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ORIGINAL ARTICLE

Optimal depth of electromyographic endotracheal tube: A novel approach using video laryngoscopy

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Abstract

Background: Electromyographic (EMG) endotracheal tubes with surface electrodes are used during neck surgery to prevent recurrent laryngeal nerve (RLN) injury. Proper positioning of the EMG tube is of paramount importance. In this study, we aimed to compare the use of video laryngoscopy with other methods for achieving the optimal depth of the EMG tube.

Methods: We retrospectively enrolled 489 adult patients (with 675 nerves at risk [NAR]) undergoing surgery using the EMG endotracheal tube. Patients were categorized into three groups with: rigid laryngoscope (n = 140, NAR = 187), conventional laryngoscope (n = 262, NAR = 370), and video laryngoscope (n = 87, NAR = 118). A formula for predicting optimal depths of the EMG tube was obtained from data of the standard group with rigid laryngoscope. Depths of the EMG endotracheal tube were measured and postoperative RLN injuries were analyzed.

Results: Based on linear regression, the formula was derived for predicting the optimal depth of EMG endotracheal tube (cm) = 11.028 + 0.635 * gender (female = 0; male = 1) + 0.069 * height (cm). Compared to conventional laryngoscope, intubation of EMG tube with video laryngoscope resulted in less discrepancy between its actual value and optimal value, and the tube depth was more correct (OR = 2.888, 95% CI = 1.753–4.757, $p < 0.001$). All five postoperative permanent RLN injuries were found in the group with conventional laryngoscope.

Conclusion: EMG endotracheal tube insertion with video laryngoscopy is superior to conventional laryngoscopy, as well as an alternative to rigid laryngoscopy. The video laryngoscopy is a novel approach to get optimal depth of EMG endotracheal tube during neck surgery.

Keywords: Electromyographic endotracheal tube; Recurrent laryngeal nerve injuries; Thyroid surgery; Video laryngoscope

1. INTRODUCTION

A variety of complications occur after thyroid surgery. Such complications include recurrent laryngeal nerve (RLN) injury and hematoma formed at the surgical wound. Moreover, RLN palsy is a potentially catastrophic complication.[1] The reported incidence of RLN palsy varies widely, depending on the type of disease, the type and extent of thyroid resection. RLN damages with resultant vocal cord paralysis cause symptoms of varying severity, from voice impairment affecting life quality, chronic cough resulting from aspiration, to stridor with acute airway obstruction leading to a potential airway emergency.[2] Hence, it is clinically important to develop maneuvers to reduce risks of RLN injury.

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In thyroid surgery, the gold standard procedure for nerve preservation is the routine visual identification of RLN.[3,4,5] Apart from visual identification, intraoperative neuromonitoring (IONM) is also applied to prevent nerve injury. Guidelines from the American Academy of Otolaryngology Head and Neck Surgery recommend IONM use in thyroid surgery to prevent nerve damages.[6] Several neuromonitoring instruments have been developed. Among them, the nerve integrity monitor (NIM) electromyographic (EMG) endotracheal tubes with surface electrodes have gained widespread popularity due to their noninvasive, safe nature, and easier use. Until now, monitor dysfunction has been continuously reported. Incorrect positioning electrodes of EMG tube, which can result in IONM equipment failure and potentially risking RLN injuries was the main cause,[7] especially in patients with poor glottic views under conventional direct laryngoscopy. Because of this, the proper positioning of the EMG tube during RLN monitoring is of paramount importance. Video laryngoscopy appears to be a good means for correct positioning of NIM tube.[8] However, few studies have been reported on comparing video laryngoscopy with other methods on accurate positioning of EMG tube.

The aim of the present study is to find an efficient maneuver to intubate the EMG endotracheal tube to an optimal depth for the functioning of the tube. We wanted to investigate its benefits in minimizing RLN injuries.

2. METHODS

2.1. Patient enrollment

The study protocol was approved by the Institutional Review Board of Taichung Veterans General Hospital (No: CE21213A). We reviewed medical records of our hospital patients who received Medtronic NIM standard reinforced EMG endotracheal tube (Medtronic, Jacksonville, Florida, USA) intubation during surgical resection for thyroid, parathyroid, or neck dissection for various diseases from January 2018 to October 2019. A total of 505 patients were initially enrolled, but finally 489 were analyzed after excluding 16 cases due to young ages (<20 years old), preoperative diagnosis of vocal cord palsy, or incomplete records of relevant data on the medical charts (Fig. 1).

2.2. Techniques of EMG endotracheal tube intubation

For all participants, anesthesia was induced with intravenous administration of 1 to 2 μg/kg fentanyl, 1 mg/kg lidocaine, 1 to 2 mg/kg propofol, and standard dose of muscle relaxant (either of succinylcholine, rocuronium, cisatracurium). The patient was then intubated and maintained with either propofol or sevoflurane, and the analgesic fentanyl. No additional muscle relaxant was given after the first administration.

Among 489 retrospectively reviewed participants, a portion of patients received EMG endotracheal tube insertion by an anesthesiologist, followed by an otorhinolaryngologist who examined and adjusted the tube until middle of the blue-marked region at level of vocal cord with rigid laryngoscope once patient positioning for surgery was complete. We selected these cases and considered them having the standard depth of EMG tube in our study. In the remaining cases, patients received no checking of the final position of the EMG tube through the rigid laryngoscope, but instead the intubation techniques were performed by either conventional laryngoscope or video laryngoscope. The anesthesiologist tried to put the blue-marked region of EMG tube at level of vocal cord with conventional laryngoscope. The final position of EMG tube was defined based on the subsequent successful Tap test, that is, with the clinician tapping over the trachea resulting in an artifact prior to the beginning of surgery. The other cases were intubated with video laryngoscope by the anesthesiologist after neck extension. We placed middle of the blue-marked region at level of the vocal cord until bilateral true vocal cords were well in contact with electrodes. Then, we confirmed the final tube depth after it was moved to the right mouth angle.

2.3. Variables

Outcome variables were the depth of the EMG tube. The insertion depth was measured from the tip of tube to the right corner of mouth. We also recorded the postoperative RLN injury during the 6 months period after operation. The incidence of RLN injury is more accurately described in terms of nerves at risk (NAR) rather than the number of patients. Vocal cord palsy recovered within six months was defined as transient events, whereas the motility of the vocal cords not recovering within 6 months after surgery was regarded as permanent RLN palsy.

2.4. Statistical analyses

All statistical analyses were performed using SPSS statistical software version 25.0 (IBM, Armonk, New York, USA). Continuous variables were presented as mean ± standard deviation. Categorical variables were expressed as absolute numbers. Categorical variables were compared using Pearson's chi-square test. For continuous variables, we performed the Kolmogorov-Smirnov test to check for normal distribution. Differences in normally distributed continuous variables among three groups were evaluated with the one-way analysis of variance, and differences in nonparametric continuous variables between two groups with the Mann-Whitney *U* test. Statistical significance

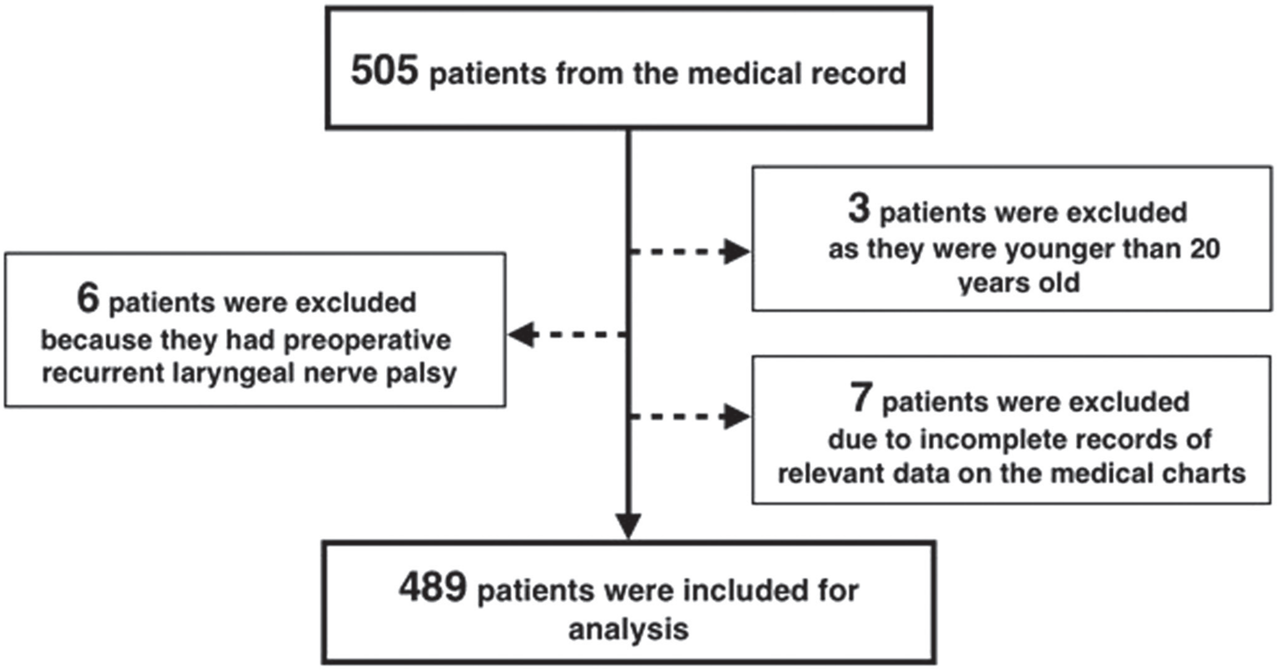

Fig. 1 Flow chart of the retrospective study. Five hundred five patients were enrolled from medical records using key words "Electromyographic endotracheal tube." Three patients were excluded because they were younger than 20 years old. Six patients were excluded because they had preoperative recurrent laryngeal nerve injury that may influence the incidence of postoperative recurrent laryngeal nerve. Finally, seven patients were excluded due to incomplete records of relevant data on the medical records. A total of 489 patients were included in the final analysis.

was set at p value less than 0.05. Stepwise multiple linear regression was applied to obtain a formula to predict the optimal depth of EMG tube based on the patient's parameters.

3. RESULTS

3.1. Patient demographics

Complete datasets were obtained from 489 participants and 140 (28.6%) of them considered standard datasets as in the group of rigid laryngoscope. In the remaining patients, 262 (53.6%) were in the group of conventional laryngoscope, and 87 (17.8%) were in the group of video laryngoscope. As shown, 373 (76.3%) patients were female. The age, gender, body height, and classification of American society for anesthesiologist physical status (ASA) were all similar across groups (p = 0.179, p = 0.092, p = 0.367, p = 0.444, respectively), while body weights were significantly different across the three groups (p = 0.016). Among 489 participants, 303 received unilateral surgical procedures and 186 received bilateral surgical procedures. A total of 675 NAR were included. Based on the number of NAR, we found no difference across the three groups in the surgical variables analyzed, including the percentage of total thyroidectomy, reoperation, and malignancy (p = 0.208, p = 0.811, p = 0.515, respectively). A summary of the patient's characteristics is shown in Table 1.

3.2. Linear regression equation for predicting the optimal depth of EMG endotracheal tube based on patient parameters

In the standard group of rigid laryngoscope, a stepwise multiple linear regression analysis was performed based on patient parameters including age, gender, body height, and body weight. We found that only gender (regression coefficient β = 0.635, p = 0.024) and body height (regression coefficient β = 0.069, p < 0.001) had significant correlations with the EMG tube depth. Other parameters like age and body weight had no association with the depth of the EMG tube (p > 0.05). The coefficient of determination R^2 of this linear regression was 0.318. Therefore, the equation for this linear regression was the optimal depth of EMG endotracheal tube (cm) = 11.028 + 0.635 * gender (female = 0; male = 1) + 0.069 * height (cm).

3.3. Accuracy for depth of EMG endotracheal tube

Since the optimal depths of the EMG tube were defined as the above equation, we entered value of gender and body height in that equation to obtain an optimal value of EMG tube depth for individual participants. After that, we calculated for each patient the disparity in EMG tube depth (i.e., difference between its actual and optimal values expressed in absolute value). The mean absolute value of the difference is 0.86 ± 0.74 cm in the group of rigid laryngoscope; 1.45 ± 0.86 cm in the group of conventional laryngoscope; and 1.03 ± 0.8 cm in the group of video laryngoscope. Compared with standard group of rigid laryngoscope, the group of video laryngoscope showed no obvious difference in the accuracy of tube depth (p = 0.11), while the group of conventional laryngoscope revealed a significant difference (p < 0.001) (Fig. 2). We further categorized the absolute values of difference between actual and optimal values into either correct depth (when the difference was <1 cm) or incorrect depth (difference ≥1 cm). The group of video laryngoscope resulted in more correct depths in comparison with the group of conventional laryngoscope (OR = 2.888, 95% CI = 1.753–4.757, p < 0.001) (Table 2).

3.4. Postoperative complications

The incidence of RLN injury was calculated based on the number of NAR. There were 675 NAR included. At the 6-month follow-up, 33 nerves developed postoperative RLN palsy and five were permanent injuries. Overall, the incidence of postoperative RLN injury was 0.74% for permanent, 4.15% for transient, and 4.89% for total RLN palsy. We found no differences across the three groups in permanent, transient and total RLN injuries (p = 0.13, p = 0.74, p = 0.344, respectively). All five cases of permanent RLN injuries were in the group of conventional laryngoscope (1.35%), compared with none of such permanent RLN palsy found in the remaining two groups (Table 3).

4. DISCUSSION

In this study, we found that EMG endotracheal tube insertion with video laryngoscope is superior to conventional laryngoscope in terms of optimal depth and fewer postoperative RLN injuries. Compared with the standard method of checking the final EMG tube position with rigid laryngoscope, intubation

Table 1

Demographic characteristics among the three groups

	Rigid Laryngoscope (Standard)	Conventional Laryngoscope	Video Laryngoscope	
	n = 140	n = 262	n = 87	p
Patient variables				
Age, years	50.56 ± 14.77	52.30 ± 12.81	49.51 ± 12.72	0.179
Gender, female/male	98/42	204/58	71/16	0.092
Body height, cm	161.16 ± 8.06	160.23 ± 7.90	159.72 ± 8.26	0.367
Body weight, kg	66.68 ± 12.78	62.54 ± 11.50	61.69 ± 11.09	0.016
ASA, I/II/III	27/98/15	55/162/45	18/57/12	0.444
Procedures				
Unilateral procedure	93	154	56	
Bilateral procedure	47	108	31	
Nerves at risk	187	370	118	
Surgical variables				
Total thyroidectomy [a]	95	217	65	0.208
Reoperation [a]	17	38	10	0.811
Malignancy [a]	105	191	66	0.515

[a] Calculated based on nerves at risk.

ASA = classification of American society for anesthesiologist physical status.

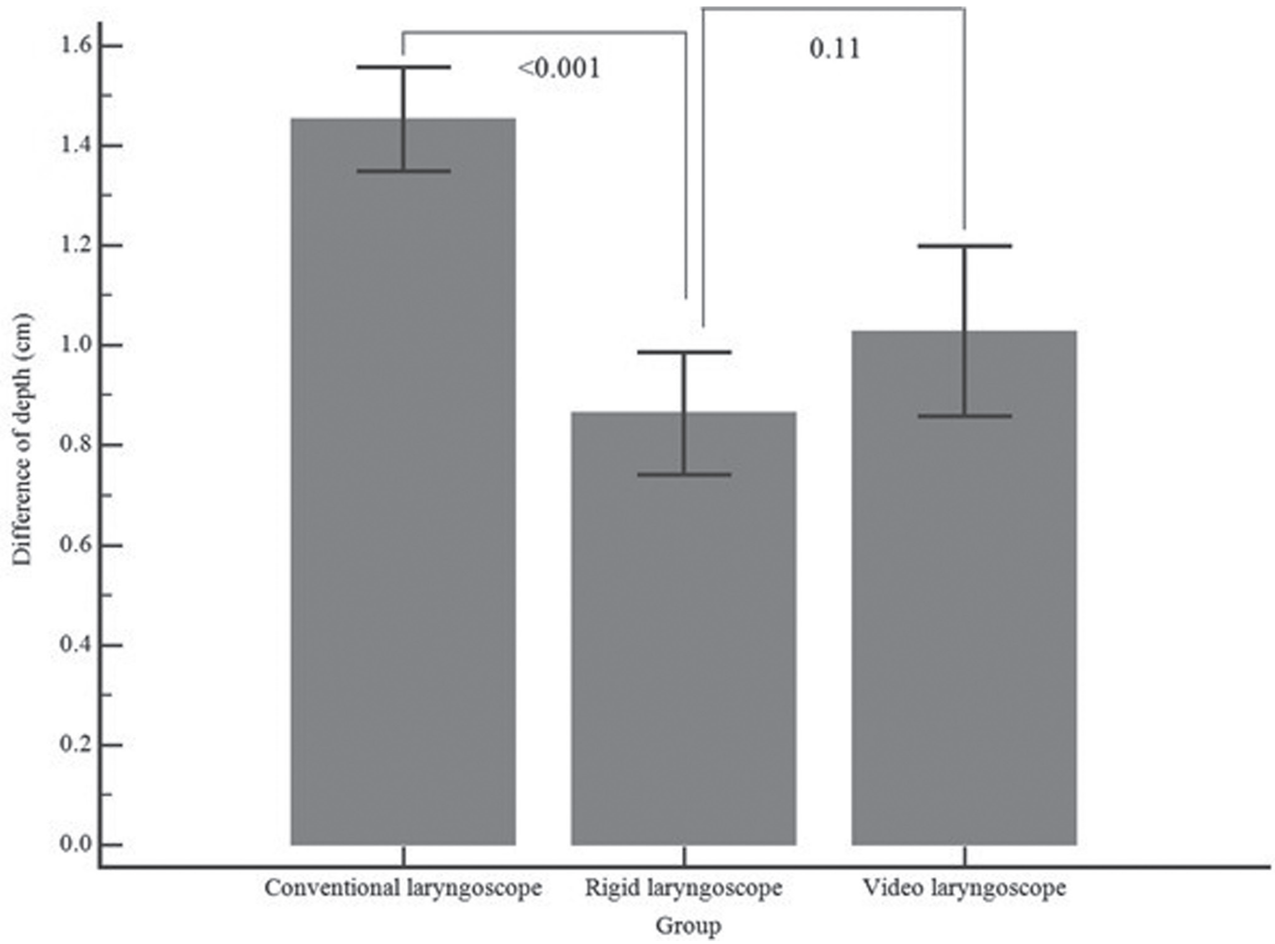

Fig. 2 Comparison of the absolute value of difference between actual and optimal depth among groups. There was a significant difference between group of rigid laryngoscope and group of conventional laryngoscope ($p < 0.001$). No statistically difference was noted between group of rigid laryngoscope and group of video lasryngoscope ($p = 0.11$).

using video laryngoscope had no statistically difference in the accuracy of tube depth and the incidence of RLN injury that had occurred postoperatively.

The female predominance (76%) of our demographic data was similar to those reported in previous studies.[9,10] This suggested that thyroid patients are predominantly female. No difference was found among the three groups in terms of age, gender, body height and ASA classification ($p > 0.05$). In contrast, body weights were statistically different across groups ($p = 0.016$). However, such discrepancy had little influence on the outcome of EMG tube depth because body weight was not correlated with tube depth, a finding that is also consistent with the previous literature.[9] Besides, malignancy, reoperation and total thyroidectomy are potential predictors of postoperative RLN injury.[1,5] Thus, we also included these surgical factors for analysis and found no difference across the three groups ($p > 0.05$).

The proper positioning of the EMG tube during RLN monitoring is of paramount importance. Improper depths of the EMG tube could lead to IONM equipment dysfunction due to electrodes malposition. About the optimal depth of EMG tube, 20.6 ± 0.97 cm in men and 19.6 ± 1.0 cm in women were reported in the series of Lu et al.[9] In our study, the mean optimal depth of EMG endotracheal tube was 23.3 ± 0.45 cm in men and 21.9 ± 0.42 cm in women. Compared to the data reported by Lu et al., our study revealed deeper EMG tube depths. For any given position change in a patient, the direction and magnitude of endotracheal tube displacement would be unpredictable. Tsai et al. found severe EMG tube displacement ranged from 16 mm upward to 5 mm downward as had occurred after neck extension.[11] Yap et al. also reported that nearly 6 cm of possible endotracheal tube movement as the patient is taken from a neutral to a fully extended position.[12] Therefore, the discrepancy in the recommended depths of EMG tube between our study and previous research is likely different extent of neck extension. Several formula were reported to estimate the optimal endotracheal tube length in an orotracheally intubated patient.[13] However, there was no useful formula for EMG tube depth to this date. From linear regression, we found that gender and body height had significant correlations with the proper depth of EMG tube. There was a trend of deeper tube depth

Table 2

Comparison of the correct depth of EMG endotracheal tube

	Depth of EMG tube		
	Correct [a]	Incorrect [b]	Total
Video laryngoscope	52	35	87
Conventional laryngoscope	89	173	262
Total	141	208	349
OR = 2.888, 95% CI = 1.753–4.757, $p < 0.001$			

[a] Absolute value of difference between actual and optimal depth < 1 cm
[b] Absolute value of difference between actual and optimal depth ≥ 1 cm
CI = confidence interval; EMG = electromyography; OR = odds ratio.

Table 3

Comparison for postoperative RLN injury among the three groups

	Rigid Laryngoscope	Conventional Laryngsoscope	Video Laryngoscope	
	NAR = 187	NAR = 370	NAR = 118	*p*
Permanent (%)	0	5 (1.35%)	0	0.13
Transient (%)	6 (3.21%)	17(4.59%)	5 (4.24%)	0.74
Total (%)	6 (3.21%)	22 (5.94%)	5 (4.24%)	0.344

NAR = nerves at risk; RLN = recurrent laryngeal nerve.

with male subjects (β = 0.635, $p = 0.024$) or those with greater body height (β = 0.069, $p < 0.001$). Other patient parameters such as age and body weight had no obvious correlation with the depth of the EMG tube ($p > 0.05$). These results are in line with the previous research.[9,13] In addition, we also found the relationship that the optimal depth of EMG endotracheal tube (cm) = 11.028 + 0.069 * body height (cm) + 0.635 * gender (female = 0, male = 1) based on linear regression. We postulate that by taking body height into consideration, a more accurate EMG tube depth can be derived. Indeed, one should better adjust the EMG tube position individually, rather than based on a single reference value to determine the insertion depth of EMG endotracheal tube.

To ensure correct positioning of electrodes, after full extension of neck, it is recommended to routinely check the position by laryngofibroscopy.[10,14] In our hospital, the otorhinolaryngologists typically examine and adjust electrodes positions with rigid laryngoscopy to determine the final tube position. However, for surgeries not conducted by otolaryngologists, the final electrode positions were not checked with rigid laryngoscopy. The video laryngoscopy has proven to be effective and safe for orotracheal intubation with good glottic view, independent of the alignment of the oral, pharyngeal, and tracheal axis. Some recent studies reported that video laryngoscopy is associated with improved glottic visualization compared with the conventional laryngoscopy.[15,16] Kanotra's study supported that video laryngoscopy provides an excellent means to ensure the correct positioning of the NIM tube.[8] However, few studies have compared between video laryngoscopy and other methods for the correct positioning of the EMG tube. In our study, EMG tube intubation with video laryngoscopy resulted in smaller discrepancy between its actual and optimal values, resulting in a more correct tube depth than the conventional laryngoscopy at an odds ratio of 2.888 (95% CI = 1.753–4.757, $p < 0.001$). Moreover, EMG tube insertion with video laryngoscope allows intubation and checking of final position carried out at the same time, rather than in two separate procedures. Therefore, compared with the conventional laryngoscopy, the depth of EMG endotracheal tube can be achieved more correctly with video laryngoscopy. For getting to an optimal EMG tube depth, this is therefore an alternative to rigid laryngoscopy or laryngofibroscopy.

Previous studies reported that the incidence of RLN injury in thyroid surgery with IONM is 0.16% to 1% for permanent injuries and 1.07% to 6.4% for transient injuries.[1,5,7,10,17,18] In the current study, we calculated the incidence of RLN injury based on the number of NAR and a total of 675 nerves were included. Overall, the incidence of RLN injury we found was 4.89%, within which 0.74% was permanent events and 4.15% was transient events. Our findings are consistent with the previous literatures. All five permanent RLN palsies were in the group of conventional laryngoscope (1.35%). There was no such postoperative permanent RLN injury at all with either rigid laryngoscopy or video laryngoscopy. On the other hand, there was no statistically difference in transient RLN injuries across three groups ($p = 0.74$). Because the incidence of RLN injury is relatively rare, our sample size of 675 nerves was insufficiently large for reliable evaluation. Hence, we concluded that checking the final EMG tube position with the rigid laryngoscope or video laryngoscope can achieve more appropriate depths to guarantee the function of the tube and to minimize permanent RLN injury.

IONM has been applied to prevent nerve injury. There was evidence that IONM could reduce the incidence of RLN injury compared to visual identification only.[17] On the other hand, a meta-analysis found no conclusive evidence for the superiority or inferiority of IONM over conventional visual identification only.[18] Despite the role of IONM in reducing the incidence of RLN injury during thyroid surgery remains controversial, RLN monitoring is valued by many surgeons for its potential benefits of more reliable nerve identification. In our hospital, most patients undergoing thyroid surgery receive Medtronic NIM standard reinforced EMG endotracheal tube intubation for neuromonitoring. The tube has four (two pairs) stainless steel wire surface recording electrodes (blue-marked region with 25 mm) embedded in silicone of the main shaft of the endotracheal tube. The surface electrodes when correctly placed will make contact with bilateral vocal cords to guarantee the function of the tube and to minimize RLN injury. Otherwise, neuromonitoring would be dysfunction. After the EMG tube was inserted and taped at mouth angle, we can assess its position by tube depth rather than by visualizing the contact between blue-marked region and vocal cord directly. Therefore, we tried to predict its optimal depth by an equation. Other than improper depth, malrotation of this tube can also lead to poor contacts between surface electrodes and vocal cords. However, our datasets had no records on the rotational error. Some novel monitoring techniques, such as the Medtronic NIM Trivantage EMG endotracheal tube, have been developed.[19] These novel monitoring endotracheal tubes include a larger electrode surface area to maximize referential EMG recording coverage and ensure ultimate signal stability, independent of tube rotation. Further studies with such novel neuromonitoring techniques would be helpful.

The main limitation of this study are its retrospective nature and nonrandomized design. When using EMG tube for nerve stimulation, we should considered the depth of the neuromuscular blockade and neuromonitorings with Train of Four monitor (TOF) is requisite. Because the TOF were not included in National Health Insurance, we do not routinely used them before and incomplete data of TOF were recorded on the medical chart for retrospective analysis. Future prospective controlled trials are needed. Other weak point of our study is its small sample size. Since the incidence of RLN injury is relatively rare, a larger sample size would give more reliable results.

In conclusion, optimal depth of EMG endotracheal tube is necessary to guarantee the tube function and reduce nerve injury. To acquire the optimal depth of EMG endotracheal tube, intubation with video laryngoscopy is superior to conventional laryngoscopy, as well as being an alternative to rigid laryngoscopy. Video laryngoscopy is a novel approach to achieve optimal depth of EMG endotracheal tube during neck surgery.

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