



Normative electromyography data and influencing factors in intraoperative neuromonitoring using adhesive skin electrodes during thyroid surgery

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Background: Skin electrodes have been reported to be a useful alternative recording method for intraoperative neuromonitoring (IONM) and show typical electromyography (EMG) waveforms while overcoming the shortcomings of the EMG endotracheal tube. However, the skin electrodes showed relatively lower evoked amplitudes than other recording methods. In this study, we analyzed normative EMG data using skin electrodes and factors that affect the evoked amplitude of thyroid IONM.

Methods: In total, 167 patients [242 nerves at risk (NAR)] who underwent thyroidectomy under IONM with adhesive skin electrodes were analyzed. A pair of skin electrodes was attached to the lateral border of the lamina of the thyroid cartilage. Evoked EMG data, including mean amplitude and latency, obtained after stimulation of the recurrent laryngeal nerve (RLN) and vagus nerve (VN), were collected and analyzed.

Results: The mean amplitudes of RLN and VN recorded via skin electrodes were 255.48 ± 96.53 and 236.15 ± 69.72 μ V, respectively. The mean latency of the right and left RLN was 3.22 ± 0.03 and 3.49 ± 0.08 mS, respectively. The mean latency of the right and left VN was 5.37 ± 0.80 and 7.57 ± 0.10 mS, respectively. The mean amplitude was significantly lower in the obesity, male, and total thyroidectomy (TT) groups. As body mass index (BMI) and age increased, the amplitude of EMG tended to decrease significantly.

Conclusions: The evoked amplitude recorded with the skin electrodes was relatively low. A larger surgical extent, obesity, male sex, and age >55 years showed significantly lower evoked amplitudes.

Keywords: Neuromuscular monitoring; thyroid gland; recurrent laryngeal nerve (RLN); vagus nerve (VN); electrodes

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Introduction

Intraoperative neuromonitoring (IONM) has been reported to help identify the nerve early, safely dissect the nerve, and predict postoperative vocal cord movements in thyroid surgery (1). Currently, the most popular electromyography (EMG) signal recording method for thyroid IONM is to use an endotracheal tube with surface electrodes (EMG tube), which has been the best established to date and is easy to use if the equipment is ready (1). However, the EMG tube has the disadvantage of false-positive loss of signal (LOS) due to poor contact between the EMG tube and vocal folds (2). IONM using needle or skin electrodes has been proposed as an alternative method (3-8). Among them, the skin electrode is the most noninvasive and free of false-positive LOS due to tube malposition and has an economic advantage compared to the EMG tube (6-8). However, skin electrodes have the disadvantage that the evoked amplitude value is relatively low and an appropriate standard value has not yet been established.

In this study, we analyzed normative thyroid IONM data recorded via skin electrodes and factors, such as age, sex, side and extent of surgery, and body mass index (BMI), which could affect the evoked amplitude of thyroid IONM. We present this article in accordance with the STROBE reporting checklist (available at <https://gs.amegroups.com/article/view/10.21037/gS-23-428/rc>).

Methods

Patients

This retrospective study reviewed the medical records of

Table 1 Clinicopathological characteristics

Clinicopathologic characteristics	Value
Number of patients	167
NAR, n	242
Type of surgery, n (hemithyroidectomy/total thyroidectomy)	92/75
Age (mean \pm SD, years)	51.92 \pm 12.53
Sex (M:F), n	22:145
Body mass index (mean \pm SD, kg/m ²)	24.38 \pm 3.09
Tumor size (mean \pm SD, cm)	0.86 \pm 0.64
Pathology, n	
Papillary thyroid carcinoma	137
Follicular neoplasm	16
Benign thyroid disease	14

NAR, nerves at risk; SD, standard deviation; M, male; F, female.

167 consecutive patients with 242 nerves at risk (NAR) who underwent conventional thyroid lobectomy or total thyroidectomy (TT) with IONM using skin electrodes between May, 2020 and June, 2021. This study was conducted in accordance with the Declaration of Helsinki (as revised in 2013). The Institutional Review Board of Pusan National University Hospital approved this study (No. 1910-042-084) and waived the requirement for informed consent. All enrolled patients showed normal glottic function on preoperative laryngoscopic examination. Clinicopathological characteristics, such as age, sex, BMI, surgical extent, tumor size, and tumor pathology, were analyzed (*Table 1*).

General anesthesia and monitor setup

After standard general anesthesia, anesthesia was maintained with sevoflurane, and neuromuscular blockade was not administered during surgery. All patients were placed in the Rose position and a pair of skin electrodes (DSE3125, Medtronic Xomed Inc., Jacksonville, FL, USA) was attached to the lateral border of the thyroid cartilage lamina (*Figure 1A*). The NIM-Neuro 3.0 system (Medtronic Xomed Inc.) was used for IONM analysis. The duration of stimulation was set at 100 μ S, with a frequency of 4 Hz. Recurrent laryngeal nerve (RLN) and vagus nerve (VN) stimulation was performed after extraction of the thyroid specimen, and evoked EMG data, including mean amplitude

Highlight box

Key findings

- A larger surgical extent, obesity, male sex, and age >55 years showed significantly lower evoked amplitudes in thyroid intraoperative neuromonitoring using skin electrodes.

What is known and what is new?

- Skin electrodes have been reported to be a useful alternative recording method for intraoperative neuromonitoring.
- The evoked amplitude recorded with the skin electrodes was relatively low. A larger surgical extent, obesity, male sex, and age >55 years showed significantly lower evoked amplitudes.

What is the implication, and what should change now?

- Surgeons should think various clinical factors when interpreting electromyographic data in thyroid intraoperative neuromonitoring using skin electrodes.

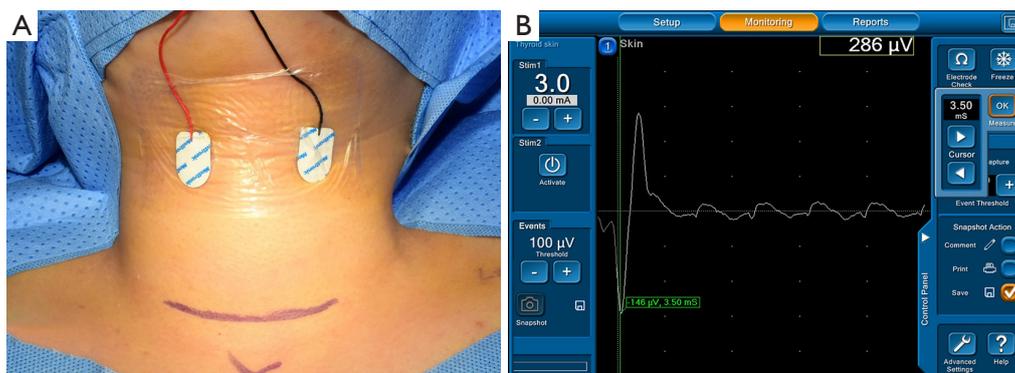


Figure 1 A representative photo of thyroid IONM using adhesive skin electrodes. (A) Patient; (B) IONM data. IONM, intraoperative neuromonitoring.

and latency, were recorded (*Figure 1B*). Furthermore, the recorded EMG values were compared according to clinical factors, such as age, sex, side and extent of surgery, and BMI.

Statistical analysis

The collected EMG data were expressed as mean \pm standard error and compared for each variable using a paired *t*-test and one-way analysis of variance. Multiple regression analysis was performed to assess the effects of age and BMI on EMG data. Statistical significance was set at $P < 0.05$. Statistical analyses were performed using the Statistical Package for the Social Sciences version 27 for Windows (IBM Corp., Armonk, NY, USA).

Results

A total of 167 patients with 242 NARs were included in the study. The ratio of hemithyroidectomy (HT) to TT was 92:75. The mean age of the patients was 51.92 ± 12.53 years (range, 24–78 years). Among the 167 patients, 137 had papillary thyroid carcinoma, 16 had follicular neoplasm, and 14 had benign thyroid disease. The mean tumor size was 0.86 ± 0.64 cm. The mean BMI was 24.38 ± 3.09 kg/m².

The mean amplitude of both RLN and VN recorded via skin electrodes was 264.37 ± 101.49 and 243.71 ± 77.82 μ V, respectively. The mean latency of the right and left VN was 5.37 ± 0.08 and 7.57 ± 0.10 mS, respectively. There were no cases of LOS in the current study.

Comparison of EMG data according to surgical side

Of the 242 NARs, 132 were left and 110 were right. The

mean amplitude of the left and right VN was 241.95 ± 79.45 and 249.97 ± 76.83 μ V, respectively. The mean latency of the left and right VN was 7.57 ± 0.10 and 5.37 ± 0.08 mS, respectively. The mean amplitude of the left and right RLN was 270.45 ± 104.87 and 262.31 ± 98.96 μ V, respectively. The mean latency of the left and right RLN was 3.49 ± 0.08 and 3.22 ± 0.03 mS, respectively. There was no statistical difference in the amplitude value according to the surgical side but a statistical difference in the VN latency according to the surgical side ($P < 0.01$) (*Table 2*).

Comparison of EMG data according to sex

Of the 242 NARs, 38 were from men, and 204 were from women. The mean amplitude values of VN according to sex were as follows: men, 200.50 ± 57.12 μ V and women, 254.35 ± 79.18 μ V ($P < 0.05$). The mean latency values of the VN according to sex were as follows: men, 6.44 ± 0.10 mS and women, 6.39 ± 0.13 mS. The mean amplitude of RLN for men and women was 196.05 ± 77.68 and 280.44 ± 101.49 μ V, respectively. The mean latency of RLN for men and women was 3.73 ± 0.13 and 3.58 ± 0.09 mS, respectively. There were no significant differences in latency according to sex in RLN and VN. Otherwise, there was a statistically significant difference in the amplitude value according to the surgical side in the RLN and VN ($P < 0.001$) (*Table 2*).

Comparison of EMG data according to surgical extent

Of the 242 NARs, 92 were in the HT group and 150 in the TT group. The mean amplitude values of both VN and RLN according to the surgical extent were the following: the VN HT group, 261.89 ± 88.49 μ V; VN TT group,

Table 2 Analysis of electromyography data according to clinical parameters

Parameters	Nerve	Subtypes	NAR (n)	Amplitude (mean ± SD, μV)	P value	Latency (mean ± SD, mS)
Side	VN	Left	132	241.95±79.45	0.84	7.57±0.10
		Right	110	249.97±76.83		5.37±0.08**
	RLN	Left	132	270.45±104.87	0.76	3.49±0.08
		Right	110	262.31±98.96		3.22±0.03
Sex	VN	Male	38	200.50±57.12***	<0.001	6.44±0.10
		Female	204	254.35±79.18		6.39±0.13
	RLN	Male	38	196.05±77.68***	<0.001	3.73±0.13
		Female	204	280.44±101.49		3.58±0.09
Surgical extent	VN	HT	92	261.89±88.49	0.01	6.68±1.54
		TT	150	236.15±69.72*		6.62±1.44
	RLN	HT	92	285.57±108.82	0.02	3.42±0.65
		TT	150	255.48±96.53*		3.25±0.50
Age (years)	VN	<55	113	266.44±89.69	<0.001	6.25±1.49
		≥55	129	226.44±60.39***		6.35±1.55
	RLN	<55	113	291.39±110.67	<0.001	3.32±0.72
		≥55	129	244.44±88.37***		3.35±0.48

Statistical difference: *, P<0.05; **, P<0.01; ***, P<0.001. NAR, nerves at risk; SD, standard deviation; VN, vagus nerve; RLN, recurrent laryngeal nerve; HT, hemithyroidectomy; TT, total thyroidectomy.

236.15±69.72 μV; RLN HT group, 285.57±108.82 μV; and RLN TT group, 255.48±96.53 μV. The mean latency values of both VN and RLN according to the surgical extent were as follows: the VN HT group, 6.68±1.54 mS; VN TT group, 6.62±1.44 mS; RLN HT group, 3.42±0.65 mS; and RLN TT group, 3.25±0.50 mS. There were no significant differences in latency according to BMI in both RLN and VN. However, the mean amplitude value of the TT group was significantly lower than that of the HT group for the VN and RLN (P<0.05) (Table 2).

Comparison of EMG data according to BMI

We classified the patient group according to the Asia-Pacific BMI classification (normal, <18.5 kg/m²; overweight, 18.5–22.9 kg/m²; and obesity, ≥23 kg/m²). Of the 242 NARs, 93 were in the normal group, 59 in the overweight group, and 90 in the obesity group. The mean amplitude values of both VN and RLN according to BMI were as the following: the VN normal group, 261.58±68.57 μV; VN overweight group, 240.85±90.62 μV; VN obesity group, 226.89±75.44 μV; RLN normal group, 288.86±95.36 μV;

RLN overweight group, 272.56±116.87 μV; and RLN obesity group, 233.97±90.50 μV. The three groups showed significant differences in mean amplitude values. The mean amplitude values of VN (P<0.05) and RLN (P<0.01) in the obese group were significantly lower than those of the normal group (Table 3). In multiple regression analyses, as BMI increased, the RLN amplitude tended to decrease significantly (P<0.01) (Table 4). Similarly, the VN amplitude tended to decrease with increasing BMI, but no statistical significance was observed (Table 5).

Comparison of EMG data according to age

According to the American Joint Committee on Cancer staging system, patients were classified according to the age of 55 years. Of the 242 NARs, 113 were aged <55 years and 129 were aged ≥55 years. The mean amplitude values of both VN and RLN according to the age group were as follows: the VN aged <55 group, 266.44±89.69 μV; VN aged ≥55 group, 226.44±60.39 μV; RLN aged <55 group, 291.39±110.67 μV; and RLN aged ≥55 group, 244.44±88.37 μV. The patients aged ≥55 years showed significantly lower amplitude values

Table 3 Analysis of electromyography data according to BMI classification

Nerve	BMI group [†]	NAR	Amplitude (mean ± SD, μV)	F	P value	Scheffe
VN	Normal (a)	93	261.58±68.57	4.161	0.017*	a<c
	Overweight (b)	59	240.85±90.62			
	Obesity (c)	90	226.89±75.44			
RLN	Normal (a)	93	288.86±95.36	6.403	0.002**	a<c
	Overweight (b)	59	272.56±116.87			
	Obesity (c)	90	233.97±90.50			

[†], categories are based on Asia-Pacific BMI classification: normal, <18.5 kg/m²; overweight, 18.5–22.9 kg/m²; obesity, ≥23 kg/m². Statistical difference: *, P<0.05; **, P<0.01. BMI, body mass index; NAR, nerves at risk; SD, standard deviation; VN, vagus nerve; RLN, recurrent laryngeal nerve; F, F-static.

Table 4 Multiple regression analysis of the effects of BMI and age on evoked amplitude (recurrent laryngeal nerve)

Variables	Unstandardized coefficients		Standardized coefficients (β)	T (P value)	Collinearity statistics	
	B	SE			Tolerance	VIF
(Constant)	479.475	63.171		7.590 (<0.001)***		
BMI	-6.180	2.227	-0.188	-2.775 (0.006)**	0.997	1.003
Age	-1.236	0.551	-0.152	-2.246 (0.026)*	0.997	1.003
Adjusted R square			0.046			
Durbin-Watson			1.986			

Statistical difference: *, P<0.05; **, P<0.01; ***, P<0.001. BMI, body mass index; B, beta; SE, standard error; T, t-static; VIF, variance inflation factor.

Table 5 Multiple regression analysis of the effects of BMI and age on evoked amplitude (vagus nerve)

Variables	Unstandardized coefficients		Standardized coefficients (β)	T (P value)	Collinearity statistics	
	B	SE			Tolerance	VIF
(Constant)	353.674	49.189		7.190 (<0.001)***		
BMI	-0.724	0.429	-0.116	-1.689 (0.093)	0.997	1.003
Age	-2.962	1.734	-0.118	-1.708 (0.089)	0.997	1.003
Adjusted R square			0.016			
Durbin-Watson			1.847			

Statistical difference: ***, P<0.001. BMI, body mass index; B, beta; SE, standard error; T, t-static; VIF, variance inflation factor.

than those aged <55 years (P<0.001) (Table 2). In multiple regression analyses, as age increased, the RLN amplitude tended to decrease significantly (P<0.05) (Table 4). The VN amplitude decreased with age, but the difference was not statistically significant (Table 5).

Discussion

Wu *et al.* reported for the first time the results of thyroid

IONM using adhesive skin electrodes (8). Using porcine models, although the evoked amplitude value of the adhesive skin electrode was lower than that of the EMG tube, IONM could be successfully performed without false positives, and the stress injury of the RLN could be evaluated identically to that of the EMG tube. Furthermore, unlike the EMG tube, which showed a false LOS when there was a trachea displacement, the adhesive skin electrode showed a stable signal (8). Lee *et al.* successfully performed thyroid IONM

in human patients using adhesive skin electrodes. In their study, some NARs showed amplitudes of ≤ 100 μV , but all showed biphasic waveforms (6). Liddy *et al.* performed thyroid IONM using an anterior laryngeal electrode attached to the thyroid cartilage; their study showed that the amplitude was relatively lower (up to 83%) than the EMG tube, but there were no differences in latency (9). Previously, we compared the EMG data recorded using the EMG tube and the skin electrode simultaneously in the same patient (7). The amplitude of the skin electrode was approximately one-third of the EMG tube.

Previous studies have shown that skin electrodes have several advantages: (I) they are noninvasive; (II) they are free from false-positive LOS due to tube malposition; and (III) they are economical (6-8). Unfortunately, the adhesive skin electrode does not have as many previous research results as the EMG tube, so the normative value ranges and event threshold have not yet been established.

In this study, the normative values of thyroid IONM using adhesive skin electrodes and factors that could affect the amplitude values were analyzed. IONM data were obtained for all NARs without a false LOS during the study period. The mean amplitude of both RLN and VN recorded via skin electrodes was 264.37 ± 101.49 and 243.71 ± 77.82 μV , respectively. These values correspond to approximately 32–35% of the amplitude of the EMG tube (7,10). Furthermore, the mean latency of the right VN was 5.37 ± 0.80 mS and the left VN was 7.57 ± 1.02 mS. These values correspond to approximately 137% of the latency of the EMG tube (7,10). The normative value of the current study was only one-third of the EMG tube amplitude value compared to previous reports (7,10,11). This assumes that the distance between the vocal cord muscle where the EMG signal is generated and the skin electrode that records the EMG signal is relatively far compared to the EMG tube; thus, signal attenuation occurs due to barriers, such as cartilage, muscle, and fat, that could increase resistance.

Factors affecting the values of the EMG data, such as surgical side, surgical extent, sex, BMI, and correlations were analyzed. The amplitude tended to decrease significantly with greater surgical extent, male sex, obesity, and age ≥ 55 years. These clinical factors may have confounding factors each other. However, the reason for this tendency is assumed to be that the thickness of the neck tends to increase in men and obese people, and as a result, the distance between the adhesive skin electrode and the vocal cord muscles increases, resulting in EMG signal attenuation. Furthermore, the amplitude was significantly

lower in the TT group than in the HT group, which is believed to be related to the flap elevation range. The resistance between the adhesive skin electrode and vocal cord muscles increased as the flap elevation range increased, causing signal attenuation.

This study has the limitations such as retrospective, non-comparative design, insufficient number of cases. And although skin electrodes are useful, the standard IONM method so far is the EMG tube.

Conclusions

In conclusion, the mean amplitude of both RLN and VN recorded via skin electrodes was 264.37 ± 101.49 and 243.71 ± 77.82 μV , respectively, which corresponded to approximately one-third of the EMG tube. The factors influencing the amplitude values were sex, surgical extent, BMI, and age. Male sex, larger surgical extent, obesity, and age ≥ 55 years showed significantly lower amplitude values.

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Footnote

Reporting Checklist: The authors have completed the STROBE reporting checklist. Available at <https://gs.amegroups.com/article/view/10.21037/gc-23-428/rc>

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Conflicts of Interest: All authors have completed the ICMJE uniform disclosure form (available at <https://gs.amegroups.com/article/view/10.21037/gc-23-428/coif>). The authors have no conflicts of interest to declare.

Ethical Statement: The authors are accountable for all aspects of the work in ensuring that questions related to the accuracy or integrity of any part of the work are appropriately investigated and resolved. The study was conducted in accordance with the Declaration of Helsinki (as

revised in 2013). The Institutional Review Board of Pusan National University Hospital approved this study (No. 1910-042-084) and waived the requirement for informed consent.

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