Intraoperative SEP monitoring in neurosurgery around the brain stem and cervical spinal cord: differential recording of subcortical components

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The results of intraoperative monitoring of median nerve somatosensory evoked potentials (SEPs) were evaluated in 75 neurosurgical patients in order to assess the role of differential derivation of brain stem (P14) and spinal cord (N13) wave activity. These components were compared with the conventionally recorded neck potential ("N13") that reflects overlap of P14 and N13. The spinal cord N13 wave was recorded from the posterior to anterior lower aspect of the neck and the brain stem P14 wave from the midfrontal scalp to the nasopharynx; both derivations enabled isolated low-artifact recording of these components. In 18.7% of patients, moderate to major latency and/or amplitude shifts of N13 or P14 were found that were masked in conventional neck-scalp recordings of "N13". There was a 6.7% false-negative rate in this series. Using a neck-scalp derivation alone, a 14.7% false-negative rate would have resulted and an isolated worsening of the P14 component (with stable neck potential) in six cases would have been overlooked. It is concluded that the proposed SEP recording technique allows independent assessment of spinal cord and brain stem activity. It is, therefore, superior to the conventional neck-scalp derivation technique, in which important information may be concealed or even lost due to the overlap of the brain stem P14 and spinal cord N13 potentials.

KEY WORDS  •  intraoperative monitoring  •  somatosensory evoked potentials  •  brain stem  •  cervical spine

Intraoperative monitoring of median nerve somatosensory evoked potentials (SEPs) is now widely used in neurosurgery; its significance and usefulness have been outlined in several original investigations and textbooks.\textsuperscript{5}220,28,26 Besides aneurysm surgery, it is particularly useful in operations involving the brain stem, cranio-cervical junction, and cervical spine. Under clinical conditions (including surgery), SEP monitoring for detection of electrophysiological abnormalities in these regions often involves the following. A scalp-scalp electrode montage (C3/Fz, C4/Fz) is placed above the contralateral hand area against a midfrontal reference for cortical potential recording, and a neck-scalp montage (C7/Fz, C2/Fz) is placed over the spinous process of the C7 or C2 vertebra against a midfrontal reference for derivation of subcortical activity. The latter yields the conventional so-called "neck potential" ("N13"). This neck potential, however, represents the overlap of a negative spinal cord component (N13) and a positive brain stem component (P14). While these two waveforms both contribute to the easily reproducible compound neck potential in normal subjects, they may be differentially affected in neurosurgical manipulations near their respective sites of generation. In theory, changes in latency and/or amplitude of one component may be masked by the other (unchanged) component in conventional neck-scalp recordings. This masking effect can be avoided by a recording technique that isolates N13 and P14 potentials.\textsuperscript{5,6,8,10,14,19,24,29,31,32}

Spinal cord N13 component can be derived from two electrodes placed on the posterior and anterior lower neck (C7/jugular fossa (jug)) as was described by Demedt and colleagues.\textsuperscript{6}7 and Restuccia and Mauguière.\textsuperscript{24} The derivation of brain stem P14 potential was originally described by Cracco and Cracco\textsuperscript{4} as far-field recording from a scalp electrode using a noncephalic reference (for example, Fz/shoulder). This latter technique, however, may be difficult to apply in the operating room because of the long interelectrode distance leading to increased artifact. To eliminate this problem, we use a nasopharyngeal reference (Fz/Pg), which allows the rostral segment of P14 to be recorded without difficulty even in electrically active settings such as the operating room or intensive care unit.\textsuperscript{83,1}

In a four-channel electrode setting, we recorded spinal cord N13, brain stem P14, the neck potential "N13", and cortical N20 tracings. In particular, the compound
TABLE 1
Stimulation and recording parameters for median nerve somatosensory evoked potentials

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Study Protocol</th>
</tr>
</thead>
<tbody>
<tr>
<td>stimulus site</td>
<td>median nerve (wrist)</td>
</tr>
<tr>
<td>stimulus intensity</td>
<td>just above motor threshold</td>
</tr>
<tr>
<td>stimulus duration</td>
<td>0.2 msec</td>
</tr>
<tr>
<td>stimulus repetition rate</td>
<td>3.0-5.4/sec</td>
</tr>
<tr>
<td>electrode montages</td>
<td>C₃/Fz, C₄/Fz, Fz/Pgz, C-7/Fz, C-7/jug</td>
</tr>
<tr>
<td>filter setting</td>
<td>10-1500 Hz</td>
</tr>
<tr>
<td>analysis time</td>
<td>500-1000</td>
</tr>
<tr>
<td>number of potentials averaged</td>
<td>500-1000</td>
</tr>
</tbody>
</table>

* Electrode placement: C₃, C₄, Fz = scalp electrode positions according to the 10-20 system; Pgz = median nasopharynx; C-7 = skin over the spinous process of the C-7 vertebra; jug = skin above the jugular fossa.

The neck potential was compared with its contributing components. Our experience in over 70 neurosurgical operations demonstrated that a recording technique isolating N₁₃ and P₁₄ may yield information that is masked or even lost in conventional neck-scalp recordings.

Clinical Material and Methods

Patient Population

Between February, 1989, and October, 1993, 85 patients undergoing neurosurgical procedures that primarily involved the posterior fossa, craniocevelar junction, or cervical spine were intraoperatively monitored by median nerve SEP recordings. Of these, 10 cases were excluded from this series due to excessive artifact or highly pathological amplitude attenuation of relevant SEP components (from the onset of general anesthesia) that made meaningful data analysis impossible. Technically sufficient and evaluable SEP data were obtained in 75 cases.

The patients ranged in age from 11 to 77 years. There were 44 females and 31 males. Diagnoses included extra- and intra-axial tumors of the brain stem and posterior fossa (19 cases), tumors of the skull base including the foramen magnum (12 cases), basilar artery aneurysms (six cases), large or giant aneurysms of the anterior cerebral circulation (five cases), upper cervical cord or vertebral column tumors (six cases), and cervical syringomyelia (27 cases).

Somatosensory evoked potentials were recorded upon stimulation of the median nerve. Details of stimulation and recording parameters are listed in Table 1. The derivation encompassed four channels, using the following electrode montages (Fig. 1): 1) scalp-scalp (C₃/Fz, C₄/Fz) for the derivation of cortical components N₂₀ and P₂₅; 2) frontal-nasopharynx (Fz/Pgz) for the derivation of the brain stem component P₁₄; 3) neck-frontal (C-7/Fz), for the derivation of the compound neck potential "N₁₃"; and 4) posterior-to-anterior lower neck (C-7/jug), for the derivation of the spinal cord component N₁₃ and peripheral components P₉ (brachial plexus) and N₁₁ (dorsal roots and dorsal columns).

Recording of P₁₄ from Fz/Pgz was preferred to non-cephalic referenced scalp derivations, such as Fz/contralateral Erb's point. We found an approximately eightfold higher artifact level when using such a non-cephalic reference, resulting in a prolongation of the averaging process by 20% to 25%. Another advantage of Fz/Pgz recordings is the clear baseline preceding the P₁₄ potential (due to in-phase cancellation of the P₉ and P₁₄ waves), which facilitates amplitude measurement.

Latencies and amplitudes of the above-described components were assessed throughout the operation. The values obtained after induction of general anesthesia and before dural incision served as the individual patient's baseline, to which all subsequent measurements were compared. In particular, the brain stem P₁₄ and spinal cord N₁₃ potentials were compared with the compound neck potential "N₁₃". Latency and amplitude changes for each of these components were classified into three groups. Major changes were defined as latency shifts of greater than 10% and amplitude shifts of greater than 50%, moderate changes as latency shifts of 5% to 10% and amplitude shifts of 25% to 50%, and minor changes as latency shifts of less than 5% and amplitude shifts of less than 25%. Within these groups, changes in SEP components were further divided into transient versus permanent. Permanent changes were defined as those not restored to baseline values by the end of surgery.

Latency increases of 10% and amplitude decreases of 50%, whether permanent or transient, were regarded as significant "warning criteria." In such cases the surgeon was informed and the operative procedure was modified whenever possible. Changes of less than 5% in latency and less than 25% in amplitude were regarded as insignificant. The intraoperative SEP recordings were retrospectively re-evaluated by an interpreter (J.C.M.) who did not assist with the intraoperative monitoring itself.

W. Wagner, et al.

J. Neurosurg. / Volume 81 / August, 1994
Intraoperative monitoring of median nerve SEP’s

![Fig. 2. Case 2. Upper: Intraoperative two-channel somatosensory evoked potential recording, scalp-scalp (C4/Fz) and neck-scalp (C-7/Fz) derivation, obtained during surgery for a C1–3 intramedullary tumor. Note the highly attenuated cortical potentials and the different peaks of the neck potential, the interpretation of which remains equivocal. Lower: A four-channel recording showing a somewhat flat spinal N13 potential and a clear brain stem P14 potential and enabling accurate identification of the subcortical peaks. It was thus possible to monitor a potential generated rostral to the level of surgery.](image)

**Illustrative Cases**

**Case 2**

This 55-year-old man harbored an intramedullary glioma at C1–3. With two-channel recording alone (Fig. 2 upper), interpretation of the relevant peaks of the neck potential would have been difficult. The four-channel derivation (Fig. 2 lower) identified the major peak in the C-7/Fz recording as N13 (not “N14”) and allowed us to monitor a component generated rostral to the operation site, revealing a moderate left-sided amplitude attenuation of P14. Although this amplitude shift was below the “warning level,” further tumor dissection and extirpation was stopped. In addition, a major N13 amplitude drop was observed that was difficult to explain, as this component is generated at a somewhat more caudal level. The patient suffered a transient motor paresis of his left arm. Somatosensory functions were not affected.

**Case 7**

This 36-year-old woman with a large meningioma of the foramen magnum (Fig. 3 left) presented with left-sided hemihypesthesia. Preoperative SEP recordings showed an unusually high interpeak latency between N13 and P14 of about 3 msec. The compound neck potential showed only a double peak and therefore would have been assessed as normal. Comparison of the preoperative and postoperative recordings showed different P14 amplitudes, demonstrating recovery of that brain stem potential. Postoperatively the patient showed clinical improvement of the sensory disturbances. During intraoperative monitoring the P14 amplitude increased gradually by more than 100% while N13 remained unchanged (Fig. 3 right). These changes would have been overlooked using conventional neck-scalp recordings, as the “N13” component did not change. Furthermore, the cortical potentials were lost after induction of general anesthesia; thus, only the separate recording of P14 allowed us to monitor a potential generated rostral to the operation site.

![Fig. 3. Case 7. Left: Magnetic resonance image of the craniocervical junction showing a large meningioma of the foramen magnum, lying at or slightly below the level of the presumed P14 generator. Right: Four-channel somatosensory evoked potential recordings at the beginning and end of tumor extirpation revealing different P14 amplitudes (a more than twofold increase after tumor removal) while spinal N13 potential and the compound neck potential “N13” remain stable. Cortical potentials were lost after induction of general anesthesia.](image)
Case 1

This 11-year-old girl had a huge acoustic neuroma (Fig. 4 left). As cortical potentials were already lacking at the beginning of the operation, only the P_{14} recording allowed us to monitor activity generated rostral to or at the level of the tumor (Fig. 4 right). The tracing showed a unilateral gradual P_{14} amplitude decrease of 50% during stepwise tumor resection (Fig. 5). There was transient postoperative sensorimotor hemiparesis.

Results

Major SEP Changes

Permanent major latency and/or amplitude shifts in one or more of the evaluated SEP components occurred in 15 patients. In seven cases, this was seen at the cortical level only. Details and postoperative clinical correlates for the eight patients with altered subcortical potentials are given in Table 2. Permanent major changes in P_{14} in seven patients were reflected in neck-scapal derivation of "N_{13}" in only one patient (Case 4). This patient had no measurable spinal cord N_{13} potential due to cervical syringomyelia, so there was no spinal counterpart overlapping brain stem activity (P_{14}) in the compound neck potential. Major changes in N_{13} occurred in only one patient (Case 2) who harbored an intramedullary glioma (C1-3); these were reflected in the neck potential. In addition, transient major changes were found for N_{13} in six cases, for P_{14} in 10 cases, and for "N_{13}" in nine cases.

Moderate SEP Changes

Permanent SEP changes of only moderate degree were observed in 10 patients. Seven had amplitude decreases of 25% to 50% or latency increases of 5% to 10% in P_{14}, which correlated with respective alterations
Intraoperative monitoring of median nerve SEP’s

**TABLE 2**

<table>
<thead>
<tr>
<th>Case No.</th>
<th>Age (yrs)</th>
<th>Sex</th>
<th>Diagnosis</th>
<th>N13</th>
<th>P14</th>
<th>&quot;N13&quot;</th>
<th>Postop Neurological Status</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>Lat Amp</td>
<td>Lat Amp</td>
<td>Lat Amp</td>
<td>Lat Amp</td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>11, F</td>
<td></td>
<td>— —</td>
<td>— —</td>
<td>lt major decrease</td>
<td>— —</td>
<td>lt hemiparesis</td>
</tr>
<tr>
<td>2</td>
<td>55, M</td>
<td></td>
<td>— lt major decrease</td>
<td>— lt mod decrease</td>
<td>— lt major decrease</td>
<td>— lt major decrease</td>
<td>motor paresis, lt arm</td>
</tr>
<tr>
<td>3</td>
<td>37, F</td>
<td></td>
<td>rt mod decrease</td>
<td>rt major increase</td>
<td>rt mod decrease</td>
<td>— —</td>
<td>ataxia</td>
</tr>
<tr>
<td>4</td>
<td>54, M</td>
<td></td>
<td>0 0</td>
<td>0 0</td>
<td>lt major increase</td>
<td>— —</td>
<td>improvement of spontaneous breathing normal</td>
</tr>
<tr>
<td>5</td>
<td>56, F</td>
<td></td>
<td>— —</td>
<td>— —</td>
<td>bilat major increase</td>
<td>— —</td>
<td>ataxia</td>
</tr>
<tr>
<td>6</td>
<td>67, F</td>
<td></td>
<td>0 0</td>
<td>rt major increase</td>
<td>— —</td>
<td>ataxia</td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>36, F</td>
<td></td>
<td>— —</td>
<td>— —</td>
<td>lt major increase</td>
<td>— —</td>
<td>recovery from lt hemiparesis</td>
</tr>
<tr>
<td>8</td>
<td>59, F</td>
<td></td>
<td>— —</td>
<td>— —</td>
<td>lt major decrease</td>
<td>— —</td>
<td>spinal ataxia, impaired vibration sense in lt arm</td>
</tr>
</tbody>
</table>

*Abbreviations: N13 = negative 13-msec waveform; P14 = positive 14-msec waveform; "N13" = conventionally recorded compound neck potential; — no change; mod = moderate; 0 = component missing.

of "N13" in four patients. In two of these cases, postoperative worsening of brain stem function was observed.

**Correlation Between P14 N13 and "N13"**

In nine patients major relevant changes were observed in the brain stem P14 component, without parallel changes in the neck potential in eight of them. These changes included permanent worsening in four patients (Cases 1, 3, 6, and 8), permanent improvement in two (Cases 5 and 7), and transient worsening in two (Table 2). Thus, these amplitude or latency shifts were masked in conventional neck-scare recordings and would have been overlooked without separate recordings of P14 or N13 (Figs. 5 and 6). Analogous findings were observed in patients with cervical syringomyelia, where a decreased or absent N13 potential could not be clearly assessed in neck-scare recordings since P14 was mostly normal. Moderate changes in P14 or N13 components without corresponding alteration in "N13" were observed in six patients. In no case were there major or moderate amplitude or latency shifts of the compound neck potential "N13" with corresponding changes in P14 or N13.

**Correlation Between SEP’s and Outcome**

Comparison with postoperative clinical findings yielded 10 false-negative results, that is, postoperative clinical worsening without major intraoperative SEP changes (Table 3). The (additional) postoperative deficits affected motor function in five patients, brain stem function (such as level of consciousness and cranial nerve function) in four, and somatosensory function in one patient. Thus, only one patient had a clear-cut postoperative deficit attributable to the lemniscal system without significant intraoperative SEP changes.

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**TABLE 3**

<table>
<thead>
<tr>
<th>Case No.</th>
<th>Age (yrs), Sex</th>
<th>Diagnosis</th>
<th>Postop Neurological Deficit</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>55, M</td>
<td>intramedullary glioma (C1-3)</td>
<td>motor paresis, lt arm</td>
</tr>
<tr>
<td>9</td>
<td>42, M</td>
<td>clival chordoma</td>
<td>drowsiness, ataxia</td>
</tr>
<tr>
<td>10</td>
<td>47, F</td>
<td>pontine glioma</td>
<td>motor paresis, rt arm</td>
</tr>
<tr>
<td>11</td>
<td>22, F</td>
<td>brain-stem glioma</td>
<td>drowsiness, cranial nerve dysfunction</td>
</tr>
<tr>
<td>13</td>
<td>63, M</td>
<td>pinealoma</td>
<td>drowsiness</td>
</tr>
<tr>
<td>14</td>
<td>63, F</td>
<td>clival chordoma</td>
<td>somatosensory deficit, both arms</td>
</tr>
<tr>
<td>15</td>
<td>33, M</td>
<td>clival syringomyelia</td>
<td>motor paresis, rt arm</td>
</tr>
<tr>
<td>16</td>
<td>64, F</td>
<td>cervical syringomyelia</td>
<td>motor paresis, rt arm</td>
</tr>
<tr>
<td>17</td>
<td>52, M</td>
<td>basilar tip aneurysm</td>
<td>coma, extensor rigidity</td>
</tr>
</tbody>
</table>

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*J. Neurosurg. / Volume 81 / August, 1994*
### Table 4

<table>
<thead>
<tr>
<th>Case No.</th>
<th>Age (yrs), Sex</th>
<th>Diagnosis</th>
<th>Intraop SEP Findings</th>
<th>Postop Neurological Deficit†</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>11, F</td>
<td>large acoustic neuroma</td>
<td>major P₁₄ amp decrease, “N₁₃” unchanged, N₂₀ lacking</td>
<td>It sensorimotor hemiparesis</td>
</tr>
<tr>
<td>3</td>
<td>37, F</td>
<td>large acoustic neuroma</td>
<td>mod P₁₄ amp decrease, major P₁₄ lat increase; “N₁₃” unchanged, mod N₂₀ amp decrease</td>
<td>transient limb ataxia</td>
</tr>
<tr>
<td>6</td>
<td>67, F</td>
<td>cervical syringomyelia</td>
<td>major P₁₄ lat increase, “N₁₃” unchanged, mod N₂₀ lat increase</td>
<td>increase in spinal ataxia, unchanged motor function</td>
</tr>
<tr>
<td>8</td>
<td>59, F</td>
<td>intramedullary cavernoma (C-3)</td>
<td>major P₁₄ amp decrease, “N₁₃” unchanged, mod N₂₀ amp decrease</td>
<td>spinal ataxia, impaired arm vibration sense</td>
</tr>
<tr>
<td>18</td>
<td>53, F</td>
<td>tentorial meningioma</td>
<td>N₂₀ lost, P₁₄ unchanged</td>
<td>It sensorimotor hemiparesis</td>
</tr>
<tr>
<td>19</td>
<td>43, F</td>
<td>giant ICA aneurysm</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

* Abbreviations: ICA = internal carotid artery; P₁₄ = positive 14-msec waveform; amp = amplitude; “N₁₃” = conventionally recorded compound neck potential; N₂₀ = negative 20-msec waveform; mod = moderate; lat = latency.

† Sides of clinical findings correspond to sides of SEP stimulation.

**Discussion**

In the clinical application of median nerve SEP recording, the derivation of a cortical (N₉₀) and a subcortical (“N₁₃”) potential seems to be a widely used minimum standard. Several studies have shown, however, that in the conventional neck potential recording using a midfrontal reference, there exists in the 14-msec latency range an overlap of two different potentials. These are the brain stem P₁₄ component (which is probably generated in the medial lemniscus) and the spinal cord N₁₃ component (which is generated in the cervical dorsal horn at C-5 and C-6). These components are differentially affected in the course of various diseases involving their respective sites of generation. Impairment of these potentials is masked in neck-scalp recording, in which N₁₃ and P₁₄ overlap. For these reasons, the use of a scalp reference in derivations from the neck has often been criticized. Investigations in patients with multiple sclerosis involving the brain stem, in those with syringomyelia, or in brain death have shown the advantage of separate derivations of N₁₃ and P₁₄ as compared with more conventional recording of the compound neck potential.10-15,21,28,29,31,32

This criticism, however, has only seldom been taken into account in intraoperative SEP monitoring.20 The guidelines for intraoperative evoked potential monitoring recommended by the American Electroencephalographic Society2 describe a system for recording SEP’s in cervical spine surgery. Although the proposed electrode montage, which includes scalp derivations using a noncephalic reference, would allow for an isolated recording of brain stem P₁₄ only the assessment of “N₁₃” from neck-scalp derivations (besides brachial plexus and cortical components) is suggested. The revised guidelines for clinical evoked potential studies recommend abandonment of the neck-scalp derivation, but, to the best of our knowledge, this point is not at the present time reflected in published work on intraoperative SEP testing.

In the vast majority of published studies on intraoperative SEP monitoring,20,21,23,24,25,27 the co-
Intraoperative monitoring of median nerve SEP’s

potbound neck potential “N₁₃” (derived from neck-scalp montages) serves as the only subcortical reference potential (for example, when calculating the central conduction time). In aneurysm surgery of the anterior cerebral circulation, the two-channel derivation used most often (cortical N₂₃ and subcortical “N₁₅”) seems sufficient, as there is no expected impairment of subcortical potentials. In neurosurgical procedures involving the posterior fossa, craniocervical junction, or cervical spine, however, isolated impairment of one of these components is possible because these structures contain the generator sites of brain stem P₁₄ and spinal cord N₁₃ potentials. Such impairment may be overlooked or underestimated in conventional neck-scalp recordings where these two components overlap. The reason for two-channel SEP recording in such neurosurgical operations may be the practical advantage of an easy-to-record neck potential in the electrically noisy environment of an operating room. In this setting, particularly, the scalp far-field recording of P₁₄ with a noncerebral reference is often difficult or even impossible to perform.⁵

The electrode montages presented here allowed for stable monitoring of the N₁₃ and P₁₄ potentials. Comparison with the conventionally recorded neck potential showed that the separate derivation of these two components often yielded information that was missed in neck-scalp recordings. In 14 (18.7%) of 75 patients, such a discrepancy could be observed for major or moderate amplitude or latency shifts. The most clinically important incidence of false-negative monitoring results in this study was 6.7%. With neck-scalp recording alone, it would have been more than twice as high (14.7%). This result of our study was expected due to nonsurgical investigations in patients with comparable brain stem or spinal cord pathologies, which demonstrated the masking effect of an overlap of N₁₃ and P₁₄ in the compound neck potential.⁹,₂₄,₂₅

Of course, a P₁₄ latency shift (with stable N₁₃) also may be assessed by recording the cortical N₂₃ potential. Cortical components are much more influenced by general anesthesia, however, and may be primarily lost in intraoperative monitoring by the additive suppressive effect of narcotics and the underlying pathology. In such cases, P₁₄ recording is particularly useful (Figs. 3 right and 4 right).

Conclusions

We draw the following conclusions from our observations:

1) Spinal and brain stem components of the compound neck potential “N₁₃” should be separately derived in intraoperative SEP monitoring since brain stem P₁₄ and spinal cord N₁₃ potentials may behave differently. Isolated latency or amplitude shifts are mostly overlooked or underestimated in conventional recordings of the neck potential, which may possibly result in an increase in the false-negative rate of more than twofold.

2) The electrode setting described here allows low-artifact recording of spinal cord N₁₃ and brain stem P₁₄ potentials in the operating room, as nonencephalic references with long interelectrode distances are avoided.

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