

# Early detection of recurrent laryngeal nerve damage using intraoperative nerve monitoring during thyroidectomy

Tian Yu<sup>1,\*</sup> , Fei-liang Wang<sup>2,\*</sup>,  
Ling-bing Meng<sup>3</sup>, Jian-kun Li<sup>1</sup> and Gang Miao<sup>1</sup>

## Abstract

**Objective:** This study aimed to investigate risk factors for early recurrent laryngeal nerve (RLN) damage during thyroid surgery with intraoperative nerve monitoring (IONM) technology to avoid RLN damage during surgery.

**Methods:** Data were retrospectively collected from 93 patients who underwent thyroidectomy at Beijing Hospital. All operations were performed by the same surgeon. A four-step procedure of IONM was used during the operation to determine the amplitude and latency of the RLN.

**Results:** The majority (51.6%) of patients who underwent surgery had thyroid carcinoma. Lymphadenectomy was carried out in 55 (59.1%) patients. A strong association was observed between temporary injury of the RLN and the extent of resection. The risk of temporary injury of the RLN during total thyroidectomy was three times that during right thyroid lobectomy (odds ratio = 3.13). The results of left lobectomy were also different from those of right lobectomy because the RLN was more likely to be damaged during left lobectomy.

**Conclusions:** Assessment of the amplitude and latency of the RLN can help to assess the integrity of the RLN. The extent of resection affects the functional integrity of the RLN.

<sup>1</sup>Department of General Surgery, Beijing Hospital, National Center of Gerontology, Beijing, P.R. China

<sup>2</sup>Department of Ultrasonography, Beijing Hospital, National Center of Gerontology, Beijing, P.R. China

<sup>3</sup>Neurology Department, Beijing Hospital, National Center of Gerontology, Beijing, P.R. China

\*These authors contributed equally to this work.

## Corresponding author:

Gang Miao, Department of General Surgery, Beijing Hospital, National Center of Gerontology, No. 1 Dahua Road, Dong Dan, Beijing 100730, P.R. China.

Email: [miaogang72@qq.com](mailto:miaogang72@qq.com)



## Keywords

Thyroid, recurrent laryngeal nerve, surgery, intraoperative nerve monitoring, risk factor, endocrine surgery, thyroidectomy

Date received: 1 August 2019; accepted: 29 October 2019

## Introduction

The incidence of thyroid cancer has sharply risen in recent years and it has become the sixth most common cancer among women in the United States.<sup>1</sup> Thyroid cancer has gradually become a global public health concern, causing a substantial social and economic burden.<sup>1,2</sup> Surgery is the cornerstone treatment for thyroid cancer, and large numbers of thyroid surgeries are performed worldwide. Recurrent laryngeal nerve (RLN) injury is one of the most dangerous complications of thyroid surgery, and this injury greatly affects the quality of life of patients. Nerve damage may result in hoarseness in patients with severe cases and may even lead to difficulty in breathing.<sup>3</sup> The reported incidence of TLN injury varies among studies. The incidence of transient injury of the RLN ranges from 5% to 8%, and the permanent damage rate ranges from 0.3% to 3%.<sup>4-6</sup> The methods used to avoid injury to the RLN during thyroid surgery have been greatly debated. Direct visualization of this nerve was once considered the gold standard for protecting the RLN.<sup>7</sup> In recent years, the emergence of intraoperative nerve monitoring (IONM) technology has provided further technical support for protecting the RLN. A number of research teams have conducted studies to investigate whether IONM reduces the incidence of damage to the RLN compared with direct visualization of the RLN. However, previous studies have focused on clinical RLN injury,<sup>8,9</sup> and studies on temporary injury

of the RLN are limited.<sup>10</sup> Therefore, in this study, we used IONM data obtained during surgery to examine the risk factors for temporary injury of the RLN during thyroid surgery.

## Material and methods

### Patients

In this retrospective study, we reviewed data that were collected from patients who underwent thyroidectomy in Beijing Hospital from July 2016 to January 2017. The study was approved by the Beijing Hospital Ethics Committee. Our research-related principles followed the International Standard Guidelines<sup>11</sup> for Electrophysiological Recurrent Laryngeal Nerve Monitoring during Thyroid and Parathyroid Surgery. All of the patients agreed to use the IONM system and signed informed consent for intraoperative data collection.

Patients who had previous thyroid surgery were excluded from the study. All of the patients had preoperative and postoperative voice examinations to assess vocal cord function, and patients with vocal cord dysfunction were also excluded from the study.

### Preoperative preparation and anesthesia

All patients in the study were operated on by the same surgeon. Surgical decisions were made according to the 2015 American Thyroid Association Guidelines.<sup>12</sup> The patients were placed in the supine position

with the shoulders raised and the head tilted back to extend the neck. Surgeries for the whole group of patients were carried out under general anesthesia with combined inhalation and intravenous anesthesia. Tracheal intubation was carried out by using a reinforced tracheal intubation surface electrode with wire intubation (Medtronic, Minneapolis, MN, USA). A stimulating probe was set to four stimulations per second with a stimulation duration of 100 ms.<sup>11</sup> Anesthesia was administered by the same anesthesiologist. We ensured that the electrode was fully in contact with the bilateral vocal cords. A curved incision was made along the natural skin crease 2 cm above the suprasternal notch. Considering the effect of muscle relaxants on nerve monitoring, we followed international guidelines<sup>11</sup> and the patients were provided a small dose of rapid-acting muscle relaxant during induction of anesthesia. Nerve monitoring usually started approximately 30 minutes after induction, at which point muscle relaxants had little effect on nerve monitoring.<sup>13,14</sup> No muscle relaxants were added during monitoring in any of the patients.

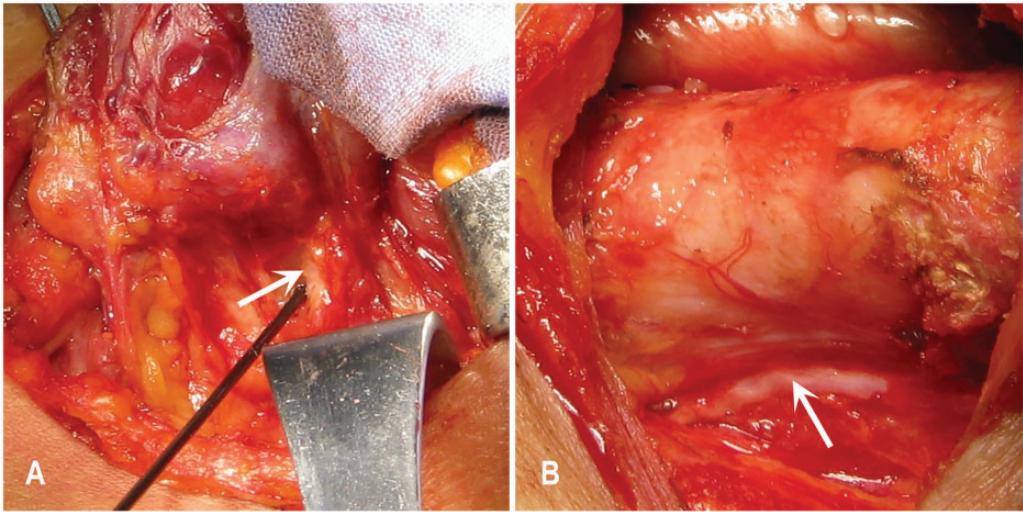
### *Steps of IONM*

The four-step procedure of IONM proposed by Chiang et al.<sup>15</sup> was used during the operation. We obtained electromagnetic signals by directly stimulating the nerves. The first step was to obtain the V1 signal, and we needed to find the vagus nerve between the internal jugular vein and the common carotid artery. An electromagnetic signal from the vagus nerve was obtained before identification of the RLN. The signal consisted of the amplitude and latency from the responses of the laryngeal muscle. The latency was defined as time measured in milliseconds between the stimulation artefact and the onset of electromyography. The amplitude was defined as the

maximum deflection from the baseline electromyographic (EMG) wave measurement in millivolts (mV).<sup>16</sup> The second step was to obtain the R1 signal and RLN was identified at the tracheo-esophageal groove (Figure 1A). The isthmus of the thyroid was then cut off, the anterior tracheal fascia was separated, the superior and inferior thyroid arteries were ligated, and the glandular lobes were lifted to the tracheal side to further expose the RLN. When the RLN was dissected completely from Berry's ligament, we stimulated the RLN and then obtained the R2 signal, which completed the third step (Figure 1B). The fourth step was to obtain the V2 signal. When we finally achieved hemostasis of the operative field, we stimulated the vagus nerve at the level of the thyroid cartilage and obtained the V2 signal. When lymphadenectomy needed to be performed, the RLN and the vagus nerve needed to be stimulated again to obtain the R2 and V2 signals. We performed a comprehensive assessment that included amplitude and latency to determine whether the RLN was temporarily injured. If the R2 signal was weaker than the R1 signal, this was defined as temporary injury of the RLN.

### *Statistical analysis*

Statistical analyses were carried out using IBM SPSS version 24.0 (IBM Corp., Armonk, NY, USA). We assessed the normality of variables and the neural monitoring signal data are expressed as the mean  $\pm$  standard deviation. The latency and amplitude data were compared using the parametric two-sample Student's *t*-test. Associations between temporary injury of the RLN and the clinical surgical characteristics of the patients were analyzed using the chi-squared test. Bivariate correlations between study variables were calculated using Spearman's rank correlation coefficient. Single factor analysis and



**Figure 1.** The position of the recurrent laryngeal nerve during thyroid surgery. Intraoperative nerve monitoring was used to locate the recurrent laryngeal nerve before thyroidectomy and to obtain the R1 signal (A). The recurrent laryngeal nerve was reconfirmed after thyroidectomy and the R2 signal was obtained (B). The recurrent laryngeal nerve is indicated by the white arrow.

multivariate binary logistic regression were applied to identify the risk factors for temporary injury of the RLN. The results was considered statistically significant if the two-tailed P value was  $<0.05$  for all tests.

## Results

The characteristics of the patients in our study are shown in Table 1. A total of 93 patients were included in this study. The age of the patients ranged from 24 to 78 years and the average age was 50 years. The patients were predominantly women and the male to female ratio was approximately 3.2:1. Total thyroidectomy was performed in 16 patients. Left and right hemithyroidectomies were performed in 31 and 46 patients, respectively. The majority of patients who underwent surgery had thyroid carcinoma. The second most common diagnosis was obstructive or substernal goiter, followed by multinodular goiter and thyroid adenoma. Lymphadenectomy

was carried out in 55 (59.1%) patients. There were no complications due to IONM.

Nerve signals, such as the R1 and V1 signals, can be identified from electrophysiological data before nerve dissection.<sup>16</sup> The mean latency and mean amplitude of R1 and V1 signals are shown in Table 2. The mean latency of the left vagus nerve was significantly higher than that of the right vagus nerve (two-sample Student's t-test,  $P < 0.001$ ). There was no significant difference in the mean latency between the right and left RLNs. We found a sex difference in the amplitude of the vagus nerve because the amplitude of the vagus nerve in women was significantly higher than that in men (1.39 mV vs 1.01 mV,  $P = 0.02$ ). There were no significant differences in the mean amplitude between the left and right RLNs or vagus nerves.

A strong association was observed between temporary injury of the RLN and the extent of resection ( $P = 0.03$ , Table 3). However, temporary injury of the RLN was

**Table 1.** Characteristics of the patients.

Characteristics	Number of patients (n = 93)	Percentage
Age (years)		
≥60	23	24.7
<60	70	75.3
Sex		
Female	71	76.3
Male	22	23.7
Diseases		
Thyroid carcinoma	48	51.6
Obstructive or substernal goiter	24	25.8
Multinodular goiter	7	7.5
Thyroid adenoma	5	5.4
Others	9	9.7
Extent of resection		
Total thyroidectomy	16	17.2
Left hemithyroidectomy	31	33.3
Right hemithyroidectomy	46	49.5
Lymphadenectomy		
Yes	55	59.1
No	38	40.9

**Table 2.** Amplitude and latency of RI and VI signals before thyroid resection.

	Vagus (VI)		P	Recurrent laryngeal nerve (RI)		P
	Left	Right		Left	Right	
Amplitude (mV)						
Mean ± SD	1.21 ± 0.76	1.38 ± 0.77	0.29	1.68 ± 1.01	1.47 ± 0.79	0.26
No. of patients	44	49		44	49	
Latency (ms)						
Mean ± SD	5.16 ± 1.25	4.18 ± 0.99	<0.001	2.15 ± 0.40	2.05 ± 0.43	0.25
No. of patients	44	49		44	49	

SD: standard deviation.

not associated with age, sex, or lymphadenectomy. Spearman analysis of the neural monitoring signal and surgical intervention showed that the latency of the V2 signal was significantly correlated with the extent of resection ( $P < 0.001$ ) (Table 4). The latency of the R2 signal was also significantly correlated with the extent of resection ( $P = 0.01$ ). We also analyzed the relative

risk indicated by surgical intervention in temporarily injured RLNs. Multivariate binary logistic regression was used to determine the risk factors (Table 5). The risk of temporary injury of the RLN during total thyroidectomy was three times greater than that during right thyroid lobectomy (odds ratio = 3.13,  $P = 0.03$ ). However, lymphadenectomy, age, and sex were not risk factors.

**Table 3.** Characteristics of the patients in the normal group and RLN temporary injury group.

	Normal group	RLN temporary injury group	P
Age (years)			
≥60	12	11	0.43
<60	30	40	
Sex			
Female	31	40	0.62
Male	11	11	
Extent of resection			
Total thyroidectomy	5	11	0.03
Left thyroid lobectomy	10	21	
Right thyroid lobectomy	27	19	
Lymphadenectomy			
Yes	25	30	0.94
No	17	21	

**Table 4.** Spearman analysis of the correlations between neural monitoring signals and surgical intervention.

	VNA2		VNL2		RLNA2		RLNL2	
	Spearman correlation	P	Spearman correlation	P	Spearman correlation	P	Spearman correlation	P
Extent of resection	0.21	0.04	-0.38	<0.0001	0.15	0.14	-0.24	0.01
Lymphadenectomy	0.07	0.47	0.06	0.56	0.1	0.33	0.12	0.25

VNA2: amplitude of the V2 signal; VNL2: latency of the V2 signal; RLNA2: amplitude of the R2 signal; RLNL2: latency of the R2 signal.

**Table 5.** Multivariate binary logistic regression.

Characteristics	Number of patients	OR	95% CI	P
Sex				
Female	23	1		0.6
Male	70	1.3	0.29–2.02	
Age (years)				
<60	22	1		0.44
≥60	71	0.69	0.27–1.77	
Extent of resection				
Right thyroid lobectomy	46	1		0.03
Left thyroid lobectomy	31	2.98	1.15–7.75	
Total thyroidectomy	16	3.13	0.93–10.48	
Lymphadenectomy				
Yes	55	1		0.95
No	38	1.03	0.45–2.36	

OR: odds ratio; CI: confidence interval.

## Discussion

RLN injury is considered a major complication of thyroid surgery and usually causes thyroid operation-related disputes. If the RLN is injured during thyroid surgery, the postoperative quality of life of the patient can be greatly affected. The RLN injury rate has been reported to range from 0.5% to 10%.<sup>3,6,17</sup> Most authors believe that routine exposure of the RLN during thyroidectomy can protect the anatomical integrity of nerves and reduce the rate of nerve injury.<sup>18</sup> Development of IONM over the years has contributed to localization and exposure of the RLN during surgery.<sup>5</sup> However, even if the anatomical integrity of the nerve is ensured during the operation, nerve injury after the operation cannot be completely avoided. Previous studies on the mechanism of RLN injury in thyroid surgery focused on discussion of the clinical injury rate.<sup>6,17</sup> However, there have been few studies on temporary injury of the RLN.<sup>8</sup> Importantly, a visually intact RLN does not mean that the RLN is functionally intact.<sup>19</sup> IONM technology has enabled recognition of the temporary effects of RLN function during surgery. This technology can provide early warning signs for surgeons, who can then take measures to avoid causing clinical injury to the RLN. In particular, IONM can indicate non-dissociative damage, such as that from clamping, traction, suction, and electric cautery, which cannot be recognized and judged by the naked eye. In the current study, we used this technique during thyroid surgery to examine the possible risk factors for temporary injury of the RLN.

IONM uses the principles of electrophysiology. During surgery, the area that the RLN travels is stimulated by a hand-held probe to depolarize the nerves and produce nerve impulses. If there is no damage to the nerve downstream of the stimulus point, the nerve impulse is transmitted down to

the vocal cord muscle to produce EMG signals. The EMG signal is received through an electrode on the surface of the endotracheal tube on the vocal cord. The signal then continues to be transmitted to the monitor to form the EMG waveform and to prompt a tone.<sup>20-22</sup> The severity of RLN injury is determined by analyzing the waveform, amplitude, and latency of the vocal cord EMG signal. Scott et al. showed that increased latency and decreased amplitude indicated that the nerve had become injured, and if the function of the nerve recovered, the signal returned to normal.<sup>23,24</sup>

A multi-institutional study analyzed 16,448 consecutive surgeries and a total of 29,998 nerves at risk during resection. The authors of this previous study found that the risk of RLN paralysis was influenced by the type of operation (primary vs reoperative surgery) and the extent of resection (subtotal vs total lobectomy) rather than by the technique used for nerve identification (visual identification vs RLN monitoring).<sup>8</sup> This study's protocol differed from our study only in the use of "no signal reduction" and an "absent signal" indicated by characteristic ticking sounds occurring before or after resection, but did not document quantitative EMG potentials. In our study, we documented EMG potentials and analyzed the specific amplitudes and latencies of the vagus nerve and the RLN. We also focused on whether the RLN was temporarily affected, taking action to stop the operation immediately and identify the reason for a reduction in signal. We found that there was a significant relationship between the extent of resection and temporary injury of the RLN. The risk of temporary injury of the RLN during total thyroidectomy was three times greater than that during right thyroid lobectomy. This result is consistent with the results of previous studies as follows. Dralle et al. concluded that the risk of permanent

RLN paralysis was significantly higher in those undergoing lobectomy than in those undergoing subtotal resection (1.34% vs 0.68).<sup>8</sup> These results suggest that surgeons should consider the complications and benefits when they decide on the extent of surgery. The 2015 American Thyroid Association guideline states that hemithyroidectomy may be sufficient for patients without extrathyroidal extension and without radiologically or clinically involved cervical lymph node metastasis.<sup>12,25–27</sup>

In our study, lymphadenectomy, age, and sex were not risk factors of temporary injury of the RLN. The anatomy of the right and left RLNs is different. The left RLN winds around the aortic arch and travels almost vertically up to the trachea. However, the right RLN winds around the subclavian artery and then travels obliquely towards the larynx; the beginning of the right RLN is a long distance from the trachea.<sup>28,29</sup> However, few studies have examined the differences between left and right RLN injury.<sup>30</sup> Interestingly, our study showed that the left RLN was more susceptible to surgical manipulation than the right RLN, as shown by the higher risk of temporary injury of the RLN during left thyroidectomy. Some studies showed that there were no differences between the left and right RLNs.<sup>31,32</sup> A study by Zambudio et al. reported that the right RLN was injured more regularly than the left RLN.<sup>33</sup> Whether there is any difference in the risk of RLN injury needs to be assessed by subsequent studies.

A multicenter study involving six centers analyzed the normal quantitative parameters of IONM.<sup>34</sup> This previous study showed that the right vagus nerve showed a significantly ( $P < 0.001$ ) larger median amplitude and a significantly ( $P < 0.001$ ) shorter latency compared with the left vagus nerve. Phelan et al. conducted a prospective IONM study in which 58 patients were enrolled.<sup>16</sup> They found that the right

and left RLN latencies were similar. The latency of the left vagus nerve was greater than that of the right vagus nerve, but this difference was not significant. The latency of the RLN was significantly shorter than that of the vagus nerve. The amplitude of the right vagus nerve was significantly greater than that of the left vagus nerve. There was no difference in the amplitude of either the RLN or the vagus nerve between men and women.<sup>16</sup> Our results are mostly consistent with these previous results. In our study, we found that the mean latency of the left vagus nerve was significantly longer than that of the right vagus nerve. With regard to sex differences, we found that the amplitude of the vagus nerve in women was significantly higher than that in men. Phelan et al. and Lorenz et al. showed similar findings to those of our study.<sup>16,34</sup> Our data may provide a reference for development of international guidelines.

There are some limitations to our study. We performed voice tests on patients before and after surgery, but this approach may be subjective. Preoperative and postoperative laryngoscopy examinations have been recommended in some previous studies. Gianlorenzo et al. found that fiber-optic laryngoscopy was essential for detecting vocal cord paralysis after thyroidectomy.<sup>28</sup> Postoperative laryngoscopy may detect RLN injury after surgery, but IONM data also have some value for predicting RLN injury. Additionally, our study was a single-center study, all patients in the study were operated on by the same surgeon, and the anesthesia was performed by the same anesthetist. We also excluded patients who had previous thyroid surgery and patients with vocal cord dysfunction. Therefore, the optimal physiological range for signaling of the RLN could not be determined. Further research is required to help establish the standards for IONM



and help to determine the cause of RLN injury.

## Conclusion

As an assistive technology, IONM is being widely applied during thyroid surgery, and the safety and effectiveness of this technology have been gradually recognized by an increasing number of surgeons. Assessment of the amplitude and latency of the RLN can help to assess the integrity of the RLN. IONM provides early precautionary information to direct surgical actions performed in an operation. The choice of surgical procedure may affect functional integrity of the RLN, and the risk of temporary injury of the RLN during total thyroidectomy is three times that during right thyroid lobectomy. Benefits to the patient and risks of complications should be fully considered when doctors make decisions regarding the extent of resection.

## Acknowledgments

We are thankful to all participants in this study. We also thank Ling-bing Meng for providing statistical assistance and suggestions during the submission process.

## Authors' contributions

TY and FLW performed the experiments, and contributed to writing and submitting the manuscript. LBM and JKL made substantial contributions to research conception and they also designed a draft of the research process. GM was involved in development of the intervention and the study protocol. All authors read and approved the final manuscript.


## Declaration of conflicting interest

The authors declare that there is no conflict of interest.

## Funding

This study was supported by the Beijing Natural Science Foundation (Grant No. 7172194).

## ORCID iD

Tian Yu  <https://orcid.org/0000-0002-3223-1773>

## References

1. Siegel RL, Miller KD and Jemal A. Cancer statistics, 2019. *CA Cancer J Clin* 2019; 69: 7–34.
2. Davies L and Welch HG. Current thyroid cancer trends in the United States. *JAMA Otolaryngol Head Neck Surg* 2014; 140: 317–322.
3. Lynch J and Parameswaran R. Management of unilateral recurrent laryngeal nerve injury after thyroid surgery: a review. *Head Neck* 2017; 39: 1470–1478.
4. Kandil E, Abdel Khalek M, Aslam R, et al. Recurrent laryngeal nerve: significance of the anterior extralaryngeal branch. *Surgery* 2011; 149: 820–824.
5. Sanabria A, Ramirez A, Kowalski LP, et al. Neuromonitoring in thyroidectomy: a meta-analysis of effectiveness from randomized controlled trials. *Eur Arch Otorhinolaryngol* 2013; 270: 2175–2189.
6. Joliat GR, Guarnero V, Demartines N, et al. Recurrent laryngeal nerve injury after thyroid and parathyroid surgery: incidence and postoperative evolution assessment. *Medicine (Baltimore)* 2017; 96: e6674.
7. Lahey FH and Hoover WB. Injuries to the recurrent laryngeal nerve in thyroid operations: their management and avoidance. *Ann Surg* 1938; 108: 545–562.
8. Dralle H, Sekulla C, Haerting J, et al. Risk factors of paralysis and functional outcome after recurrent laryngeal nerve monitoring in thyroid surgery. *Surgery* 2004; 136: 1310–1322.
9. Hermann M, Hellebart C, Freissmuth M. Neuromonitoring in thyroid surgery: prospective evaluation of intraoperative electrophysiological responses for the prediction of recurrent laryngeal nerve injury. *Ann Surg* 2004; 240: 9–17.

10. Schneider R, Randolph GW, Sekulla C, et al. Continuous intraoperative vagus nerve stimulation for identification of imminent recurrent laryngeal nerve injury. *Head Neck* 2013; 35: 1591–1598.
11. Randolph GW, Dralle H, Abdullah H, et al. Electrophysiologic recurrent laryngeal nerve monitoring during thyroid and parathyroid surgery: international standards guideline statement. *Laryngoscope* 2011; 121: S1–S16.
12. Haugen BR, Alexander EK, Bible KC, et al. 2015 American thyroid association management guidelines for adult patients with thyroid nodules and differentiated thyroid cancer: the American thyroid association guidelines task force on thyroid nodules and differentiated thyroid cancer. *Thyroid* 2016; 26: 1–133.
13. Lu IC, Tsai CJ, Wu CW, et al. A comparative study between 1 and 2 effective doses of rocuronium for intraoperative neuromonitoring during thyroid surgery. *Surgery* 2011; 149: 543–548.
14. Marusch F, Hussock J, Haring G, et al. Influence of muscle relaxation on neuromonitoring of the recurrent laryngeal nerve during thyroid surgery. *Br J Anaesth* 2005; 94: 596–600.
15. Chiang FY, Lu IC, Kuo WR, et al. The mechanism of recurrent laryngeal nerve injury during thyroid surgery—the application of intraoperative neuromonitoring. *Surgery* 2008; 143: 743–749.
16. Phelan E, Potenza A, Slough C, et al. Recurrent laryngeal nerve monitoring during thyroid surgery: normative vagal and recurrent laryngeal nerve electrophysiological data. *Otolaryngol Head Neck Surg* 2012; 147: 640–646.
17. Gibelin H, Sierra M, Mothes D, et al. Risk factors for recurrent nodular goiter after thyroidectomy for benign disease: case-control study of 244 patients. *World J Surg* 2004; 28: 1079–1082.
18. Hermann M, Alk G, Roka R, et al. Laryngeal recurrent nerve injury in surgery for benign thyroid diseases: effect of nerve dissection and impact of individual surgeon in more than 27,000 nerves at risk. *Ann Surg* 2002; 235: 261–268.
19. Brajcich BC and McHenry CR. The utility of intraoperative nerve monitoring during thyroid surgery. *J Surg Res* 2016; 204: 29–33.
20. Kwak HY, Dionigi G, Kim D, et al. Thermal injury of the recurrent laryngeal nerve by THUNDERBEAT during thyroid surgery: findings from continuous intraoperative neuromonitoring in a porcine model. *J Surg Res* 2016; 200: 177–182.
21. Vicente DA, Solomon NP, Avital I, et al. Voice outcomes after total thyroidectomy, partial thyroidectomy, or non-neck surgery using a prospective multifactorial assessment. *J Am Coll Surg* 2014; 219: 152–163.
22. Calò PG, Medas F, Gordini L, et al. Interpretation of intraoperative recurrent laryngeal nerve monitoring signals: The importance of a correct standardization. *Int J Surg* 2016; 28: S54–S58.
23. Scott AR, Chong PS, Brigger MT, et al. Serial electromyography of the thyroarytenoid muscles using the NIM-response system in a canine model of vocal fold paralysis. *Ann Otol Rhinol Laryngol* 2009; 118: 56–66.
24. Scott AR, Chong PS, Hartnick CJ, et al. Spontaneous and evoked laryngeal electromyography of the thyroarytenoid muscles: a canine model for intraoperative recurrent laryngeal nerve monitoring. *Ann Otol Rhinol Laryngol* 2010; 119: 54–63.
25. Cooper DS, Doherty GM, Haugen BR, et al. Revised American thyroid association management guidelines for patients with thyroid nodules and differentiated thyroid cancer. *Thyroid* 2009; 19: 1167–1214.
26. Frangos S, Iakovou IP, Marlowe RJ, et al. Acknowledging gray areas: 2015 vs. 2009 American thyroid association differentiated thyroid cancer guidelines on ablating putatively low-intermediate-risk patients. *Eur J Nucl Med Mol Imaging* 2017; 44: 185–189.
27. Haugen BR. 2015 American thyroid association management guidelines for adult patients with thyroid nodules and differentiated thyroid cancer: what is new and what has changed. *Cancer* 2017; 123: 372–381.
28. Makay O, Icoz G, Yilmaz M, et al. The recurrent laryngeal nerve and the inferior thyroid artery—anatomical variations during

- surgery. *Langenbecks Arch Surg* 2008; 393: 681–685.
29. Serpell JW, Yeung MJ and Grodski S. The motor fibers of the recurrent laryngeal nerve are located in the anterior extralaryngeal branch. *Ann Surg* 2009; 249: 648–652.
  30. Woodson GE, Hughes LF and Helfert R. Quantitative assessment of laryngeal muscle morphology after recurrent laryngeal nerve injury: right vs. left differences. *Laryngoscope* 2008; 118: 1768–1770.
  31. Dionigi G, Boni L, Rovera F, et al. Postoperative laryngoscopy in thyroid surgery: proper timing to detect recurrent laryngeal nerve injury. *Langenbecks Arch Surg* 2010; 395: 327–331.
  32. Thomusch O, Sekulla C, Walls G, et al. Intraoperative neuromonitoring of surgery for benign goiter. *Am J Surg* 2002; 183: 673–678.
  33. Zambudio AR, Rodriguez J, Riquelme J, et al. Prospective study of postoperative complications after total thyroidectomy for multinodular goiters by surgeons with experience in endocrine surgery. *Ann Surg* 2004; 240: 18–25.
  34. Lorenz K, Sekulla C, Schelle J, et al. What are normal quantitative parameters of intraoperative neuromonitoring (IONM) in thyroid surgery. *Langenbecks Arch Surg* 2010; 395: 901–909.