Original Article

Application of patch stimulator for intraoperative neuromonitoring during thyroid surgery: maximizing surgeon's convenience

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Background: Intraoperative neuromonitoring (IONM) is frequently used in thyroid surgery to reduce recurrent laryngeal nerve (RLN) injury by providing the surgeon with real-time feedback on nerve stimulation during dissection. We applied a disposable adhesive patch electrode to a dissecting instrument to transfer electrical stimulation to the dissecting instrument for IONM during thyroid surgery. This study aimed to evaluate the feasibility of using the patch stimulator approach for IONM during thyroid surgery.

Methods: We reviewed the medical records of patients who underwent thyroidectomy using both conventional stimulator and adhesive patch stimulator for IONM. The electromyography (EMG) amplitudes of the vagal and the RLNs before (V1, R1) and after thyroid resection (V2, R2) were alternatively checked with each type of stimulator at the same location of each nerve.

Results: Fifteen consecutive patients (4 males, 11 females) were included in this analysis, and a total of 38 nerves (19 vagus nerves and 19 RLNs) were evaluated. No statistically significant differences were seen in the mean amplitudes evoked by the patch stimulator and the conventional probe stimulator for the V1 signal (825.5±394.6 *vs.* 821.8±360.9 μV, P=0.954), R1 signal (1,044.8±471.2 *vs.* 1,039.2±507.4 μV, P=0.898), R2 signal (1,037.8±495.0 *vs.* 938.2±415.8 μV, P=0.948), or V2 signal (812.5±391.9 *vs.* 787.3±355.7 μV, P=0.975).

Conclusions: The patch stimulator was safely and effectively used for IONM during thyroid surgery and provided similar nerve monitoring responses as the conventional stimulator. This approach may be used to enhance the surgeon's convenience during thyroid surgery.

Keywords: Neuromuscular monitoring; electrodes; electromyography (EMG); thyroidectomy

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Introduction

Recurrent laryngeal nerve (RLN) injury is a highly undesirable complication during thyroid surgery because it can lead to hoarseness, dysphonia, dysphagia, pulmonary aspiration, and life-threatening airway obstruction (1,2). Intraoperative neuromonitoring (IONM) is increasingly being used routinely in thyroid surgery, as it has been shown to prevent RLN injury by facilitating identification of the nerve anatomically, as well as enabling recognition of anatomic variants, leading to preservation of the nerve's functional integrity (3,4).

Traditional intermittent IONM (I-IONM) is performed using a conventional nerve stimulator, which is a handheld probe that stimulates the potential target structure intermittently during surgery (5). Using this technique, the function of the RLN can only be evaluated at the moment of stimulation, and thus, the nerve is still at risk of injury during the time gap between stimulations. Furthermore, the need to repeatedly shift between surgical instruments and the conventional stimulator is troublesome for the surgeon and time-consuming.

Recently, new monitoring tools and methods have been developed to solve the problems of I-IONM and to enhance both the surgeon's convenience and patient safety. Stimulating dissecting instruments with combined functionality were developed with the ability to perform both dissection and nerve stimulation. The first proposed method was to tape stimulation electrical wires directly to the dissecting tools (6,7). Many other variations of stimulating dissecting instruments have been proposed thereafter, such as detachable magnetic stimulators and attachable ring stimulators (8,9). However, we noticed that these approaches each have their own limitations, including being too costly, too bulky, or prone to detachment from dissecting tools.

To overcome the disadvantages of these instruments, we devised an adhesive *patch stimulator* approach to IONM. An adhesive patch electrode commonly used in transcutaneous electrical nerve stimulation therapies (Surface Electrode Ambu Neuroline 700 15-K/C/12, Ambu, Copenhagen) was attached to a dissecting instrument to transfer electrical stimulation to the dissecting instrument. The adhesive patch electrode is small (20×15×1 mm^3), lightweight (4 grams), inexpensive (US $2.5), disposable, and easily applied onto dissecting instruments. The aim of this study is to evaluate the feasibility of using the patch stimulator for IONM during thyroid surgery, by comparing the electromyography (EMG) amplitudes of nerves stimulated by a patch stimulator and a conventional stimulator.

We present the following article in accordance with the STROBE reporting checklist (available at https://dx.doi.org/10.21037/gs-21-327).

Methods

Patients

We used both a conventional stimulator and the patch stimulator for nerve stimulation for IONM during each thyroid surgery at Seoul Metropolitan Government Seoul National University Boramae Medical Center from April 5, 2021 to April 30, 2021. We retrospectively reviewed the IONM records of all patients who underwent thyroid surgery during the study period. The study was conducted in accordance with the Declaration of Helsinki (as revised in 2013). This study was approved by the Institutional Review Board of the Seoul Metropolitan Government Seoul National University Boramae Medical Center (IRB number: 30-2021-53) and individual consent for this retrospective analysis was waived.

Anesthesia and monitoring setup

Anesthesia was induced with lidocaine (30 mg) and propofol (1.5 mg/kg) injections, then maintained with target-controlled infusions of propofol and remifentanil using infusion pumps. Rocuronium (0.6 mg/kg) was administered for muscle relaxation. A surgical thyroid pillow was used for positioning the patient prior to intubation to prevent inadvertent tube displacement. Endotracheal intubation was performed using an EMG endotracheal tube (Medtronic, Jacksonville, FL, USA). The surface electrodes on the tube were placed at the level of the vocal cords. Immediately after tube fixation, neostigmine (2 mg) and glycopyrrolate (0.4 mg) were administered for the reversal of neuromuscular blockade. One anesthesiologist (J.L) performed or supervised all anesthetic procedures.

Equipment setup and nerve monitoring were performed following the standardized procedures of the International Neural Monitoring Study Group (INMSG) guidelines (10). Nerve integrity monitoring (NIM) was performed using the NIM-response 3.0 system (Medtronic, Jacksonville, Florida). The stimulus current was set to 1 mA with a frequency of 4 Hz, the event threshold was set to 100 mV, and the stimulation duration was set to 100 ms. The cutoff

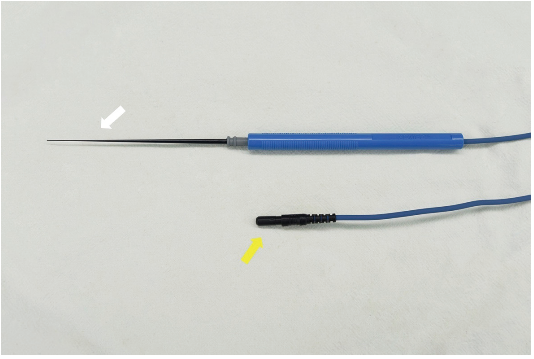

Figure 1 Conventional stimulator. Handheld probe tip (white arrow) connected to the monitoring system via connector (yellow arrow).

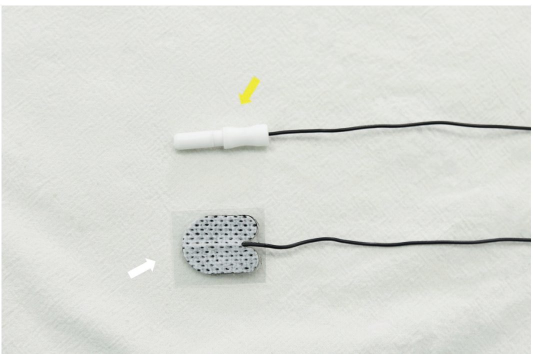

Figure 2 Adhesive patch electrode. Adhesive electrode patch (white arrow) connected to the monitoring system via connector (yellow arrow).

value for the vagus nerve (VN) response and RLN response was set at 100 µV.

IONM procedures using the conventional stimulator and the patch stimulator

Both the conventional stimulator and the patch stimulator were used for each operation. The conventional stimulator (Prass Standard Monopolar Stimulator Probe, Medtronic, FL, *Figure 1*) was connected to the monitoring system and use d during surgery by stimulating the nerves with the tip of the probe. The patch stimulator (*Figure 2*) was prepared by wrapping the adhesive electrode pad around one ring of the mosquito forceps used for dissection. After connecting the wires to the monitoring system, nerve monitoring was implemented with the mosquito forceps during dissection (*Figure 3*).

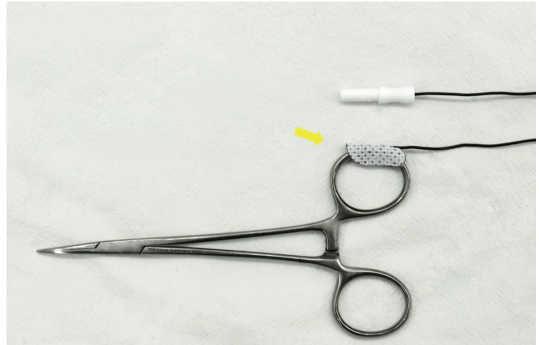

Figure 3 Patch stimulator. An adhesive patch electrode is applied on mosquito forceps (yellow arrow) to transfer electrical stimulus to the nerve through the instrument.

Surgery was performed by a single surgeon (Y.J.C.). VN and RLN nerve stimulations were performed before and after resection, using both the patch stimulator and the conventional stimulator. The V1 and R1 signals were defined as the EMG signals from the VN and RLN, respectively, upon their initial identification prior to thyroid resection. The VN and RLN were first stimulated by the patch stimulator and then stimulated by the conventional stimulator at the same location of each nerve. The R2 and V2 signals were defined as the EMG signals of the RLN and VN, respectively, after thyroid gland removal. The VN and RLN were stimulated at the same location of the nerve by the patch stimulator followed by the conventional stimulator alternatively.

Statistical analysis

All data are presented as mean ± standard deviation for continuous variables. Statistical analysis was performed by the chi-square test, and two tailed values of $P < 0.05$ were considered statistically significant. All analyses were performed using SPSS 26.0 software for Windows (IBM, Armonk, New York, USA).

Results

A total of 15 consecutive patients (4 males and 11 females) were included in the study. Patient characteristics are summarized in *Table 1*. The mean age was 50.9±12.0 years, and the mean body mass index was 25.3±3.8. The mean tumor size at the longest diameter was 1.4±0.9 cm. Eleven (73.3%) patients underwent lobectomy and four (26.7%)

Table 1 Patient characteristics

Patient characteristics	Total patients (N=15)
Gender (male:female)	4:11
Age (years)	50.9±12.0
Body mass index (kg/m^2)	25.3±3.8
Tumor size in longest diameter (cm)	1.4±0.9
Extent of operation	
Lobectomy	11 (73.3)
Total thyroidectomy	4 (26.7)
Diagnosis	
Papillary thyroid carcinoma	10 (66.7)
Follicular cell adenoma	3 (20.0)
Hurthle cell adenoma	1 (6.7)
Graves' disease	1 (6.7)
Vocal cord palsy	0 (0.0)

All data are presented as mean ± standard deviation or as n (%), unless stated otherwise.

underwent total thyroidectomy. The final pathological diagnoses consisted of 10 cases of papillary thyroid carcinomas, three cases of follicular cell adenomas, one case of Hurthle cell adenomas, and one case of Graves' disease. No vocal cord palsy occurred in any of the patients (*Table 1*).

Table 2 shows the EMG amplitude profiles of RLN and VN stimulated by the patch stimulator and a conventional probe stimulator. A total of 38 nerves (19 RLNs and 19 VNs) were evaluated. When stimulated with each of the stimulators, the V1, R1, R2, and V2 signals of all the nerves had amplitudes of more than 500 µV, except in one patient who had V1 and R1 signals of more than 500 µV but R2 and V2 signals of less than 500 µV. No postoperative vocal cord palsy was seen in this patient. The mean amplitudes evoked by the patch stimulator and the conventional probe stimulator were 935.8±426.1 and 928.0±414.4 µV for the V1 signal, 1,165.6±537.3 and 1,143.0±547.7 µV for the R1 signal, 1,082.8±522.4 and 1,071.6±527.0 µV for the R2 signal, and 872.7±453.2 and 877.6±507.1 µV for the V2 signal, respectively. The mean differences between the amplitudes evoked by the two types of stimulators were 70.8±65.3 µV for the V1, 70.9±72.4 µV for the R1, 155.1±187.1 µV for the R2, and 83.8±110.2 µV for the V2 signals. There were no statistical differences in the mean amplitudes between the two groups for the V1 (P=0.954), R1 (P=0.898), R2 (P=0.948), and V2 (P=0.975) signals.

Discussion

Although IONM is increasingly being routinely used in thyroid surgery and has become the standard practice in high-risk cases, there is still debate over whether I-IONM reduces RLN injury during thyroid surgery (11,12). RLN injury, recognized by loss of signal, has been reported even with I-IONM. The suggested reason for the loss of signal is that I-IONM does not provide real-time monitoring, thus I-IONM detects nerve injury only after the damage has occurred (4,13). The RLN is still at risk of injury proximally to the site of intermitted stimulation and during the interval between nerve stimulations (14).

Continuous IONM (C-IONM) was subsequently established to overcome the limitations of I-IONM (15). By placing a monopolar automatic periodic stimulation electrode on the VN, constant nerve function monitoring is possible throughout the whole course of surgery, allowing the surgeon to dissect and stimulate at the same time (16). However, C-IONM requires the risky procedure of dissecting the carotid sheath and fully exposing the VN to place the electrode on the nerve (17,18). Hemodynamic instability and reversible vagal neuropraxia have also been associated with C-IONM, suggesting that this approach may cause patient harm (19). Furthermore, there is still controversy over whether C-IONM actually reduces the risk of RLN injury (20).

Recently, the use of stimulating dissecting instruments that combine the beneficial features of both I-IONM and C-IONM has been proposed. Stimulating dissecting instruments, which are conventional surgical instruments that are connected to a monitoring system by stimulation wires or attachable stimulators, provide the surgeon with an effective way to perform dissection while simultaneously carrying out nerve stimulation (6,7). In addition to real-time nerve monitoring, stimulating dissecting instruments reduce the time interval between stimulations because they do not require the surgeon to constantly switch between the stimulator and the dissecting instrument, unlike conventional I-IONM monopolar probe stimulators.

The first documented stimulating dissecting instruments were prepared by connecting the surgical instruments to the monitoring system with stimulation wires bound to the instruments with a transparent film (6). Afterwards, the application of different types of stimulators, including a magnetic attachable stimulator and an attachable ring

Table 2 EMG amplitude profiles of recurrent laryngeal nerve and vagus nerve stimulated by a patch stimulator and a conventional stimulator

Patient number	Side	V1 (μV)			R1 (μV)			R2 (μV)			V2 (μV)		
		Patch	Probe	Diff*	Patch	Probe	Diff*	Patch	Probe	Diff*	Patch	Probe	Diff*
1	Rt	550	571	21	538	522	16	967	737	230	587	576	11
1	Lt	627	551	76	929	797	132	1,061	1,084	23	805	738	67
2	Rt	1,769	1,659	110	1,407	1,405	2	661	507	154	501	432	69
2	Lt	704	882	22	1,050	1,053	3	1,078	1,057	21	841	866	25
3	Lt	523	677	154	1,024	1,013	11	1,194	959	235	718	529	189
4	Rt	666	658	8	777	841	64	660	667	7	807	918	111
5	Lt	567	567	0	1,196	1,002	194	647	818	171	699	697	2
6	Rt	752	690	62	560	575	15	650	633	17	524	715	191
7	Lt	1,133	1,152	19	1,350	1,544	194	1,445	1,188	257	1,084	933	151
8	Rt	668	624	44	796	796	0	785	757	28	700	696	4
8	Lt	561	530	31	675	611	64	915	759	156	542	547	5
9	Rt	1,386	1,300	86	2,236	2,311	75	2,391	2,092	299	1,942	1,801	141
10	Rt	1,648	1,851	203	1,977	1,998	21	1,759	1,761	2	1,446	1,453	7
10	Lt	689	624	65	1,414	1,458	44	1,125	1,071	54	701	615	86
11	Rt	819	796	23	844	713	131	862	821	41	888	862	26
12	Lt	1,513	1,461	52	2,144	2,084	60	2,025	1,937	88	1,025	1,052	27
13	Rt	1,312	1,078	234	722	765	43	248	278	30	166	163	3
14	Rt	1,367	1,333	34	1,795	1,558	237	1,271	2,048	777	1,900	2,353	453
15	Lt	527	628	101	713	671	42	829	1,186	357	705	729	24
Mean		935.8	928.0	70.8	1,165.6	1,143.0	70.9	1,082.8	1,071.6	155.1	872.7	877.6	83.8
SD		426.1	414.4	65.3	537.3	547.7	72.4	522.4	527.0	187.1	453.2	507.1	110.2
P value†				0.981			0.978			0.599			0.871

*, difference in EMG amplitudes evoked by a patch stimulator and a conventional probe stimulator. †, P value for the mean amplitudes between the two groups. Rt, right side; Lt, left side; V1, initial electromyography signal of the vagus nerve before surgical dissection; R1, initial electromyography signal of the recurrent laryngeal nerve upon initial identification; R2, electromyography signal of the recurrent laryngeal nerve after thyroidectomy; V2, electromyography signal of the vagus nerve after thyroidectomy; EMG, electromyography; SD, standard deviation.

stimulator, were developed using the same concept of stimulating dissecting instruments (8,9). These attachable stimulators are more convenient in terms of preoperative instrument preparation and applicability to all metallic surgical instruments, and their nerve detection capabilities have been shown to be comparable to that of conventional stimulators (6,8,9). However, there are some disadvantages to the attachable stimulators. A drawback of the magnetic attachable stimulator is its easy accidental detachment from the dissecting instrument, which can delay surgical procedures. The ring stimulator is bulky, and nerve stimulus cannot be delivered if the rubber ring becomes loosened from the surgical instrument. Lastly, these attachable stimulators are costly and not widely commercialized because they were developed specifically for IONM.

On the other hand, the patch stimulator used in our study is an adhesive nerve stimulator electrode commonly used for transcutaneous electrical nerve stimulation for therapeutic purposes, including pain relief and biofeedback therapies (21,22). In our study, the patch stimulator showed

Table 3 Comparison of different types of stimulators

	Conventional probe stimulator	Magnetic attachable stimulators	Ring stimulators	Patch stimulator
Simultaneous dissection	Impossible, need to change instruments	Possible	Possible	Possible
Size	Probe body: 100×10×10 mm^3; Tip: 90×5×5 mm^3	Magnet size: 40×5×4 mm^3	Ring size: 50×5×2 mm^3	Electrode size: 20×15×1 mm^3
Weight	30 g	24 g	19 g	4 g
Price	Probe body: US $80; Tip: US $30	US $430	US $175	US $2.5
Accessibility	Accessible	Not commercialized yet	Not commercialized yet	Accessible
Preparation	Not needed	Magnetically attached to the stimulating dissecting instrument	Placed on dissecting tool by securing the ring around the stimulating dissecting instrument	Placed on stimulating dissecting instrument using the adhesive part of the electrode
Storage after use	Probe body: cleaning and sterilization needed; Tip: Single-use	Cleaning and sterilization needed	Cleaning and sterilization needed	Disposable, single-use

good conductivity compared to conventional stimulators, demonstrating its applicability for IONM during thyroid surgeries. Adhesive patch electrodes are small (20×15×1 mm^3), lightweight (4 grams) and can be easily applied to dissecting tools using the adhesive part of the patch stimulator. The adhesive makes accidental detachment from the surgical instruments less likely compared to other attachable stimulators, such as the magnetic attachable stimulator and the ring stimulator. Furthermore, the patch stimulators are disposable and inexpensive (US$ 2.5) per single patch stimulator. There is no need to clean, disinfect, and reprocess them after each surgery, unlike reusable nerve stimulators, which require the same high level of care and maintenance as any other non-disposable surgical instrument (23). A comparison of the different types of stimulators is summarized in *Table 3*.

There are some limitations to using the patch stimulator approach. One limitation is that the patch stimulator can only be applied to one surgical instrument at a time. If a surgeon decides to apply the patch stimulator to another instrument, the task of taking the adhesive off the first instrument and applying it to another can be cumbersome and time-consuming. However, because most surgeons usually use one stimulating dissecting instrument per surgery, one patch stimulator usually is sufficient. Another limitation of using the patch stimulator is that, like other stimulating dissecting instruments, the surgical instruments are not insulated. If the tip of the instruments comes in contact with structures other than the nerves, the electrical current will most likely be inadequately dispersed during stimulation, and as a result, the appropriate voltage needed for identifying the nerves may be insufficient. To solve this potential problem, a higher voltage of stimulus (2–3 mA) could be given to identify the nerves, and extra care should be made to avoid contact with surrounding structures during nerve stimulation. To overcome this issue, new surgical instruments that are entirely insulated except for the tip could be developed for effective nerve stimulation. We took care not to allow the monopolar or energy-based device to make contact with the stimulating dissecting instrument. Doing so could result in a blown fuse in the nerve monitoring system when the electric current is transferred to the system. Lastly, this study has a small sample size. Nevertheless, we showed the feasibility of the use of patch stimulators for IONM, and anticipate that this study will be a basis for further studies with larger sample size.

Conclusions

EMG signals of the VN and RLN stimulated by the patch stimulator were comparable to those stimulated by the conventional stimulator. The patch stimulator allows the surgeon to simultaneously dissect and stimulate the nerves and can be safely and effectively used for IONM during thyroid surgery.

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Footnote

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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 study was approved by Institutional Review Board of the Seoul Metropolitan Government Seoul National University Boramae Medical Center (IRB number: 30-2021-53) and individual consent for this retrospective analysis was waived.

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