure 1). The needle electrodes were inserted sagittally and centrally in each bilateral TC area, and EMG recordings were taken (Figure 1).

Associations between the EMG signal and needle orientation

To determine the optimal orientation of the needle when inserted in each area of the TC, the direction of insertion was labelled similar to the hands of an analogue clock around the centre of each area (Supplemental Figure 2). Thus, the needle was inserted in the centre and subsequently directed in 12 different directions, corresponding to each hour of the clock. EMG recordings were taken at each position. The optimal direction was considered the position that obtained the highest EMG signals.

RLN monitoring during retraction

To detect and confirm RLN monitoring by the TC needle electrodes, a nerve traction injury model described by Wu et al. [11] was utilized (Figure 3). Briefly, the RLN was carefully dissected and a 1.5-mm wide vascular rubber loop was gently positioned around the nerve and retracted slowly. The EMG parameters were recorded by both the TC and ET electrodes, with the TC electrode in optimal position. The traction was held until the alarm of the CIONM equipment sounded, at which time the traction was stopped, with standby until EMG recovery. Finally, traction of the RLN was implemented until loss of signal.

Response of EMG amplitude and latency to manipulation of the trachea or RLN retraction

To determine if manipulation of the trachea influenced the EMG recordings, the trachea was gently pushed or pulled toward or away from the operator on each side, and changes in the recordings during this manipulation were recorded.

Statistical analysis

All data are reported as mean ± standard deviation. Statistical analyses were performed using the software package SPSS® v. 22 for Windows® (IBM, Armonk, New York, USA). Multiple group comparisons were analysed with one-way analysis of variance (ANOVA). Two-group comparisons were performed using Student's *t*-test. $P < 0.05$ was considered statistically significant.

Results

Measuements of TC thickness and widths

According to the preoperative ultrasonograms, the thicknesses of the left and right sides of the TC were 2.75 ± 0.75 mm (1.8-4.1 mm) and 2.65 ± 0.71 mm (1.5-3.6 mm). The postoperative calliper measurements showed that the thicknesses of the left and right sides of the TC were 2.42 ± 0.82 mm (1.51-4.21 mm) and 2.50 ± 0.76 mm (1.59-4.3 mm). There were no significant differences between the preoperative and postoperative measurements in terms of thickness of the left and right sides of the TC ($P = 0.512$).

The thickness of the nine delineated areas of the TC were also determined (Figure 1). Areas 7, 8, and 9 were too thick for viable recording, and were not further used in this study. The thicknesses of areas 1-6 were, respectively, 1.82 ± 0.16 mm, 1.88 ± 0.30 mm, 2.29 ± 0.26 mm, 3.53 ± 0.66 mm, 3.31 ± 0.26 mm, and 1.95 ± 0.29 mm. The mean thicknesses of the suitable areas of the TC (areas 1-6) ranged from 1.8 to 3.5 mm.

The widths of the left and right sides of the TC were 33.50 ± 1.91 mm (range 32-36 mm) and 31.75 ± 2.36 mm (30-35 mm), respectively, and the lengths were 43.50 ± 6.25 mm (36-50 mm) and 43.25 ± 6.65 mm (35-50 mm) on the post-operative calliper measurements.

Associations between EMG values and area of needle insertion

The EMG values recorded by the TC electrodes were higher in areas 4-6 than that in areas 1-3 (Table 1; Figure 2A). The amplitudes recorded by the TC electrodes in areas 4 and 5 were significantly higher than that of the ET electrodes; while the amplitude of area 6 and the ET electrodes were similar ($P = 0.713$). There was no difference in latencies observed between the TC and ET electrodes.

Associations between the EMG profile and depth of needle insertion

The EMG profiles that resulted from the TC needles inserted at 2, 5, or 12 mm were not significantly different (Table 1, Figure 2B). The latencies between the TC and ET electrodes were also similar. It became clear that placing the needle in area 5 at the edge of the TC was difficult. This area is deep in the neck, with the cartilage close to the surrounding muscle and the needle was unstable when placed in the sagittal position.

Associations between the EMG signal and needle orientation

The test to determine the optimal needle orientation found that there was no significant difference among the 12 positions ($P = 0.837$). In addition, in each of the 12 positions, the EMG amplitudes to the TC electrodes were greater than that of the ET electrodes, while the latencies of the TC and ET electrodes were comparable (Figure 2C).

Latency recorded by TC electrodes relative to that of the ET electrodes

There were no significant differences in the latencies of the EMG recordings between the ET and TC electrodes. The mean latencies of the TC electrodes were similar to that of the ET electrodes at all four stimulating points (Figure 2D).

RLN monitoring during retraction

The nerve traction injury model described by Wu et al. [11] was utilized to detect and confirm RLN monitoring (Figure 3). Both the TC and ET electrodes received the EMG signal from the APS®. The TC electrodes recorded the modified amplitude profile earlier than did the ET surface electrodes. Specifically, the decline, 50% decrease baseline, and recovery of the amplitude of the TC electrodes were earlier by 0.38 ± 0.92, 0.88 ± 1.25, and 3.88 ± 1.89 s compared with the ET electrodes. When testing for loss of signal, the amplitude drop of the TC electrodes was 5.25 ± 1.98 s earlier than that of the ET electrodes (Table 2).

Response of EMG amplitude and latency to manipulation of the trachea or RLN retraction

Manipulation of the trachea (Supplemental Figure 3A) and traction of the RLN (Supplemental Figure 3B) both affected the EMG amplitudes from the ET electrode.

DISCUSSION

This study assessed the feasibility of using needle electrodes in the thyroid cartilage (TC) to obtain an EMG signal profile of the RLN during thyroid surgery, and evaluated TC electrodes relative to endotracheal tube (ET) electrodes for EMG performance. A porcine model was used to determine whether anatomical dimensions of the cartilage influence the TC recordings. Moreover, the optimal area for recording, and the best insertion depth and orientation of the needle in terms of the highest EMG amplitude were estimated. Recording from the TC was not affected by the anatomical TC dimensions. While the recorded amplitude at TC area 4 was highest, the depth of electrode needle insertion or needle orientation had no significant effect. The TC electrodes were observed to register changes in amplitude quicker and to a higher amount in response to RLN traction events when compared to ET electrodes, while the latencies were similar.

These results show that the TC needle electrodes deliver larger amplitude values during IONM, and more stable EMG signals during tracheal manipulation, compared with the ET electrodes. Higher amplitudes at the beginning of thyroid surgery are considered very helpful for the entire monitoring process, being a prerequisite for the evaluation of quantitative changes and surgical strategy, and prediction of postoperative vocal cord function [1,5,16]. In addition, stable EMG parameters are very important to estimate nerve function during surgery, especially during thyroid surgery with CIONM, and stability is important to serve as reference in cases of alarming events or loss of signal. When using ET surface electrodes, significant EMG amplitude alterations can occur due to tube malposition alone, leading to false-positive results [2,3-5,17].

In the present study, during the model of RLN retraction injury, the TC electrodes detected the adverse event of amplitude decline earlier than did the ET electrodes. Theoretically, the recordings of the TC electrodes and ET electrodes should be the same, and therefore these results are notable. Interestingly, Fujimoto et al. also observed different rise times when recording muscle contractile properties by surface electrodes and needle electrodes [18]. The difference may be due to the different receiving sites or contacts between the electrodes and muscles, which lead to different distances between main effect muscles and the recording electrodes. While there is no similar previous study addressing this, the signal receiving features of the two electrodes may provide a clue. The ET electrodes record through contact with the vocal cords. When the nerve is stimulated, the vocal cords open and close, and the best contact is reached when the vocal cords close. During the RLN traction injury experiment, the extent of vocal cord closing and action potential decrease gradually. In addition, the position and depth of the ET can easily change[5].

These all may affect the recording response time and sensitivity of the ET electrodes. This does not happen to TC electrodes, because they are inserted firmly into the TC and transmit EMG signals through permanent contact with the tissues. Thus TC electrodes may be more sensitive than ET electrodes because there is no shift or interference, and signals from the TC electrodes reflect more accurately the real time events. Another advantage of the TC needle electrodes is that significant displacement can be easily identified at the time of surgery [1,6,11,19-21].

This study also evaluated different methods of insertion of TC electrodes, in terms of area, depth, and orientation. There was no correlation between EMG amplitude and depth of needle insertion, nor between EMG amplitude and any of the tested needle orientations.

Amplitudes perceived by the TC electrodes in area 4 were significantly higher than that of the other TC areas, or by the ET electrodes. The EMG result was confirmed by TC specimen analysis. Anatomically, the thyroarytenoid muscle is mainly located in areas no. 3, 4, and 5 (Figure 10). The surgeon should also appreciate that the vocal cord is located approximately half way down the TC and the lateral and posterior cricothyroid muscles. These muscles also govern the movement of the vocal cords, are innervated by the RLN, and are also located in the TC areas 4 and 5.

Electrophysiologically, another potential mechanism of transcartilage recording can be by sensing muscle activity inside the TC (i.e., the voice box). The EMG recording at bilateral TC area 4 was better than that at bilateral areas 1, 2, and 3, because the needle could sense a larger area of muscle activity in the voice box. The EMG amplitude in area 4 was also significantly larger than that of area 3 in the same anatomical transverse plane, and the same was observed in areas 6 and 2 as well. Thus, anatomical factors may be more influential than electrophysiological factors with regard to the signal amplitude. Area 5 is at the edge of the TC, deep in the neck, and the cartilage is close to the surrounding muscle. This makes it difficult to reliably insert the needle in this area. Thus, area 4 in the TC was found to be the optimal area for placing the electrodes.

The latency values did not differ by type of recording electrode, needle insertion area, nor needle insertion depth or orientation. This result is understandable, since the latency is associated only with the length of the nerve conduction pathway [1,22].

The stability of the EMG amplitudes from the TC electrodes was greater than that of the ET electrodes. This is because the needle tips are inserted firmly into the TC and the receiving portion is visible to the surgeons. Thus, surgeons are able to prevent changes in the position of the TC electrodes. These features are very different from the ET electrodes. The ET electrodes are inserted into the trachea and the receiving portion is invisible to the surgeon; only the distal segment of the tube can be fixed around the mouth, but not the recording electrodes. Thus, shifts in the position of the ET electrodes can easily occur [3-5,17].

There are limitations to this study and more experimental and clinical studies are required before translating these findings into clinical practice. While the method seems logical for bilateral conventional surgery, in some unilateral surgeries with a small incision, or in endoscopic surgeries, it may be difficult to expose the bilateral thyroid area in order to insert the needle electrodes. There are also some cautions regarding complications associated with needle electrodes. Needle recording electrodes inserted into the muscle around the larynx do raise the possibility of trauma, including laryngeal hematoma and vocal cord laceration, and also infection, cuff deflation, need for reintubation, retained fractured needle segment, and accidental needle dislodgement during surgery [1]. In this experimental study, the mean thicknesses of TC areas 4 and 5 was >3 mm, and the EMG amplitude did not correlate with needle insertion depth nor orientation. A perichondral insertion to a depth of less than 3 mm into the avascular area 4 may be a safe and effective method for placement of the needle electrode.

IONM has been an effective auxiliary tool in the surgical management of thyroid disease, not only in the United States and Europe, but its use is also increasing in Asia, with institutions beginning to perform more monitored thyroidectomies [9,23,24]. New technologies in surgery can however lead to increases in healthcare costs, because they are more expensive than previous treatments and because more patients are treated [25,26]. When compared to ET electrodes, TC electrodes have the obvious advantage in terms of cost. The present findings could pave the wave for a noninvasive IONM recording electrode to be designed in the near future, which could be quickly and easily applied and able to transmit an optimal EMG signal.

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Disclosure

The authors declare that there is no conflict of interest.

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