Conducted somatosensory evoked potentials during spinal surgery

Part 2: Clinical applications

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In 27 patients undergoing laminectomy, spinal cord function was monitored by epidural bipolar recordings of conducted spinal somatosensory evoked potentials (SEP's) across the laminectomy site, with calculation of spinal conduction velocity (CV). In control cases without myelopathy, the CV remained relatively constant (± 3%) even during prolonged operations, despite markedly changing levels of anesthesia. Acute CV changes were detected intraoperatively in three cases: these patients displayed improvement after extramedullary (Case 1) and intramedullary decompression (Case 2), and deterioration after direct unilateral dorsal column injury (Case 3). These intraoperative CV alterations correlated postoperatively with changes in the neurological examination. Although a unilateral lesion confined to the dorsal column abolished the ipsilateral SEP in Case 3, complete anterior quadrant lesions did not consistently change the CV (Case 4). This further suggests that the SEP is generated entirely by ipsilateral dorsal column activation. Accurate measurement of this dorsal column conduction velocity across the operative field provides a very sensitive means of monitoring spinal cord function during operations for neurosurgical spinal lesions.

KEY WORDS - spinal evoked potentials - epidural electrodes - somatosensory evoked potentials - spinal cord

In the preceding paper,4 we have described a technique for recording spinal somatosensory evoked potentials (SEPs) during spinal operations using bipolar epidural electrodes. Measurement of spinal conduction velocity (CV) across the operative field was proposed as a potentially safe, reliable, and sensitive means of intraoperatively monitoring spinal cord function. This paper addresses the question of whether permanent postoperative changes in neurological function, especially deterioration, can be predicted by intraoperative changes in spinal cord CV. Similar attempts to correlate changes in intraoperative cortical evoked potentials with the postoperative neurological status of patients have been reported.6,7 In addition, since the generator of the SEP has not been definitively identified within the spinal cord, pathological correlation is necessary in a substantial series of patients in order to establish the source of the monitored SEPs in humans.

The present study describes the results of SEP monitoring in our preliminary series of 27 patients. Of these, four patients had changes in postoperative function. The results are discussed with reference to the value of epidural bipolar SEP monitoring in predicting altered postoperative spinal cord function and in identifying the SEP generator.

Clinical Material and Methods

Twenty-seven patients undergoing spinal operations were monitored with the epidural bipolar SEP technique as described previously.4 This initial series includes a control group of 12 patients without myelopathy who were undergoing operations for intractable pain: myelotomy in three, ganglionectomy in three, implantation for dorsal column stimulation in three, corpectomy in two, and rhizotomy in one. Fifteen patients had preoperative myelopathies due to the following spinal lesions: tumors in nine, arterio-
Venous malformations (AVM's) in two, spondylosis in two, arachnoiditis in one, and tethered cord in one. Monitoring was performed in nine extradural and 18 intradural spinal operations. The monitoring methods were as described in detail in the preceding paper.4

Neurological function deteriorated postoperatively in one case. Wound infections occurred in two patients early in the series. With the use of prophylactic oxacillin, there were no wound infections in the last 22 cases. No complications were directly attributable to electrode placement or to the monitoring technique.

Results

The results of monitoring the patients without myelopathy have been presented in a preceding paper.4 In 12 of the 15 patients with spinal cord lesions, intraoperative SEP's were detected rostrally as well as caudally. However, SEP's rostral to the operative field were not detected preoperatively in three patients with extensive or complete dorsal column lesions: two with tumors and one with a large spinal AVM. The SEP latencies varied from 8.0 to 22.8 msec, depending on the cord lesion and height of the patient. Spinal CV varied from 0 to 78 m/sec depending on the same factors. During prolonged operations, SEP amplitudes varied ± 40% without associated postoperative neurological changes. In contrast, CV and, therefore, SEP latencies remained constant in all patients, showing no postoperative change in neurological function.

In four cases (15%), there were significant intraoperative changes in spinal CV across the operative field. All four of these patients showed a corresponding change in their postoperative neurological status: two patients were improved and two had increased postoperative deficits.

Case 1

This 44-year-old man presented with progressive paraparesis. Examination showed an upper thoracic sensory level in response to pinprick. Joint position and vibratory sensation were normal. Myelography revealed a left anterolateral extramedullary tumor at T-3. A T2-5 laminectomy was performed. Intraoperative epidural SEP monitoring before the dura was opened demonstrated an abnormally slow thoracic CV of 27 m/sec across the lesion from T-1 to T-6 (Fig. 1B). When the dura was opened, there was an abrupt increase in CV, stabilizing over the next hour prior to tumor removal. During the 3 hours of tumor removal, the improved CV remained constant at 31 m/sec (Fig. 1A). Postoperatively, the patient experienced rapid improvement in his paraparesis and became ambulatory with resolution of his sensory level. It was interesting that the improved CV related to dural opening and not to tumor resection.

Case 2

This 39-year-old man developed back pain, lower extremity spasms, a spastic gait, and urinary retention. Neurological examination showed lower extremity spasticity, paraparesis, ankle clonus, hypesthesia to T-8 (left greater than right), and absent vibratory sense below the waist bilaterally. A myelogram revealed an intramedullary mass extending from T-4 to T-6. Thoracic laminectomy was performed from T-7 to T-2. Dural opening revealed a dorsal intramedullary spinal lipoma. Prior to tumor removal, there were low-amplitude SEP's and a slow CV (41.1 m/sec) on the right, and no detectable SEP on the left (Fig. 2C

Illustrative Cases

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FIG. 2. Case 2. Epidural somatosensory evoked potential (SEP) monitoring during resection of an intramedullary spinal lipoma extending from T-4 to T-6 in a patient with myelopathy. A: Following lipoma resection, stimulation of the right common peroneal (CP) nerve produced SEPs at T-10 and T-2 at 275 minutes after the onset of intraoperative monitoring. Conduction velocity (CV) was 38.6 m/sec; conduction distance (CD) was 173 mm; the CP nerve stimulus parameters were 14 mA, 6.3 Hz, and 0.2 msec. B: Following lipoma resection, stimulation of the left CP nerve produced SEPs at T-10 and T-2 at 275 minutes after onset of monitoring. The CV was 25.8 m/sec; CD was 173 mm; the CP nerve stimulus parameters were unchanged. C: Before lipoma resection, 45 minutes from the onset of recording, small-amplitude SEPs at T-2 were recordable only on the right and absent on the left, correlating with a greater preoperative dorsal column deficit on the left.

and Table 1). After tumor resection with a Cavitron ultrasonic aspirator, recovery of the left SEP was observed, with a CV of 25.8 m/sec (Fig. 2B); the right SEP remained relatively constant with a CV of 38.6 m/sec (Fig. 2A). The patient had postoperative improvement in paraparesis, spasticity, and dorsal column function. He became ambulatory and recovered urinary control.

Case 3

This 71-year-old man with pelvic pain secondary to metastatic bladder carcinoma underwent a thoracolumbar midline myelotomy for pain. The patient had no clinically apparent dorsal column deficit preoperatively, and was ambulatory. Laminectomy was performed from L-1 to T-10. Intraoperative SEP monitoring demonstrated an initial CV from L-3 to T-9 of 28 to 30 m/sec bilaterally (Fig. 3A and C). The CV remained stable until 0.75 hours from onset of monitoring when an abrupt loss of SEP was noted on the right (Fig. 3B and C). At this time the midline myelotomy was in progress at T-11. The amplitude and latency of the left SEP showed transitory deterioration (Fig. 3C and D). There was no recovery of the right SEP over the remaining hour of recording.

Postoperatively, the patient had complete loss of right dorsal column function as well as paraparesis. There was also 100% pain relief. The wound was reexplored but no significant intra- or extradural hematoma was found. Two months postoperatively the patient died of cancer, and postmortem myelin-stained sections of the thoracic cord just rostral to the myelotomy demonstrated extensive degeneration of the right dorsal column (Fig. 4).

Case 4

This 62-year-old woman with left hip pain secondary to metastatic cervical cancer underwent a right T-3 anterolateral cordotomy. Initial intraoperative...
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Fig. 3. Case 3. Epidural somatosensory evoked potential (SEP) and spinal conduction velocity (CV) monitoring during a thoracolumbar (L-5 to T-11) midline myelotomy for pelvic cancer pain. A: Intraoperative epidural SEP's were recorded at the T-9 spinal level with right (R) or left (L) common peroneal (CP) nerve stimulation prior to start of the myelotomy. Initial CV's were slightly low, possibly secondary to post-irradiation peripheral neuropathy. The CP nerve stimulus parameters were: 14 mA, 6.3 Hz, and 0.2 msec. B: During myelotomy the amplitude and latency of the right SEP at T-9 was abruptly lost, and that on the left deteriorated transiently as demonstrated by SEP recording 1.25 hours from the onset of monitoring. C: Intraoperative CV measurement for right and left SEP's during the myelotomy demonstrated an abrupt deterioration on the right at 45 minutes, during myelotomy at the T-11 spinal level. The caudal segmental SEP at L-3 (not shown) had a latency of 14.2 msec; inter-electrode latency was 3.9 msec; conduction distance was 115 mm; CV was 29 to 30 m/sec before myelotomy. D: The SEP amplitude at T-9 on each side, recorded during myelotomy, demonstrated the loss of the right SEP at 45 minutes from the onset of monitoring.

epidural SEP recordings demonstrated a normal upper thoracic CV of 72 to 74 m/sec bilaterally (Fig. 5A and B). The cord was rotated 45° before an incision was made in the anterolateral quadrant, without changing the CV. A lesion was made at the midline, transecting the entire right anterior quadrant of the cord. After cordotomy, the CV on the right decreased significantly (p < 0.10) to 44.2 ± 12.8 m/sec with increased variability (Fig. 5C and Table 2). The CV on the left remained unchanged at 73.4 ± 1.8 m/sec. Postoperatively, the patient had 90% pain relief and patchy analgesia up to T-6 on the left. There was no detectable clinical deficit in dorsal column function on either side.

Another patient in this initial series underwent an anterolateral cordotomy at T-2, with complete contralateral analgesia to T-6, without a significant decrease in the ipsilateral CV.

Discussion

Observations in experimental animals, including primates, have suggested that conducted SEP's recorded from the dorsal spinal cord are generated primarily, if not exclusively, by the dorsal column ipsilateral to the side of peripheral nerve stimulation. This is supported by the findings in our 27 patients. First, the initial intraoperative SEP's also appeared to
FIG. 4. Case 3. Section at the T-10 spinal cord level rostral to the midline myelotomy, illustrating extensive right posterior column demyelination and degeneration. The lesion was associated with the intraoperative loss of the right SEP and postoperative loss of proprioception on the right. Loyez myelin and cresyl violet counter-stain. Upper Left: × 5. Upper Right: Higher-power section at T-10 demonstrating degeneration and demyelination of the right dorsal column. × 15. Lower Right: Higher-power section at T-10 demonstrating a relatively intact left dorsal column. × 15.

FIG. 5. Case 4. Intraoperative epidural somatosensory evoked potential (SEP) monitoring before and after a right T-3 anterior-quadrant cordotomy for cancer pain. A: Pre-cordotomy, 60 minutes after onset of monitoring, polyphasic right SEPs were recorded at T-6 and C-7. Conduction velocity (CV) was 72.8 m/sec; conduction distance (CD) was 134 mm; right common peroneal (CP) nerve stimulation parameters were 12 mA, 6.3 Hz, and 0.2 mm. B: Precordotomy, 60 minutes after onset of monitoring, polyphasic left SEPs were recorded at T-6 and C-7. The CV was 74.4 m/sec; CD was 134 mm; left CP nerve stimulation parameters were 12 mA, 6.3 Hz, and 0.2 mm. C: Postcordotomy at T-3 on the right, 150 minutes after onset of recording, SEPs persisted at C-7. The CV remained constant on the left, but decreased slightly, although significantly (p < 0.10), on the right to 57.3 m/sec (mean 44.2 ± 12.8 m/sec). The CP nerve stimulation parameters were unchanged.

...depend primarily on the preoperative integrity of the ipsilateral dorsal column. Thus, patients with preoperative proprioceptive deficits had intraoperative SEPs with conduction velocities and amplitudes below normal. In another study, using intrathecal spinal recording techniques, decreased velocity and amplitudes of SEPs were observed in patients with either peripheral neuropathies or degenerative spinal disorders. Second, the operative manipulation in Case 3, resulting in total unilateral loss of the SEP, correlated postoperatively with a loss of proprioception and with a lesion found at postmortem examination, confined primarily to the right dorsal column (Fig. 4). Finally,
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lesioning the other ascending sensory tracts by a complete anterior quadrant cordotomy produced only slight or no change in the CV (Case 4). These results further suggest that in man the ipsilateral dorsal column is the principal, and perhaps only, generator of the human conducted SEP. Further observations correlating changes in intraoperative SEP or CV, postoperative neurological status, and histopathology will be necessary to determine definitively whether other sensory tracts make any significant contribution to the human SEP.

Marked intraoperative variations in SEP amplitudes (± 40%) were observed without postoperative changes in the neurological examination. These variations in intraoperative SEP amplitude, furthermore, did not correlate with anesthetic levels or cord manipulation even in control cases. Neuroleptanalgesia used for these patients has been shown to affect segmental SEP's, but did not appear to alter the conducted SEP's recorded in these cases.

In contrast, the major changes in intraoperative spinal CV did correlate with postoperative changes in the clinical assessment of spinal cord function, especially with respect to the dorsal columns (Cases 1, 2, and 3). Significant but lesser changes in intraoperative CV were not associated postoperatively with clinically detectable changes in proprioception. This suggests that the intraoperative measurement of spinal CV using these bipolar techniques may be a more sensitive assessment of dorsal column function than the clinical neurological examination (Cases 1 and 4).

In conclusion, monitoring spinal sensory CV across the operative field is a simple, reliable, safe, and very sensitive technique for intraoperative monitoring of spinal cord function.

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