# Monitoring of Motor and Somatosensory Evoked Potentials during Brain Surgery

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# Monitoring of Motor and Somatosensory Evoked Potentials during Brain Surgery

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A Master's Thesis submitted to the Department of Medicine, the Graduate School of Yonsei University in partial fulfillment of the requirements for the degree of Master of Medical Science

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June 2017

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**ABSTRACT**

# Monitoring of Motor and Somatosensory Evoked Potentials during Brain Surgery

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**BACKGROUND:** During brain surgery, intraoperative monitoring of somatosensory evoked potentials (SEPs) and motor evoked potentials (MEPs) is important for prediction of post-operative motor deterioration. The aim of this study is to identify which cut-off point of SEPs and MEPs changes are the most reliable for the prediction of postoperative motor deterioration after brain surgery.

**METHODS:** By medical chart review among patients who underwent brain surgery between December 2015 and December 2016, 100 patients with intraoperative monitoring records of SEPs and MEPs were screened. Muscle strength was assessed by Medical Research Council (MRC) scale in all patients a day before surgery, within 48 hours postoperatively, and 4 weeks later. We analyzed sensitivity and specificity of prediction of motor deterioration using each patient's changes in intraoperative SEPs or MEPs. To find the best cut-off point of SEPs and MEPs, receiver operating characteristic (ROC) curve analysis was conducted.

**RESULTS:** In this study, non-tumor disease was 61(61%) and tumor disease was 39(39%). The sensitivity of pre-existing alarm criteria; latency delay more than 10% from baseline SEPs was 8.3% and amplitude reduction more than 50% from baseline MEPs was 58.3%, and the specificity for predicting motor deterioration was 97.7% for SEPs and 87.5% for MEPs, respectively. By ROC curve analysis, the maximally discriminating point for intraoperative SEPs latency change and intraoperative MEPs amplitude change were 7.1% and 59.5%, respectively. For clinical utility, 7.0% SEPs change and 60.0% MEPs change values were used for best-cut off point. With these cut-offs, the sensitivity of SEPs and MEPs was 66.7% and 58.3%, and the specificity was 80.7% and 90.9%, respectively. Significant intraoperative MEPs changes over the best cut-off value showed higher sensitivity than that of SEPs changes for postoperative motor deterioration. Sensitivity of patients with either SEPs or MEPs changes was 83.3% and specificity was 73.9%. A correlation test proved significant association between SEPs and MEPs changes (*P*=0.04).

**CONCLUSION:** For brain tumor surgery, we suggest new alarm criteria which are cut-off value of 7% delay of SEPs latency or 60% reduction of MEPs amplitude. Further accumulation of cases would provide a more precise cut-off value to use as the alarm criteria.

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Key words: Intraoperative neurophysiological monitoring, Brain, Somatosensory evoked potentials, Motor evoked potentials

# Monitoring of Motor and Somatosensory Evoked Potentials during Brain Surgery

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## I. INTRODUCTION

Cerebral ischemia in intracranial surgery has great relevance in postoperative motor deficits and fresh cerebral infarction, all of which significantly increase the occurrence of mortality[1]. Postoperative motor deficits following neurosurgical procedures result in significant morbidity and mortality rates as well as increased medical costs associated with an extended length of stay and rehabilitation[2]. Temporary occlusion in the absence of adequate collateral circulation can result in cerebral hypoperfusion[3]. Intraoperative neurophysiologic monitoring (IONM) with the use of somatosensory-evoked potentials (SEPs) can detect decreases in cerebral blood flow, allowing the surgeon time for intraoperative adjustments that can restore and improve blood flow and result in subsequent reversal of SEPs changes[3]. There is a close relationship between reduction in SEPs amplitude and reduced cerebral blood flow, and SEPs monitoring is widely used to detect cerebral ischemia[4]. This process involves monitoring of the functional integrity of the neural pathways and mapping of techniques for identification and preservation of the cranial nerves, their motor nuclei, and corticospinal or corticobulbar pathways during posterior-fossa and brainstem surgery[5]. Motor evoked potentials (MEPs) have shown superiority to SEPs in detecting functional disturbances of the pyramidal motor pathways in terms of both sensitivity and specificity[6]. SEPs monitoring is not sensitive enough for the detection of subcortical ischemia, which is caused by blood flow disruptions to the deep perforating arterial branches[7]. Somatosensory evoked potentials (SEPs) and motor evoked potentials (MEPs) monitorings are the gold standard for real-time functional observation of the corticospinal tract during tumor surgery[8]. IONM has been utilized in an attempt to minimize neurological damage during surgery, to identify important neural structures in the operative field, and thus to avoid and/or limit significant postoperative impairments[9].

During brain surgery, intraoperative monitoring of somatosensory evoked potentials (SEPs) and motor evoked potentials (MEPs) are important for prediction of post-operative motor deterioration. The aim of this study is to identify which cut-off point of SEPs and MEPs changes are most reliable for postoperative motor deterioration after brain surgery.

# II. PATIENTS AND METHODS

## 1. Subjects

Between December 2015 and December 2016, intraoperative MEPs or SEPs were monitored during 100 patient for brain operations. All operations were performed by extensively experienced neurosurgeons. Prospective analysis was done on the patient data including IONM records, medical records, operative narratives, anesthesia records and outpatient clinical records. Preoperatively, 88 patients were neurologically intact and 12 patients had motor deteriorations. The baseline characteristics of the patients are listed in Table 1.

## 2. Anesthesia

Rocuronium bromide (Esmeron®, 50-150 mg) was administered intravenously as a short-acting muscle relaxant to facilitate endotracheal intubation. No paralytic agents were subsequently administered.

General anesthesia was induced by total intravenous anesthesia with remifentanil (Ultiva®), propofol (Fresofol®), or midazolam (Vascam®) in several combinations to initiate and maintain general anesthesia. During anesthesia, body temperature, direct radial artery pressure, pulse rate, oxygen saturation, and end-tidal carbon dioxide concentration were continuously monitored. All patients were kept normothermic and normotensive.

## 3. Intraoperative neurophysiologic monitoring (IONM) technique

IONM was performed by a single skilled technician using Cascade (Cadwell Industries Inc., Kennewick, WA, USA). In all 100 patients, both MEPs and SEPs were monitored.

### *Somatosensory Evoked Potentials (SEPs)*

Somatosensory evoked potentials were elicited by electrical stimulation of the median nerve at the wrist and the posterior tibial nerve at the ankle (intensity 40 mA, duration 0.2 ms, with a repetition rate of 5 Hz). SEPs were recorded from needle electrodes placed on the scalp at C3 (right median nerve), C4 (left median nerve), and Cz (right or left tibial nerve) referenced to Fpz according to the 10-20 international electroencephalography (EEG) system.

### *Motor Evoked Potentials (MEPs)*

Motor evoked potentials were obtained by multipulse transcranial electric stimulations using the Cascade electrical stimulator (Cadwell Industries Inc.). Transcranial electric motor evoked potentials were recorded bilaterally from abductor pollicis brevis muscles in the upper extremities, and tibialis anterior muscles in the lower extremities using a pair of needle electrodes inserted 3 cm apart in each muscle. Short trains of 6 square-wave stimuli of 0.5 ms duration with an interstimulus interval of 5 ms were delivered with up to 2 Hz of repetition rate through needle electrodes placed at C1 and C2, according to the 10-20 international EEG system. A C1/C2 montage is preferable for right extremity MEPs, while C2/C1 is preferentially used to elicit left extremity MEPs. To elicit lower extremity MEPs, a Cz/Fz montage was used, which produces less intense muscle twitching. The intensity of the stimulus was gradually escalated by 50 mV increments (from 50 mV to a maximum of 400 mV) until MEP amplitudes were maximized above a minimum of 10 mV.

***Alarm criteria for evoked potentials***

Neurophysiological monitoring was performed throughout the surgical procedures. Baseline EPs were obtained at least 60 minutes after intubation, and after the muscle relaxant effect had faded.

Values of $N_{20}$ latencies of median SEPs, $P_{37}$ latencies of tibial SEPs, peak-to-peak amplitudes of MEPs were continuously monitored. More than a 50% reduction in amplitude compared to baseline MEPs was considered as a significant change. Prolongation of N20 or P37 latencies more than 10% from baseline SEPs were defined as a significant change. If any significant EPs changes occurred, the surgeons were promptly informed and the surgical procedures were stopped temporarily until the values of EPs returned to normal. However, if no signal reversal occurred even after the surgical correction immediately prior to signal change, cessation of the procedure was considered.

## 4. Neurologic examination

The motor status of each patient was evaluated before surgery, 48 hours after surgery and 4 weeks later. The strengths of 10 key muscles were measured. Muscle strength was evaluated using the Medical Research Council (MRC) scale on a range from 0 to 5. The total score ranged from 0 to 50 points on each side. Any reduction in the motor score with 1 point or more compared to the preoperative evaluation was considered as postoperative neurologic motor deterioration.

Postoperative weakness observed within 48 hours after surgery which recovered after four weeks was considered as transient motor deterioration. If the decreased motor score at 48 hours did not recover in four weeks, the patient was considered to have persistent postoperative motor deterioration. Each statistical analysis was done to reveal the correlations between the results of intraoperative changes of SEPs or MEPs and the motor status according to each type of the brain diseases.

## 5. Statistical Analysis

Association between SEPs and MEPs change was conducted by correlation analysis. The sensitivity, specificity, positive predictive value and negative predictive value which were used in previous studies' as the alarm criteria for the prediction of postoperative motor deterioration were calculated. To maximize the value of sensitivity, receiver operating characteristic (ROC) curve analysis was performed, then, sensitivity, specificity, PPV and NPV of best cut-off point were analyzed. Compared to continuous value, Mann-Whitney U test was conducted. Data was analyzed with SPSS ver. 20.1 (IBM, Armonk, NY, USA), and a *P*-values of <0.05 were considered statistically significant.

# III. RESULTS

## 1. Patient characteristics

A total of 100 patients were enrolled in this study and baseline characteristics of the patients are presented in **Table 1**. The median age was 58.5 years (range 7-83), and 56 (56%) patients were female. The average values of preoperative and postoperative motor score (MRC scale) were 97 and 94.9, respectively. A large proportion of these patients' illness was due to vascular disease (61 patients), and un-ruptured aneurysm (39 patients) was the most common disease type. In addition, eight patients with ruptured aneurysm/SAH and 8 patients with carotid stenosis were also included. Regarding tumor disease, 39 patients were included, and meningioma was the most common disease type (16 patients). Patients with glioblastoma, astrocytoma and craniopharyngioma were also included. Other diseases included were glioma, chordoma, choroid plexus papilloma, pineal gland tumor and papillary glioneuronal tumor.

**Table 1. Patient characteristics**

| Characteristics | No. (%) |
|---|---|
| Age, median (range) | 58.5 (7-83) |
| Sex | |
| Female | 56 (56%) |
| Male | 44 (44%) |
| Motor Score (MRC scale) | Mean score (range) |
| Preoperative, mean (range) | 97(55-100) |
| Postoperative, mean (range) | 94.9(50-100) |
| Diagnosis | |
| Vascular disease (Group 1) | |
| Unruptured Aneurysm | 39(39%) |
| Ruptured Aneurysm and SAH | 8(8%) |
| Carotid stenosis | 8(8%) |
| Cavernous malformation | 2(2%) |
| Arteriovenous malformation | 2(2%) |
| Moyamoya disease | 2(2%) |
| Tumor disease (Group 2) | |
| Metastatic brain tumor | 3(3%) |
| Meningioma | 16(16%) |
| Glioblastoma | 9(9%) |
| Astrocytoma | 3(3%) |
| Craniopharyngioma | 3(3%) |
| Others* | 5(5%) |

SAH, Subarachnoid hemorrhage; No, Number

*Other diseases included glioma, chordoma, choroid plexus papilloma, pineal gland tumor and papillary glioneuronal tumor.

**2. Patterns of postoperative motor deterioration**

Of the 100 patients, 12 had postoperative motor deterioration **(Table 2**). Baseline motor score was evaluated by the MRC scale, and 78 patients had 100 point and others (22 patients) had a less than 100 point scale. Ninety five percentages of patients with baseline motor intact had no motor change after brain surgery and 5% of patients had motor deterioration. However, 36% of patients with baseline motor deficit had postoperative motor deterioration.

**Table 2. Postoperative motor change by preoperative motor score**

| Pre-operative Motor Score | Post-operative<br>Motor improvement | <br>No motor change | <br>Motor deterioration |
|---|---|---|---|
| 100 (n=78) | 0 | 74 | 4 |
| <100 (n=22) | 3 | 11 | 8 |

Characteristics of the 12 patients with postoperative motor deterioration are described in **Table 3**. All of them suffered from persistent motor deterioration after brain surgery. Among the 12 patients with postoperative motor deterioration, there was only one patient with vascular disease, whose diagnosis was ruptured cerebral aneurysm. Others were tumor disease and meningioma was the most common disease type with postoperative motor deterioration. Eight patients had changes in ether SEPs or MEPs. One had SEPs changes alone and MEPs changes alone were observed in 7 patients. Four patients had neither SEPs nor MEPs changes.

**Table 3. Patients with persistent motor deterioration after brain surgery**

| Case | Age/Sex | Diagnosis | Location | SEPs change(%) | MEPs change(%) |
|---|---|---|---|---|---|
| 1 | 7/M | Chordoma | Clivus | 9.63 | 74.74 |
| 2 | 48/F | Craniopharyngioma | Rt suprasella | 7.14 | 61.65 |
| 3 | 72/F | Glioblastoma | Rt. temporoparietal lobe | 9.94 | 85.51 |
| 4 | 24/M | Anaplastic Astrocytoma | Rt. frontoparietal lobe | 7.24 | 98.27 |
| 5 | 60/F | Craniopharyngioma | suprasella area | 1.11 | 99.74 |
| 6 | 46/M | Metastatic brain tumor | Rt parietal lobe | 17.42 | 21.47 |
| 7 | 56/M | Metastatic brain tumor | Lt. parietal lobe | 4.46 | 35.55 |
| 8 | 43/M | Glioblastoma | Lt. parietal lobe | 5.36 | 86.47 |
| 9 | 48/M | Atypical meningioma | Lt. frontoparietal lobe | 3.27 | 38.43 |
| 10 | 58/M | Ruptured cerebral aneurysm | Rt. IC ant. choroidal artery | 9.38 | 27.73 |
| 11 | 75/F | Meningioma | Lt. parasagittal area | 9.54 | 31.44 |
| 12 | 61/M | Meningioma | Rt. frontal convexity | 9.04 | 75.05 |

### 3. Changes of SEPs and MEPs after brain surgery

Preoperative SEPs and MEPs were measured and postoperative EPs were also measured. From these results, changes in SEPs and MEPs were calculated and the values of each parameter are shown in **table 4**. Median change of SEP latency delay and MEP amplitude reduction were 4.9% and 29.3%, respectively. MEPs changes were more prominent than SEPs changes.

**Table 4. Changes of SEPs and MEPs after brain surgery**

| | SEPs latency Delay (%) | MEPs amplitude Reduction (%) |
|---|---|---|
| Minimum | -1.590 | 0.0 |
| 25% Percentile | 3.233 | 17.85 |
| Median | 4.940 | 29.30 |
| 75% Percentile | 7.128 | 41.50 |
| Maximum | 17.42 | 99.78 |
| Mean | 5.295 | 32.78 |
| Standard Deviation | 3.021 | 25.23 |

No, number of patients; SEPs, somatosensory evoked potentials; MEPs, motor evoked potentials

We investigated whether there was an association between SEPs and MEPs changes, there was significant association between the two parameters (*P* = 0.04, **Figure 1**).

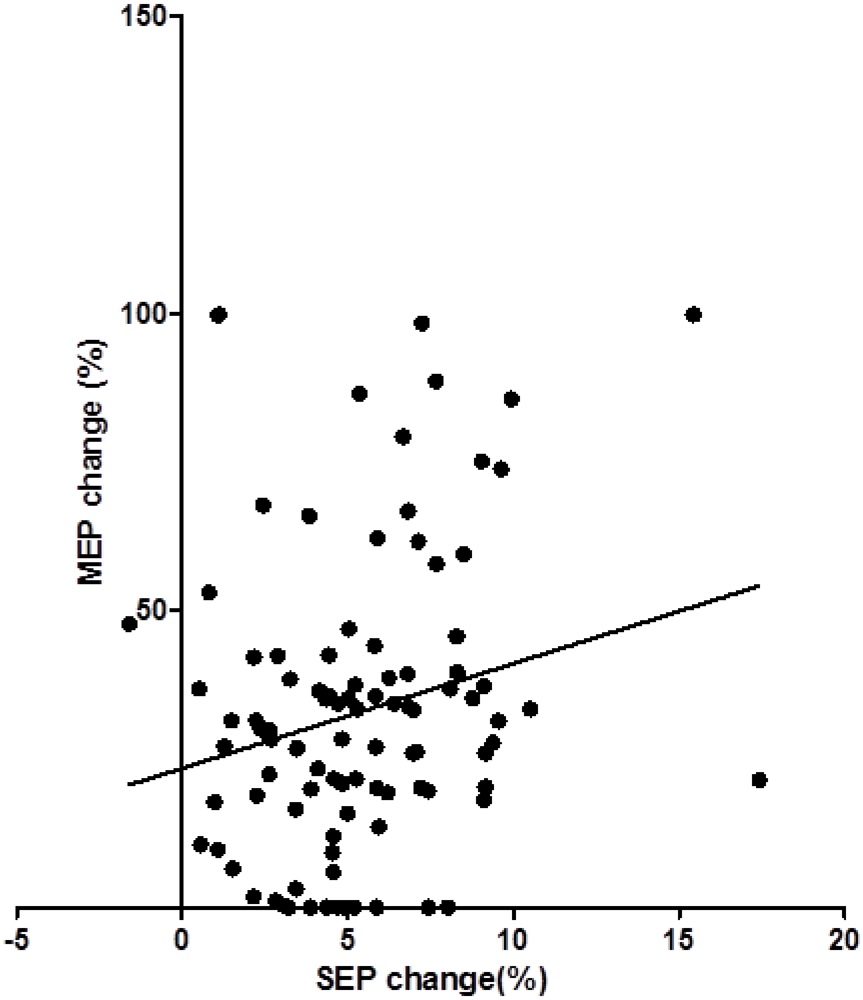


**Figure 1. Correlation between SEPs and MEPs changes (%)**

### 4. Sensitivity, specificity, PPV and NPV

First, the sensitivity and specificity of SEPs and MEPs changes with the previous alarm criteria was evaluated **(Table 5)**. Sensitivity and specificity of SEPs change with more than 10% delay was 8.3% and 96.7%, respectively, and MEPs changes with more than 50% reduction were 58.3% and 87.5%. Sensitivity of patients with either SEPs or MEPs change was increased from 8.3% to 66.7%, and specificity was increased from 96.7% to 100%. PPV and NPV were also evaluated for previous alarm criteria. PPV and NPV of SEPs change alone were 33.3% and 88.7%. These value of MEPs change alone were 38.9% and 93.9%. Prediction of postoperative motor deterioration using either SEPs or MEPs change was evaluated and PPV and NPV were 100% and 95.6%.

**Table 5. Sensitivity, specificity, PPV and NPV of intraoperative monitoring with pre-existing alarm criteria during brain surgery**

| Changes (%) | No. | Sensitivity (%) | Specificity (%) | PPV (%) | NPV (%) |
|---|---|---|---|---|---|
| SEP (>10) | 3 | 8.3 | 96.7 | 33.3 | 88.7 |
| MEP (>50) | 18 | 58.3 | 87.5 | 38.9 | 93.9 |
| Either SEP or MEP | 20 | 66.7 | 100 | 100 | 95.6 |

No, number of patients; PPV, positive predictive value; NPV, negative predictive value; SEP, somatosensory evoked potentials; MEP, motor evoked potentials

Due to the low sensitivity in the found in previous studies, we intended to identify a new alarm criteria using ROC curve analysis. Based on this analysis, 7.1% and 59.5% change were selected as the best points for SEPs and MEPs changes (**Figure 2 and 3**). The same results were obtained in 39patients who underwent brain tumor surgery.

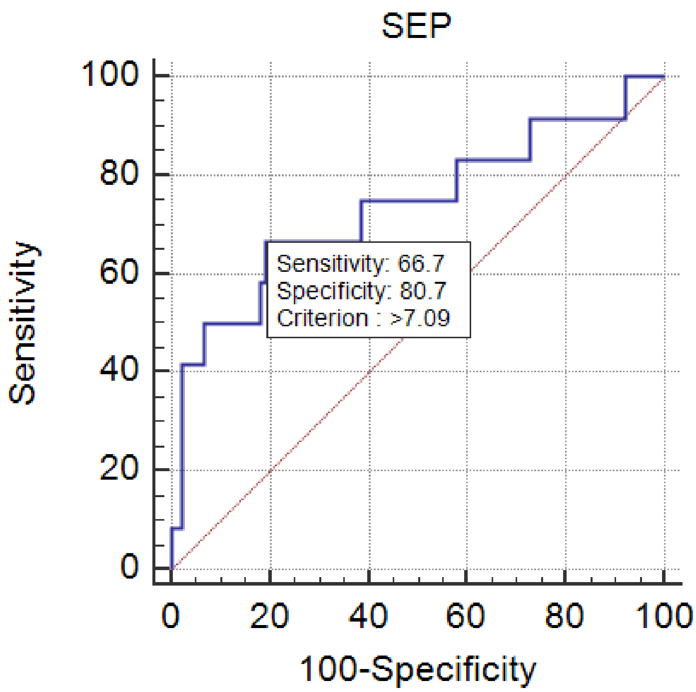


**Figure 2. ROC curve for the best cut-off point of SEPs change (%) predicting postoperative motor deterioration**

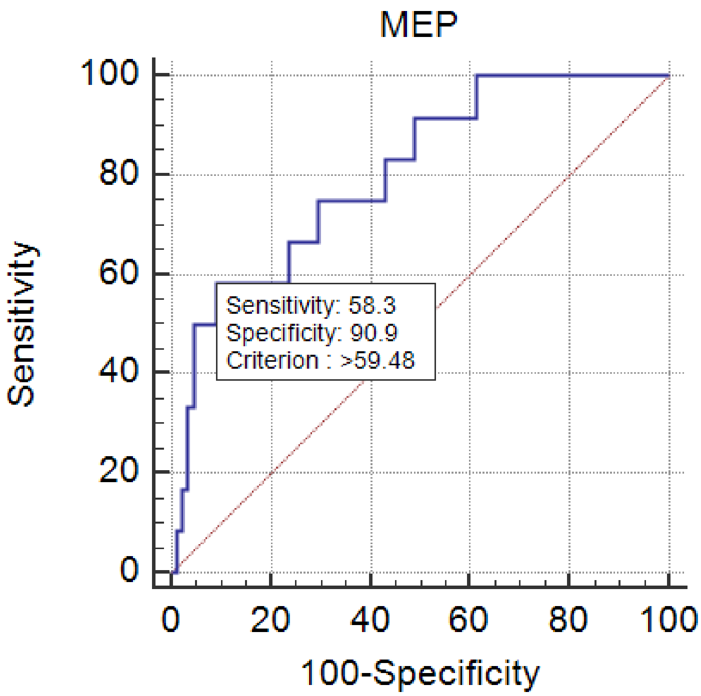


**Figure 3. ROC curve for the best cut-off point of MEPs change (%) predicting postoperative motor deterioration**

After finding the best cut off point, we evaluated this value for the sensitivity, specificity, PPV and NPV of prediction of postoperative motor deterioration. The value of each parameter was shown in **table 6**. Interestingly, sensitivity and NPV of either SEPs or MEPs were significantly improved compared with that of the previous alarm criteria. Sensitivity of SEPs change alone with more than 7% change was 66.7% and that of MEPs change with more than 60% change was 58.3%. Correspondingly, specificity and PPV of each parameter were decreased.

**Table 6. Sensitivity, specificity, PPV and NPV of intraoperative monitoring with the best-cut off point during brain surgery**

| Changes (%) | No. | Sensitivity (%) | Specificity (%) | PPV (%) | NPV (%) |
|---|---|---|---|---|---|
| SEPs (>7) | 25 | 66.7 | 80.7 | 32 | 94.7 |
| MEPs (>60) | 15 | 58.3 | 90.9 | 46.7 | 94.1 |
| Either SEPs or MEPs | 33 | 83.3 | 73.9 | 30.3 | 97 |

No, number of patients; PPV, positive predictive value; NPV, negative predictive value; SEPs, somatosensory evoked potentials; MEPs, motor evoked potentials

**5. Subgroup analysis of SEPs and MEPs changes after brain surgery**

We also evaluated the SEPs and MEPs changes for prediction of postoperative motor deterioration according to disease type. At first, we compared the SEPs latency delay and MEPs amplitude reduction according to disease type. Median change of SEPs latency delay and MEPs amplitude reduction in the vascular group were 4.7% and 27%, respectively and median change of SEPs latency delay and MEP amplitude reduction in the tumor group were 5.9% and 37.3%, respectively. Both SEPs change and MEPs change were more prominent in the tumor group than in the vascular group. (**Table 7)** MEPs changes were more prominent than SEPs changes in vascular and tumor group, both. **(Figure 4**).

**Table 7. Differences of the changes in intraoperative EPs between patients with vascular and tumor disease**

| | SEP latency Delay (%) | | MEP amplitude Reduction (%) | |
|---|---|---|---|---|
| | Vascular Group | Tumor Group | Vascular Group | Tumor Group |
| No. | 61 | 39 | 61 | 39 |
| Minimum | 0.5200 | -1.590 | 0.0 | 0.0 |
| 25% Percentile | 2.795 | 3.430 | 14.71 | 20.10 |
| Median | 4.710 | 5.890 | 27.04 | 37.33 |
| 75% Percentile | 6.515 | 8.100 | 35.16 | 65.94 |
| Maximum | 15.43 | 17.42 | 99.78 | 99.74 |
| Mean | 4.976 | 5.795 | 26.37 | 42.80 |
| Standard Deviation | 2.687 | 3.457 | 19.36 | 29.97 |

No, number of patients; SEPs, somatosensory evoked potentials; MEPs, motor evoked potentials

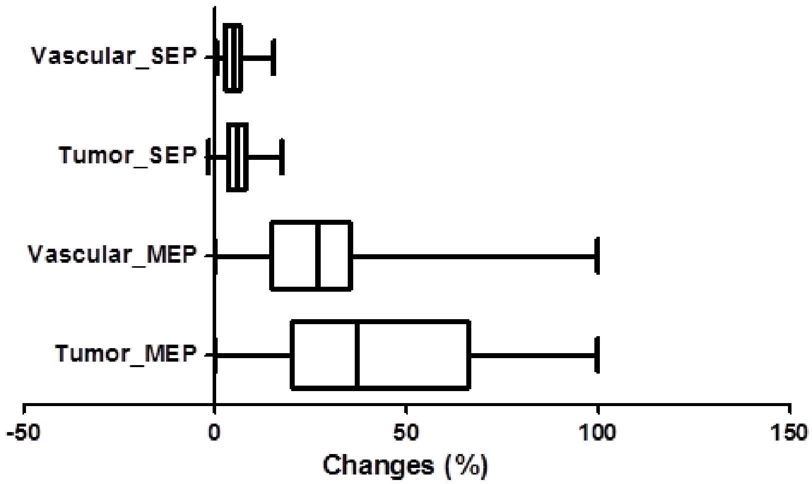


**Figure 4. SEPs and MEPs changes(%) between vascular and tumor disease**

**6. Subgroup analysis of sensitivity, specificity, PPV and NPV**

Subgroup analysis was also performed, and EPs change with previous alarm criteria was evaluated (**Table 8**). In tumor disease group, Sensitivity was 72.7% and specificity of 78.6% when either SEP or MEP changed.

**Table 8. Sensitivity, specificity, PPV and NPV of intraoperative monitoring with pre-existing alarm criteria during brain tumor surgery**

| Changes (%) | No. | Sensitivity (%) | Specificity (%) | PPV (%) | NPV (%) |
|---|---|---|---|---|---|
| Tumor disease (motor weakness =11) | | | | | |
| SEPs (>10) | 1 | 9.1 | 100 | 100 | 73.7 |
| MEPs (>50) | 7 | 63.6 | 78.6 | 53.9 | 84.6 |
| Either SEPs or MEPs | 8 | 72.7 | 78.6 | 57.1 | 88 |

No, number of patients; PPV, positive predictive value; NPV, negative predictive value; SEPs, somatosensory evoked potentials; MEPs, motor evoked potentials

We also evaluated sensitivity, specificity, PPV and NPV using the best cut-off point. Of patients with brain tumor disease, eleven patients with postoperative motor deterioration were observed. Sensitivity and NPV of either SEPs or MEPs were significantly improved compared with that of the previous alarm criteria. Sensitivity of either SEPs or MEPs change was 81.8% and specificity was 60.7% in brain tumor disease group. Correspondingly, specificity and PPV of each parameter were decreased. When we checked only MEPs, specificity , PPV and NPV were increased with best-cut off criteria.

**Table 9. Sensitivity, specificity, PPV and NPV of intraoperative monitoring with the best-cut off point during brain tumor surgery**

| Changes (%) | No. | Sensitivity (%) | Specificity (%) | PPV (%) | NPV (%) |
|---|---|---|---|---|---|
| Tumor disease (motor weakness =11) | | | | | |
| SEPs (>7) | 14 | 63.6 | 75 | 50 | 85.2 |
| MEPs (>60) | 12 | 63.6 | 82.1 | 58.3 | 85.2 |
| Either SEPs or MEPs | 20 | 81.8 | 60.7 | 45 | 89.5 |

No, number of patients; PPV, positive predictive value; NPV, negative predictive value; SEPs, somatosensory evoked potentials; MEPs, motor evoked potentials

# IV. DISCUSSION

Combined SEPs and MEPs monitoring provides a great deal of information during brain surgery. In this study, we monitored 100 patients in all, and of the total, 12 patients experienced postoperative neurological weakness characterized as permanent neurological deterioration. Eleven out of these 12 were patients who had fallen under the category of having a brain tumor as the initial reason for brain surgery.

Both in the vascular and tumor group, the range of MEPs change was larger than the range of SEPs change. However, there was no statistical significance. The pre-existing cut off value was defined as the decrease of SEPs latency by more than 10% or the decrease of MEP amplitude by more than 50% in most existing articles. With this criterion, the sensitivity was 66.7% and the specificity was 100% in detecting impending neurologic deteriorations after brain surgery. EPs monitoring by best cut-off alarm criteria have a sensitivity of 83.3% and a specificity of 73.9% in detecting impending neurologic deteriorations after brain surgery.

In the tumor group, the sensitivity was 72.7% and specificity was 78.6% for the pre-existing alarm criteria respectively, and the sensitivity was 81.8% and specificity was 60.7% for the best cut-off point. Also in the case of MEPs monitoring, the PPV was 53.9% and NPV was 84.6% for the pre-existing alarm criteria respectively, and the PPV was 58.3% and NPV was 85.2% for the best cut-off point. With the the best cut-off value, NPV increased in both SEPs and MEPs monitorings.

Only increasing the sensitivity at the time of surgery may actually be a problem in the feedback with the operator at the time of operation, so more diverse solutions should be considered for practical application. Our results have been adjusted by monitoring during surgery, so it seems to have already influenced postoperative results. When the cut-off point is changed in the brain tumor patients, the sensitivity is increased but the specificity is lowered because the standard is lowered. At least for brain tumor patients, it can be applied differently from the conventional cut-off value.

The use of SEPs is advantageous for the following reasons: it does not provoke unwanted movement of the patient during surgery, and it is easily quantifiable.[9] Also SEPs may avoid false negatives from high intensity MEPs stimulation activating sites deep in the cortex.[10] They provide direct information about somatosensory regions and pathways, and also monitoring when MEPs cannot be obtained from patients with significant preoperative weakness.[11] SEPs are useful in avoiding nerve injuries associated with positioning of the limbs, neck and head.[12]

However, SEPs are sensitive only to cortical mantle ischemia in the middle cerebral artery territory.[3] It should be pointed out that SEPs monitoring typically is insensitive to strokes in the rostral frontal, temporal, and occipital lobes as well as to subcortical ischemia, particularly that which occurs secondary to perforating vessel perturbation.[3]

Several studies have demonstrated the benefit of the IONM and especially MEPs monitoring in avoiding direct damage to the corticospinal tract during surgery for supratentorial lesions.[13] Studies have shown a clear relationship of MEPs loss and permanent postoperative neural deficit during aneurysm occlusion of basilar, vertebral, and middle cerebral artery aneurysms.[14] MEPs also may be more sensitive and show changes faster than SEPs for brainstem ischemia caused by perforating artery occlusion during basilar tip aneurysm surgery.[15] Lesions outside the primary motor cortex or pyramidal tract unrelated to MEP detection, such as the basal ganglia, and thalamus or hemorrhage extending to the center of the somatosensory cortex and the intraparietal sulcus could similarly interfere with the recovery of motor function.[16-18] Various studies have reported that MEPs monitoring is useful during brain tumor removal.[19-22]

The combination of MEPs and SEPs monitoring during surgery for intraparenchymal and extraparenchymal brainstem lesions has become a safe, reliable, and sensitive method to detect and reduce injury to the brainstem, allowing early intervention to avoid permanent impairment[23]. SEPs/MEPs monitoring in intracranial aneurysm surgery demonstrated whose interest in detecting and correcting intraoperative ischemic risk.[24] SEPs provide an established modality for monitoring of the function of the somatosensory pathways during surgery on the spinal cord, brain, and brainstem to detect iatrogenic neurological injury, a very good indicator of brainstem integrity. However, SEPs are sensitive to anesthetics agents, and some studies found that the effects of anesthetics interfered with SEPs recording.[25]

Although MEPs can be monitored under the standard total intravenous anesthesia (TIVA) protocol, it is highly vulnerable to inhalation anesthesia, and even a low dose of halogenated inhalation anesthetics can abolish or significantly interfere with MEPs recording.[26] Recording of MEPs requires the transmission of a neural signal through the neuromuscular junction, and the use of muscle relaxants (neuromuscular blockers) during surgical procedures can significantly affect the amplitude of MEPs.[27] In our study, there was no statistically significant correlation between SEPs and MEPs changes. But the patients who have motor deterioration experienced greater MEPs change. It is difficult to determine whether these new deficits occurred as the result of intraoperative ischemic events or technical errors in SEPs monitoring or postoperative delayed ischemic events, in which case it would be impossible for SEPs monitoring to recognize them.[3]

Nonetheless, SEPs and MEPs monitoring during brain surgery has its limitations. The first is that different surgeons performed their operations in different ways and the patients’ underlying diseases or conditions were not reflected in the study. Moreover, this study strictly defined ‘motor weakness’ as even a single point fall on the MRC scale. Therefore, it included even mild weakness, which presumably also affected sensitivity and specificity. An additional weakness of our study is that sensory deficits were not checked and our focus was only on the motor outcomes. The follow-up, conducted 1 month later, was also a limitation. Additional follow-ups at 6 and 12 months would enable better interpretations of the benefits of SEPs and MEPs monitoring. Multimodal monitoring provides surgeons with more complete neurological information, which is expected to provide additional information regarding risk factors, and further enhance sensitivity.

# V. CONCLUSION

Intraoperative SEPs and MEPs monitoring is highly specific for predicting impending strokes and neurologic deteriorations after brain surgery and IONM has become more widespread in recent years.

The sensitivity and specificity of a intraoperative SEPs and MEPs monitoring may be different depending on the surgical procedure and location of the brain lesion. Brain tumor surgery and cerebro-vascular surgery have different results and values for IONM monitoring because of the different approaches. Therefore, appropriate monitoring methods should be studied to obtain the compatible results of surgical approaches such as cerebro-vascular surgery or brain tumor resection surgery.

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**ABSTRACT**

뇌 수술 시 운동 및 체성감각 유발전위를 통한 추적감시

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**서론**: 뇌 수술 중 체성감각 유발전위(SEPs)와 운동 유발전위(MEPs)의 모니터링은 수술 후 운동 저하를 예측하는데 중요하다. 따라서 본 연구의 목적은 수술 중 SEPs와 MEPs의 변화량을 이용하여 뇌 수술 후 운동 결함을 예측하기 위해 변화량의 가장 적절한 기준값을 제안하는 것이다.

**방법**: 본 연구는 2015년 12월부터 2016년 12월까지 뇌수술을 받은 100명의 환자들을 대상으로 SEPs와 MEPs의 수술 중 모니터링 기록을 검토하여 진행하였다. 또한 모든 환자에서 수술 24시간 전, 수술 후 48 시간 이내, 그리고 4 주 후에 각각 MRC (Medical Research Council) 척도를 이용하여 근력을 측정하였다. 수술 중 체성감각 유발전위 또는 운동 유발전위의 변화를 이용하여 수술 후 운동 결함 예측의 민감도와 특이도를

분석 하였다. 체성감각 유발전위와 운동 유발전위의 최적 차단 지점을 찾기 위해 Receiver Operating Characteristic (ROC) 곡선 분석을 수행 하였다.

**결과**: 환자들 중에서 비-종양 (non-tumor) 환자는 61 명 (61 %)이었고 종양 환자는 39 명 (39 %) 이었다. 기존의 alarm criteria로 체성감각 유발전위 (잠시의 10 % 이상 연장)의 수술 후 운동 결함 예측 민감도는 8.3 % 였고, 운동 유발전위 (진폭이 50 % 이상 감소)의 민감도는 58.3 % 였다. 특이도의 경우 체성감각 유발전위는 87.5 %, 운동 유발전위는 100 %로 각각 확인 되었다. ROC 곡선 분석에 의하면 수술 중 체성감각 유발전위 잠시 변화와 수술 중 운동 유발전위 진폭 변화를 최대로 구별 할 수 있는 점은 각각 7.1 %와 59.5 %였다. 임상적 유용성을 위해서 7.0% 체성감각 유발전위 잠시 변화와 60.0% 운동 유발전위 진폭 변화가 최적의 cut-off로 결정 되었다. 이 cut-off에서 체성감각 유발전위와 운동 유발전위의 민감도는 각각 66.7 %와 58.3 % 였고 특이도는 각각 80.7 %와 90.9 %였다. 수술 중 운동 유발전위의 변화가 체성감각 유발전위 변화보다 더 높은 민감도를 보였다. 체성감각 유발전위 또는 운동

유발전위 중 하나 이상에서 변화가 있는 환자의 경우 민감도는 83.3 % 였고 특이도는 73.9 %였다. 체성감각 유발전위와 운동 유발전위 간의 상관 관계 테스트는 유의한 연관성을 증명하였다 (*P* = 0.04).

**결론**: 본 연구는 뇌 수술을 받는 환자들에서 체성감각 유발전위 잠시 시간의 경우 7 % 연장 값, 그리고 운동 유발전위 진폭은 60 % 감소한 값을 새로운 alarm criteria로 제안하였고, 수술 중 운동 유발전위의 변화가 수술 후 운동 결함 예측에 더 민감하였다. 앞으로 더 많은 사례가 축적되면 보다 정확한 alarm criteria cut-off 값을 제안 할 수 있을 것으로 생각된다.

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핵심되는 말 : 수술 중 신경 생리 모니터링, 체성감각 유발전위, 운동 유발전위, 뇌 수술