Somatosensory evoked potentials and neurological grades as predictors of outcome in acute spinal cord injury

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An analysis of Motor Index score, pinprick sensory score, joint position sense score, somatosensory evoked potential (SSEP) grade in the ulnar (SSEP_u) and posterior tibial (SSEP_p) regions, and overall SSEP grade (mean SSEP_u+p) was conducted in 36 patients with cervical spinal cord injuries to determine the relationship of these scores, both individually and in combination, to functional outcome (as determined using the Barthel Index) at 6 months after injury. The clinical and electrophysiological data were obtained on the same day within 2 weeks after injury. Nineteen patients underwent two SSEP tests 1 week apart within the first 3 weeks following injury in an attempt to identify mean SSEP_u+p improvement. Somatosensory evoked potential grading was based on the presence or absence of the cortical evoked potential, the amplitude of the early cortically generated waveform (P22 or P37), and the interpeak latency across the lesion site.

Mean SSEP_u+p had the strongest individual relationship with outcome (R-square 0.75, p < 0.0001) and mean SSEP_u+p improvement over a 1-week interval during the first 3 weeks after injury was associated with Motor Index score improvement over a 6 month period. Joint position sense score was the best clinical predictor of outcome (R-square 0.64, p < 0.0001). Mean SSEP_u+p correlated with outcome more closely than the combination of Motor Index score and pinprick sensory score. Mean SSEP_u+p in combination with all three clinical indicators produced the strongest correlation with outcome (R-square 0.87, p < 0.0001).

This study confirms the prognostic value of quantitative SSEP analysis for patients with acute spinal cord injuries.

KEY WORDS • evoked potentials • spinal cord injury • neurological grading • prognosis • electrophysiology

A n accurate prognosis for recovery in patients with spinal cord injury is useful in planning acute management, rehabilitation, and counseling. Improved imaging techniques, such as computerized tomography, demonstrate spinal cord compression26,31 but, in our experience, have failed to correlate well with either neurological deficit or prognosis for recovery.11

Somatosensory evoked potential (SSEP) testing has been shown to have value in predicting recovery,23,24,26-30,38 but this has recently been questioned.15,21,37 The present study attempts to compare the prognostic value of our SSEP grading system with neurological examination in a more rigorous manner to determine the best prognostic test or combination of tests for patients with acute spinal cord injuries. Our new SSEP grading system places less emphasis on cortical evoked potentials (CEP's) and more on the interpeak latency across the lesion site and the amplitude of the early cortically generated SSEP waveform (P22 for the ulnar SSEP (SSEP_u) and P37 for the posterior tibial SSEP (SSEP_p)).

Materials and Methods

Normative Studies

The SSEP_u and SSEP_p on the left and right sides were recorded from 20 normal subjects. The ulnar and posterior tibial nerves were stimulated at the wrist and ankle, respectively, with a stimulus intensity twice the amount needed to evoke a visible muscle twitch, a stimulus duration of 0.2 msec, and a stimulus rate of 3.1 Hz. Somatosensory evoked potential recordings were obtained from 10-mm gold-plated electroencephalographic cup disc electrodes placed on the surface of the skin with an impedance of less than 5 kOhms. The locations of the four recording electrode pairs for SSEP_u+p testing were: 1) the scalp overlying the contralateral
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FIG. 1. Normal ulnar nerve somatosensory evoked potential (SSEP) showing the interpeak latency between the peripheral nerve action potential (EP) and the P/N13 waveform and the P22 amplitude measurements used in the ulnar SSEP grading system. EP cont = contralateral Erb's point; EP ipsi = ipsilateral Erb's point; C3' and C4' = contralateral somatosensory cortex; Cv2 = C-2 spinous process; Fpz = frontoparietal zone; S = stimulation; SD = standard deviation.

somatosensory cortex (C3’ or C4’) and the contralateral Erb’s point (EP); 2) the ipsilateral EP and the frontoparietal zone (Fpz); 3) the C-2 spinous process and the Fpz; and 4) C3’ or C4’ and the Fpz (Fig. 1). The four SSEP recording electrode pair locations were: 1) the popliteal fossa and the medial condyle of the tibia; 2) the L-1 spinous process and the contralateral iliac crest; 3) C3’ and C4’ following left posterior tibial nerve stimulation or C4’ and C3’ following right posterior tibial nerve stimulation; and 4) the scalp overlying the somatosensory cortex for the legs (Cz’) and the Fpz (Fig. 2). The analogue input from each recording pair was amplified by amplifiers with a gain of 100,000 and a bandpass of 3 to 3000 Hz before being averaged by an NEC advanced personal computer with a Datacon A-D board.* The sampling rate of the system was 14.6 kHz on each channel. Analysis time for SSEPu testing was 70 msec on all four channels, although the display time was 55 msec for all channels; again, channel 4 had a dual display time of 55 msec and 110 msec to search for later CEP waveforms. Each four-channel average contained at least 500 responses. A minimum of two-four-channel averages (epochs) were superimposed for waveform reproducibility.

Clinical Data

Only patients with acute cervical spinal cord injuries with a C-7 neurological level or higher were admitted to the study. Measurements of SSEPu and SSEPw were obtained bilaterally using identical equipment and recording techniques to those described in the normative study. The first series of SSEP measurements was recorded within 2 weeks after injury and, whenever possible, a second series of SSEP measurements was obtained 1 week later. On both occasions, the SSEPu and SSEPw were graded on the left and right on a scale of 1 to 4 depending on the presence or absence of the CEP waveform, the interpeak latencies across the lesion site, and the amplitude of P22 following ulnar nerve stimulation or of P37 following posterior tibial nerve stimu-

* Amplifier, Model 12A5, manufactured by Grass Instrument Co., Quincy, Massachusetts; Datacon A-D board manufactured by Clark-Davis Medical Systems, London, Ontario, Canada.
FIG. 2. Normal posterior tibial nerve somatosensory evoked potential (SSEP) showing the interpeak latency between the lumbar potential and the P37 waveform and the P37 amplitude measurements used in the posterior tibial SSEP grading system. Fpz = frontoparietal zone; C3' and C4' = contralateral somatosensory cortex; Cz' = somatosensory cortex for the legs; L1 = L-1 spinous process; IC = iliac crest; IC cont = contralateral iliac crest; pop. fossa = popliteal fossa; med. condyle tib. = medial condyle of the tibia; S = stimulation; SD = standard deviation.

TABLE 1

<table>
<thead>
<tr>
<th>Grade</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>CEP absent up to 110 msec</td>
<td></td>
</tr>
<tr>
<td>P37 absent (later CEP waveforms present) or P37 present but abnormal amplitude (&lt; 0.5 μV)</td>
<td></td>
</tr>
<tr>
<td>abnormal IPL between lumbar potential and P37 (&gt; 19.7 msec); normal P37 amplitude</td>
<td></td>
</tr>
<tr>
<td>normal up to and including P37</td>
<td></td>
</tr>
<tr>
<td>CEP absent up to 70 msec</td>
<td></td>
</tr>
<tr>
<td>P32 absent (later CEP waveforms present) or P32 present but abnormal amplitude (&lt; 0.9 μV)</td>
<td></td>
</tr>
<tr>
<td>abnormal IPL between the peripheral nerve action potential and P/N13 (&gt; 4.9 msec) or P/N13 absent; normal P32 amplitude</td>
<td></td>
</tr>
<tr>
<td>normal up to and including P32</td>
<td></td>
</tr>
</tbody>
</table>

* CEP = cortical evoked potential; IPL = interpeak latency.

Neurological Examination

Neurological examinations were performed by neurosurgery residents at the time of admission and by physiotherapists at the time of SSEP testing and 6 months postinjury. The neurological examination included motor, pinprick, and joint position sense testing.

Motor Examination. Five motor actions from each limb were graded using the Motor Index score.17 A total score was calculated out of 100 for each patient (Table 2).
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Fig. 3. Ulnar somatosensory evoked potential Grade 2. P22 is present but with an abnormally low amplitude. C3' = contralateral somatosensory cortex; Fpz = frontoparietal zone; Cv2 = C-2 spinous process; EP cont = contralateral Erb's point; EP ipsi = ipsilateral Erb's point; EP = peripheral nerve action potential; CH = channel.

Fig. 4. Posterior tibial somatosensory evoked potential (SSEP) Grade 3. The interpeak latency between the lumbar potential (LP) and the P37 waveform is abnormally prolonged. Cz' = somatosensory cortex for the legs; Fpz = frontoparietal zone; C3' and C4' = contralateral somatosensory cortex; L1 = L-1 spinous process; IC cont = contralateral iliac crest; pop. fossa = popliteal fossa; med. condyle tibia = medial condyle of the tibia; CH = channel.
**TABLE 2**  
*Motor Index scoring system*

<table>
<thead>
<tr>
<th>Muscle</th>
<th>Motor Grade</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>On Left</td>
</tr>
<tr>
<td>shoulder abduction</td>
<td>5</td>
</tr>
<tr>
<td>wrist extension</td>
<td>5</td>
</tr>
<tr>
<td>elbow extension</td>
<td>5</td>
</tr>
<tr>
<td>grip</td>
<td>5</td>
</tr>
<tr>
<td>finger abduction</td>
<td>5</td>
</tr>
<tr>
<td>hip flexion</td>
<td>5</td>
</tr>
<tr>
<td>knee extension</td>
<td>5</td>
</tr>
<tr>
<td>ankle dorsiflexion</td>
<td>5</td>
</tr>
<tr>
<td>great toe extension</td>
<td>5</td>
</tr>
<tr>
<td>ankle plantar flexion</td>
<td>5</td>
</tr>
<tr>
<td>total (out of 100)</td>
<td>50</td>
</tr>
</tbody>
</table>

* Motor Index adapted from Lucas and Ducker. 17  
† The motor grading system is defined as follows: 0 = Absent: total paralysis; 1 = Trace: palpable or visible contraction; 2 = Poor: active movement through range of motion (ROM) with gravity eliminated; 3 = Fair: active movement through ROM against gravity; 4 = Good: active movement through ROM against resistance; and 5 = Normal.

**Sensory Examination.** Pinprick sensation was determined as normal, impaired, or absent for each dermatome below the level of the lesion. For example, if a patient had a C-5 injury, then there were 50 dermatomes below the level of the lesion ((3 cervical + 12 thoracic + 5 lumbar + 5 sacral) × 2 sides). The percentage of normal, impaired, or absent dermatomes below the level of the lesion was multiplied by a severity factor of 1 for normal, 0.5 for impaired, or 0 for absent before being summed to give a composite sensory score out of 100.

**Joint Position Sense Testing.** Joint position sense was obtained from the great toe of each foot. For each foot, a score 1 was given if great toe joint position sense was present and 0 if it was absent. Then the mean great toe position sense score (mean position) was calculated.

**Barthel Index.** The Barthel Index \(^{19}\) was used to grade functional outcome 6 months after injury. The Barthel Index tested hand function, bowel and bladder function, and activities of daily living skills for a composite score out of 100 (Table 3).

### Results

#### Normal Study

Normal limits were determined for the interpeak latency between the peripheral nerve action potential and the P/N13 waveform, the P22 amplitude and latency following ulnar nerve stimulation, the interpeak latency between the lumbar potential and the P37 waveform, and the P37 amplitude and latency following posterior tibial nerve stimulation. The upper limit of normal for the interpeak latencies was established from normal individuals by calculating the mean plus 2.5 standard deviations. For the P22 and P37 amplitudes, the 99% confidence level was used as the cutoff for the lower limit of normal. Normal results are shown in Table 4.

**Spinal Cord-Injured Patients**

Nine cervical spinal cord-injured patients were excluded from the study because of peripheral neuropathy (two cases), head injury (two cases), unclear SSEP waveforms (four cases), or loss to follow-up review (one case). Thirty-two male and four female patients with cervical spinal cord injuries were included in the study. Two patients had motor deficits beginning at the C-4 level, 13 at C-5, 18 at C-6, and three at C-7. Nine patients had neurologically complete injuries (that is, complete loss of motor and sensory function below the level of injury), and the remaining 27 had neurologically incomplete injuries. All patients had Motor Index scores, pinprick scores, mean SSEPu scores, mean SSEP, scores, and mean SSEPu+0 scores obtained on the same day within 2 weeks postinjury. Joint position sense scores were obtained from 29 patients at this time. All patients were fitted with halo vests. Nine patients had operative procedures for spinal stabilization, spinal decompression, or both. All patients had their final outcome determined 6 months postinjury by Barthel Index and Motor Index scores.

A model-selection method (R-square method, SAS version 6.03) that performed regression models with all combinations of independent variables was used to determine which independent variable or combination of variables (initial Motor Index score, pinprick score, mean position, and mean SSEPu+0) best predicted the Barthel Index score at 6 months postinjury (dependent variable). Mean SSEPu and mean SSEP were substituted for mean SSEPu+0, and the exploratory model-building method was repeated.

The regression analyses indicated that both models were significant at the p < 0.0001 level. None of the independent variables were eliminated, suggesting that all of them had a relationship with the Barthel Index score at 6 months. In the first model, the initial mean SSEPu+0 score obtained less than 2 weeks postinjury was
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**TABLE 4**
Normative data from 20 individuals

<table>
<thead>
<tr>
<th>Peak*</th>
<th>Latencyt (msec)</th>
<th>Amplitude‡ (uV)</th>
</tr>
</thead>
<tbody>
<tr>
<td>ulnar</td>
<td></td>
<td></td>
</tr>
<tr>
<td>EP-P/N13 IPL</td>
<td>3.8 + 1.1</td>
<td></td>
</tr>
<tr>
<td>EP</td>
<td>10.3 + 2.6</td>
<td></td>
</tr>
<tr>
<td>P2</td>
<td>24.4 + 5.4</td>
<td>0.9</td>
</tr>
<tr>
<td>posterior tibial</td>
<td></td>
<td></td>
</tr>
<tr>
<td>LP-P37 IPL</td>
<td>15.9 + 3.8</td>
<td></td>
</tr>
<tr>
<td>LP</td>
<td>22.5 + 5.3</td>
<td></td>
</tr>
<tr>
<td>P37</td>
<td>39.2 + 7.5</td>
<td>0.5</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

* IPL = interpeak latency; EP = peripheral nerve action potential; LP = lumbar potential.
† Values are means + 2.5 standard deviations.
‡ Lower limit with 99% confidence.

**TABLE 5**
Relationship (R-square) between scores obtained less than 2 weeks postinjury and outcome (Barthel Index) at 6 months postinjury

<table>
<thead>
<tr>
<th>Early Scores*</th>
<th>R-Square</th>
</tr>
</thead>
<tbody>
<tr>
<td>mean position, score alone</td>
<td>0.64</td>
</tr>
<tr>
<td>Motor Index score alone</td>
<td>0.49</td>
</tr>
<tr>
<td>pinprick sensory score alone</td>
<td>0.45</td>
</tr>
<tr>
<td>all clinical scores†</td>
<td>0.80</td>
</tr>
<tr>
<td>mean ulnar SSEP score alone</td>
<td>0.52</td>
</tr>
<tr>
<td>mean posterior tibial SSEP score alone</td>
<td>0.68</td>
</tr>
<tr>
<td>mean overall SSEP score alone</td>
<td>0.74</td>
</tr>
<tr>
<td>best two scores‡</td>
<td>0.80</td>
</tr>
<tr>
<td>best three scores§</td>
<td>0.83</td>
</tr>
<tr>
<td>all scores‖</td>
<td>0.87</td>
</tr>
</tbody>
</table>

* Position, = great toe position sense; SSEP = somatosensory evoked potential. All scores had a significant relationship with outcome (Barthel Index) at 6 months postinjury (p < 0.0001).
† Clinical scores include the mean position, score, the Motor Index score, and the pinprick sensory score.
‡ Best two scores include the mean overall SSEP score and the mean position score.
§ Best three scores include the mean overall SSEP score, the mean position score, and the Motor Index score.
‖ All scores include the mean overall SSEP score and the three clinical scores.

FIG. 5. The relationship between the initial mean overall (ulnar and posterior tibial) somatosensory evoked potential (SSEP\(_{u+t}\)) grade obtained less than 2 weeks after injury and the Barthel Index score (outcome) at 6 months after injury. The straight line (R-square = 0.75) was determined from regression analysis. Each tick represents one patient.

the single most powerful predictor of the Barthel Index score at 6 months (R-square 0.75) (Fig. 5). Mean position, at the time of SSEP testing was ranked the most powerful clinical predictor of the Barthel Index score at 6 months (R-square 0.64). Mean position, combined with initial mean SSEP\(_{u+t}\), was the best combination of two variables (R-square 0.80). The best combinations of three variables (R-square 0.83) were, in descending order, initial mean SSEP\(_{u+t}\), mean position, score, and Motor Index score at the time of SSEP testing. The pinprick score at the time of SSEP testing had the weakest relationship with the Barthel Index score at 6 months (R-square 0.45). In the second model, the initial mean SSEP, (R-square 0.68) was more accurate than the initial mean SSEP\(_{u}\) (R-square 0.52) in predicting the Barthel Index score at 6 months. Results are shown in Table 5.

Two-tailed t-test analysis revealed that patients with an initial mean SSEP\(_{u}\) of 1 (bilaterally absent CEP's following posterior tibial nerve stimulation) had a significantly lower Barthel Index score at 6 months (t = 9.22, df = 34, p < 0.0001) and showed less improvement in Motor Index score over 6 months (F(1,34) = 13.18 df = 1, p = 0.0009) than patients with an initial mean SSEP, of greater than 1 (Fig. 6). This applied to clinically incomplete injuries as well as to complete injuries. Furthermore, four clinically incomplete spinal cord-injured patients with absent CEP's (initial mean SSEP, = 1) had a lower 6-month Barthel Index score than other patients with clinically incomplete injuries with CEP's present (initial mean SSEP, > 1; t = 4.16, df = 26, p = 0.0003), although on neurological examination at the time of SSEP testing, the two groups were not statistically different (Motor Index score: t = 1.39, df = 26, p = 0.18; pinprick sense: t = 1.49, df = 26, p = 0.15). This suggests that the mean SSEP, obtained within 2 weeks after injury may offer better early prognostic information for patients with incomplete injuries than the Motor Index score and pinprick examination.

Nineteen patients had two SSEP tests performed 1 week apart within the first 3 weeks following injury. Patients without mean SSEP\(_{u+t}\) improvement over the 1 week (eight cases) had significantly less Motor Index score improvement over 6 months than those with mean SSEP\(_{u+t}\) improvement (seven cases) (t = 3.6, adjusted df = 7.1, p = 0.008; Fig. 7). Four patients had Grade 4 initial mean SSEP\(_{u+t}\) scores and therefore could not improve. Mean SSEP\(_{u+t}\) improvement over 1 week
FIG. 6. The relationship between the presence or absence of the initial mean posterior tibial somatosensory evoked potential (SSEP) obtained less than 2 weeks after injury and the Motor Index score obtained at less than 2 weeks after injury and 6 months after injury. CEP = cortical evoked potential.

FIG. 7. The relationship between the change in mean overall (ulnar and posterior tibial) somatosensory evoked potential (SSEP) grade within 3 weeks after injury and the change in Motor Index score within the first 6 months after injury.

was related to the initial mean SSEP grade because none of the three patients with an initial mean SSEP of 1 (CEP's absent within 2 weeks after injury) showed any mean SSEP improvement over 1 week. In contrast, seven of 12 patients with an initial mean SSEP of greater than 1 (CEP's present within 2 weeks after injury) went on to have mean SSEP improvement over 1 week, which, as described earlier, indicated a better chance for improvement in Motor Index score over 6 months.

Discussion

Background

Early investigators analyzed the CEP up to 150 to 200 msec after stimulation to predict outcome following spinal cord injury. They found a normal CEP in the early stages following injury or one that progressively normalized within the first few weeks after injury to be harbinger of further neurological recovery, whereas a grossly abnormal or absent CEP suggested a poor prognosis for further recovery. More recent studies have cast some doubt over the ability of the CEP to predict recovery. McGarry et al. found that, of 25 spinal cord-injured patients, nine with normal CEP latencies were paraplegic, whereas eight with prolonged CEP latencies had "useful ambulation."

Ziganow supported previous assertions that the early CEP from spinal cord-injured patients correlated with discharge neurological status. Unfortunately, proponents on both sides used SSEP analysis that focused only on CEP waveforms. The CEP waveforms after P22 (from the upper limb SSEP test) or after P37 (from the lower limb SSEP test) are probably the most unreliable basis for analysis and grading because they can be affected by factors unrelated to spinal cord injury, such as medication and level of consciousness, unlike the earlier spinal and subcortical SSEP's. The unreliability of the CEP may have been one pitfall of previous SSEP grading systems and may explain contradictory conclusions found by earlier investigators regarding the prognostic power of SSEP testing in spinal cord injury.

SSEP Grading System Design

Our SSEP grading system emphasizes the more reliable SSEP's which occur up to and including P22 or P37. The SSEP grade incorporates waveforms generated from the brachial plexus, high cord/caudal brainstem (P/N13), sensorimotor cortex (P22), and the interpeak conduction time in the large fiber sensory system from the distal brachial plexus to the high cord/caudal brainstem. (The ulnar SSEP was the upper limb SSEP of choice because it enters the spinal cord via the C8-T1 dorsal roots, which lay below the neurological level of the lesion for all patients in our study.) Our SSEP grading system incorporates waveforms generated from the cauda equina/conus medullaris (lumbar potential), the sensorimotor cortex (P37), and the conduction time.
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in the large fiber sensory system from the cauda equina to the sensorimotor cortex.5,18,30,36

Somatosensory evoked potential Grade 1 is contingent upon the CEP being absent and is therefore associated with a more severe spinal cord injury than SSEP Grade 4 (present CEP with a normal P22 or P37, amplitude and a normal interpeak latency across the level of the lesion). The pathophysiological distinction between SSEP Grade 3 (prolonged interpeak latency across the injury level) and SSEP Grade 2 (a decreased P22 or P37, amplitude) is less clear because both can be caused by a conduction block or conduction delay. For example, a prolonged interpeak latency across the injury level could reflect a conduction block in the fastest-conducting fibers contributing to the P/N13, or P3 waveform, not just a conduction delay across the injury site. Conversely, a decreased P22 or P37 amplitude might not just reflect a conduction block in contributing axons but could reflect a conduction delay across the injury site resulting in a low-amplitude, temporally dispersed response,20 which could fail to synaptically activate higher-order neurons that contribute to P22 or P37, and thereby reduce amplitude even further.9 Notwithstanding, the fact that our SSEP grading system was the single most powerful predictor of outcome (Barthel Index score) at 6 months postinjury suggests that the SSEP parameters we chose for interpretation and their rank of importance in the grading system were appropriate.

Selection of Outcome Measures

The Barthel Index was chosen to measure patient outcome at 6 months postinjury because: 1) it tests the patient's ability to perform several meaningful tasks necessary for daily living, including bowel and bladder control,19 and 2) it has high interjudge reliability.16 Level of spinal cord injury was unlikely to erroneously affect the 6-month Barthel Index score because 89% of the patients had the same neurological level (C5–6). The Motor Index score was used instead of the Barthel Index score as the measure of clinical improvement within 6 months after injury because a baseline Barthel Index score could not be obtained when the patient was lying down in halo traction in the early stages following spinal cord injury.

Summary of Findings

In common with most previous investigators,4,24,28,29,37 we believe that patients with absent CEP's (SSEP\textsubscript{u+t} = Grade 1) in the early stages following injury do not have a likelihood of useful neurological recovery. However, unlike some previous reports,4,37,38 we found that all neurologically complete patients had absent CEP's, making SSEP testing in these patients redundant because it added nothing to the neurological examination. In contrast, the SSEP had a unique role in predicting outcome for patients with neurologically incomplete injuries because such patients with absent CEP's had a significantly poorer outcome than patients with incomplete injuries and present CEP's, even though the two groups could not be distinguished on the basis of their early clinical neurological examinations.

Patients who had improvement in mean SSEP\textsubscript{u+t} grade over a 1-week interval during the first 3 weeks after injury had significantly greater Motor Index score improvement over 6 months than patients with a stable or deteriorating mean SSEP\textsubscript{u+t} grade. This supports earlier assertions that SSEP improvement was a harbinger of further neurological recovery.28,29 We therefore recommend that SSEP testing be done at least twice (at a minimum of 1 week apart) for all patients with present CEP's in the early stages following injury.

The mean SSEP\textsubscript{u+t} was more accurate than the mean SSEP\textsubscript{u}, alone or the mean SSEP, alone in predicting functional outcome (Barthel Index score) at 6 months postinjury, which is likely due to a larger amount of spinal cord white matter being tested. Since mean SSEP\textsubscript{u+t} was the single most powerful predictor of outcome, it was not surprising to discover that mean position, was the single most powerful clinical predictor. Both are thought to be mediated through the dorsal columns,7,13 but there is increasing evidence to show that the dorsal columns do not mediate position and vibration sense in man27,34 and that the SSEP, while ascending in the dorsal columns, may travel up additional spinal cord pathways such as spinocerebellar and ventrolateral tracts.36

Reasons for SSEP Prognostic Value

The prognostic value of the SSEP may be due to its hardiness as a result of its transmission through these multiple spinal cord pathways. Less global spinal cord injuries may not affect all pathways contributing to the SSEP, thereby improving the SSEP's chances for sparing, with the degree of SSEP sparing related to the extent of the injury. Somatosensory evoked potential transmission through peripherally located white matter may also contribute to SSEP hardiness because the pathophysiological processes following spinal cord injury affect the central gray matter first and then, within a few hours, progress outward in a centrifugal pattern to affect the white matter of the cord.22,33 the extent and severity of this pathological centrifugal process are related to the force of the initial trauma.32 These anatomical considerations are not likely to be the only reason for unique SSEP hardiness because clinical scores, such as the Motor Index score, are also likely to depend on multiple pathway contributions located in peripheral spinal cord white matter.25,35

Further evidence in favor of SSEP hardiness comes from reports that suggest that the SSEP can be nearly normal even when many of its peripheral afferents or second-order sensory fibers have been blocked.3,8 This SSEP hardiness has also been shown in animal studies where spinal SSEP's following sciatic nerve stimulation were more resistant to moderate spinal cord ischemia than the spinal potentials following motor cortex stim-
ulation in incomplete spinal cord injury.\textsuperscript{1,10} This supports the notion that the sensory pathways contributing to the early SSEP grade may be more resistant to the effects of incomplete spinal cord injury than the motor pathways contributing to the Motor Index score.

It should be mentioned that the manner in which we scaled the Motor Index score and pinprick sensory score may have influenced their prognostic power; many patients with incomplete spinal cord injury had low motor and sensory scores which, in general, tended to underestimate the potential for recovery. Perhaps Motor Index and pinprick sensory scores would be stronger predictors of outcome if more weight were placed on low scores; it has been shown that patients with only a small amount of motor and/or sensory sparing in a 24-hour period following spinal cord injury have significantly more potential for recovery than those who have a neurologically complete injury.\textsuperscript{14,18}

Conclusions

Our findings suggest that the function of the spinal cord pathways contributing to the SSEP grade and position, as well as SSEP grade changes during the first 3 weeks after injury are good prognostic indicators of functional recovery at 6 months. The next step is to apply the statistical values obtained from the four prognostic scores (mean SSEP\textsubscript{e+p}, mean position\textsubscript{e}, Motor Index score, and pinprick sensory score) to a new group of spinal cord-injured patients to determine the accuracy and certainty of outcome prediction for each test alone and in combination with the others. By prospectively applying this model to a new group of spinal cord-injured patients, we will avoid statistical bias that occurs when applying the model to the same group of patients from which it was derived.

Acknowledgments

The authors thank Marco Katic for statistical analysis, Jill Cain for preparation of the manuscript, and Ken Klettke and Marie Lehman for the artwork.

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Manuscript received May 1, 1989.
Accepted in final form September 29, 1989.
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