

Feasibility and Predictability of Intraoperative Monitoring in Patients with Intradural Extramedullary and Epidural Metastatic Spinal Tumors

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Abstract

Objectives: To evaluate the feasibility, sensitivity and specificity of IOM for IDEM and ED metastatic spinal tumours, and to assess usefulness of SSEP for patients in whom MEP was not measurable.

Methods and materials: One hundred and one consecutive patients with IDEM and ED metastatic spinal tumours at the cord level (C1 to L1) received surgery under SSEP and/or MEP was included. Feasibility of IOM was defined to be negative in case of no measurable MEP or SSEP under general anaesthesia after confirmation of reversal of neuromuscular block. More than 50% change of MEP or SSEP amplitude and more than 10% delay of SSEP latency were evaluated as positive signs of IOM change.

Results: MEP was measurable in 74 out of 101 trials, thus feasibility is 73%. Patient with normal motor power showed higher feasibility than those with motor power 3 or less. (93% vs. 39%) Among 74 patients with measurable MEP, 19 patients showed positive MEP change and 14 patients got worse of their motor power postoperatively.

Keywords: Spinal cord neoplasm; Extramedullary neoplasms; Spinal metastasis; Intraoperative monitoring; Somatosensory evoked potential; Motor evoked potential

Introduction

The intraoperative neurophysiologic monitoring (IOM), represented by motor evoked potential (MEP) and somatosensory evoked potential (SSEP), provides the functional integrity of spinal cord, and has become one of the essential procedures to avoid neural injury during spinal surgery [1-4].

The importance of SSEP was appreciated earlier in the spinal deformity surgery, at which the correction of deformity and fixation might cause stretching or compression of the spinal cord [1,2,5]. Later, MEP has played role in intramedullary spinal cord tumour surgery, where motor and sensory pathway could be separately dissected [6,7]. Among spinal tumours, intradural extramedullary (IDEM) and epidural (ED) metastatic spinal tumours are ideal for monitoring surgical manipulation of spinal cord as those tumours are free of both intrinsic pathologic condition of spinal cord and selective spinal cord dissection such as myelotomy. Hence, IOM for IDEM and ED metastatic spinal tumour surgery could purely reflect net results of surgical condition.

It has been reported that MEP is more reliable to predict postoperative neurologic deficit with higher sensitivity than SSEP. However, for patients who had impaired motor function preoperatively, MEP is often not measurable due to cord dysfunction and/or intraoperative conditions. Whereas SSEP can be monitored in larger proportion of patients than MEP even in patients with motor deficit as it is less vulnerable to systemic conditions including neuro-muscular junction and its tract is composed of relatively numerous number of neurons in ascending dorsal column. Thus estimating predictability of SSEP for motor function is valuable in these patients with preoperative motor deficit. In IDEM and ED metastatic spinal tumour surgery, SSEP might reflect the functional integrity not only of dorsal column but also of motor tract as long as the spinal cord maintains its anatomical integrity throughout the surgery. However, reports of IOM for spinal tumour surgery is relatively rare and frequently mixed up with other spinal procedure, hence only a few of separate study of reporting IOM result of IDEM of ED metastatic spinal tumour surgery can be found [8-10].

In this retrospective study, we analysed; 1) feasibility of MEP and

SSEP according to preoperative motor deficit and 2) potential of SSEP for predict postoperative motor deficit in patients with unmeasurable MEP in patients with IDEM and ED metastatic spinal tumours.

Materials and Methods

Eligibility

Between May 2009 and September 2015, 124 consecutive patients received operations for spinal tumors in National Cancer Center, Goyang, Korea. Among them, 9 patients with intramedullary spinal tumours were excluded according to the study purpose. Also, other 11 patients with lumbosacral tumours lower than L1 were excluded because their results did not reflect physiology of spinal cord per se but cauda equine. In 2 patients with spinal metastatic tumours, IOM was not available due to emergency based operation. Finally, 101 patients with IDEM and ED metastatic spinal tumour surgery performed under IOM were included and retrospectively analysed.

MEP monitoring protocol

MEPs were obtained on preoperative baseline and on surgeon's demand during the operation using transcranial electrical stimulation. Protektor™ IOM (Xltek Ltd., Ontario, Canada) monitoring system was used. Disposable low profile needle electrodes (Chalgren Enterprise Inc., CA, USA) were placed subcutaneously at C3 and C4 positions according to the international 10-20 EEG electrode System. Upper extremity MEPs were recorded by pairs of needle electrodes that were inserted bilaterally in the abductor pollicis brevis/abductor minimi

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digiti muscle and lower extremity MEPs in the tibialis anterior/abductor hallucis muscle. The stimulation parameters used were as follows: short trains of five rectangular stimuli, inter-stimulus interval of 2ms and intensity of 300-400V. The stimulation intensity was set to maintain adequate responses (more than 50 uV) from all monitored-muscles, and then fixed throughout the procedure. Baseline recordings were attempted after the initiation of general anaesthesia and before skin and Dural incision or fixation.

SSEP monitoring protocol

SSEPs were monitored on preoperative baseline and continuously during the operation in all cases. Briefly, rectangular constant-current stimuli of 300 microsecond duration with intensities up to 30mA were applied to the median nerve at the wrist or tibia nerve at the ankle at the stimulation rate of 2.31Hz. The upper extremity SSEPs were recorded at 2 cm behind C3 or C4 versus Fz and the lower extremity SSEPs were recorded at Cz versus Fz, with a band pass from 30 to 1000 Hz and averaging of 100 sweeps.

Positive change of IOM

The positive parameter was the loss of muscle MEPs or a 50% drop of the MEP amplitude. The parameter for SSEP was a 50% drop of amplitude or 10% delay of the latency. If once decreased or delayed MEP or SSEP were recovered to more than 50% of the baseline amplitude or to less than 10% delay during the operating time, we consider those changes as 'negative'.

Anesthesia

Anaesthesia was conducted to all of patients with constant continuous infusion of propofol (80 to 150 µg/kg/min) with or without minimal support of halogenated anaesthetics such as Sevoflurane. Short-acting muscle relaxants such as rocuronium were used only for intubation but not thereafter.

Feasibility of IOM

After induction of general anaesthesia, we measured IOM before surgical draping. In case of no measurable MEP or SSEP, we confirm the reversal of neuromuscular block by peripheral nerve stimulator (train of four monitoring). If there is still no measurable MEP or SSEP after the confirmation, we decided that MEP or SSEP was not feasible in those cases.

Clinical analysis parameters

The clinical information of patients was investigated from electronic medical record archive. Preoperative motor power was graded by the Medical Research Council system (grade 0 to 5) and we define the least grade among 4 extremities as the patient's preoperative one. Postoperative motor power grade was evaluated at acute period after full recovery from general anaesthesia (postoperative 2 days) and before rehabilitation treatment. Functional status of patients was graded using the Frankel grade classification and Karnofsky performance status (KPS) score. We considered drop of patient's motor power ≥1 grade postoperatively as a positive event.

Results

Clinical characteristics

Clinical characteristics of the 101 patients received IDEM and ED metastatic spinal tumour surgery under MEP/ SSEP are summarized in Table 1. There were 59 male patients and 42 female patients at a median age of 57 (range 13-80) at the time of surgery. Anatomically, 72

Characteristics	No. of patients (n=101)
Gender (male/female)	59/42
Median age (range)	57 (13-80)
Spinal location	
Metastatic (epidural)	72
IDEM	29
Spine level	
Cervical	15
Cervico-thoracic	6
Thoracic*	80
Preoperative motor power	
5	41
4	37
3	18
0-2	5
Operation	
Laminectomy and tumor removal	45
Decompression and posterior fixation	16
Decompression, anterior reconstruction and posterior fixation	39
Anterior approach to cervical spine	
*Thoracic spine to 1st lumbar spine	1
Note: Motor power is described by Medical Research Council (MRC) motor power scale.	
Abbreviations: IDEM, Intradural extramedullary tumor; KPS, Karnofsky Performance Scale	

Table 1: Clinical characteristics of the spinal tumor patients with intraoperative monitoring.

spinal tumours were epidural (ED) tumours and remained 29 tumours were intradural extramedullary tumours (IDEM). Histologically, all 72 ED tumours were metastatic spinal tumours and lung was the most frequent organ of primary cancer (n=21). While among IDEM tumours, one case is metastatic spinal tumour from small cell lung cancer and the most frequent tumour type was schwannoma (n=18) followed by meningioma (n=7). Involved spinal level was mainly thoracic including thoracolumbar junction down to L1 (n=80, 79%) followed by cervical level (n=15). Six cases were located at cervico-thoracic junction.

Seventy-eight patients (77%) maintained ambulatory function preoperatively as motor grade ≥4 or Frankel grade D or E. Other 18 patients had low extremity motor power of grade 3 and remaining 5 patients showed motor power of grade 0 to 2. In 45 patients, only laminectomy and tumour removal was done. In other 16 patients, partial fascetomy and/or corpectomy require transpedicular screw fixation of adjacent vertebrae. Another 39 patients underwent decompression including removal of involved vertebral body and anterior reconstruction in addition to laminectomy and posterior fixation. Remaining 1 patient received anterior approach to C5 lesion including corpectomy, mesh cage insertion and plate and screw fixation.

Postoperative decrease of motor power grade occurred in 23 patients (23%). Clinical factors including Spinal location (ED vs. IDEM), age (< 60 vs. ≥ 60), preoperative motor power grade (0-3 vs 4-5) and the type of surgery (with or without anterior vertebral body reconstruction) were evaluated for influence on postoperative motor power decrease, and the results were not significant (Data not shown).

Feasibility and predictability of IOM according to preoperative motor power grade

MEP and SSEP were attempted to all of 101 patients. Feasibility of

MEP and SSEP according to preoperative motor grade is summarized in Table 2. Among 101 patients who underwent MEP monitoring, MEP was measurable in 74 patients (73%). SSEP was better feasible than MEP as 94 out of 101 patients was successfully monitored (93%, Fischer's exact test, $p < 0.01$).

MEP was measurable for 38 out of 41 patients (93%) who showed motor grade 5 and for 27 among 37 patients with motor power grade 4 (73%). But, only 7 out of 18 patients (39%) with motor grade 3 showed measurable MEP. For patients whose motor power was trace or nil (grade 0-2), MEP was measured in 2 out of 5 these patients. Overall, the feasibility of MEP according to motor power grade is significantly reduced in patients with motor power grade 3 or less (non-ambulatory) compared to that in patients maintaining ambulatory function of motor grade 4 or 5 (39% vs. 83%, Chi-square test, $p < 0.0001$).

SSEP was obtainable in all 41 (100%) patients with motor grade 5, in 34 out of 37 patients (92%) with grade 4, in 16 among 18 patients (89%) with grade 3 and in 3 out of 5 patients with motor grade was 0-2. It is noticeable that the proportion of measurable SSEP in patients with motor grade 3 or less is significantly higher than that of MEP (82% vs. 39%, Fisher's exact test, $p < 0.01$).

Sensitivity, specificity and predictability of MEP and SSEP

Among 74 patients received spinal surgery with measurable MEP, 19 patients showed decrease or loss of MEP amplitude during the operation. Thirteen out of these 19 patients revealed postoperative worsening of motor power (true positive). Among the other 6 patients without postoperative motor deficit (false positive), three patients showed low extremity MEP significant decrease meet the criteria for

'positive' change during operation while both upper extremity MEP and SSEP showed no change. Intraoperative hypothermia was blamed to be responsible for false positive result in these 3 patients as all these patients had intraoperative hypothermia and exposed cord was thoracic level. Another patient with C4 metastasis experienced loss of upper extremity MEP with significant decrease of lower extremity MEP on sustained intraoperative hypothermia. Yet, another patient showed relatively acute drop and loss of lower extremities MEP on decompression of thoracic spinal cord. Both MEP was recovered in 5 minutes but left low extremity MEP was lost again on fixation procedure and not normalized until the end of operation. The 6th patient showed sudden loss of right low extremity MEP on the occurrence of intraoperative hypotension due to massive blood loss over 3 liters while the other 3 extremities kept baseline amplitude of MEP. Despite of no recovery of lost MEP, her postoperative motor function was normal. The other 55 patients did not reveal MEP change during the operation time but one patient with L1 metastatic spinal tumour receiving partial corpectomy, anterior reconstruction with bone cement and posterior screw fixation experienced postoperative left L5 radiculopathy in spite of no MEP change. Actually, we performed spontaneous EMG monitoring for this patient and EMG occurred during the L1 corpectomy via posterior approach. She recovered completely 3 months after the operation. As a result, MEP had an overall sensitivity of 93%, specificity of 90%, positive predictive value (PPV) of 68%, and negative predictive value (NPV) of 98% (Table 3).

As we define a decrease of motor power as end result, sensitivity of SSEP is relatively low. Among 94 patients whose SSEP was available for IOM, 15 patients showed a 50% decrease of SSEP amplitude or 10% delay of SSEP wave and among these 13 patients revealed postoperative motor power decrease. The other 79 patients did not show definite change of SSEP and 71 of these patients were free of motor power decrease whereas 8 of these patients experienced postoperative motor grade decrease. Thus, SSEP had an overall sensitivity of 62%, specificity of 97%, PPV of 87%, and NPV of 90% (Table 3).

Usefulness of SSEP in patients whose MEP was not measurable

As the feasibility of MEP is worse than that of SSEP, there were 24 patients for whom MEP was not measurable but SSEP could be monitored. Among these 24 patients, seven patients suffered from postoperative motor power decrease and 4 of these patients showed positive SSEP change during the operation. Whereas in the other 17 patients, one patient showed SSEP decrease but revealed no postoperative motor power change. Hence, SSEP for postoperative motor power decrease in patients without measurable MEP was evaluated as a sensitivity of 57%, specificity of 94%, PPV of 80%, and NPV of 84% (Table 4). We could suggest that in case of 'not-measurable' MEP, SSEP could predict the postoperative motor power at a predictability of 83%.

Illustrative case

54-year-old, already diagnosed with metastatic renal cell carcinoma female patient visited emergency room due to a week-long progressive weakness of both lower extremities with a month-long back pain. Neurological examination revealed a weakness of G4+ of both lower extremities and hypaesthesia below T10 dermatome. MRI showed metastatic lesion on T8 with epidural cord compression (Figure 1, left). She had received left nephrectomy and lesionectomy of L3 metastatic lesion followed by involved field radiation and had experienced local recurrence of L3 lesion 7 months after the initial operation. She underwent radical corpectomy of L3 and fixation with cage. At that time, she unfortunately got a L3 root injury due to postoperative/ post-

Preoperative status	Feasible/total	
	MEP	SSEP
Total	74/101 (73%)	94/101 (93%)
Motor grade		
5	38/41 (93%)	41/41 (100%)
4	27/37 (73%)	34/37 (92%)
3	7/18 (39%)	16/18 (89%)
0-2	2/5 (40%)	3/5 (60%)

Note: The numbers in parenthesis are percentage of IOM feasible cases out of total trial.

Table 2: Feasibility of lower extremity MEP and SSEP according to preoperative motor grade in only metastatic tumors.

IOM modality		Post-operative motor grade	
		Decreased	Not decreased
MEP (n=74)	Changed	13	6
	Not changed	1	54
SSEP (n=94)	Changed	13	2
	Not changed	8	71

Note: The sensitivity, the specificity and the predictability of MEP was 93%, 90% and 91%, respectively. The sensitivity, the specificity and the predictability of SSEP for postoperative motor decrease was 62%, 97% and 90% (See details in the Results section).

Table 3: Predictability of MEP and SSEP for spinal tumors.

SSEP change (n=24)	Post-operative motor grade	
	Decreased	Not decreased
(+)	4	1
(-)	3	16

Note: The sensitivity, the specificity and the predictability of SSEP for motor change was 57%, 94%, and 83%, respectively.

Table 4: Predictability of SSEP for motor change in patients whose MEP was not measurable.



Figure 1: Illustrative case of a surrogate SSEP change in a patient with metastatic renal cell carcinoma, who had no measurable MEP. T1 weighted gadolinium enhanced MRI showed metastatic T8 spinal tumor with mild to moderate cord compression (left). It became collapsed and caused severe cord compression right after involved field radiation of 3,000 cGy in 10 fractions (right).

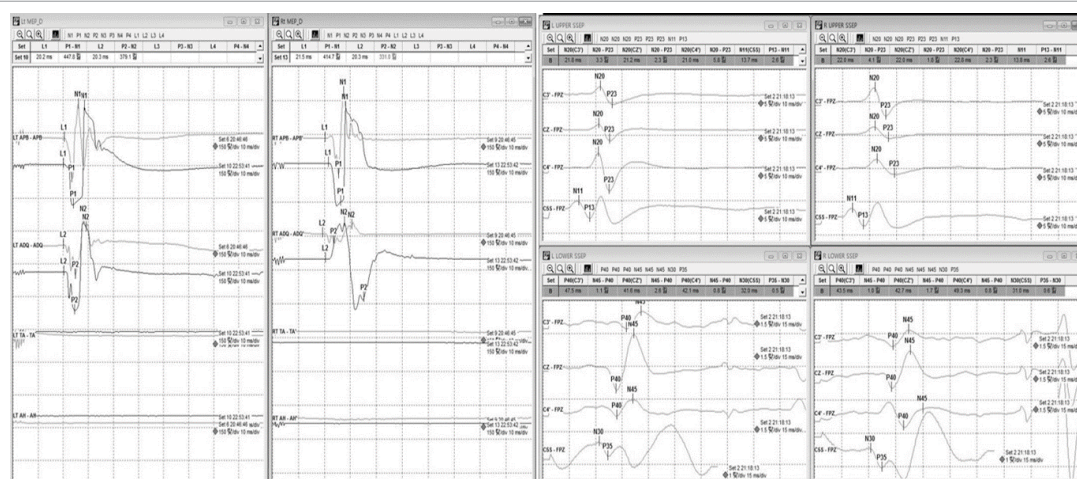


Figure 2: MEP after general anesthesia showed normal MEP on upper extremities (left, upper) while no measurable wave was evoked on lower extremities (left, lower), whereas SSEP was normal in upper extremities (right, upper) and slightly delayed but measurable in lower extremities (right, lower).

radiation during the corpectomy. This new metastatic T8 tumor was the only metastatic lesion on subsequent imaging study. We recommended decompression with fixation but she refused operation due to her painful experience of L3 radiculopathy. Two weeks after radiation to T8 lesion, her back pain got worsened too intolerable to opioid and her leg weakness progressed to grade 2-3. Follow up MRI revealed near total collapsed of T8 and subsequent increased compression of spinal cord (Figure 1, right). She gave consent to emergency operation. Baseline MEP after anesthesia induction showed well-measured both upper extremities while no measurable MEP on both lower extremities (Figure 2, left). However, SSEP could be measured on both upper extremities (Figure 2, right, upper) and also on both lower extremities although less than 10% of delay was noticeable (Figure 2, right, lower). During the operation, SSEP was continuously monitored and at the time of laminectomy, SSEP was suddenly lost and never return during the whole procedure (Figure 3). Right after the operation, her lower extremity was plegic then recovered over a couple of months to grade 1-2. However, her lower extremity motor power could not have recovered to preoperative level until she died of lung metastasis 2 years after.

Discussion

Although this is a retrospective study, we firstly analysed the feasibility of IOM in patients with an IDEM or ED metastatic spinal tumour compressing spinal cord according to preoperative motor power grade along with sensitivity and specificity of both MEP and SSEP for postoperative motor deficit. And also, we suggested the usefulness of SSEP for postoperative motor deterioration in patients without measurable MEP, at which the spinal cord keep their anatomical integrity throughout the operation, at a predictability of 83%.

Feasibility of IOM in patients with preoperative neurological deficit

We can find a clue that the feasibility of SSEP/ MEP is decreased in patients with preoperative neurologic deficits in the literature. Accad bled et al. reported a result of combined IOM in scoliosis surgery in a relatively large number of patients ($n=191$) [11]. They grouped their patients into idiopathic and neuromuscular scoliosis. The feasibility of IOM was significantly lower in neuromuscular group (various degrees of lower extremities function) compared to

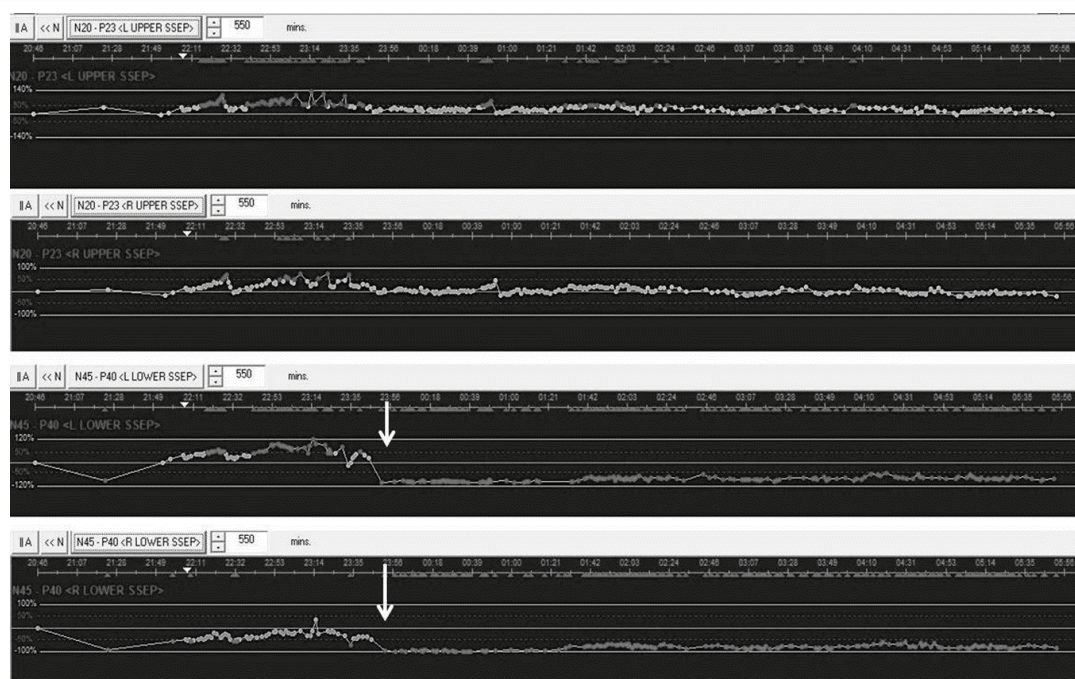


Figure 3: Chronological monitoring of SSEP showed sudden loss of SSEP in lower extremities (arrow) and it did not recover to the baseline level till the end of operation.

idiopathic group (normal preoperative spine MRI) in both SSEP and MEP ($p < 0.001$). Chen et al. reported the feasibility of transcranial MEP in patients with preoperative motor weakness [8]. Their patients were composed of brain tumours, spinal tumours and spinal deformity and 93 out of 341 total patients had 'motor deficit' (no further detailed description). The feasibility of MEP in patients with motor weakness was significantly lower than that of patients without weakness (39.1% vs. 78.9%, $p < 0.001$). In our study, we investigated the feasibility of IOM according to preoperative motor grade, which is more detailed analysis than previous studies. Although we failed to show linear proportional relationship between motor power grade and MEP feasibility, we could observe significant difference of the feasibility at preoperative motor power more than grade 3 (ambulatory) or not. MEP was successfully obtained in 83% of ambulatory patients (motor grade 4-5) and the success rate significantly decreased to 39% in non-ambulatory patients (motor grade 0-3). Similar results were found in a study of MEP during surgery for intramedullary spinal cord tumours by Morota et al. [6]. Although they did not calculate the MEP feasibility according to preoperative motor grade, we could retrieve the significant difference of MEP feasibility in patients with 'moderate-to-severe' preoperative deficit (motor grade 3 or lower, 3/11 patients, 27%) compared with that of patients with 'no-to-mild' deficit (motor grade 4-5, 16/21 patients, 76%, $p = 0.02$). As MEP reflects neural integrity of corticospinal tract, we assume that the success rate of MEP tends to decrease with motor weakness, at which less number of functional motor neuron exists.

In general, MEP is affected more frequently by systemic conditions such as anaesthesia, hypotension, hypothermia, lesion location, and preoperative motor deficit than SSEP [8,12]. Hence, reported feasibilities of MEP are lower than those of SSEP in the same patients setting. Quraishi et al. reported the feasibility of IOM in surgery of adult spinal deformity. SSEP and MEP were measurable in 101 of 102 (99%) and 12 of 16 (75%), respectively [4]. Pelosi et al. reported the feasibility of SSEP as 122/126 (97%) and that of MEP as 106/126 (84%) in patients with heterogeneous disease from spinal deformity to trauma. The lower feasibility of MEP seems aggravated in a pathologic spinal cord and it

was reflected in a study of Wilson-Holden et al. They analysed data from 38 pediatric patients with spinal cord pathology (astrocytoma, syringomyelia, etc.) underwent corrective spinal deformity surgery and the feasibility of MEP (51%) was far behind that of SSEP (93%) in these patients. The relative low feasibility of MEP could be attributed to vulnerable neuromuscular junction, relatively a few functional axon and sensitive anterior spinal cord function to ischemia, myelopathy from previous radiation and so on [6,12,13]. Also in our study, SSEP was more successfully obtained than MEP (93% vs 73%, $p < 0.01$), and was still measurable in 83% of patients with preoperative motor grade 3 or less. It implies that SSEP is less vulnerable to causative factors for motor weakness.

Predictability of MEP and SSEP for postoperative motor deficit

Not only intraoperative condition such as hypotension, surgical procedure, etc. but also type of spinal disease (i.e. spinal deformity vs. intramedullary tumour) and the definition of end result (neurologic deficit) can affect both sensitivity and specificity of IOM. Differences of IOM related values can be found in comparison of spinal surgery for deformity versus spinal tumours. Studies of IOM in spinal deformity surgery reported an end result occurrence (postoperative deficit) of less than 1%. Hence, it was natural that specificity of IOM was around 99% and sensitivity varied according to wake-up test result [2,14]. Meanwhile, in the surgery for intramedullary tumour, at which postoperative neurologic deficit occur at higher rate and wake-up test is rarely applicable, the sensitivity is still high but specificity comes out less accurately. Morota et al. reported a MEP sensitivity of 100% in all 3 patients, who showed more than 50% decrease of MEP amplitude resulted in paraplegia at immediate postoperative period [6]. Cheng et al. also presented 100% sensitivity of transcranial MEP in all 6 patients with MEP changes out of 12 paediatric patients with intramedullary tumours [7]. And they evaluated SSEP changes and only 3 out of 7 patients with SSEP changes showed postoperative sensory deficit. Our study is unique in dealing with spinal tumour keeping their anatomical integrity throughout the spinal surgery. In our study, MEP had a

sensitivity of 93% with one exception of postoperative motor weakness from radiculopathy. Thus, we could tell that if MEP is acquired and not significantly decreased or lost during surgery, these patients had no possibility of postoperative motor deficit from the cord injury. However, based on the PPV of 68%, if the patients showed a decreased MEP during surgery, surgeon should try to find possible causes from both surgical procedure and systemic conditions such as intraoperative hypotension or hypothermia. Although we did not have a valid protocol to deal with intraoperative IOM changes, we routinely check out an integrity of electrical circuit or the connection of the IOM device and train of four monitoring. In case of hypothermia or hypotension, anaesthesiologist tried to correct them as much as possible. However, prolonged exposures of the spinal cord with massive saline irrigation are sometimes unavoidable to cause hypothermia. Massive bleeding from hyper vascular metastatic lesion especially in hepatocellular carcinoma or lung cancer is unstoppable until the tumour is completely resected. We could stop procedure for several minutes or even reverse it during the fixation but sometimes it was not possible during the tumour resection or tumour-involved structure removal. Because MEP has potentials to spontaneously recover after suspension of surgical manipulation of cord. Also, we carefully irrigate surgical field with warm saline help to keep surgical field warm [15]. We need to verify these results after correction of bias (i.e. degree of preoperative deficit, occurrence of intraoperative hypotension or hypothermia) in a large number of patients in a future study.

SSEP is in general less affected by systemic condition including general anaesthesia than MEP and is rather specific than sensitive for postoperative motor deficit [13]. SSEP carrying information of dorsal column integrity has to be less sensitive to postoperative motor deficit. Hence, cases with serious postoperative deficit in spite of intact SSEP can be found in the previous studies [16-20]. The 'false negative' of SSEP for postoperative neurological deficit need be defined if it is for motor deficit or hypaesthesia before reporting those sensitivity and specificity. Predictive value of SSEP for motor deficit has been reported frequently in 1990s when MEP was yet to be standardized for spinal surgery. Khan et al. adopted SSEP alone for 508 cases of cervical corpectomy. Relatively low sensitivity of SSEP for postoperative neurological deficit was natural in cervical spine corpectomy surgery, at which dorsal column located away from direct surgical manipulation. As 11 out of 12 cases of postoperative neurological deficit was root injury, sensitivity of SSEP was as low as 77% [21]. However, if they define postoperative neurological deficit as 'motor weakness' from spinal cord injury, the sensitivity of SSEP become 100% (1 case of permanent SSEP change resulted in quadriplegia). Similar 'mis-targeting' of SSEP for postoperative neurological deficit can be resulted from applied spinal level as SSEP can hardly monitor the integrity of sensory pathway at lumbosacral level [22]. Paradiso et al. [23] performed untethering of 44 cases of adult tethered cord syndrome under monitoring of SSEP and EMG. Two patients developed new postoperative deficit but only one patient showed SSEP changes.

We can hardly find a result of SSEP change for postoperative sensory deficit in terms of either quantitative or objective description of sensory change in the previous study [24,25]. At this retrospective study, we give up to measure postoperative sensory change as all that we could retrieve was subjective expression of patients about sensory change and vague dermatomal distribution. Our SSEP had an overall sensitivity of 62%, specificity of 97%, PPV of 87%, and NPV of 90% for postoperative motor deficit. Lower sensitivity and higher specificity is similar to previous studies.

Effectiveness of SSEP in patients without measurable MEP

Once again, SSEP was the standard method for IOM in spinal

deformity surgery before MEP became available, and indirectly represent functional integrity of corticospinal tract [2,22]. We assumed that as long as the cord integrity is preserved, expected ischemia from cord compression or stretching affects both motor and sensory pathways.

Monitoring only SSEP could be tragic in selective cases [16,20]. Deletis et al. warned not to allow SSEP alone in intramedullary spinal cord tumor surgery, where traction, coagulation or ultrasonic aspiration can selectively damage either motor or sensory pathways [22]. However, he also suggested that SSEP can be an alternative to MEP, when it is not available, as long as the integrity of spinal cord is ensured. Nuwer et al. reported through multi-center, retrospective survey that false negative SSEP was only 0.063% (34 out of 50,207 surveyed cases) after scoliosis surgery. Khan et al. [26] reported that SSEP without MEP or EMG could reduce neurologic injury even during anterior cervical surgery. Their SSEP had a sensitivity of 77.1%, specificity of 100%, PPV of 100%, and NPV of 98.3%. In our study, twenty-four patients had only SSEP without MEP during the spinal surgery and showed predictability of 83% for postoperative motor deficit. Although there were 3 false negative cases resulted in the sensitivity of 57%, 94% of specificity of SSEP is encouraging in the surgery for IDEM and ED metastatic spinal tumor without measurable MEP.

Effect of intraoperative hypotension and hypothermia on IOM

In our study, six false positive MEP cases were with intraoperative hypotension and/ or hypothermia. Intraoperative hypothermia may result in false positive reads for IOM changes but it may not lead to a harmful effect on postoperative motor function. For intraoperative hypotension, however, some authors believe it may be responsible for unexpected postoperative neurological deficits [22,27,28]. We need to pay special attention to real perfusion pressure of the exposed spinal cord, which is usually located higher than blood pressure cuff in prone position. Also patients' medical problems such as diabetes and hypertension are considered to be related to IOM via hypothermia and hypotension. It has been reported diabetic neuropathy or diabetes itself influence to intraoperative core temperature [29,30].

Future directions of IOM for spinal tumor surgery

It is no doubt that IOM could reduce postoperative neurologic deficit after spinal tumor surgery and multimodality IOM or MEP is better than SSEP alone for protecting patient's motor function. However, practical problems to be solved in spinal tumor surgery are as follows; 1) unlikely to scoliosis or stenosis surgery, it is hard to stop or reverse the surgical procedure, 2) continuous monitoring of MEP is impossible due to muscle fatigue and disruption of microscopic operative field from muscle contraction, 3) MEP is frequently unable to be monitored in patients with preoperative motor weakness, and 4) SSEP can be monitored continuously but has to be delayed for summation.

'D wave' measured from electrode placed epidural space distal to surgical level could be avoid the bias of vulnerable neuromuscular junction and hence lower the rate of false positive change. Although D wave indicates functional integrity of fast neurons in corticospinal tract more specifically, D wave can be monitored apparently lower rate than (muscle) MEP in spinal tumor surgery probably due to technical difficulty [31,32].

We still do not have absolute solution of monitoring corticospinal tract for patients, in whom MEP is not measurable up to now. To minimize the chance of spinal cord damage, we should monitor MEP in every surgical step toward tumor removal if possible and stop surgical procedure immediately after SSEP change in these patients.

Conclusion

We evaluated the feasibilities of MEP and SSEP during 101 surgeries of IDEM and ED metastatic spinal tumors. The feasibility in non-ambulatory patients (motor grade 3 or less) was 39% of MEP and 83% of SSEP, respectively and those are significantly lower than those of ambulatory patients. MEP showed sensitivity of 93% and SSEP revealed sensitivity of 62% for postoperative motor deficit. Also, we investigated if SSEP could be used as a surrogate monitor for postoperative neurologic deficit when MEP could not be obtainable and the predictability was 83%.

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