Kaohsiung Journal of Medical Sciences (2016) 32, 135–141

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journal homepage: http://www.kjms-online.com

ORIGINAL ARTICLE

Exclusive real-time monitoring during recurrent laryngeal nerve dissection in conventional monitored thyroidectomy

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Received 24 December 2015; accepted 16 February 2016
Available online 30 March 2016

KEYWORDS
Intraoperative neurophysiological monitoring;
Recurrent laryngeal nerve;
Thyroidectomy

Abstract During conventional intermittent intraoperative neuromonitoring (IONM) in thyroidectomy, recurrent laryngeal nerve (RLN) injury is detected by an electromyographic (EMG) loss of signal (LOS) after the nerve dissection. Exclusive continuous monitoring during the phase of RLN dissection may be helpful in detecting adverse EMG changes earlier. A total of 208 RLNs at risk were enrolled in this study. Standardized IONM procedures were followed. We continuously stimulated the RLN at the lower exposed end with a stimulator to exclusively monitor the real-time quantitative EMG change during RLN dissection. Once the amplitude decreased by more than 50% of the initial signal, the surgical maneuver was paused and the RLN was retested every minute for 10 minutes to determine amplitude recovery before restarting the dissection. The procedure was feasible in all patients. No LOS was encountered in this study. Nineteen RLNs had an amplitude reduction of more than 50%. Eighteen nerves showed gradual amplitude recovery (16 nerves had a traction injury and two nerves had a compression injury). After 10 minutes, the recovery was complete (i.e., >90%) in eight nerves, 70–90% in seven nerves,

Conflicts of interest: All authors declare no conflicts of interest.

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http://dx.doi.org/10.1016/j.kjms.2016.02.004

and 50–70% in three nerves. Among these 18 nerves, only one nerve developed temporary vocal palsy because it was exposed to unavoidable repeated nerve traction after restarting the dissection. Another nerve showed no gradual recovery from thermal injury, and developed temporary vocal palsy. The temporary and permanent palsy rates were 1% and 0%, respectively. During intermittent IONM, exclusive real-time monitoring of the RLN during dissection is an effective procedure to detect an adverse EMG change, and prevent severe RLN injuries that cause LOS.

Introduction

Intraoperative neuromonitoring (IONM) during thyroid surgery has gained widespread acceptance as an adjunct to the gold standard of visually identifying the recurrent laryngeal nerve (RLN) [1–6], detecting RLN anatomic variations [7–9], and elucidating RLN injury mechanisms [3,4,10,11]. In addition, IONM can help clinicians predict vocal cord function outcome and plan intra- and postoperative treatment [12,13]. However, RLN injuries still occur with the application of IONM. Recurrent laryngeal nerve injury often occurs during dissection. Chiang et al. [3] reported that 8.6% of nerves developed loss of signal (LOS) after complete RLN dissection. Snyder et al. [10] reported that 3.8% of nerves in their study had LOS after nerve dissection. Dionigi et al. [11] reported that 6.9% of RLNs experienced LOS after the resection of the thyroid in video-assisted thyroidectomy. These results suggest that the RLN is at high risk of injury during the phase of its dissection.

Conventional IONM administers intermittent stimulation with a handheld stimulation probe. The functional integrity of the RLN is limited to the short-time interval of the direct nerve stimulation and the site of stimulation, if distal to the nerve injury. The RLN is still at risk for damage during the time gap between two nerve stimulations, and nerve injury is detected by the LOS [14,15]. Several varieties of electrodes used to stimulate the vagus nerve (VN) have been designed for continuous IONM (*C*-IONM) technology; however, several issues limit its widespread use such as the need to open the carotid sheath [16], the 360° circumferential dissection of the VN [15], the difficulty of implanting the electrode in some complicated surgical cases [15], the potentially adverse effects of VN stimulation [17], and the necessity of having to use a handheld stimulating probe, its availability, and its cost-effectiveness [15]. Therefore, there are some surgeons who feel discouraged from performing C-IONM and question whether monitoring the whole course of operation is truly needed.

Because most intraoperative RLN injuries occur during the combined phase of medial thyroid traction and RLN dissection [3,10,11], a simple and safe procedure for the real-time monitoring of nerve function during this period would be the most important issue for surgeons. There is no doubt that C-IONM technology can provide seamless monitoring of nerve function during the whole course of surgery [14,15,18]. However, because current C-IONM may not be very popular and available in some areas, an alternative simple and safe method to apply conventional intermittent IONM is crucial for monitoring nerve function continuously during the risky phase of RLN dissection. This study aimed to investigate the feasibility of detecting an adverse change in the EMG signal earlier, and thereby prevent severe nerve injuries that cause LOS, by continuously stimulating the RLN at the lower exposed end with a stimulating probe to exclusively monitor the real-time quantitative EMG amplitude change during RLN dissection.

Methods

Patients

The study was approved by the Institutional Review Board of China–Japan Union Hospital of Jilin University (Changchun City, China; grant no. 20160101). Written informed consent was obtained from each patient. Patients were informed of the intent to use this monitoring system potentially to aid in the localization and identification of the RLN and to assess its function during the operation. No financial or professional association exists between the authors and the commercial company whose neuromonitoring product was studied.

From April 2014 to September 2014, 120 consecutive patients (33 men and 87 women; aged 14–66 years; mean age, 44.1 years) who underwent thyroid operations for various thyroid diseases (99 malignancies, 21 benign lesions, 20 reoperations, 100 primary operations) were prospectively enrolled in this study. They were treated by the same surgery group. In total, 18 unilateral lobectomies and 102 bilateral total thyroidectomies were performed. Fourteen nerves were excluded from this study (12 nerves with preoperative vocal palsy, and two nerves were non-RLNs). Thus, there were 208 nerves at risk in this study.

Setup of the intraoperative nerve monitoring system

The anesthesia and equipment setup followed the standard procedures [1] and were accomplished by the IONM team of China–Japan Union Hospital of Jilin University (Changchun City, China). All patients were intubated with a standard reinforced electromyography (EMG) endotracheal tube (internal diameter of 6.0 mm and 7.0 mm for women and men respectively; Medtronic Xomed, Jacksonville, FL, USA) for general anesthesia. All patients received rocuronium (0.3 mg/kg) in a single dose preoperatively [19]. However, no additional muscle relaxants were administered during general anesthesia. To ensure that the electrodes were perfectly in contact with the true vocal cords, the endotracheal surface electrodes' position was routinely checked by laryngofiberoscopic examination after the neck was placed at full extension [6]. The electrodes from the EMG endotracheal tube were connected to the nerve monitoring system (NIM 3.0, Medtronic Xomed, Jacksonville, FL, USA). A Prass monopolar ball-tip stimulating probe (Medtronic Xomed) was used for VN and RLN stimulation. The stimulation duration was set at 100 μs; the event threshold, at 100 μV; and the stimulus current at 1—3 mA with a frequency of 4 Hz.

Standardized IONM procedures

Standardized IONM procedures were strictly followed [4], and the largest EMG amplitudes were captured and registered at every step. Vagus nerve stimulation (i.e., the V signal) was routinely performed without dissection of the carotid sheath, as previously described [16]. We obtained the V_1 signal before the lateral thyroid dissection. The RLN was then localized and identified at the level of the inferior thyroid pole. The R_1 signal was obtained when the RLN was first identified. After the complete RLN dissection, the RLN was stimulated at the most proximal end to obtain the R_2 signal. The VN was stimulated to obtain the V_2 signal after accomplishing complete hemostasis of the wound.

Exclusive real-time monitoring during RLN dissection

During the RLN dissection procedure, we continuously stimulated the most proximal end of exposed RLN (i.e., R_p point) with a handheld ball-tip stimulator (Figure 1), and continuously monitored the quantitative and quality change in the EMG amplitude. The ball-tip, flexible, and adaptable probe provides atraumatic contact to the nerve [16]; it is gently touched to the lateral surface of the RLN with a recommended safety stimulation intensity of 1 mA to avoid the risk of nerve damage with this procedure [1,20] (Figure 1). The R_1 amplitude EMG signals were the references for the full dissection procedure.

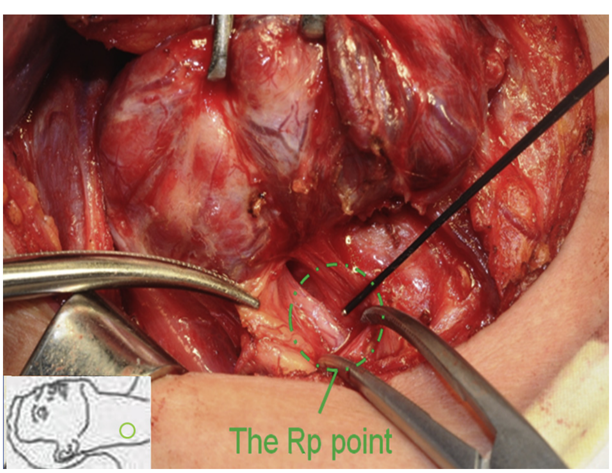

Figure 1. During recurrent laryngeal nerve (RLN) dissection, the most proximal point (R_p) of the exposed RLN is continuously stimulated by a handheld stimulating probe. The quantitative change in the electromyographic amplitude is carefully monitored.

In our previous experimental study [21], we noted a progressive partial EMG loss when the RLN was under stress during the operation. In addition, if the stress was terminated early, before the LOS (i.e., when the amplitude decrease was more than 50%), the EMG signal showed nearly full recovery in 10 minutes. Therefore, we adopted this policy in this study: the surgical maneuvers were paused and the thyroid traction was released immediately if the EMG amplitude decreased more than 50% of the R_1 signal during the operation. The next step in the surgical maneuver was surgical "standby": *de facto* we rested the RLN and retested the nerve function every minute for at least 10 minutes to observe, expect, and determine the possible recovery of the EMG amplitude. We restarted the operation again with meticulous dissection and gentle traction. Before closing the wound, the final EMG amplitudes were registered by stimulating the RLN at the entry point (i.e., R_{2d} signal) and the lowest exposed point (i.e., R_{2p} signal). If the amplitude reduction was more than 50%, compared to the proximal-to-distal RLN stimulation, we checked the whole exposed RLN to pinpoint the weak or disrupted point of electrical conduction (i.e., the nerve injured area) on the RLN [3] (Table 1).

True LOS was defined as an absence of the primary, normal, biphasic waveform at supramaximal stimulation (a 3-mA current was used in this study) with an amplitude that was decreased to <100 μV. It was managed in accordance with the troubleshooting algorithm described in the current guidelines [1].

Documentation

All exposed RLNs were documented photographically with a high-resolution camera to show visual nerve integrity during the operation [4]. All patients received a preoperative and postoperative video recording of vocal cord movement with flexible laryngofiberoscopy, when they were admitted to the hospital and on the first day after surgery [22]. When vocal dysfunction was identified, they were initially followed up every 2 weeks, and then every 4 weeks thereafter until recovery was achieved. A dysfunction was considered permanent if it persisted 6 months postoperatively. Measurement of the RLN palsy rate was based on the number of nerves at risk.

Results

No complications occurred with continuous stimulation at the most proximal end of exposed RLN with the handheld stimulating probe in this study. Among the 208 RLNs, 19 (9.13%) RLNs experienced an EMG amplitude reduction of more than 50% during the phase of RLN dissection. We successfully stopped all surgical maneuvers before the EMG signal degraded to LOS. After 10 minutes of the standby

Table 1 The characteristics of 19 recurrent laryngeal nerves with an electromyographic amplitude decrease of more than 50% during dissection.

No.	Gender/ age (y)	Procedure	Disease	Side	During RLN dissection			During "Standby" maneuver			Final EMG before closing the wound				Post-op
					Initial R1 signal (μV)	Decreased signal (μV)	Signal reduction (%)	EMG gradual recovery	Recovered signal (μV)	Signal reduction (%)	Weak point	R_{2d} signal (uV)	R_{2p} signal (uV)	Mechanism of injury	Vocal cord palsy (duration)
1	F/23	TL	PTC	L	1371	596	57%	+	1243	9%	Yes	2102	1872	Traction	—
2	F/61	TT	PTC	L	1420	684	52%	+	1037	27%	—	207	184	Traction	Palsy (2 mo)
3	F/46	TT	PTC	R	781	385	51%	+	957	0%	—	841	906	Traction	
4	F/23	TT	PTC	L	761	354	53%	+	639	16%	—	460	423	Traction	—
5	F/39	TT	PTC	L	970	483	51%	+	1021	0%	Yes	627	327	Traction	—
6	F/40	TT	PTC	L	903	332	63%	+	602	33%	—	602	572	Traction	—
7	F/55	TT	NG	L	2546	1167	54%	+	1785	30%	—	1785	1627	Traction	—
8	F/33	TL	PTC	R	1509	681	55%	+	1483	2%	Yes	2128	1483	Traction	—
9	F/33	TT	PTC	R	1587	408	74%	+	1116	30%	Yes	2026	1483	Compression	—
10	F/42	TT	PTC	R	504	241	52%	No	258	49%	Yes	911	254	Thermal	Palsy (2 mo)
11	F/43	TT	PTC	L	1875	275	85%	+	1001	47%	Yes	1888	818	Compression	—
12	M/14	TT	PTC	L	1317	591	55%	+	901	32%	—	874	906	Traction	—
13	F/28	TT	PTC	L	1184	585	51%	+	1150	3%	—	692	686	Traction	—
14	F/33	TT	PTC	L	1462	671	54%	+	1392	5%	Yes	652	454	Traction	—
15	F/46	TT	NG	L	1270	361	72%	+	950	25%	—	1289	1491	Traction	—
16	M/42	TT	PTC	L	709	316	55%	+	756	0%	—	1564	1536	Traction	—
17	F/44	TT	PTC	L	1312	556	58%	+	1001	24%	—	1273	1069	Traction	—
18	F/33	TT	PTC	L	777	346	55%	+	856	0%	—	814	733	Traction	—
19	F/44	TT	PTC	L	1803	386	79%	+	1330	26%	—	1039	1330	Traction	—

EMG = electromyographic; F = female; L = left side; M = male; NG = nodular goiter; PTC = papillary thyroid carcinoma; R = right side; R_{2d} = EMG amplitude obtained by stimulating the recurrent laryngeal nerve at the entry point; R_{2p} signal = EMG amplitude obtained by stimulating the recurrent laryngeal nerve at the lowest exposed point; RLN = recurrent laryngeal nerve; TL = unilateral total lobectomy; TT = bilateral total lobectomy.

maneuver, 18 nerves showed a progressive gradual amplitude recovery and one nerve showed a persistent decrease.

Of the 18 nerves with a gradual amplitude recovery, 16 nerves had a traction injury and 2 nerves had a compression injury. The recovery rate in comparison to the initial R_1 signal was greater than 90% (i.e., complete recovery) in eight nerves, incomplete (80—90%) in one nerve, 70—80% in six nerves, 60—70% in one nerve, and 50—60% in two nerves. The mean standby was 6.53 $\pm$ 2.56 minutes. Among these 18 nerves, only one nerve (Case No. 2), which was adhered to a huge recurrent malignant goiter, developed temporary vocal palsy because of unavoidable repeated nerve traction. It ultimately had poor EMG recovery; the final R_{2p} amplitude was 184 μV, which was an 87% reduction, compared to R_1 (Table 1). The nerve functioned well approximately 2 months after the operation. The remaining 17 nerves showed stable EMG activity after restarting the operation with more meticulous dissection and gentle traction, and all showed normal vocal cord function postoperatively.

One nerve showed an EMG amplitude reduction greater than 50% during RLN dissection, but had no gradual recovery after the standby maneuver was performed because of thermal injury (Table 1, Case No. 10), which resulted when the nerve was inadvertently touched by a heated harmonic scalpel that just stopped activation. This nerve functioned well approximately 2 months after operation.

Among the other 189 RLNs that did not experience a substantial EMG amplitude decrease during the RLN dissection, all nerves showed normal postoperative vocal cord function. Therefore, the incidence of temporary and permanent palsy rates was 0.96% and 0%, respectively.

With regard to the mechanism of nerve injury, 16 nerves had traction injury, two nerves had compression injury, and one nerve had thermal injury (Table 1). Among these 19 nerves, seven nerves (representing four traction injuries, two compression injuries, and one thermal injury) had a weak point of electrical conduction (i.e., the nerve injured area [3]) on the exposed RLN before the wound was closed. All injured nerve segments were distal to the first exposed end of the RLN, but none of them was visually apparent.

Discussion

In this study, we attempted to overcome the limitation of conventional intermittent IONM that can only recognize RLN injury by detecting the LOS after nerve dissection. To exclusively monitor the real-time quantitative EMG change during the risky phase of RLN dissection, we continuously stimulated the RLN at the lower exposed end with a stimulator (Figure 1). We used an EMG amplitude decrease of more than 50% as a warning criterion. We found it was useful for detecting an adverse signal change in a more timely fashion. Nineteen (9.13%) RLNs had an EMG amplitude reduction of more than 50% during the phase of RLN dissection. We also successfully stopped all surgical maneuvers before the EMG degraded to a LOS (Table 1). The procedure was feasible in all patients and did not result in any morbidity. No complete LOS was encountered in this study, and only two (0.96%) nerves (one nerve with an unavoidable repeated traction injury and one nerve with a thermal injury) developed temporary postoperative RLN palsy for 2 months. These results highlight the importance of real-time monitoring of the RLN function during its dissection. The procedure of exclusive real-time monitoring during RLN dissection described in this study could be an effective and feasible alternative method to overcome the limitation of using intermittent IONM in thyroid surgery.

The causes of RLN injury can be transection, clamping, traction, electrothermal injury, ligature entrapment, or ischemia. Recurrent laryngeal nerve traction injury is the most common mechanism of RLN injury [3,10,11]. Recurrent laryngeal nerve traction injury is difficult to avoid because medial retraction of the thyroid lobe is a necessary surgical procedure during thyroid surgery. The conventional use of intermittent IONM detects nerve injury after its occurrence, and it is difficult to prevent this kind of nerve injury. Therefore, several varieties of electrodes for the stimulation of the VN have been designed for C-IONM technology that provides seamless monitoring of nerve function during the whole course of surgery [14,15,18]. Continuous IONM is useful for preventing an imminent traction injury by the early detection of its characteristic feature of EMG signal change during traction injury [23,24]. The EMG signal showed a progressive decrease in amplitude in combination with increased latency during acute traction distress, and the signals showed progressive gradual recovery after the traction was relieved early [21].

In this study, we continuously and exclusively stimulated the most proximal end of the exposed RLN with a handheld stimulating probe, and monitored the real-time quantitative change in the EMG amplitude. We found that this simple method also helped to detect an adverse signal change early during the RLN dissection. Among 19 RLNs with a pending nerve injury, 16 (84%) nerves had a traction injury that was manifested by a progressive amplitude decrease during thyroid traction and gradual recovery within 10 minutes after traction release. We restarted the operation with more meticulous nerve dissection and gentle thyroid traction. We saved 15 nerves with a good EMG signal after complete RLN dissection; however, one nerve (Case No. 2) with a large tumor was exposed to unavoidable repeated traction, which ultimately resulted in a substantial (87%) EMG amplitude reduction and temporary vocal palsy. The EMG evolution of this nerve correlated with previous animal experiment findings that showed that EMG activity can recover if the traction stress is relieved before the LOS, and that the recovery was worse if repeated traction was applied to the RLN [21].

We experienced two nerves (Cases No. 9 and 11) that were inadvertently compressed by tissue forceps during the nerve dissection. Abrupt substantial reduction of EMG amplitude was detected and the compression was released immediately. We found that the EMG gradually recovered from 408 μV to 1116 μV (i.e., 70% recovery of the initial R_1 signal) in Case No. 9 and from 275 μV to1001 μV (i.e., 50% recovery of the initial R_1 signal) in Case No. 11 after 10 minutes. Both patients had normal vocal cord movement postoperatively. We also experienced an interesting case of thermal injury. The RLN in Case No. 10 inadvertently touched the heated harmonic scalpel that just stopped activation. Abrupt substantial reduction of the EMG amplitude was detected, and we immediately noticed the injury. The heated harmonic scalpel was in contact with the RLN for less than 1 second; however, the decreased EMG amplitude did not recover after 10 minutes of waiting. We did not find any change in the RLN under direct vision after the complete RLN dissection, but a precise weak point of nerve conduction was detected on the injured area. Vocal cord palsy was confirmed by postoperative laryngoscopy, but cord mobility functioned well approximately 2 months after the operation. The findings of this thermal-injured nerve correlated with recent animal study findings that showed that thermal injury to the RLN may not be visually apparent and IONM can be a tool used for the early detection of acute thermal stress [25]. Another animal study [26] also showed that the residual heat of the harmonic scalpel could cause RLN thermal injury. The authors of that study suggest that a 10-second cooling time at room temperature or a 2-second cooling time after touching the sternocleidomastoid muscle is helpful in preventing thermal damage [26].

Alterations of the contact quality between the vocal cord and the tube electrodes can also result in a substantial change in the EMG amplitude because of the surgical manipulation of the thyroid or trachea [6,27]. However, in our clinical experience, a substantial EMG change caused by a position change in the tube was less frequent. Surgeons should regard a substantial amplitude reduction as a warning sign and consider the possibility of acute distress of the nerve.

In this study, only one nerve that was affected by thermal injury showed a persistent amplitude decrease. The other 18 nerves (16 nerves with traction injury and two nerves with compression injury) all showed progressive gradual amplitude recovery and 15 (83%) nerves showed an EMG recovery of more than 70% within 10 minutes of waiting. Therefore, pausing the surgical maneuver immediately and waiting 10 minutes to determine the recovery of EMG amplitude is worthwhile. In addition, to prevent a second injury, more meticulous dissection of the RLN and gentle thyroid traction should be used after restarting the operation.

A higher initial EMG amplitude is necessary for monitoring the quantitative change in the EMG amplitude and detecting an imminent injury earlier. To ensure that the EMG tube is placed at the proper position during endotracheal intubation or adjusting the tube position during the operation to allow an initial EMG amplitude of 500 μV or more is our routine procedure. No complications occurred in this study; however, this procedure was inconvenient in comparison to current C-IONM technology because it requires an assistant to hold the stimulating probe to stimulate the RLN continuously during nerve dissection. Therefore, the concept of a stimulating dissecting instrument that combines the function of a handheld stimulating probe and dissecting forceps may provide surgeons with a simpler, convenient, and effective way to monitor a nerve's function instantly during the risky phase of RLN injury in conventional intermittent IONM [28].

Conclusion

This study demonstrated that continuously stimulating the most proximal end of an exposed RLN is a useful method to monitor nerve function simultaneously during a RLN dissection in conventional intermittent monitored thyroidectomy. It helps detect adverse EMG changes so that a surgical maneuver can be modified in a more timely way, and thereby prevent severe RLN injuries, which may further reduce the RLN palsy rate.

Acknowledgments

Part of this work was presented during the 8th Annual Meeting of the Chinese College of Surgeons and the 19th Annual Meeting of the European Society of Surgery in Beijing, China May 15—17, 2015.

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