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Functional diagnosis using multimodal spinal cord evoked potentials in cervical myelopathy

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Abstract The electrophysiological measurement of spinal cord evoked potentials (SCEPs) has been established as a tool for diagnosing the spinal level responsible for cervical myelopathy. Only a few studies, however, employed multimodal SCEPs for this purpose. The objective of this study was to investigate the correlation between multimodal SCEPs recorded during cervical laminoplasty and magnetic resonance imaging (MRI) abnormalities in 18 patients aged 70 years and older versus 32 patients less than 65 years of age. Both the SCEPs and MRIs showed higher incidences of multiple-level cord involvement in the older group than in the younger group. Discrepancies in the spinal levels involved between the SCEPs and the MRIs were found in 12 patients (67%) for the older group and 6 patients (19%) for the younger group. The accuracy of the MR images in localizing the lesion site was significantly lower in the older group than in the younger group, indicating that MR images tend to show clinically silent cord compression in elderly patients. Because spinal cord compression can appear without functional change in elderly patients, electrophysiological evaluations with intraoperative multimodal SCEP studies are a useful addition to MRI for understanding the pathology of myelopathy.

Key words Cervical myelopathy · Spinal cord evoked potential · Elderly patient

Introduction

The electrophysiological measurement of intraoperative spinal cord evoked potentials (SCEPs) has been established as a method for spinal cord monitoring or localization of cord involvement of a spinal lesion.[1,6,7,12,14,15] The SCEP studies contribute to performing a safe operation as well as localizing the spinal level responsible for myelopathy. However, in most reports, the method of obtaining the SCEPs was restricted to a single mode stimulation, and there are only a few reports on multimodal SCEPs for localizing cord involvement for cervical myelopathy.[7,12] We conducted multimodal SCEP studies to detect the exact level responsible for the main functional change in cervical myelopathy: (1) ascending SCEPs after stimulation of the lower thoracic spinal cord; (2) descending SCEPs after transcranial electric stimulation; and (3) segmental SCEPs after peripheral nerve stimulation. The clinical significance of these measurements has rarely been focused on cervical myelopathy in elderly patients.[14,15]

The objective of this study was to examine the correlation between intraoperatively recorded multimodal SCEPs and magnetic resonance imaging (MRI) abnormalities, comparing the results of an older patient group with those of younger group.

Materials and methods

Patients

Fifty consecutive patients who had undergone posterior decompression surgery for cervical myelopathy were included in this study. Patients were classified into two groups: 18 patients aged 70 years and older (older group), and 32 patients less than 65 years (younger group). The mean ages of the older group and the younger group were 77 years (range 70–87 years) and 51 years (range 36–64 years), respectively. There were 10 men and 8 women in the older group and 22 men and 10 women in the younger group. The older group consisted of 17 patients with cervical spondylotic myelopathy and 1 with intervertebral disc herniation. The younger group consisted of 25 patients with cervical spondylotic myelopathy and 7 with intervertebral disc herniation. Neurologic conditions were assessed using the scoring system developed by the Japanese Orthopaedic Association (JOA). With the JOA score before and after

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surgery, the recovery rate (RR) was defined[3] as RR = (Σ postoperative JOA scores − Σ preoperative JOA scores) / (17 − Σ preoperative JOA scores) × 100. The mean follow-up periods were 41 months (range 27–76 months) for the older group and 43 months (range 33–79 months) for the younger group.

Magnetic resonance imaging

Preoperatively, all patients underwent MRI examination (1.5-tesla Singa; General Electric Systems, Milwaukee, WI, USA) using a circular surface coil. T1- and T2-weighted axial and sagittal images were obtained with a spin-echo sequence. T1-weighted axial and sagittal images were obtained with a repetition time (TR) of 400–500 ms, an echo time (TE) of 13–20 ms, four excitations, and 5-mm slice thickness. T2-weighted axial and sagittal images were obtained with a TR of 3000–4000 ms, a TE of 120–130 ms, four excitations, and 5-mm slice thickness.

Morphological deformities of the spinal cord, due to compression or impingement, and increased spinal cord signal intensities were considered important when judging the level of MRI abnormalities.

Electrodiagnosis

For all patients, intraoperative electrodiagnosis with the SCEPs were planned and informed on written forms. All patients of the study underwent posterior cervical decompression with laminoplasty. Additional foraminotomy was performed in combination with laminoplasty in two patients of the older group. The multimodal SCEPs were recorded intraoperatively, the ascending SCEPs after stimulation of the lower thoracic spinal cord, the descending SCEPs after transcranial electric stimulation, and the segmental SCEPs after peripheral nerve stimulation of the ulnar or median nerves. A square-wave pulse 0.2 ms in duration was delivered with the intensity of 10 mA to the lower thoracic spinal cord, three times the motor threshold to the ulnar or median nerves, and 100 mA for transcranial electrical stimulation. The responses were recorded from platinum needle electrodes (Unique Medical, Tokyo, Japan) inserted into the ligamentum flavum in the surgical field (Fig. 1) and averaged and stored in the Nicolet Viking IV system (Nicolet Biomedical, Madison, WI, USA). A needle electrode inserted into the erector spinae muscle served as the reference electrode. The SCEP findings (e.g., a decrease in amplitude of the negative peak of more than 50% or its disappearance) and monophasic positive potentials were regarded as signifying electrophysiological abnormalities of the spinal segment.[12]

The level of spinal cord involvement shown by the MR images and the SCEPs were compared between the older and younger groups. Statistical analysis was performed using the unpaired *t*-test and the chi-squared test. $P < 0.05$ was considered statistically significant.

Fig. 1. Responses were recorded from platinum needle electrodes inserted into the ligamentum flavum in the surgical field

Results

The preoperative JOA score averaged 7.0 points (range 2.0–10.5) in the older group, and 11.1 points (range 5.5–16.5) in the younger group. The preoperative scores of the older group were significantly lower than those of the younger group ($P < 0.05$).

The postoperative JOA scores at the time of the final follow-up averaged 12.1 points (range 8–15 points) in the older group and 14.3 points (range 10.5–17.0 points) in the younger group. The postoperative scores of the older group were significantly lower than those of the younger group ($P < 0.05$). The mean RRs at the time of final follow-up were 49% (range 14%–71%) for the older group and 55% (range 0%–100%) for the younger group. Although the pre- and postoperative JOA scores of the older group were significantly lower than those of the younger group, there was no significant difference in the RRs between the two groups.

Preoperative MR images revealed that 6 patients had single-level cord compression, and 12 had cord compression at more than two levels in the older group. In contrast, MRI revealed that 26 patients had single-level cord compression and 6 had cord compression at more than two levels in the younger group.

The spinal levels affected, as indicated by the SCEPs, were as follows: in the older group, C3/4 for 6 patients (33%), C4/5 for 8 patients (44%), C5/6 for 6 patients (33%), and C6/7 for 1 patient (6%); in the younger group, the affected levels were C3/4 for 3 patients (9%), C4/5 for 8 patients (25%), C5/6 for 16 patients (50%), and C6/7 for 5 patients (16%) (Table 1). The C3/4 and

Table 1. Level of spinal cord involvement shown by the magnetic resonance images and SCEPs

	Older group (n = 18)		Younger group (n = 32)	
Affected spinal level	MRI	SCEPs	MRI	SCEPs
C3/4	7	6	5	3
C4/5	10	8	10	8
C5/6	11	6	17	16
C6/7	5	1	7	5
C7-T1	2	0	0	0

SCEPs, spinal cord evoked potentials; MRI, magnetic resonance imaging

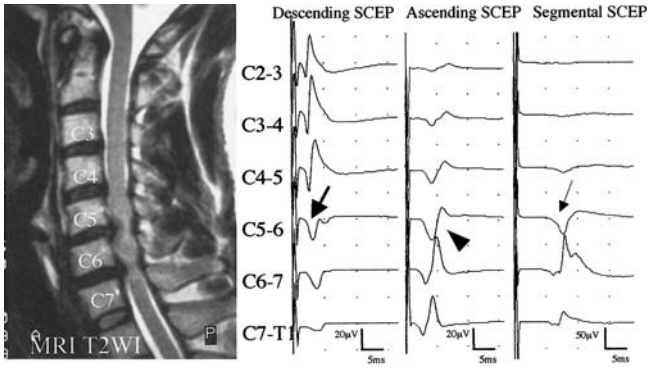

Fig. 2. Patient was a 44-year-old man. T2-weighted sagittal magnetic resonance (MR) image showing multiple-level cord compression at *C4/5*, *C5/6*, and *C6/7*. The descending spinal cord evoked potentials (*Descending SCEP*) showing a decrease in amplitude at C5/6 (*large arrow*), the *Ascending SCEP* showing a positive potential at C5/6 (*arrowhead*), and the *Segmental SCEP* showing a positive potential at C5/6 (*small arrow*). Despite multiple-level cord compression on the MR image, the SCEPs revealed single-level involvement at C5/6

C4/5 levels were more likely to be affected in the older group ($P < 0.05$).

There were discrepancies between the findings of the MR images and the SCEPs in both groups. The intraoperative SCEP studies showed relatively fewer spinal segments involved compared to those found by the MRI studies in both groups (Fig. 2). In the older group, 12 patients (67%) had MRI evidence of cord compression at more than two levels, but only 4 patients (22%) showed SCEP abnormalities at two levels (Fig. 3). The SCEPs revealed a single-level involvement in six patients with cord compression at two levels, and in two patients with cord compression at more than three levels on the MR images (Table 2). In the younger group, six patients (19%) had MRI evidence of compression at more than two levels, but only two patients (6%) showed SCEP abnormalities at two levels. The SCEPs

Table 2. Relation of the spinal levels involved between MRI and SCEPs

MRI		SCEPs	
Levels	No. of patients	Levels	No. of patients
Older group (n = 18)			
One	6	One	5
		Normal	1
Two	7	One	6
		Two	1
≥Three	5	One	2
		Two	3
Younger group (n = 32)			
One	26	One	24
		Normal	2
Two	5	One	3
		Two	2
≥Three	1	One	1
		Two	0

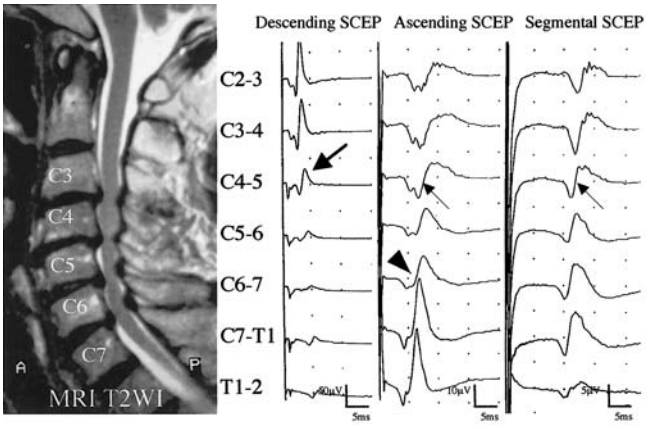

Fig. 3. Patient was a 77-year-old man. T2-weighted sagittal MR image showing multiple-level cord compression at *C3/4*, *C4/5*, *C5/6*,and *C6/7*. The *Descending SCEP* show a decrease in amplitude at C4/5 (*large arrow*), the *Ascending SCEP* show a decrease in amplitude at C6/7 (*arrowhead*) and a positive potential at C4/5 (*small arrow*), and the *Segmental SCEP* show a decrease in amplitude of the first wave at C4/5 (*small arrow*). This case was diagnosed by the SCEPs as having two levels of cord involvement, at C4/5 and C6/7

revealed a single-level involvement in three patients with cord compression at two levels, and in one patient with cord compression at more than three levels on the MR images (Table 2). None of the patients showed SCEP abnormalities at more than three levels in either group. One patient in the older group and two patients in the younger group, who had single-level cord compression on the MR images, did not show significant SCEP abnormalities of the spinal segment. The JOA scores of the patients were 11, 13, and 16.5, respectively. Cord compression shown by MR images were not ac-

companied by the SCEP abnormalities in 12 patients (67%) in the older group and 6 patients (19%) in the younger group. The accuracy of the MR images in localizing the lesion site was significantly lower in the older group than in the younger group ($P < 0.05$).

Discussion

Electrophysiological examinations may be used to identify the level of spinal cord compression responsible for the clinical symptoms, which is sometimes difficult only through imaging examinations, especially in elderly patients who have multisegmental cervical spondylosis or a narrow spinal canal. The SCEP studies involving both spinal cord and peripheral nerve stimulation have been reported as a method of intraoperative level diagnosis in cervical myelopathy.[12,14,15] In the current study, we also recorded the descending SCEPs following transcranial electrical stimulations to assess the function of the motor pathways.[5] The motor evoked potentials after transcranial electrical stimulation were previously used for intraoperative monitoring of spinal cord function.[1] The current study of multimodal SCEPs, which employed spinal cord stimulation, transcranial electrical stimulation, and peripheral nerve stimulation, enables surgeons to identify more precisely the levels of spinal cord dysfunction.

The MRI examination is the most common tool for detecting the level of spinal cord involvement in cervical myelopathy. However, the MR images demonstrate morphological abnormalities of the cord but not functional impairment, and not all cord compression shown by MR images is associated with cord dysfunction. In the current study, the dissociation between MRI evidence of cord compression and SCEP abnormalities was assessed in older and younger patient groups. The SCEPs disclosed relatively fewer spinal segment abnormalities than did the MR images in both the older and the younger groups. Discrepancies between cord compression on MR images and SCEP abnormalities were found in 12 patients (67%) in the older group and 6 patients (19%) in the younger group, suggesting a higher incidence of clinically silent cord compression in elderly patients. Whereas our results of multimodal SCEP studies also showed a higher incidence of multiple-level cord involvement in the older group than in the younger group, this tendency was more than offset by a further high incidence of asymptomatic spinal cord compression in the older group. Consequently, there was a greater discrepancy between the MR image findings and the functional diagnosis in the older group than in the younger group. In fact, Teresi and associates[17] reported that asymptomatic spinal cord impingement was observed on MRI scans in 11 of 42 (26%) patients over 64 years of age, but in 9 of 58 (16%) patients under 64 years of age. Moreover, it was reported that the upper cervical segments of C3/4 and C4/5 were more likely to be affected in elderly patients.[9,14,15] Our results also showed more frequent occurrence of symptomatic spinal cord compression on MR images at C3/4 and C4/5 in the older patient group.

Because of the increase in the elderly population in recent decades, an increasing number of operations for cervical myelopathy have been performed in elderly patients. Although relatively poor surgical outcomes have been reported for elderly patients with cervical myelopathy compared to those reported for younger patients, satisfactory functional results in elderly patients have been noted in several reports.[2,8,10,16] This was the case with the current study showing the RR values not significantly different between the older and younger groups. Despite the fact that elderly patients frequently have considerable postoperative complications,[13] surgery for cervical myelopathy is beneficial if the operation is appropriately planned.

In general, extensive decompression with laminoplasty might be safer for addressing multiple-level spinal cord compressions unless the exact levels responsible for the main functional change are accurately diagnosed. The current study has shown that multimodal SCEP recordings help delineate the conduction abnormalities and determine the optimal levels of surgical intervention especially for multiple-level cord compression seen in elderly patients.[14,15]

It should be pointed out that the ascending SCEPs are primarily mediated by the dorsal spinocerebellar tract and dorsal columns,[11] and the descending SCEPs are possibly mediated by the pyramidal tract.[4] It follows that our technique identified only the most caudal conduction abnormalities in the sensory pathways and the most rostral ones in the motor pathways. Therefore, it is possible that our data may have overlooked additional levels of conduction abnormalities more rostrally in the sensory pathways and more caudally in the motor pathways. In addition, the current study failed to show any abnormality in three patients. These three patients had relatively higher preoperative JOA scores, indicating mild neurological deficits. There may be limitations of SCEPs when diagnosing less symptomatic cervical myelopathy. Nevertheless, the multimodal SCEP study can disclose more abnormalities than can a single-mode study.

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