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Comparison of intraoperative neuromonitoring accuracies and procedures associated with alarms in anterior versus posterior fusion for cervical spinal disorders

A prospective multi-institutional cohort study

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Abstract

A prospective multicenter cohort study. To clarify the differences in the accuracy of transcranial motor-evoked potentials (TcE-MEPs) and procedures associated with the alarms between cervical anterior spinal fusion (ASF) and posterior spinal fusion (PSF). Neurological complications after TcE-MEP alarms have been prevented by appropriate interventions for cervical degenerative disorders. The differences in the accuracy of TcE-MEPs and the timing of alarms between cervical ASF and PSF noted in the existing literature remain unclear. Patients (n = 415) who underwent cervical ASF (n = 171) or PSF (n = 244) at multiple institutions for cervical spondylotic myelopathy, ossification of the posterior longitudinal ligament, spinal injury, and others were analyzed. Neurological complications, TcE-MEP alarms defined as a decreased amplitude of ≤70% compared to the control waveform, interventions after alarms, and TcE-MEP results were compared between the 2 surgeries. The incidence of neurological complications was 1.2% in the ASF group and 2.0% in the PSF group, with no significant intergroup differences (*P*-value was .493). Sensitivity, specificity, negative predictive value, and rate of rescue were 50.0%, 95.2%, 99.4%, and 1.8%, respectively, in the ASF group, and 80.0%, 90.9%, 99.5%, and 2.9%, respectively, in the PSF group. The accuracy of TcE-MEPs was not significantly different between the 2 groups (*P*-value was .427 in sensitivity, .109 in specificity, and .674 in negative predictive value). The procedures associated with the alarms were decompression in 3 cases and distraction in 1 patient in the ASF group. The PSF group showed Tc-MEPs decreased during decompression, mounting rods, turning positions, and others. Most alarms went off during decompression in ASF, whereas various stages of the surgical procedures were associated with the alarms in PSF. There were no significant differences in the accuracy of TcE-MEPs between the 2 surgeries.

Abbreviations: ADM = abductor digitorum minimum, ASF = anterior spinal fusion, CDH = cervical disc herniation, CSM = cervical spondylotic myelopathy, FHB = flexor hallucis brevis, IONM = intraoperative spinal neuromonitoring, OPLL = ossification of the posterior longitudinal ligament, PSF = posterior spinal fusion, TA = tibialis anterior, TcE-MEPs = transcranial motor-evoked potentials, TP = true positive.

Keywords: anterior spinal fusion, cervical spine, intervention, intraoperative neurophysiological monitoring (IONM), posterior spinal fusion, transcranial electrical stimulation-muscle motor-evoked potentials (TcE-MEPs)

The authors have no funding and conflicts of interest to disclose.

The datasets generated during and/or analyzed during the current study are available from the corresponding author on reasonable request.

Level of evidence: 3.

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1. Introduction

Anterior and posterior cervical decompression and fusion are effective for cervical spondylotic myelopathy (CSM),[1] ossification of the posterior longitudinal ligament (OPLL),[2] traumatic cervical spinal injury,[3] and spinal tumors.[4,5] Neurologic functions generally improve after cervical fusion and decompression[6,7]; however, neurologic complications have been reported in a few cases, with incidences ranging from 0.35% to 2.2% in anterior cervical fusion and from 0.59% to 2.56% in posterior cervical fusion.[8–10]

Intraoperative spinal neuromonitoring (IONM) has been widely used to prevent neurological complications in spinal surgeries; however, the criteria for its use may differ depending on the type of surgery.[11] Recently, the criterion of a 70% decrease in the amplitude of transcranial motor-evoked potentials (TcE-MEPs) has been shown as a useful alarm point to prevent neural damage in high-risk spinal surgeries.[12,13] In a previous report, the sensitivity of the criterion was 95% and the specificity was 91%.[12] Additionally, interventions have been effective in preventing neurological complications after TcE-MEP alarms in CSM and OPLL.[14]

Despite the existing literature, the differences between cervical anterior spinal fusion (ASF) and posterior spinal fusion (PSF) remain unclear concerning the prevention of neurological complications under the TcE-MEP standardized alarm points. Thus, this study aimed to clarify the differences in the accuracy of TcE-MEPs between these 2 types of fusion surgeries and to investigate the surgical procedures associated with neurological monitoring in a prospective cohort, using the alarm point criterion of a 70% decrease in the amplitude of TcE-MEPs.[12]

2. Materials and methods

2.1. Inclusion/exclusion criteria for patients

A total of 3625 patients who had undergone spinal surgery between 2014 and 2017 were registered in a prospective multicenter survey on the IONM from the Monitoring Committee of the Japanese Society for Spine Surgery and Related Research. Exactly 584 cervical spinal fusion cases were extracted from that total. Of the 584 patients who had undergone cervical spinal fusion, the following were excluded: 13 with 1-stage anteroposterior spinal fusion, 45 with combined thoracic and lumbar lesions, 14 with intramedullary or intradural extramedullary spinal cord tumors, 4 with osteosynthesis, 3 with an impossible derivation of control waves, and 90 with incomplete data. In total, 415 patients who met the inclusion criteria were included in this study (Fig. 1).

Each institution provided clinical information, including age, sex, body mass index, diagnoses, surgical procedures, surgical time, blood loss, number of fused vertebrae, alarm for TcE-MEPs, body temperature at the alarm, intervention for alarm, neurological complications, and results of TcE-MEPs.

2.2. Ethical consideration

This survey was approved by the Review Board Committee of each institution, and all patients provided informed consent to participate in the study.

2.3. Transcranial motor-evoked potential monitoring

The transcranial stimuli were delivered in 5 to 10-stimulus trains with an inter-stimulus interval of 2 ms, a 100 mA to 200 mA intensity, a 200 ms to 500 ms duration, a 50 Hz to 1000 Hz filter, and a 100-s recording time. Corkscrew-type stimulating electrodes (Nihon Koden Inc., Tokyo, Japan) were bilaterally and symmetrically inserted 5 cm lateral and 2 cm anterior to central zero.

TcE-MEPs were recorded from the deltoid, biceps, triceps, abductor pollicis brevis, abductor digiti minimi, quadriceps femoris, hamstrings, tibialis anterior, gastrocnemius, abductor hallucis, and sphincter muscles, all of which were selected based on the disease conditions.

Under general anesthesia, the initial TcE-MEPs were recorded before incision, after which control values were recorded after exposure of the spinal bone surface, and the amplitudes of TcE-MEP waveforms were measured for each invasive situation. In this prospective survey, the alarm point was defined as a decreased amplitude of ≤70% compared to the control waveform. When an alarm went off, we promptly checked blood pressure, body temperature, administration of muscle relaxants, depth of anesthesia, interference from other medical electrical equipment, and connection problems. Then we addressed the problems. For factors of decreasing amplitudes that were not found at other sites but at the surgical site, we checked and addressed the problems at the surgical site.

We defined a true positive (TP) as a TcE-MEP alarm without >70% recovery of amplitude at the end of the surgery with a new neurological motor deficit observed after surgery, and a false positive as a TcE-MEP alarm without > 70% recovery of amplitude at the end of the surgery with no new neurological motor deficit observed after surgery. True negative was defined as the absence of any TcE-MEP alarms during surgery with no new neurological deficit after surgery, and false negative was defined as a new neurological deficit after surgery without any alarms of TcE-MEPs during surgery. In this study, when the TcE-MEP waveform went back to normal after the intervention due to the alarms and a patient exhibited no new neurological deficits after surgery, the case was considered a rescue case. Therefore, rescue cases were separated from false positive cases in this study.

A new neurological motor deficit was defined as when postoperative manual muscle testing was worse than 1 level on the Medical Research Council scale compared to the preoperative manual muscle testing.

2.4. Anesthesia management

Total intravenous anesthesia was induced by intravenous infusion of propofol (3–4 μg/mL), remifentanil (2 μg/kg), and vecuronium (0.12–0.16 mg/kg), and anesthesia was maintained by intravenous infusion of propofol (100–150 μg/mL/min) and remifentanil (1 μg/kg/h). In principle, vecuronium was used only when muscle tension interfered with surgery (0–0.04 mg/kg/h). The intraoperative mean arterial pressure was controlled at >80 mm Hg.

2.5. Statistical analysis

We divided the patients into ASF and PSF groups and performed univariate analyses. Continuous variables were

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compared between the 2 groups using the Mann–Whitney *U* test, while categorical variables were compared between the 2 groups using the chi-squared test or Fisher exact test. All analyses were performed using SPSS ver. 22 (IBM Corp., Armonk, NY). A value of $P < .05$ was considered statistically significant.

3. Results

3.1. Comparison of demographic data

Demographic data are shown in Table 1. Age and body mass index at the time of surgery were higher in the PSF group than in the ASF group. The number of patients with degenerative cervical spinal disorders was higher in the ASF group. In contrast, in the PSF group, the number of patients with trauma and spinal instability cases was almost the same as that of those with degenerative cases, such as CSM and OPLL. Surgical time was longer, and blood loss and the number of fused vertebrae were significantly higher in the PSF group than in the ASF group.

3.2. Neurological complications and accuracy of transcranial motor-evoked potentials

The neurological complications and accuracy of the TcE-MEPs are presented in Table 2. The incidence of neurological complications was 1.2% (2/171) in the ASF group and 2.0% (5/244) in the PSF group, with no significant difference between the groups (*P*-value was .493). The sensitivity, specificity, and negative predictive values were 50.0%, 95.2%, and 99.4%, respectively, in the ASF group and 80.0%, 90.9%, and 99.5% in the PSF group, respectively (*P*-value was .427, .109, and .674 for sensitivity, specificity, and negative predictive values, respectively). The accuracy of the TcE-MEPs did not differ significantly between the 2 groups. New neurological deterioration resulted from spinal cord damage despite the intervention after the alarms went off in all true-positive cases in both groups and from nerve root injury in 2 false-negative cases. In those cases, 4 patients recovered from neurological damage, and 1 did not recover, while the conditions of 2 patients were unknown due to a lack of follow-up. The body temperature was an average of 36.5 degrees ranged from 35.8 to 37.5 degrees in these TP cases.

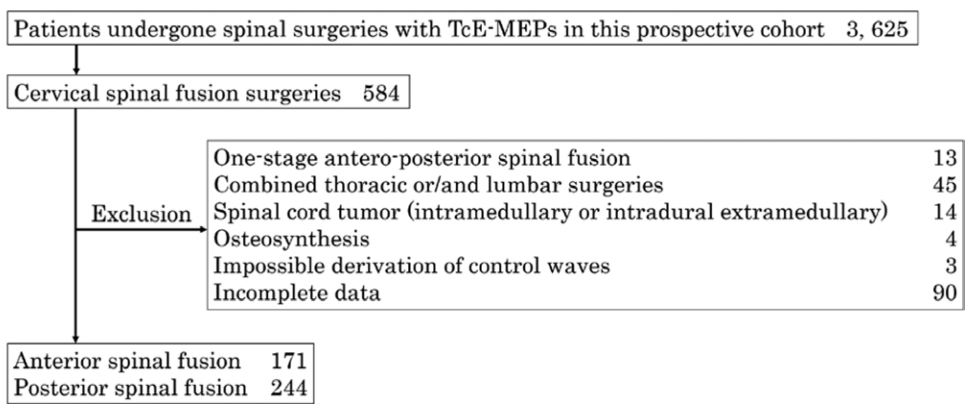

Figure 1. Flow chart of subject selection for this study.

Table 1

Demographic data from the 2 groups.

	ASF	PSF	*P* value
	N = 171	N = 244	
Age	59.5 ± 12.6	67.9 ± 14.0	<.001*
Sex	F62 M109	F110 M134	.072**
BMI	23.5 ± 4.6	25.3 ± 4.3	<.001*
Diagnosis			<.001**
CSM	49	55	
OPLL	38	51	
CDH	37	1	
CSA	21	2	
CSR	16	1	
Spondylitis	4	1	
Spinal injury	2	77	
Spinal deformity	2	8	
Spinal bone tumor	2	4	
Spinal instability	0	32	
RA	0	8	
Retro-odontoid pseudotumor	0	3	
Klippel-Feil syndrome	0	1	
Surgical time (min)	210.7 ± 120.8	238.9 ± 97.0	<.001*
Blood loss (mL)	118.8 ± 274.4	200.2 ± 328.8	<.001*
Number of fused vertebrae	2.9 ± 1.0	4.1 ± 2.0	<.001**

ASF = anterior spinal fusion, BMI = body mass index, CSM = cervical spondylotic myelopathy, OPLL = ossification of the posterior longitudinal ligament, CDH = cervical disc herniation, CSA = cervical spondylotic amyotrophy, CSR = cervical spondylotic radiculopathy, PSF = posterior spinal fusion, RA = rheumatoid arthritis.
*Mann–Whitney *U* test.
**chi-square test.

Table 2

Rate of neurological complications and accuracy of transcranial motor-evoked potentials.

	ASF N = 171	PSF N = 244	*P* value
Rate of neurological complication (%)	1.2	2.0	.493*
Accuracy of monitoring			.367*
False negative, N	1	1	
False positive, N	8	20	
True negative, N	158	211	
True positive, N	1	4	
Rescue, N	3	8	.350**
Sensitivity	50.0	80.0	.427**
Specificity	95.2	90.9	.109*
PPV	11.1	16.0	.600**
NPV	99.4	99.5	.674**

ASF = anterior spinal fusion, FN = false negative, PPV = positive predictive value, PSF = posterior spinal fusion, NPV = negative predictive value.
*Chi-square test.
**Fisher exact test.

Table 3

Rescue rate after each intervention at the time of the alarm.

Group	Diagnosis	Timing of alarm	Type of intervention	Number	Rescue rate (%)
ASF	CDH	Decompression	Suspension of surgery	2	100
	CSM	Distraction	Release of distraction and decrease of spacer height	1	100
	OPLL	Decompression	Steroid injection	1	0
PSF	CSM	Decompression	Suspension of surgery	1	0
		Insertion of screw	Removal and reinsertion of the screw on the day after surgery	1	0
		Insertion of thread wire saw into epidural space	Prompt decompression	1	100
	OPLL	Insertion of screw	Suspension of surgery	1	100
		Turn to prone from the supine position	Prompt decompression and fusion	1	0
		Decompression	Fixation	2	100
			Suspension of surgery	1	100
	SS	Mounting rod	Removal of and re-mounting rod	1	100
		Decompression	Prompt decompression	1	100
	VS	Insertion of screw	Removal of screw	1	100
	Dens fracture	Mounting rod	Steroid injection	1	0

Rescue rate = N of rescue cases * 100/(N of rescue cases + TP).
ASF = anterior spinal fusion, CDH = cervical disc herniation, CSM = cervical spondylotic myelopathy, OPLL = ossification of the posterior longitudinal ligament, PSF = posterior spinal fusion, SS = subluxation of spine, TP = true positive, VS = vertical subluxation.

In 1 of 2 the false negative cases, the patient underwent posterior decompression and fusion for cervical kyphosis and control waves were obtained from the deltoid, biceps, triceps, abductor digitorum minimum (ADM), quadriceps, tibialis anterior (TA) and flexor hallucis brevis (FHB). There was no change of intraoperative waveform for PSF, however the patient had temporary paresis in the left deltoid. In the other case who underwent ASF for cervical spondylotic radiculopathy, control waves were obtained from the deltoid, biceps, ADM, quadriceps and abductor hallucis, and the patient had temporary paresis in the triceps without change of TcE-MEPs.

There were 5 TP cases, in which 2 OPLL, 2 CSM and 1 dens fracture. The TcE-MEPs decreased or disappeared in all muscles at the distal levels of surgical intervention in OPLL cases. In the other diseases, the TcE-MEPs decreased in some muscles, but not overall. In a CSM patients who underwent PSF, we had control waveforms in the deltoid, biceps, triceps, ADM, quadriceps, TA and FHB. Amplitudes decreased to 27% in the TA and 18% in the FHB during decompression. After rescue intervention the waveforms increased over to 30% in the TA, however the amplitude was still under 30% in the FHB at final evaluation. After surgery, we found a temporal decrease in finger extensors and flexors.

3.3. Interventions at the time of transcranial motor-evoked potential alarms and rate of rescue

The types of interventions and rate of rescue are summarized in Table 3. The rescue cases were 3 (1.8%) in the ASF group and 7 (2.9%) in the PSF group. The procedures associated with alarms were decompression in 3 cases and distraction in 1 patient in the ASF group. A true-positive case was that of an OPLL patient who underwent C3 to C7 decompression and fusion and whose alarm occurred during resection of the OPLL. Three patients in rescue cases underwent single-level surgery. In contrast, instrumentation procedures were associated with alarms in approximately the same number as decompression procedures in the PSF group. The body temperature was an average of 36.2 degrees ranged from 36.1 to 36.3 degrees in the 3 rescue cases.

The PSF group showed a decrease in TcE-MEPs at various stages of the surgical procedures. The detailed flow of surgical procedures, TcE-MEPs, and interventions in rescue and true-positive cases is shown in Figure 2. In cases of screws inserted before decompression, TcE-MEPs decreased in 3 of 8 patients at the time of screw insertion. There were no alarms in cases where screws were inserted after decompression. Aside from the true-positive case, in which screws were removed and re-inserted the day after surgery, patients were rescued by immediate re-insertion or suspension of the procedure. Alarms in decompressive procedures went off in 6 cases; suspension, prompt decompression, and prompt fixation in appropriate alignment were useful for rescues in 5 of them. The alarms also went off during fixation, even after decompression, and neurological complications could be avoided by the release of fixation and re-fixation with safe alignment. The body temperature was an average of 36.1 degrees ranged from 35.2 to 37.0 degrees in the 8 rescue cases.

3.4. One illustrative case

The illustration of a 75-years-old woman with vertical subluxation treated with posterior fusion from the occiput to C4 is shown in Figure 3. TcE-MEPs of the left quadriceps decreased after inserting screws at C3, and afterward, TcE-MEPs of the bilateral deltoid and right quadriceps decreased gradually. Intraoperative computed tomography showed malposition of the left C4 pedicle screw, which was removed and re-inserted. The amplitudes of the bilateral quadriceps increased after replacement, and the patient showed no further neurological deterioration after surgery.

4. Discussion

4.1. Main findings

The incidence of new neurological complications for cervical spinal disorders was 1.2% in the ASF group and 2.0% in the PSF group. In this study, there were no significant differences in neurological complications and the accuracy of TcE-MEPs between the ASF and PSF groups. We showed that TcE-MEPs were useful in both fusion surgeries; however, they may differ in situations related to decreasing TcE-MEP amplitude. Procedures with a risk of intraoperative neurological complications, such as decompression and distraction in ASF, were not associated with TcE-MEP alarms. In contrast, multiple procedures were associated with TcE-MEP alarms in PSF patients. Therefore, further neurological deterioration could be avoided by proper interventions in 1 to 5th of ASF cases and more than 2 to 3rds of PSF cases when TcE-MEP alarms occur.

4.2. Comparison with other studies, implications, and explanation of findings

In a previous report, Thirumala et al analyzed the incidence of neurological complications using the National Inpatients Sample in the United States. They found the incidence to be 0.62% in ASF and 2.56% in posterior spinal fusion.[8] Badhiwala et al reported the incidence as 0.35% in anterior spinal fusion and 0.59% in posterior spinal fusion in a nationwide sample of

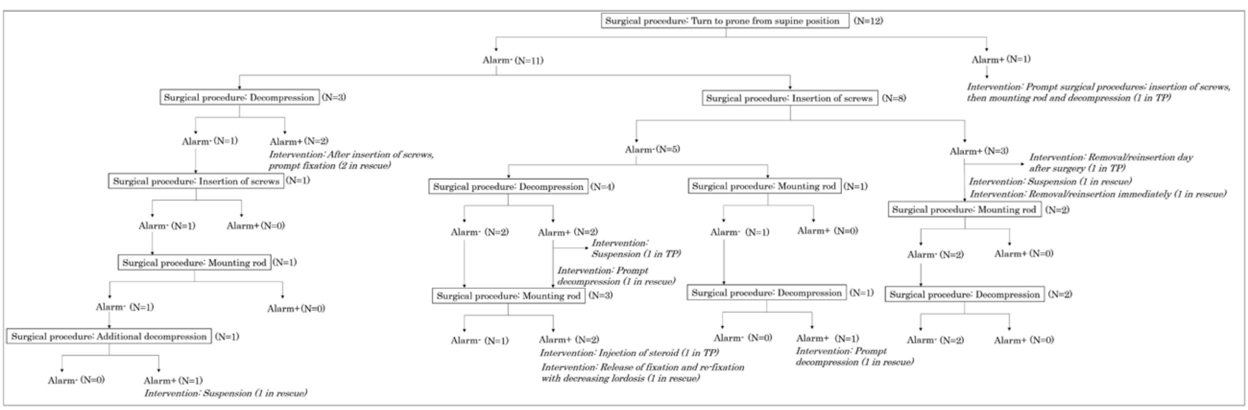

Figure 2. Flow chart of alarm timing and interventions along with surgical procedures in the true-positive and rescue cases (literature is in italics) in which posterior fusion was performed.

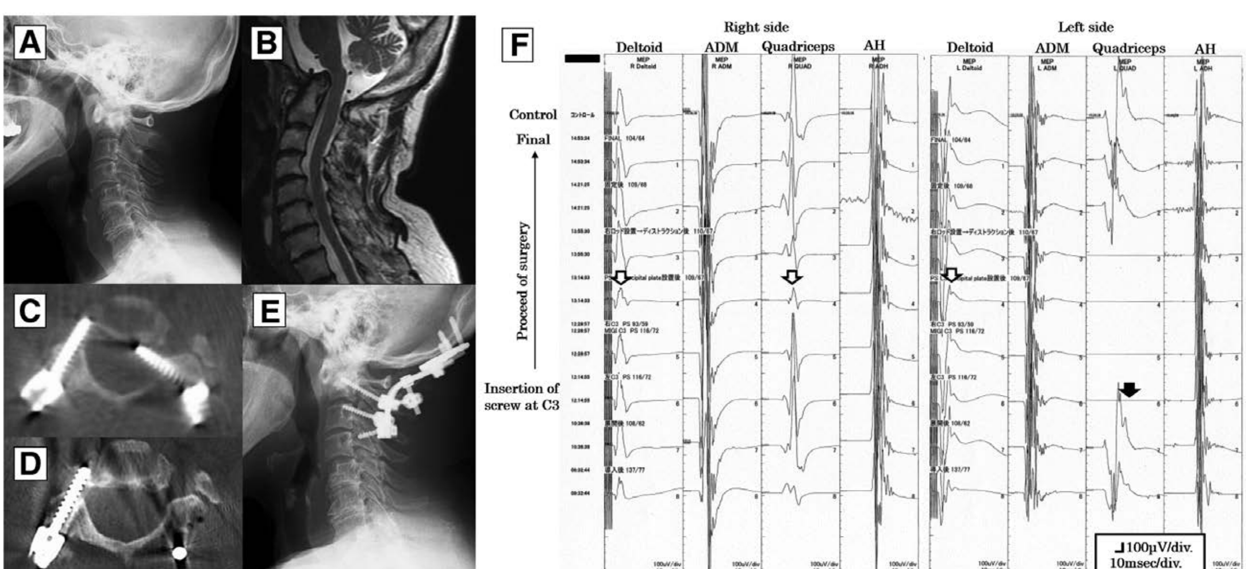

Figure 3. Radiographs and records of TcE-MEPs in a patient with vertical subluxation. (A) plain radiograph and magnetic resonance imaging before surgery. (C) Intraoperative computed tomography at the C3 level after initial insertion of the pedicle screw. (D) Computed tomography at the C3 level after removal of the left pedicle screw. (E) Plain radiograph after surgery. (F) Records of TcE-MEPs; white and black arrows show a decrease of TcE-MEPs after insertion of the C3 pedicle screw. ADM = abductor digiti minimi, AH = abductor halluces, TcE-MEP = transcranial motor-evoked potential.

Canada.[15] Both studies concluded that the rates of neurological complications were higher in posterior surgery than in anterior surgery. In our study, the incidence of neurological complications did not differ between posterior and anterior fusion surgeries; the differences from previous reports may have been affected by differences in the selection of subjects and criteria for neurological complications.

4.3. Comparison of procedures associated with neurological deteriorations

Decompression was the most frequent procedure in the ASF group, with a risk of neurological complications. Suspension of surgery could prevent new neurological deficits in patients with cervical disc herniation (CDH); however, the risk was higher in patients with OPLL than in those with CDH. In a multi-institutional study, Egawa et al found the incidence of postoperative new motor nerve palsy to be 11.8% in patients who underwent anterior decompression with fusion for OPLL.[16] Kimura et al showed that a high occupying ratio was associated with postoperative upper extremity paresis in OPLL patients who underwent ASF.[17] In their analysis using a national data set, Badhiwala et al also reported that the presence of 3 or more fused vertebrae was a risk factor for neurological complications in anterior cervical discectomy and fusion.[9] In our true-positive case in which the patient underwent ASF for OPLL, the level of fused vertebra was 4.

There were wider variations in the procedures associated with TcE-MEP alarms in the PSF group than in the ASF group. In the present study, screw insertion was often associated with waveform deterioration. This was considered an effect of the procedure on the spinal cord. The 2 mechanisms that we considered were direct damage by perforation and indirect damage due to changes in canal stenosis. Kobayashi et al reported that screw insertion before decompression compared to afterward significantly increased TcE-MEP waveform deterioration in cervical posterior fusion cases with a narrow canal at the apex of cervical lordosis.[18] Bose et al reported that the TcE-MEP waveform recovered after reduced neck extension during anterior fusion of the cervical spine.[19] In addition, the manner of loading on the spinal cord during the attachment of rods should be considered. In a previous report, posterior fixation of the cervical spine could change alignment. Cervical lordosis was therefore shown to increase after posterior fusion using pedicle screws.[20]

4.4. Strengths and limitations

To our knowledge, the comparisons performed in this study have not been previously carried out in any multicenter study with a prospective cohort and alarm criteria. Thus, the findings from this report may be useful in avoiding neurological complications when cervical fusion surgeries are performed.

This study had some limitations. First, the number of patients may have been smaller than that in previous reports regarding national IONM research on cervical spinal fusion surgery. Statistical significance may have been reported in error due to the small number of study participants. It may be necessary to increase the number of cases studied; however, this study was conducted in a prospective cohort with institutions that employed spinal surgeon specialists. Thus, one of its advantages was the judgment of rescue according to the criteria of TcE-MEPs. Second, this study included many diagnoses of cervical spinal disorders. However, the diagnoses were common in patients with true-positive and rescue cases, including CSM, cervical disk herniation, cervical OPLL, and spinal fractures. Thus, we believe that this study provides useful information for spinal surgeons and anesthesiologists performing cervical ASF and PSF.

4.5. Conclusion, recommendation, and future directions

Most alarms went off, and neurological complications occurred during decompression in ASF and various stages of the surgical procedures. Decompression and insertion of screws, mounting rod, and turning position, were associated with neurological damage and TcE-MEP alarms in PSF. Prompt decompression or fixation in adequate alignment may be necessary when the amplitude decreases during posterior procedures to avoid neurological complications. We recommend intraoperative neuromonitoring for both anterior and posterior fusion surgeries since TcE-MEPs could detect one of the triggering steps causing neurological damage in both surgeries. All the patients underwent these surgeries with the benefit of IONM.

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