Conjunct SEP and MEP monitoring in resection of infratentorial lesions: lessons learned in a cohort of 210 patients

Clinical article

KUNIHKO KODAMA, M.D., PH.D., MANI JAVADI, D.M.D., VOLKER SEIFERT, M.D., PH.D., AND ANDREA SZELÉNYI, M.D., PH.D.

Department of Neurosurgery, Hospital of the Johann Wolfgang Goethe University, Frankfurt am Main, Germany

Object. During the surgical removal of infratentorial lesions, intraoperative neuromonitoring is mostly focused on cranial nerve assessment and brainstem auditory potentials. Despite the known risk of perforating vessel injury during microdissection within the vicinity of the brainstem, there are few reports about intraoperative neuromonitoring with somatosensory evoked potentials (SEPs) and motor evoked potentials (MEPs) assessing the medial lemniscus and corticospinal tract. This study analyses the occurrence of intraoperative changes in MEPs and SEPs with regard to lesion location and postoperative neurological outcome.

Methods. The authors analyzed 210 cases in which patients (mean age 49 ± 13 years, 109 female) underwent surgeries involving the skull base (n = 104), cerebellum (n = 63), fourth ventricle (n = 28), brainstem (n = 12), and foramen magnum (n = 3).

Results. Of 210 surgeries, 171 (81.4%) were uneventful with respect to long-tract monitoring. Nine (23%) of the 39 SEP and/or MEP alterations were transient and were only followed by a slight permanent deficit in 1 case. Permanent deterioration only was seen in 19 (49%) of 39 cases; the deterioration was related to tumor dissection in 4 of these cases, and permanent deficit (moderate-severe) was seen in only 1 of these 4 cases. Eleven patients (28%) had losses of at least 1 modality, and in 9 of these 11 cases, the loss was related to surgical microdissection within the vicinity of the brainstem. Four of these 9 patients suffered a moderate-to-severe long-term deficit. For permanent changes, the positive predictive value for neuromonitoring of the long tracts was 0.467, the negative predictive value was 0.989, the sensitivity was 0.875, and the specificity 0.918. Twenty-eight (72%) of 39 SEP and MEP alterations occurred in 66 cases involving intrinsic brainstem tumors or tumors adjacent to the brainstem. Lesion location and alterations in intraoperative neuromonitoring significantly correlated with patients’ outcome (p < 0.001, chi-square test).

Conclusions. In summary, long-tract monitoring with SEPs and MEPs in infratentorial surgeries has a high sensitivity and negative predictive value with respect to postoperative neurological status. It is recommended especially in those surgeries in which microdissection within and in the vicinity of the brainstem might lead to injury of the brainstem parenchyma or perforating vessels and a subsequent perfusion deficit within the brainstem.

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Key Words • somatosensory evoked potential • motor evoked potential • infratentorial neoplasms • intraoperative neuromonitoring • brainstem cavernoma • diagnostic and operative techniques

Abbreviations used in this paper: BAEP = brainstem auditory evoked potential; coMEP = corticobulbar motor evoked potential; EEG = electroencephalography; MEP = motor evoked potential; MRC = Medical Research Council; SEP = somatosensory evoked potential; TES = transcranial electric stimulation.
cal deficits affecting the medial lemniscal pathway and the corticospinal tract. Those lesions are not detected by cranial nerve mapping, coMEPs, or BAEPs. Thus, the use of intraoperative neuromonitoring for long tract functions with somatosensory evoked potentials (SEPs) and motor evoked potentials (MEPs) might be useful, but it has only been investigated in a few studies.\(^9,10,12,23\) Whereas the benefit of MEP monitoring for supratentorial, infratentorial, and spinal neoplasms, as well as vascular lesions, has been shown, the combined analysis of MEPs and SEPs in a large cohort of infratentorial surgeries with regard to postoperative motor and sensory function has not been performed.\(^9,13,26,31,34\) We reviewed the intraoperative course of long tract neuromonitoring in a consecutive series of infratentorial surgeries to evaluate intraoperative SEP and MEP alteration and their relation to sensory and motor outcome and to lesion location.

**Methods**

Between 2002 and 2009, intraoperative neurophysiological monitoring was performed in 210 consecutive surgeries for infratentorial lesions in our institution.

**SEP Setup**

SEPs were performed with needle electrode stimulation of the median nerve at the wrist and the tibial nerve at the medial malleolus. Stimulation was performed using a square pulse with a width of 0.2–0.5 msec, an intensity of 20–40 mA, and a frequency of 3.7–5.7 Hz. The recording sites were at CP3, CP4, and CPz and high cervical, all referenced to Fz (according to the International 10–20 EEG scheme). Between 100 and 200 responses were averaged and recorded with a filter setting of 30 Hz—1000 Hz and a sweep length of 160 msec. All recordings were stored and available for post hoc analysis.

**MEP Setup**

Motor evoked potentials were elicited with transcranial electric stimulation (TES) with the train-of-5 technique (5 pulses with an individual pulse width of 0.5 msec and an interstimulus interval of 2–4 msec). The stimulation electrodes were positioned at C4, C2, Cz, C1, C3, and 6 cm anterior to Cz (also according to the International 10–20 EEG scheme), allowing for multiple stimulation electrode montages. Mainly, C1-anode/C2-cathode and C3-anode/Cz-cathode were used for left hemispheric stimulation and C2-anode/C1-cathode or C4-anode/Cz-cathode for right hemispheric stimulation. MEPs were recorded from bilateral abductor pollicis brevis muscles and tibialis anterior muscles. Additional recordings included contralateral extensor digitorum brevis, facial, and pharyngeal muscles, if applicable. For monitoring of extremity muscles, the montage with the lowest motor threshold was chosen, and the stimulation intensity was set at 20% above the highest upper-extremity motor threshold. Responses were recorded with a filter setting of 5 Hz–1000 Hz and a sweep length of 160 msec. All recordings were stored and available for post hoc analysis.

**Criteria for Warning Signs of Intraoperative Neuromonitoring Modalities**

For MEPs, an increase of the stimulation intensity to elicit a response of more than 20 mA and an amplitude decrease of more than 50% were considered significant warning signs. For SEPs, an amplitude decrease of more than 50% in 3 consecutive recordings was considered significant. These criteria were deduced from experimental and clinical studies demonstrating that permanent changes of this extent are very likely to be followed by neurological deficits. The parameters for SEPs were summarized in the 1993 international recommendations on intraoperative neuromonitoring during surgery.\(^27\) The warning criteria for MEPs followed empirical evidence\(^10,23\) and have been refined more recently.\(^17\)

**Management of Intraoperative Neurophysiological Monitoring**

Intraoperative neurophysiological monitoring was performed with commercially available systems (Ewacs System until 2004, ISIS-system from 2003 onwards; both from Inomed Co.). The standardized set-up at our institution included SEPs of median and tibial nerves; MEPs of both upper and lower limbs, as well as of lower cranial nerves; free-running electromyography and BAEPs. Baseline values for each monitoring modality were recorded after the patient was positioned. Intraoperative neurophysiological monitoring was then performed with alternating transcranially elicited MEPs, coMEPs, SEPs, BAEPs, free-running electromyography, and direct nerve stimulation according to a protocol previously described in detail.\(^26,35,36\) While dissecting the lesion, those MEPs and SSEPs reflecting the long tracts closest to the resection area were continuously monitored in an alternating mode. MEPs and SEPs of the nonoperated hemisphere were intermittently recorded in 15- to 30-minute intervals. Surgeons were alerted when neuromonitoring changes occurred that met the criteria for warning signs described above. The most recent surgical step was then reconsidered, and—if possible—immediate action was taken (e.g., irrigation with warm solution, increase of blood pressure, application of papaverine, cessation of resection, and modification of surgical strategy).

**Anesthesia**

Anesthesia was induced with bolus doses of propofol (1.5 mg/kg/remifentanil (1 μg/kg) and further maintained with propofol (3–6 mg/kg/h) and remifentanil (0.2–0.3 μg/kg/min). The muscle relaxant rocuronium (50 mg bolus), which has an intermediate duration of action, was administered for intubation purposes only.

**Clinical Assessment**

Patients’ neurological findings were available for evaluations performed pre- and postoperatively (immediately postoperatively and at discharge) as well as 3 months’ follow-up and assessed according to the patients’ charts. Clinical symptoms were graded according to motor and sensory status, as well as activity in daily life, as follows: 1) severe hemiparesis (hemiplegia, Medical Research Council [MRC] Grade 0/5, or severe hemiparesis, MRC...
Intraoperative neuromonitoring for infratentorial surgery

Grade 1–2/5), wheelchair dependent, hemianesthesia or hemihypesthesia, hemiataxia, dependent in all activities of daily life; 2) moderate hemiparesis (not able to walk, MRC Grade 3–4/5, hemihypesthesia, hemiataxia, needs some help in activities of daily life); and 3) slight hemiparesis (muscle strength MRC Grade 4/5, ambulatory, slight hemihypesthesia, independent in daily life) and no or no new motor or sensory deficit.

Data Analysis

A prospectively collected database containing pseudonymized patients’ core data (age, lesion location, histopathology, intraoperative changes in neuromonitoring modalities, pre- and postoperative outcome) was used to identify cases eligible for analysis. For further analysis, medical records and imaging studies were each reviewed by a neurosurgeon (K.K.) and research student (M.J.)—both blinded to the intraoperative neuromonitoring course—for peri- and postoperative clinical course, location of lesion, and associated operative data. Those data were then related to the intraoperative course in neuromonitoring. For statistical analysis, Fishers’s exact, chi-square, and Cramer’s V-tests were used (IBM SPSS Statistics 19).

Results

Data from 210 patients (mean age 49 ± 13 years, median 48 years, range 20–77 years; 101 male, 109 female) were eligible for analysis. The 210 surgeries were performed for a variety of lesions, including 104 skull base tumors. The distribution of locations and histopathological type are shown in Table 1.

Incidence and Distribution of Changes in Intraoperative Neuromonitoring

Overall, alterations of SEPs and/or MEPs were observed in 39 (18.6%) of the 210 patients.

The changes involved only MEPs in 3 patients (7.7% of the 39 in whom intraoperative neuromonitoring changes were observed, corresponding to 1.4% of the whole study group), only SEP changes were seen in 25 patients (64.1%, corresponding to 11.9% of the whole study group), and both MEP and SEP changes were seen in 11 patients (28.2%, corresponding to 5.2% of the whole study group). Transient changes were observed in 9 patients (23.1%) and permanent changes were observed in 27 patients (69.2%). Both permanent and transient changes affecting MEPs and/or SEPs occurred in 3 patients (7.6%, for further details see Table 2). Three (25%) of the 12 transient changes occurred in MEPs and 11 (91.7%) in SEPs. Twelve (40%) of the 30 permanent changes occurred in MEPs and 28 (93.3%) in SEPs. Permanent losses were observed in only MEPs in 1 patient, in only SEPs in 5 patients, and in both—SEPs and MEPs—in 4 patients.

In 1 (2.6%) of the 39 patients with intraoperative neuromonitoring changes, these were ascribed to technical problems, but resolved.

Patients’ Outcome

The initial postoperative neurological outcome was

<table>
<thead>
<tr>
<th>Location &amp; Histopathology</th>
<th>No. of Lesions</th>
</tr>
</thead>
<tbody>
<tr>
<td>skull base (n = 104)</td>
<td></td>
</tr>
<tr>
<td>CPA (n = 77)</td>
<td></td>
</tr>
<tr>
<td>schwannoma</td>
<td>53</td>
</tr>
<tr>
<td>meningioma</td>
<td>10</td>
</tr>
<tr>
<td>epidermoid</td>
<td>7</td>
</tr>
<tr>
<td>cholesterol granuloma</td>
<td>2</td>
</tr>
<tr>
<td>metastasis</td>
<td>2</td>
</tr>
<tr>
<td>chordoma</td>
<td>1</td>
</tr>
<tr>
<td>plexus papilloma</td>
<td>1</td>
</tr>
<tr>
<td>ependymoma</td>
<td>1</td>
</tr>
<tr>
<td>petroclival (n = 20)</td>
<td></td>
</tr>
<tr>
<td>meningioma</td>
<td>20</td>
</tr>
<tr>
<td>petrosal (n = 6)</td>
<td></td>
</tr>
<tr>
<td>meningioma</td>
<td>5</td>
</tr>
<tr>
<td>metastasis</td>
<td>1</td>
</tr>
<tr>
<td>clivus (n = 1)</td>
<td></td>
</tr>
<tr>
<td>chordoma</td>
<td>1</td>
</tr>
<tr>
<td>cerebellar hemisphere (n = 40)</td>
<td></td>
</tr>
<tr>
<td>metastasis</td>
<td>18</td>
</tr>
<tr>
<td>meningioma</td>
<td>4</td>
</tr>
<tr>
<td>hemangioblastoma</td>
<td>10</td>
</tr>
<tr>
<td>cavernoma</td>
<td>2</td>
</tr>
<tr>
<td>medulloblastoma</td>
<td>2</td>
</tr>
<tr>
<td>cyst</td>
<td>2</td>
</tr>
<tr>
<td>glioma</td>
<td>2</td>
</tr>
<tr>
<td>tentorium (n = 18)</td>
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</tr>
<tr>
<td>meningioma</td>
<td>18</td>
</tr>
<tr>
<td>vascular (n = 5)</td>
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<tr>
<td>dural fistula</td>
<td>4</td>
</tr>
<tr>
<td>AVM</td>
<td>1</td>
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<tr>
<td>4th ventricle (n = 28)</td>
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<td>ependymoma</td>
<td>21</td>
</tr>
<tr>
<td>medulloblastoma</td>
<td>2</td>
</tr>
<tr>
<td>astrocytoma</td>
<td>1</td>
</tr>
<tr>
<td>epidermoid</td>
<td>1</td>
</tr>
<tr>
<td>hemangioblastoma</td>
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</tr>
<tr>
<td>metastasis</td>
<td>1</td>
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<tr>
<td>plexus papilloma</td>
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<tr>
<td>brainstem (n = 12)</td>
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</tr>
<tr>
<td>cavernoma</td>
<td>8</td>
</tr>
<tr>
<td>astrocytoma</td>
<td>3</td>
</tr>
<tr>
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</tr>
<tr>
<td>foramen magnum (n = 3)</td>
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<tr>
<td>meningioma</td>
<td>2</td>
</tr>
<tr>
<td>chondrosarcoma</td>
<td>1</td>
</tr>
</tbody>
</table>

* AVM = arteriovenous malformation; CPA = cerebellopontine angle.
<table>
<thead>
<tr>
<th>Case No.</th>
<th>Modality</th>
<th>Type</th>
<th>Change in MEP or SEP</th>
<th>Location &amp; Type of Lesion</th>
<th>Outcome at Discharge</th>
<th>3 Months</th>
</tr>
</thead>
<tbody>
<tr>
<td>MEP (n = 3)</td>
<td>MEP</td>
<td>surg</td>
<td>trans deter</td>
<td>intramed tumor diss</td>
<td>MEP (n = 3)</td>
<td>unchanged</td>
</tr>
<tr>
<td>SEP (n = 25)</td>
<td>SEP</td>
<td>nonsurg</td>
<td>trans deter</td>
<td>anesthesia skull base meningioma</td>
<td>SEP (n = 25)</td>
<td>unchanged</td>
</tr>
<tr>
<td>MEP &amp; SEP (n = 11)</td>
<td>MEP &amp; SEP</td>
<td>nonsurg</td>
<td>trans deter</td>
<td>anesthesia petroclival meningioma</td>
<td>MEP &amp; SEP (n = 11)</td>
<td>unchanged</td>
</tr>
</tbody>
</table>

(continued)
unchanged in 139 (66.2%) of 210 cases. Sixteen patients (7.6%) developed a new neurological finding affecting the long motor and sensory tracts. Four (25%) of these 16 patients had a moderate or severe permanent hemiparesis. In the other 12 cases, the hemiparesis resolved substantially and the patients were left with only a slight permanent deficit. Thus, the incidence of an unfavorable outcome, with permanent moderate to severe hemiparesis or other unfavorable outcome, was 2.3% (5 of 210 cases). Among the patients with tumors involving the brainstem (12 intrinsic brainstem lesions, 26 petroclival and petrosal meningiomas, 28 intraventricular tumors, and 3 foramen magnum meningiomas), the overall surgical morbidity was 5.8% (4 of 69 cases).

In 18 (8.6%) of the 210 patients, surgical and nonsurgical complications within the early postoperative course or the follow-up period led to clinical or neurological deterioration and thus affected the outcome analysis. The most common neurological complications involved postoperative epidural hematoma or intraparenchymal hemorrhage (in 8 patients, 3.8%) and edema within the infratentorial compartment (in 4 patients, 1.9%). Additional complications included early tumor recurrence (in 2 patients, 0.95%) and other conditions such as lung embolism or pneumonia (in 4 patients, 1.9%).

**MEP and SEP Changes and Neurological Outcome**

Only 1 patient within the whole study group (0.48% of the overall group or 0.58% of those patients without any MEP or SEP alterations) demonstrated an unexpected hemiparesis postoperatively despite unaltered intraoperative long-tract monitoring.

Fifteen (38.5%) of 39 changes in MEPs and/or SEPs were followed by a corresponding postoperative motor or sensory deficit. Only 1 (11.1%) of the 9 patients with transient changes suffered a permanent slight deficit; but 5 (26.3%) of 19 patients with permanent intraoperative deterioration of MEPs and/or SEPs suffered a permanent deficit, which was moderate-severe in 1 patient and slight in 4 patients (no significant difference, Fisher’s exact test). Eight (72.7%) of 11 patients with permanent losses of evoked potentials and permanent deterioration in combination with transient losses suffered long-term deficits, which were equally distributed between slight and moderate-severe. This was significantly more often compared with patients who had transient changes (p = 0.0097, Fisher’s exact test) or permanent deterioration of evoked potentials (p = 0.002, Fisher’s exact test). Notably, pure sensory deficits were seen in 5 patients.

For permanent changes, positive predictive value for neuromonitoring of the long tracts was 0.467, negative predictive value was 0.989, sensitivity was 0.875, and specificity was 0.918.

**MEP and SEP Changes With Regard to Surgical Dissection and Lesion Locations**

We observed changes due to general causes (19 patients) or surgical steps (20 patients) (Table 2). Surgical steps related to changes were retractor positioning in 1 patient and dura opening in 1 patient, and occurred dur-
ing tumor resection in 18 patients (related to intramedul-
lar dissection in 7 patients and to dissection within the
vicinity of the brainstem in 10 patients).

Further analysis included the occurrence of altera-
tions of MEPs or SEPs with regard to lesion location. Les-
ions and surgical sites were grouped according to the
following locations: 1) cerebellar compartment including
tentorium meningiomas, 2) cerebellopontine angle, 3)
brainstem and fourth ventricle, 4) skull base, and 5) cer-
vicomedullary junction. Twenty-eight (71.8%) of the 39
SEP and MEP alterations were observed during surgery
for lesions involving the brainstem, fourth ventricle,
and skull base. Only in those locations were MEP and SEP
alterations followed by new neurological deficits (Table 3).

Neither sex nor side of the lesion was significantly
related to the occurrence of intraoperative changes (non-
significant, chi-square test). Lesion location and histopa-
thology were significantly correlated with patients’ out-
come (p < 0.001, chi-square test) as well as alterations in
intraoperative neuromonitoring (p < 0.001, chi-square
test). As expected, the correlation between lesion loca-
tion and histopathology was highly significant (p < 0.001,
Cramer’s V-test).

Alteration of SEPs and MEPs occurred significantly
more often during surgery in brainstem and skull base
locations (p < 0.001, both chi-square test) compared with
other locations.

Discussion

In this large group of 210 patients, neurophysiologi-
ical monitoring of infratentorial procedures followed an
institutional standard protocol. This allows for the anal-
ysis of alteration in SEPs and MEPs with regard to the
likelihood of intraoperative changes and their relation to
surgical maneuvers and clinical outcome.

The use of SEPs and MEPs was successful in all
patients, and no side effects were reported. This under-
scores yet again that intraoperative neuromonitoring of
the long tracts with SEPs and MEPs can be safely used even
if microdissection is performed and helps to identify
critical surgical steps.

**MEP and SEP Changes and Neurological Outcome**

There was a high correlation between changes in in-
traoperative neuromonitoring and clinical outcome. The
negative predictive value of 0.989, as well as the sensi-
tivity and specificity, is high. This demonstrates the ef-
cacy of long-tract monitoring to predict postoperative
outcome, which makes it a helpful tool to guide operative
strategy. The positive predictive value of 0.467 was rather
low. This may be at least partially explained by the fact
that we did not distinguish between permanent and tran-
sient alterations in neuromonitoring. Transient alterations
were less likely to be related to neurological impairment.
Permanent losses attributed to surgical maneuvers were
always followed by unfavorable outcome. This is in con-
cordance with previously published data.10,13,23,32,33,37 Of
interest is how to establish warning criteria for long-tract
SEP and MEP monitoring in infratentorial procedures.
In spine surgery with emphasis on intramedullary sur-
gery, intraoperative MEP judgment follows the “all-or-
nothing” rule.13 Up to now, there have been no objecting
reports. The only case of putative false-negative MEPs in
spine surgery has been disproven.19 Lack or resolution of
motor deficit despite the loss of MEPs is explained by 1)
the inability of spatial and temporal summation of mul-
tiple descending D-waves to depolarize the spinal alpha
motor neuron; 2) the phenomenon of “MEP fading,” an
effect especially known in spine procedures of long dura-
tion; and 3) the proposed participation of the propriospin-
al system in motor recovery in spinal cord injuries.4,5,16,28
The latter seems of importance if injury to the cortico-
spinal tract has occurred. In our own unpublished experi-

| TABLE 3: Course of intraoperative long-tract neuromonitoring, postoperative outcome at discharge, and location of
<table>
<thead>
<tr>
<th>lesion*</th>
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<tbody>
<tr>
<td><strong>Location of Lesion</strong></td>
</tr>
<tr>
<td>Cerebellum or Tent†</td>
</tr>
<tr>
<td>IONM unchanged</td>
</tr>
<tr>
<td>no deficit</td>
</tr>
<tr>
<td>hemiparesis</td>
</tr>
<tr>
<td>deficit due to postop complication</td>
</tr>
<tr>
<td>CN deficit</td>
</tr>
<tr>
<td>MEPs &amp; SEPs altered§</td>
</tr>
<tr>
<td>no deficit</td>
</tr>
<tr>
<td>hemiparesis</td>
</tr>
<tr>
<td>deficit due to postop complication</td>
</tr>
<tr>
<td>total</td>
</tr>
</tbody>
</table>

* Cervicomed = cervicomedullary; CN = cranial nerve; IONM = intraoperative neuromonitoring; tent = tentorium.
† Including 5 patients with dural fistulas and infratentorial AVM.
‡ Including 1 metastasis.
§ At least 1 method altered.
ence of MEP monitoring in recurrent cases with previous loss of MEPs there is no case in which MEPs were elicited, despite recovered ambulation.

In supratentorial surgery, even minor changes, such as an increase of motor thresholds and amplitude decrement, have reportedly been followed by long-lasting, although minor changes slight, neurological sequelae as well as alterations involving parts of the corticospinal tract in postoperative MRI. In infratentorial surgery the behavior of long-tract MEPs and SEPs seems to follow a “mixed supratentorial/spinal” rule: permanent losses of MEPs and SEPs are followed by long-lasting deficits. In our series there seems to be only one exception, and this has to be carefully considered. In this case there was no clear relationship between permanent loss of MEPs and SEPs and any surgical maneuver, and despite being of concern for the monitoring team at its occurrence, the loss was considered related to anesthesia or positioning. Our results are supported by published data (Table 4). Based on the results to date, we suggest that the rule should be that permanent MEP and SEP losses related to a surgical maneuver are followed by a permanent deficit. Interestingly, despite SEP monitoring being the first evoked-potential method introduced in intraoperative neuromonitoring, the de novo occurrence of postoperative sensory deficits has not received much attention. Although SEP alterations were analyzed separately by Kang et al. and in combination with MEP alterations by Neuloh et al. and Sarnthein et al. (Table 4), only motor outcome was described in these studies. In our study, clinical outcome analysis revealed that significant changes of SEPs resulted in persistent, disabling hemiataxia. This points out that focusing on motor outcome and MEP monitoring alone ignores the other side of the neuromonitoring coin. SEP and MEP monitoring are complementary methods and should be used in combination.

**MEP and SEP Changes With Regard to Surgical Dissection**

The higher incidence of permanent deterioration not corresponding to neurological sequelae in SEPs compared with MEPs seems to have its cause in a high rate of semisitting positions. This is quite a surprising result, as the effect also has been described for eliciting MEPs. Position-related pneumocephalus, as well as an effect of mass removal, is well known and has to be taken into consideration when judging intraoperative alterations in evoked potentials. Distribution of air cannot be precisely predicted, but pneumocephalus is most likely to occur on the operated side. The use of multiple stimulation montages for TES as well as the testing of the unaffected side additionally helps to distinguish between true-positive and false-negative changes in evoked potentials. Nevertheless, there are cases in which the cause of the change cannot be clearly distinguished. Thus, we decided to include those cases in our analysis as those had led to warning and subsequent critical discussion within the surgical team. Surgery was performed with the patient in a semisitting position in the majority of our cases, and this position was used for all fourth ventricular tumors and most tumors of the cerebellopontine angle. Although it is controversial, this position is advantageous for keep-
ing the operative field clean as a result of cerebrospinal fluid drainage and bleeding washout. The downside for intraoperative neuromonitoring might be a higher rate of “false positive” neuromonitoring alarms.

According to the scheme given in Methods, each critical change in evoked potentials was carefully considered within the context of the most recent surgical and anesthesiological steps. If anesthesia and vital parameters were in a steady state, resection was halted, the surgical site carefully inspected and further action taken: reposition of retractor if applicable, application of nimodipin if perforating vessels were involved, and continuation of resection at another site or cessation of resection. If all of those were ineffective, blood pressure was increased to establish a higher perfusion. Whenever small perforator injuries were assumed, the likelihood of potential recovery was small.

**Distribution of MEP and SEP Changes With Regard to Lesion Locations**

Clearly, lesion locations as well as the histopathology were predictive for intraoperative changes. As lesion type and location are—as expected—highly related, this is not surprising. Clearly, intraparenchymal brainstem lesions and lesions adjacent to the brainstem were highly associated with MEP and SEP alteration.

**True-Positive Findings and Their Relation to Surgical Maneuvers**

During the surgical removal of cavernoma or intrinsic brainstem lesions, intrinsic brain parenchyma is manipulated. This means, that long-tract monitoring, e.g., of the medial lemniscus in the case of SEPs and corticospinal tract in the case of MEP, is indicative for imminent parenchymal injury. MEP and SEP decrements in surgeries within the vicinity of the brainstem were observed in 47.5% of our cases, which is a substantially higher rate than for other locations of lesion removal (compared to 35% of cases of skull base tumors [9 of 26 cases] and 7.6% for lesions in all other locations.) During surgery for posterior fossa lesions, many MEP and SEP positive findings were observed in the “last minutes” of lesion removal. At this step of the lesion removal, surgical manipulation involving reaching around brainstem and manipulation of perforators is likely. Our neuromonitoring picked up the changes with reasonable sensitivity. Staged surgery can be considered in patients at high risk, especially those with petroclival meningiomas who show SEP and/or MEP changes during the initial procedure. Patients with already impaired neurological status are also more vulnerable and sensitive to surgical manipulation than those in an intact neurological state. This is important for communication within the participating teams: it is of utmost importance to maintain a high level of alertness during the last critical steps of the lesion resection.

Thus, long-tract monitoring for surgical removal within the brainstem or its vicinity seems to be advisable. In all other surgeries for lesions within the infratentorial compartment, alterations in evoked potentials were observed but never followed by any neurological sequelae. Noticeably, these changes in evoked potentials were mainly related to nonsurgical causes.

**Conclusions**

In summary, long-tract monitoring with SEPs and MEPs in infratentorial surgeries has a high sensitivity and negative predictive value with respect to postoperative neurological status. As its use is safe, it is recommended especially in surgeries for the treatment of intraxial brainstem lesions and where perforating vessels along the brainstem are manipulated.

**Acknowledgment**

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**Disclosure**

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