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Corticobulbar motor evoked potentials from tongue muscles used as a control in cervical spinal surgery

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ABSTRACT

Objective: Motor evoked potentials (MEPs) changes might be caused to the non-surgically induced factors during cervical spinal surgery. Therefore, control MEPs recorded cranially to the exit of the C5 root are highly recommendable in cervical spinal surgery. We studied whether corticobulbar MEPs (C-MEPs) from tongue muscle could be used as a control MEPs in cervical spinal surgery.
Methods: Twenty-five consecutive cervical spinal surgeries were analyzed. Stimulation of motor area for tongue was done by subcutaneous electrodes placed at C3/C4 (10–20 EEG System), and recording was done from both sides of tongue.
Results: C-MEPs were recorded successfully 24 out of the 25 (96%) tested patients. Forty-six out of fifty MEPs (92%) from tongue muscles were monitorable from the baseline. In two patients, we could obtain only unilateral C-MEPs. Mean MEPs latencies obtained from the left and right side of the tongue were 11.5 ± 1 ms and 11.5 ± 0.8 ms, respectively.
Conclusions: Monitoring C-MEPs from tongue muscles might be useful control in cervical spinal surgery. They were easily elicited and relatively free from phenomenon of peripheral stimulation of the hypoglossal nerves.
Significance: This is first study to identify the usefulness of C-MEPs as a control of cervical spinal surgery.

1. Introduction

Intraoperative neurophysiological monitoring (IONM) using transcranial muscle motor evoked potentials (MEPs) and somatosensory evoked potentials (SSEPs) is an established method for detecting perioperative neural damage during cervical spinal surgeries, including those for scoliosis, herniated intervertebral disc and tumors (Cheng et al., 2014; Kelleher et al., 2008; Park et al., 2011; Raynor et al., 2013; Sala et al., 2007; Xu et al., 2011) Although SSEPs were used first to monitor the spinal cord (Nash et al., 1977), MEPs are now considered the gold standard for monitoring the corticospinal tract (Deletis and Sala, 2008).

MEPs elicited during surgery could be influenced by various non-surgically induced changes, such as: anesthetics, medication, body temperature, blood pressure, positioning, hypoxia, ischemia, beside surgically surgery-related changes (Fishback et al., 1995; Haghighi et al., 1993; MacDonald and Janusz, 2002; Plata Bello et al., 2015; Raynor et al., 2013; Simon et al., 2010). Therefore, neurophysiologists have to differentiate non-surgically vs surgically induced changes to the parameters of MEPs. Control MEPs which are not influenced by surgery (such as MEPs recorded from the abductor pollicis brevis muscles during lower thoracic spinal surgery) could be used for this purpose.

Segmental injury, as well as long tract injuries, is a possible complication during cervical spinal surgery (Fujiwara et al., 2016). In addition, C5 palsy can occur in anterior (Nassr et al., 2012; Wang et al., 2015) or posterior surgical approach to the cervical spine (Fan et al., 2002; Imagama et al., 2010; Nassr et al., 2012; Yanase et al., 2010). Therefore, control MEPs recorded cranially to the exit of the C5 root are highly recommendable in cervical spinal surgery.

Corticobulbar MEPs (C-MEPs) from the facial, vagal, or hypoglossal innervated muscles have been used in the monitoring of cranial nerve functional integrity in brainstem or skull base surgery (Akagami et al., 2005; Deletis et al., 2009; Dong et al., 2005; Skinner, 2011). They suffer from the drawback that the stimulation and recording sites are relatively close compared to those for

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muscle MEPs. In this case, stimulation of the peripheral part of cranial nerves could be significant confounding factor. Thus, the aim of this study is to determine whether corticobulbar MEPs from tongue muscles can be used as a control for muscle MEPs in cervical spinal surgery.

2. Methods

2.1. Patients

A consecutive series of 25 cervical spinal surgeries performed between August 2015 and October 2015 was analyzed. Patient ages ranged from 22 to 79 years, with the mean being 57.2 years. The male to female ratio was 13:12. The surgical interventions were required for: cervical compressive myelopathy (n = 10); cervical herniated intervertebral disc (n = 8); intradural extramedullary tumor (n = 5); fracture (n = 1); and intramedullary tumor (n = 1). There were 15 cases with an anterior surgical approach, and 10 cases with a posterior surgical approach (Table 1). All patients were informed about the research aim and methods, and informed written consents were provided by them. The present study was approved by the Institutional Review Board at Seoul National University Bundang Hospital (B-1601/330-113).

2.2. Anesthesia

To avoid the confounding effects of anesthesia in MEP monitoring, a neuromuscular blocker was used just before intubation (rocuronium 0.5–0.9 mg/kg). Patients were premedicated with 2 mg of midazolam. Intravenous lidocaine (0.3–0.5 mg/kg) was then used for induction. Total intravenous anesthesia (TIVA) with propofol (3–4 μg/mL) and remifentanil (1.5–4 μg/mL) was used to maintain anesthesia. The anesthesiologist maintained end-tidal CO_2 in the normal range throughout surgery.

2.3. Intraoperative neurophysiological monitoring

2.3.1. Transcranial electrical stimulation

Transcranial electrical stimulation was delivered using needle electrodes according to the international 10–20 electrode placement system. The subcutaneous needle electrode was inserted at C3 (anode) and C4 (cathode) in order to stimulate the left hemisphere, and the reverse arrangement was used to stimulate the right hemisphere. These interhemispheric stimulation (C3/C4) was used for both muscle MEPs and corticobulbar MEPs from tongue muscles. Multi-pulse transcranial electrical stimulation was performed using a commercially available IONM electrical stimulator (Xltek Protektor 32 IOM system; Natus Medical Inc., Oakville, Canada). Trains of five square-wave stimuli were delivered with the following characteristics: individual pulse duration 0.05 ms, interpulse interval of 1–2 ms, intensity of 250 to 500 V. For recordings we used bandpass filtered 10–1000 Hz; and time base 100 ms. We did single pulse stimulation to rule out direct hypoglossal nerve stimulation through peripheral conduction with the same intensity as that of multi-pulse stimulation. When MEPs from tongue muscles were elicited by single pulse stimulation, we reduced the stimulus intensity till they disappeared. Single pulse stimulations were done whenever there were events of amplitude decrement in the limb MEPs (L-MEPs).

Table 1
Clinical parameters of the enrolled patients.

Clinical parameters	Number
Age (years, mean ± SD)	56.5 ± 17.6
Sex (Men/Women)	13/12
Diagnosis	
Cervical compressive myelopathy	10
Cervical herniated intervertebral disc	8
Intradural extramedullary tumor	5
Fracture	1
Intramedullary tumor	1
Approach	
Anterior	15
Posterior	10

2.3.2. Recording electrodes

The C-MEPs from hypoglossal nerve were recorded with uninsulated needle electrodes (Xian Friendship Medical Electronics Co. Xian, China) placed bilaterally in the lateral sides of the tongue. The needles are placed 5–10 mm apart (Fig. 1A; see also Topsakal et al., 2008). We used a piece of rolled gauze after needle insertion to protect the patient's tongue from the bite injury (Fig. 1B). L-MEPs were recorded from the deltoid, triceps brachii, and abductor pollicis brevis muscles for the upper extremities, and from the tibialis anterior and abductor hallucis muscles for the lower extremities muscles.

3. Results

C-MEPs from tongue muscles after transcranial electrical stimulation could be monitored in 24 of the 25 (96%) tested patients. Forty-six out of fifty (92%) C-MEPs from tongue muscles could be monitored from the baseline. The mean latencies of CMEPs of the left side and right side were 11.5 ± 1 ms and 11.5 ± 0.8 ms, respectively, while the mean amplitudes of the left side and right side were 1.13 ± 1.04 mV and 1.15 ± 1.05 mV, respectively (Table 2).

In two patients, C-MEPs could be recorded only unilaterally. In one patient, bilateral response in the tongue muscles were elicited by single pulse stimulation, dubious for direct hypoglossal nerve stimulation (Fig. 2).

One patient met a significant MEPs change during the surgery (Fig. 3). The patient was a sixty-three year old female who underwent laminoplasty due to cervical myelopathy combined with ossification posterior longitudinal ligaments (C4-C6). Monitoring of both C- and L-MEPs was performed as described above in Section 2.3.2 (see also Fig. 3A). Single pulse stimulation was also performed to rule out stimulation of the peripheral part of the cranial nerve (Fig. 3B). L-MEPs recorded distally from the myotome for deltoid muscle showed decrements immediately after laminectomy, while C-MEPs remained stable (Fig. 3C). L-MEPs showed a gradual recovery through the rest of the surgical procedure (Fig. 3D), and the patient had no subsequent motor deficits following surgery.

4. Discussion

This is the first study to demonstrate the usefulness of C-MEPs from tongue muscle as a control for L-MEPs in cervical spinal surgery. In our study, C-MEPs showed good monitorability following transcranial electrical stimulation with a C3/C4 and C4/C3 montage with TIVA using propofol and remifentanil. The latency of responses in our study was also similar to that of controls in a previous study using magnetic stimulation (Urban et al., 1996).

The tongue itself has numerous muscle fibers compared with other target muscles for C-MEPs and rich corticobular innervation. Actually, amplitude of C-MEPs from the tongue was high enough to recognize (approximately 1.1 mV) in our study. Therefore, this might be one of the explanations of high success rate of C-MEPs from tongue muscles. One patient who showed decrement of the L-MEPs during surgery might show usefulness of the C-MEPs from

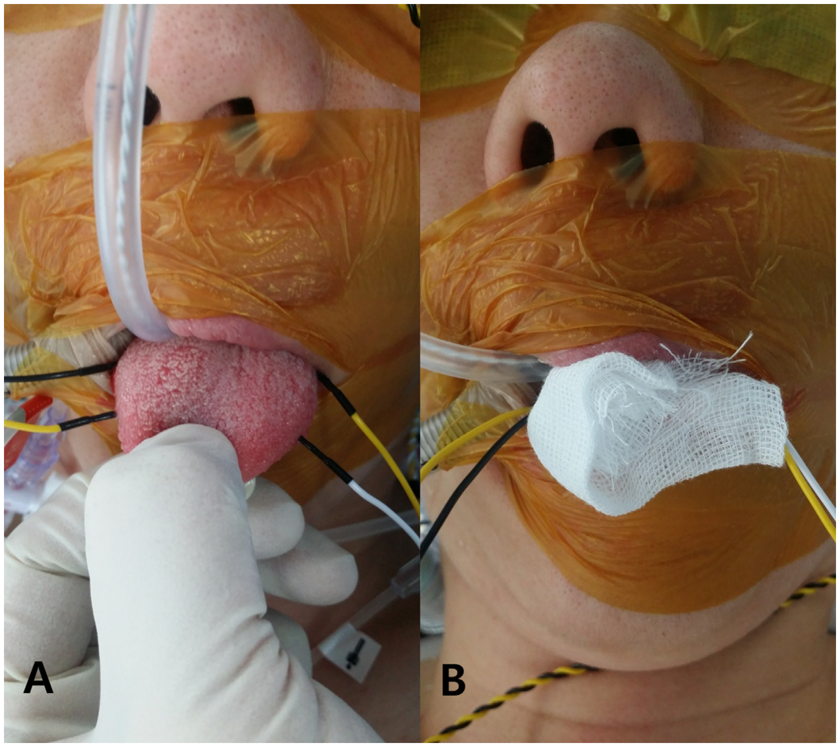

Fig. 1. Photograph of needle electrodes inserted bilaterally in the tongue. A: Needle inserted bilaterally in the anteriolateral portion of the tongue. B: Image taken after a piece of rolled gauze was inserted to prevent tongue bite injury.

Table 2
Results of hypoglossal nerve motor evoked potential recording.

Pt. No.	Age	Sex	Diagnosis	Baseline hypoglossal nerve MEP			
				Latency (ms)		Amplitude (mV)	
				Left	Right	Left	Right
1	73	M	CSM	11.2	12	0.5	0.8
2	48	M	Fracture	12	10.3	0.8	0.4
3	63	M	CSM	10.7	12.8	1.7	0.8
4	67	F	CSM	10.5	12.8	0.2	0.2
5	70	F	CSM	10	10.7	3.3	1
6	63	M	CSM	11.2	10.8	1.2	1.6
7	59	M	CSM	11.2	11.5	4.4	1.8
8	75	M	CSM	10.5	10.3	1	0.2
9	63	F	CSM	10.2	11.8	0.2	2.9
10	78	F	CSM	13.8	11.7	0.4	0.6
11	79	M	CSM	12.3	U/A	2.1	U/A
12	27	F	HIVD	13.8	12.7	0.5	0.2
13	46	F	HIVD	12	12.2	1.1	1.5
14	32	M	HIVD	11.7	11.2	0.8	0.4
15	67	F	HIVD	Peripheral stimulation +			
16	31	M	HIVD	10.7	U/A	0.7	U/A
17	76	F	HIVD	11.7	11	1.2	3.2
18	22	M	HIVD	11.7	11.8	0.3	0.1
19	47	F	HIVD	11.2	11.5	1.3	3.1
20	56	F	IDEM tumor	10.8	11.2	0.4	0.2
21	71	M	IDEM tumor	12	11.5	2.3	1.9
22	69	F	IDEM tumor	12.2	12.7	0.2	0.1
23	62	M	IDEM tumor	11.2	10.7	1.6	2.7
24	35	F	IDEM tumor	12	11.2	0.8	1.4
25	34	M	IM tumor	11.2	10.7	0.1	0.2
			Mean ± SD	11.5 ± 1	11.5 ± 0.8	1.13 ± 1.04	1.15 ± 1.05

Abbreviations: MEPs: motor evoked potentials, CSM: cervical spondylotic myelopathy, HIVD: herniated intervertebral disc, IDEM: intradural extramedullary, IM: intramedullary.

tongue muscles as a control in cervical spinal surgery (Fig. 3). If results of C-MEPs are not available, various factors not related to the surgery such as medication, body temperature, blood pressure, and technical failure should be checked. However, we noticed immediately that change in the L-MEPs was related with surgical procedure (laminectomy in this case) based on the C-MEPs. This patient had no subsequent motor deficits following surgery even though deltoid MEP was not recovered. It could be considered as

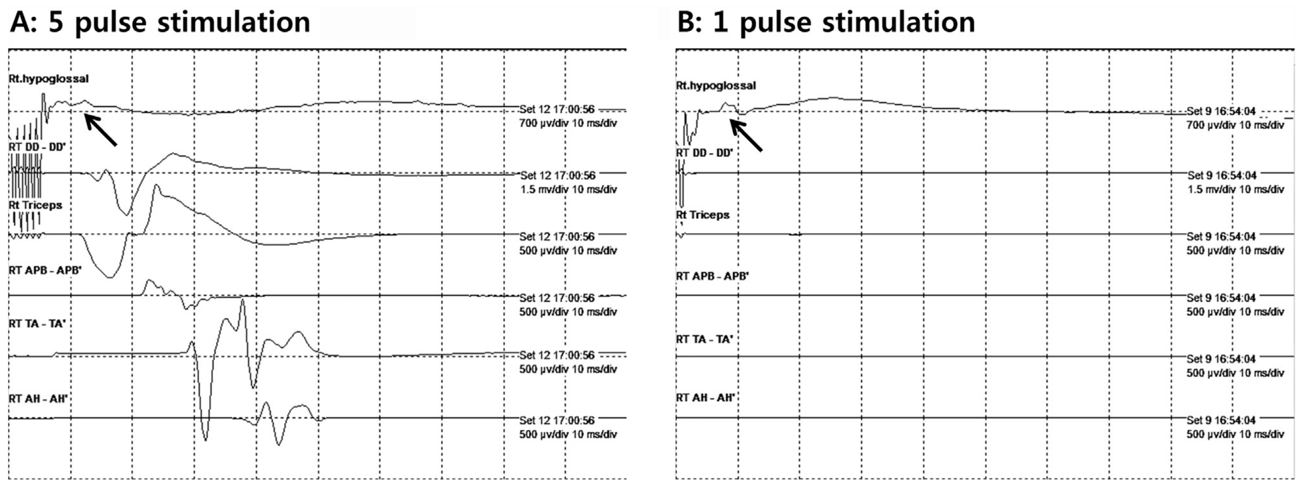

Fig. 2. A case with positive single-pulse stimulation indicative of peripheral conduction. A: There was a recognizable waveform in corticobulbar MEPs from tongue muscle at 5-pulse stimulation. B: The waveform of the hypoglossal nerve MEPs was also elicited by single-pulse stimulation. Note that there was no recognizable waveform of the limbs. DD, deltoid; APB, abductor pollicis brevis; TA, tibialis anterior; AH, abductor halluces muscles. Note that each muscle has different gain per division.

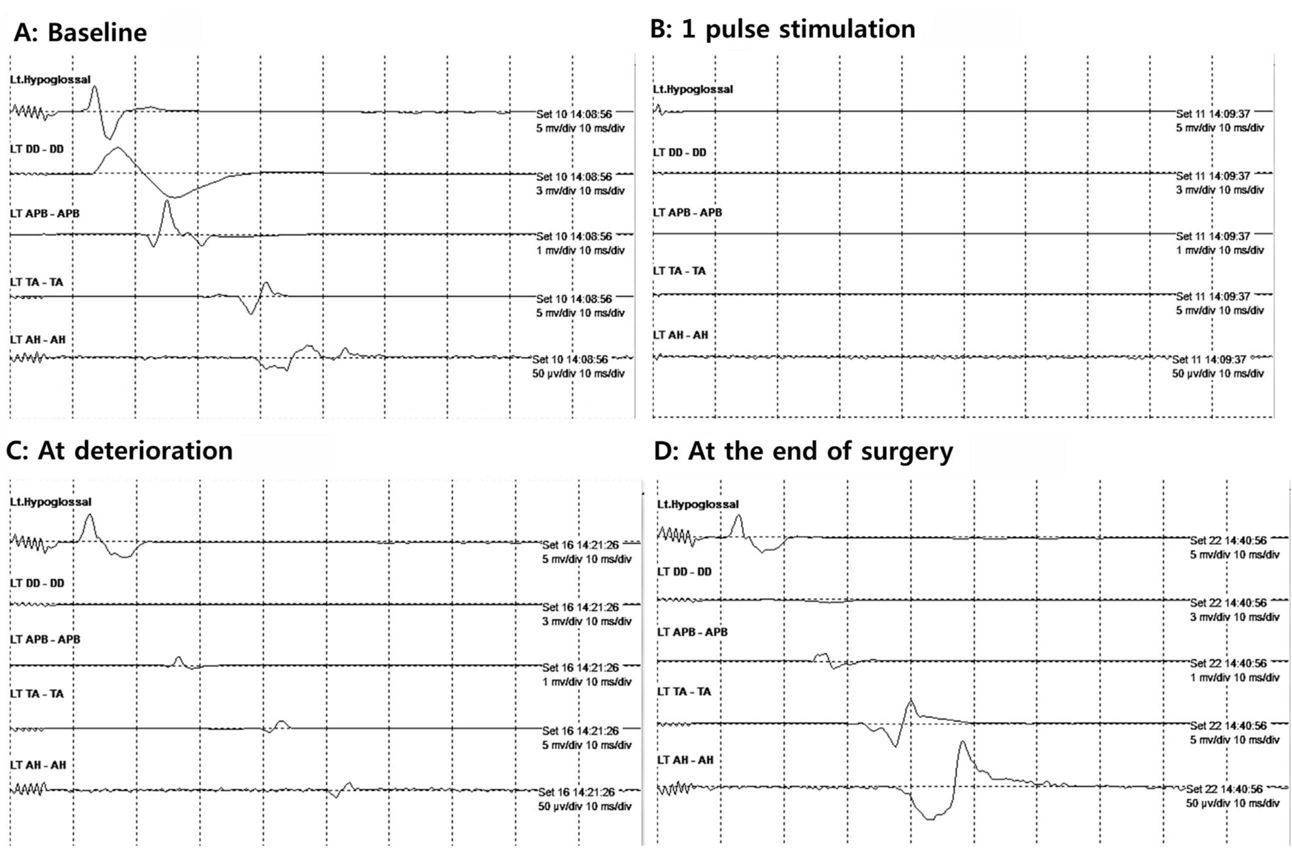

Fig. 3. Stable corticobulbar MEPs (C-MEPs) from tongue muscle despite deteriorating limb MEPs (L-MEPs) recorded caudally to the deltoid muscle. A: Baseline MEPs with 5-pulse stimulation were clearly identifiable in recordings from tongue, deltoid, abductor pollicis brevis, tibialis anterior, and abductor hallucis muscles. B: Single pulse stimulation was performed to rule out peripheral conduction. C, D: Note that C-MEPs from tongue muscle remained stable when the L-MEPs caudally to deltoid muscle deteriorated (C). Gradual recovery of the L-MEPs was shown with stable C-MEPs (D). Gain (amplification intensity) is the same for each muscle. DD, deltoid; APB, abductor pollicis brevis; TA, tibialis anterior; AH, abductor halluces muscles. Note that each muscle has different gain per division.

a false positive result. However, L-MEPs of this patient were gradually being recovered from the lower limb to upper limb when the surgery came to an end. Accordingly deltoid MEP might be recovered at least partially if the surgery had continued for a longer time. Yet, differentiation between these two possibilities could not be made. It has been also known that monitoring MEPs from deltoid muscle could fail to detect radicular lesion of C5 root and consecutively paresis of deltoid muscle (Spitz et al., 2015; Yanase et al., 2010). Furthermore, disappearance of MEPs in deltoid muscle is not always correlated with clinical outcome (Clark et al., 2013).

An interhemispheric stimulating montage using C1/C2 or C3/C4 is widely used to elicit L-MEPs recorded from arms and legs

(Macdonald, 2006; Szelenyi et al., 2007). We adopted the C3/C4 montage for transcranial electrical stimulation site for both L-MEPs and C-MEPs, because of the lowest threshold despite vigorous muscle contractions. A previous study on C-MEPs recorded from facial nerve innervated muscles found lower technical failure using stimulation 1 cm anterior to the C3/C4 montage than when stimulation was 1 cm anterior to the C1/C2 montage (1/8 vs. 3/18 failures; Dong et al., 2005). Although hemispheric C3/Cz and C4/Cz montages are recommended for C-MEPs (Akagami et al., 2005; Deletis et al., 2009; Dong et al., 2005; Skinner, 2011), it is hard to elicit L-MEPs from lower legs with such hemispheric montages (Macdonald et al., 2013). Indeed, it would require four stimuli to elicit bilateral C-MEPs from tongue muscles and L-MEPs for upper and lower extremities using a hemispheric montage. Therefore, we used an interhemispheric montage to be able to compare C-MEPs and L-MEPs simultaneously. Stimulation with interhemispheric montage (C3/C4) only required two trains of stimuli to elicit bilateral C-MEPs and L-MEPs for upper and lower extremities.

Our study showed a low rate of eliciting muscle response in tongue muscle by direct stimulation of hypoglossal nerve due to the current leak (2/50, 4%). Reducing this phenomenon is one of the big issues confronting the use of C-MEPs, because the recording site is relatively close to the stimulation site. The low incidence of direct stimulation of hypoglossal nerve, in spite of using interhemispheric stimulation (C3/C4 and C4/C3), might be related to the locations of the hypoglossal nucleus and tongue. The hypoglossal nucleus is located caudally to the facial nucleus. Thus, direct stimulation of the hypoglossal nucleus and/or hypoglossal nerve might be lesser than that of the facial nucleus. Hemispheric stimulation via C3/Cz and C4/Cz montages could serve as back-ups in those cases in which C-MEPs cannot be monitored, or when direct stimulation of hypoglossal nerve, with interhemispheric stimulation is problematic.

There are a few limitations to this study. First, we did not study other C-MEPs, but from tongue as a control MEPs for cervical spinal surgery, such as C-MEPs from the facial or vagus nerves innervated muscles. Second, we had only a single event during surgery in our patient group, so future studies will be needed to confirm the stability and reliability of the C-MEPs from tongue muscles except this surgical event.

5. Conclusion

Monitoring C-MEPs from tongue muscles might be useful control in cervical spinal surgery. They were easily elicited using interhemispheric stimulation and relatively free from confounding stimulation of hypoglossal nerves.

Conflict of interest statement

None of the authors have potential conflicts of interest to be disclosed.

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