

ORIGINAL ARTICLE

Characteristics of C6–7 myelopathy: assessment of clinical symptoms and electrophysiological findings

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Study design: This is a single-center retrospective study.

Objectives: The objective of this study was to study the clinical symptoms and electrophysiological features of C6–7 myelopathy.

Setting: This study was conducted at the Department of Orthopedic surgery, Yamaguchi University Graduate school of medicine, Japan.

Methods: A total of 20 patients with cervical compressive myelopathy were determined by spinal cord-evoked potentials or a single level of obvious magnetic resonance imaging (MRI)-documented cervical spinal cord compression. Neurological examinations included manual muscle testing and investigation of deep tendon reflex, including Hoffmann sign, and of sensory disturbance areas. Motor-evoked potentials (MEPs), compound muscle action potentials (CMAPs) and F-wave were recorded from bilateral abductor digit minim and abductor hallucis muscles. Central motor conduction time was calculated as follows: $(\text{MEPs latency} - (\text{CMAPs latency} + \text{F latency} - 1))/2$ (ms).

Results: Eighteen patients (90%) had negative Hoffmann sign. Eight patients (40%) had no sensory disturbance in the upper limbs and 8 patients (40%) had no muscle weakness in the upper limbs. We determined that patients had cervical myelopathy when their central motor conduction time measured in abductor digit minim was longer than 6.76 ms (+2 s.d.). Using this definition, the sensitivity for myelopathy was 42.8%.

Conclusion: Patients with C6–7 myelopathy may lack clinical symptoms in their hands and central motor conduction time measured in abductor digit minim tended to be less prolonged, and it only showed symptoms in their lower limbs as gait disturbance. Surgeons should bear in mind the possibility of disorders of caudal C6–7 when they encounter patients with no or few symptoms in their hands and with leg weakness or numbness.

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INTRODUCTION

The frequency of diagnosis for cervical compressive myelopathy has recently increased, reflecting an aging society. The initial clinical symptoms of cervical compressive myelopathy are general numbness and sensory disturbance in the upper limbs, reaching motor dysfunction with progression of the myelopathy. It is not difficult to diagnose cervical compressive myelopathy in typical cases by using appropriate physical and radiographic examinations. However, we have experienced a small number of patients with cervical compressive myelopathy who had only slight or no obvious clinical signs in the upper limbs. This absence of neurological signs in the upper limbs can lead to erroneous diagnosis of thoracic or lumbar spinal diseases.

However, C6–7 myelopathy is a relatively rare condition, and there have not been many studies to date. The clinical and electrophysiological findings associated with this condition therefore remain unclear. The diagnosis of C6–7 myelopathy can be difficult, depending on the distinctive neurological signs present. We have previously measured multimodal spinal cord-evoked potentials (SCEPs) to diagnose the responsible level of cervical compressive myelopathy. SCEPs are a useful and reliable way to investigate the functional integrity of the spinal cord when magnetic resonance imaging (MRI) shows evidence of compression at several levels.^{1–3} In the present

study, we assessed the clinical symptoms and electrophysiological findings in patients with C6–7 myelopathy with the aim of elucidating the characteristic features of this condition.

PATIENTS AND METHODS

Patients

A total of 20 patients with cervical compressive myelopathy were determined by intraoperative SCEPs to have a single site of conduction abnormality at the intervertebral level, or a single level of obvious MRI-documented cervical spinal cord compression. These comprise 7 cases with cervical spondylosis myelopathy, 10 with cervical disc herniation and 3 with ossification of the longitudinal ligament of the cervical spine. Central motor conduction time had been measured in 15 patients before surgery, as described below. The average patient age was 58.6 (range 40–79) years. Patients underwent cervical laminoplasty and measurement of SCEPs when MRI showed multiple compressions. They underwent anterior decompression with spinal fusion when MRI showed a single-level compression.

Written informed consent with the approval of Yamaguchi University Graduate School of Medicine was obtained for the preoperative MRI investigations and electrophysiological studies in patients. Patients who fulfilled the criteria given below were included in the study.

A diagnosis of myelopathy was established on the basis of the presence of hyperreflexia, upper or lower extremity sensory disturbance and obvious

MRI-documented cervical spinal cord compression. Sensory and motor nerve conduction velocities in peripheral nerves were within normal limits. Patients who had peripheral neuropathy, cephalopathy or thoracic compressive myelopathy were excluded.

Magnetic resonance imaging

All patients underwent MRI with a 1.5-T imaging system (Siemens Japan, Tokyo, Japan). Sections were 5-mm thick with a 2-mm gap between intersections. T1- and T2-weighted sagittal and axial images were obtained.

Neurological symptoms

We performed several neurological examinations including manual muscle testing, investigation of deep tendon reflexes including the Hoffmann sign and evaluation of areas of sensory disturbance by pin prick or light touch. Similar to previous reports, we made presumptions on the involved area of the spinal cord based on neurological signs.

We hypothesized that sensory disturbance in the little finger sometimes also includes the ring finger; involvement of C8 sensory segment, and in the middle and ring fingers; involvement of C7, according to dermatome by Brain and Watson.⁴ We hypothesized the myotomal distribution as follows: triceps in C6-8 cord segments (main myotome, C7), extensor digit communis in C7 and C8 cord segments (C8) and abductor digit minim in C8 and T1 cord segments (C8).

We hypothesized that localization of the reflex center of triceps would be at C7, and of the Hoffmann sign at C8. Diminished deep tendon reflex results from involvement of the lower motor neuron, and exaggerated deep tendon reflex results from involvement of the upper motor neuron. For example, normal or diminished triceps tendon reflex and positive Hoffmann sign indicate involvement of C5-6 level, and normal triceps tendon reflex and negative Hoffmann sign indicate caudal to C6-7 level. We assessed triceps tendon reflex, Hoffmann sign and patella tendon reflex.

Recording of central motor conduction time

All electrophysiological assessments were performed using a Nicolet Viking 4 instrument (Natus Medical Incorporated, San Carlos, CA, USA). Self-adhesive surface recording electrodes were placed on target muscles. Motor-evoked potentials (MEPs) were recorded from bilateral abductor digit minim and abductor hallucis muscles. Transcranial magnetic stimulation was delivered using the Magstim 200 instrument (The Magstim Company, Carmarthen, UK) with a circular coil having an outer diameter of 140 mm. Transcranial magnetic stimulation was applied while the patient exerted isometric voluntary contraction of the target muscles. The coil was held with its center on the Cz position of the 10-20 system for recording MEPs from the abductor digit minim and moved frontally for recording MEPs from the abductor hallucis. Transcranial magnetic stimulation intensity was set at 20% above the MEP threshold. At least 4 consecutive trials were recorded and superimposed. The shortest onset latency of the MEPs was recorded (MEP latency).

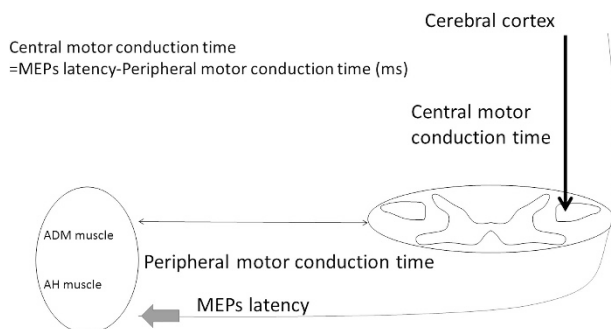


Figure 1 MEP latency was recorded in the abductor digit minim (ADM) muscle or in the abductor hallucis (AH) muscle by transcranial magnetic stimulation. The conduction time from the cerebral cortex to the motor segment was defined as central motor conduction time. This was derived by subtracting the peripheral motor conduction time from the MEP latency.

Compound muscle action potentials (CMAPs) and F waves were recorded following supramaximal electric stimulation of the ulnar nerve at the wrist and of tibial nerves at the ankle. Sixteen serial responses were obtained, and the shortest latency of F waves was measured. Peripheral motor conduction time was calculated as follows: (CMAPs latency + F latency - 1)/2. Central motor conduction time was calculated as follows: MEPs latency - Peripheral motor conduction time (ms); Figure 1). The baseline-to-negative peak amplitudes of the m waves and MEPs were measured. All muscle responses were amplified and filtered with a band-pass of 5-5000 Hz.

Control subjects

Thirty healthy subjects (average age, 42.6 years; age range, 23-73 years) with no history of injury or pathology to the upper limb were also evaluated as a control group. They underwent medical examination consisting of a detailed history regarding motor and sensory dysfunctions, followed by thorough physical examination. Exclusion criteria were a history of upper limb symptoms, glove and stocking sensory symptoms, diabetes mellitus, any form of medication, and abnormal tendon reflexes or sensory and motor examination.

Recording of SCEPs for the diagnosis of symptomatic lesions

SCEPs following transcranial electric stimulation (TES-SCEPs) and spinal cord stimulation (Spinal-SCEPs) were recorded intraoperatively in prone position when we performed cervical laminoplasty. TES was delivered as square pulses of 0.2 ms duration and at an intensity of 100 mA through needle electrodes (13R25, Dantec Dynamics, Skovlunde, Denmark) placed on the skull. The anode was placed 7 cm laterally to the right of the vertex on a line joining the external auditory meatus. The cathode was placed on the opposite side. Spinal-SCEPs were delivered by an epidural catheter electrode (UKG-100-2PM, Unique Medical corporation, Tokyo, Japan) inserted into the dorsal epidural space from the C7-T1 and T11-T12 interlaminar space. Square wave pulses (0.2 ms duration, 3 Hz rate) were delivered at an intensity of 15-20 mA. Before surgery, all SCEPs were recorded intraoperatively with recording electrodes (13R25, Dantec Dynamics) inserted in the ligamentum flavum at each interlaminar space. A reference electrode was inserted into the subcutaneous tissue in the posterior aspect of the neck for the recording of Spinal-SCEPs and TES-SCEPs. All SCEP signals were amplified and filtered with a band-pass of 20-3000 Hz using a standard evoked potential/electromyography machine (Nicolet Viking, Natus Medical Incorporated, San Carlos, CA, USA). An average of 40-60 TES-SCEPs and 40-50 spinal-SCEPs responses were obtained. Two different averaged responses were superimposed and displayed. For both TES-SCEPs and Spinal-SCEPs, intervertebral levels with a marked reduction in the size of the negative peak (>50%) were considered to be significant (Figure 2).^{2,3}

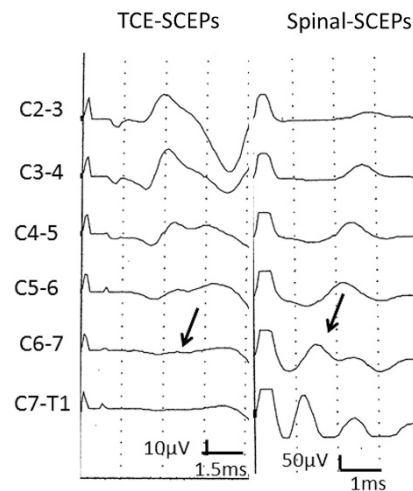


Figure 2 SCEPs obtained from patients with compressive cervical myelopathy. TCE-SCEPs and Spinal-SCEPs both showed marked attenuation of amplitude at the C6-7 level, indicating a conduction block at C6-7.

Statistical analysis

The upper limits for central motor conduction time were determined as the mean+2 s.d.). Mann-Whitney's *U*-test was used for comparison of test results between the patient and control groups. *P*-values <0.05 were regarded as statistically significant.

RESULTS

All patients showed neurological recovery after cervical surgery.

Clinical findings

Detailed clinical findings are shown in Table 1.

Initial symptoms

Eleven patients (55%) showed initial symptoms in the upper limbs, whereas 9 patients (45%) had initial symptoms in the trunk or lower limbs manifesting as numbness or gait disturbance.

Sensory disturbance

Eight patients (40%) had no sensory disturbance in the upper limbs, 2 (10%) patients had disturbance in all fingers, 1 (5%) patient in the middle to little fingers and 8 (40%) patients in the little finger and/or ring finger (Figure 3).

Muscle weakness

Eight patients (40%) had no muscle weakness in the upper limbs. One patient (5%) had muscle weakness in the triceps brachii muscle, 7 (35%) patients in the extensor digit communis and 10 (50%) patients in the abductor digit minim (Table 2).

Deep tendon reflex and Hoffmann sign

Eleven patients (55%) had diminished or absent triceps tendon reflex and 18 (90%) had negative Hoffmann sign (Table 3). Fifteen patients (75%) showed exaggerated patella tendon reflex.

Table 1 Patients' detailed clinical findings

Case	Age (years)	Sex	Disease	Area of SD	Deep tendon reflex		Manual muscle test		
					TTR/PTR	Hoffmann sign	Triceps	EDC	ADM
1	79	M	CSM	C8	↓↑	-	5	4	5
2	40	M	CSM	C8	N↑	-	5	4	4
3	64	M	CSM	C8	N/ N	-	5	5	4
4	49	M	CSM	C7	N/ N	-	5	5	5
5	54	M	CSM	C7	↓↓	-	5	4	4
6	68	M	CSM	None	↓↑	-	5	5	4
7	72	F	CSM	None	N↑	-	5	4	4
8	40	M	OPLL	C7	N↑	-	4	5	5
9	64	M	OPLL	None	↓↓	-	5	5	5
10	59	M	OPLL	None	↑↑	+	5	5	4
11	53	M	CDH	C8	↓↑	-	5	5	5
12	48	M	CDH	C8	N↑	-	5	5	4
13	58	M	CDH	C8	↓↑	-	5	4	4
14	69	F	CDH	C8	↓↑	+	5	3	3
15	51	M	CDH	C7	↓↑	-	5	5	5
16	53	F	CDH	None	N↑	-	5	5	5
17	65	F	CDH	None	↓↑	-	5	5	5
18	73	F	CDH	None	N↑	-	5	5	5
19	60	M	CDH	None	↓↑	-	5	5	5
20	54	M	CDH	None	↓/N	-	5	4	4

Abbreviations: ADM, abductor digit minim; CDH, cervical disc herniation; CSM, cervical spondylotic myelopathy; EDC, extensor digit communis; F, female; M, male; N, Normal; OPLL, ossification of posterior longitudinal ligament; PTR, patella tendon reflex; SD, sensory disturbance; TTR, triceps tendon reflex; +, presence; -, absence; ↓, diminished; ↑, exaggerated. Area of SD according to the dermatome proposed by Brain and Watson,⁴ and Yoss.⁵

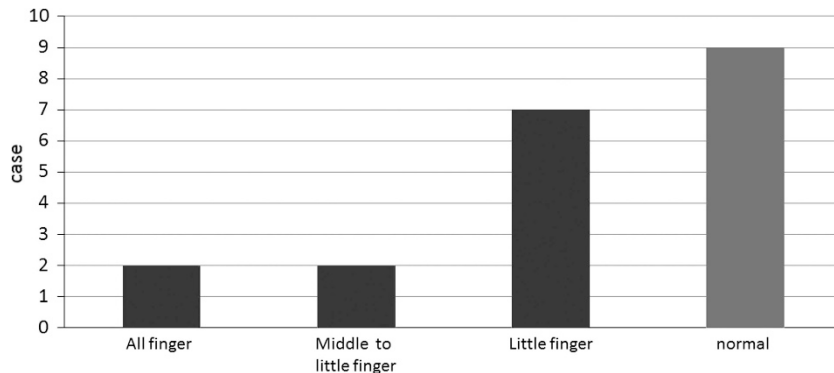


Figure 3 Eight patients (40%) had no sensory disturbance in the upper limbs, 2 (10%) patients showed disturbance in all fingers, 1 (5%) patient in the middle to little fingers and 8 (40%) patients in the little finger and/or ring finger.

Table 2 Distribution of muscle weakness

Muscle	Triceps	EDC	ADM
N (%)	1 (5)	7 (35)	10 (50)

Abbreviations: ADM, abductor digit minim; EDC, extensor digit communis.

Table 3 Correlation between TTR and Hoffmann sign

	Positive Hoffmann sign	Absent Hoffmann sign
Normal TTR	1 (5%)	8 (40%)
Exaggerated TTR	1 (5%)	10 (50%)

Abbreviation: TTR, triceps tendon reflex.

Central motor conduction time

The normal value (mean \pm s.d.) for central motor conduction time in abductor digit minim was 5.14 ± 0.81 ms (range 3.85–6.82 ms), and in abductor hallucis it was 11.41 ± 1.32 ms (range 8.95–13.6 ms).

Central motor conduction time in abductor digit minim was measured in 15 patients, and in 14 of these the central motor conduction time was successfully recorded (Table 4). The mean value for central motor conduction time in abductor digit minim was 6.94 ± 2.14 ms (range 4.2–11.5 ms), and it was significantly longer than normal values ($P = 0.001$). We determined whether patients had cervical compressive myelopathy when central motor conduction time in abductor digit minim was longer than 6.76 ms (+2 s.d.). Using this definition, the sensitivity for myelopathy was 42.8%.

Central motor conduction time in abductor hallucis was successfully recorded in 13 of 15 patients. The mean value for central motor conduction time in abductor hallucis was 18.04 ± 4.51 ms (range 13.2–27), and this was significantly longer than normal values ($P < 0.001$). We determined that patients had cervical compressive myelopathy when central motor conduction time in abductor hallucis was longer than 14.05 ms (+2 s.d.). Using this definition, the sensitivity for myelopathy was 92.3% (Figure 4).

DISCUSSION

The major findings of this study are that most patients with C6–7 myelopathy had no or few neurological signs in the upper limbs, and that the sensitivity of central motor conduction time in abductor digit minim was less than that of central motor conduction time in abductor hallucis.

Area of sensory disturbance

Several authors reported that the border between C8 and T1 sensory segments in the spinal cord is at the level of the C6–7 disc.^{6,7} Compression of the spinal cord at the C6–7 disc level could lead to involvement of the C8 sensory segment or of the T1 sensory segment. Hence, most patients would show no or only localized sensory disturbance, mostly in the little fingers of their hands. Eight patients (40%) had sensory disturbance in their little finger that sometimes also included the ring finger; involvement of C8 sensory segment,⁴ but some patients had disturbance in the thumb to middle finger. Although the reasons for this are unclear, one possible explanation is concomitant C7 radiculopathy. C7 nerve roots would distribute the lesion mainly to the middle and ring fingers.⁴ Yoss⁵ reported that sensory disturbance in thumbs was affected by the C6 nerve root, in the index and middle fingers by the C7 root and in the ring and little fingers by the C8 root. However, the distributed lesion of a single nerve root overlaps the lesion of the adjacent nerve root. Yoss⁵ also

Table 4 CMCT findings

Case	Age	Sex	Disease	ADM-CMCT	AH-CMCT
1	79	M	CSM	4.2	15.2
2	40	M	CSM	6.85	NM
3	64	M	CSM	11.5	27
5	54	M	CSM	5.6	20.9
6	68	M	CSM	7.85	26.5
7	72	F	CSM	6.95	16.65
8	40	M	OPLL	5.3	13.2
9	64	M	OPLL	NM	13.75
10	59	M	OPLL	5.85	14.8
11	53	F	CDH	5.23	17.84
13	58	M	CDH	5.3	15.2
14	69	F	CDH	10.6	20.35
18	73	F	CDH	6.55	17.95
19	60	M	CDH	9.4	NE
20	54	M	CDH	6	15.2

Abbreviations: ADM, abductor digit minim; AH, abductor hallucis; CDH, cervical disc herniation; CMCT, central motor conduction time; F, female; M, male; NE, not evoked MEPs; NM, not measured; OPLL, ossification of posterior longitudinal ligament.

reported that the distribution of sensory disturbance located only in the thumb indicated involvement of the C6 nerve root, whereas the distribution of sensory disturbance from the thumb to the middle or to all fingers indicated involvement of the C7 nerve root.

Distribution of muscle weakness

The patients in our study had muscle weakness, and half of them showed muscle weakness of abductor digit minim. We feel that abductor digit minim would be the key muscle for the diagnosis of C6–7 myelopathy. As the main myotome of abductor digit minim is C8, this resulted from involvement of the C8 motor segment.^{7,8} However, because of individual variation with this myotome, patients whose T1 segment distributed abductor digit minim dominantly would have no muscle weakness of abductor digit minim.

Extensor digit communis muscle weakness was almost accompanied with abductor digit minim muscle weakness in our study. As extensor digit communis would be contributed by C7 and C8 motor segment, this resulted from involvement of the C8 motor segment.

Deep tendon reflex and Hoffmann sign

The Hoffmann sign is reported to occur in 60–80% of patients with cervical compressive myelopathy, and it is therefore a useful neurological sign affecting pyramidal tracts.^{9,10} This sign was negative for most patients with C6–7 myelopathy in our study and could be a feature of this condition, and it indicated involvement of C8 segment. Chikuda *et al.*¹¹ reported that in patients with cervical compressive myelopathy hyperreflexia showed the highest sensitivity followed by the Hoffmann sign. In the present study, 15 patients (75%) had exaggerated patella tendon reflex and only 2 patients had positive Hoffmann sign.

Neurological level diagnosis

In summary, the neurological findings of C6–7 myelopathy could coexist with involvement of the C8 segment or T1 segment and C7 nerve root.

Neurological examination of patients with cervical compressive myelopathy according to neuroimaging is reported to be moderately accurate and reliable for determining the neurological level of disease. However, Seichi *et al.*⁷ reported that responsible levels in some

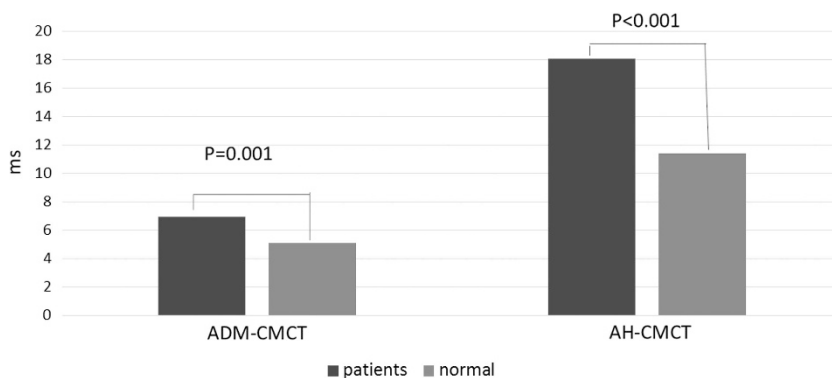


Figure 4 The mean values of ADM-CMCT (6.94 ± 2.14 ms; mean \pm S.D) in C6–7 myelopathy patients were significantly longer than normal values (5.14 ± 0.81 ms; $P=0.001$). The mean values of AH-CMCT (18.04 ± 4.51 ms) were significantly longer than normal values (11.41 ± 1.32 ms; $P<0.001$).

patients could not be determined by neuroimaging when there were multiple increased signal changes. MRI can also show spinal cord compression or increased signal intensity changes despite clinically asymptomatic presentation.¹² Although SCEPs may carry risks of infection or cerebral fluid leakage, multimodal SCEPs have some advantages. We have diagnosed the responsible level by using SCEPs to investigate the dysfunction of spinal cord when MRI showed compressions at several levels. We performed the level diagnosis of cervical compressive myelopathy based on SCEP abnormalities rather than on MRI findings. However, the neurological findings were not always concordant with the electrophysiological diagnosis. This resulted from the lesions of the spinal cord because of compression, and therefore they vary widely. Another reason is that the myotomal distribution varies between different individuals. It is therefore difficult to accurately identify the responsible level, and this was a limitation of our study.

Central motor conduction time

Measurement of central motor conduction time is a useful way to assess electrophysiological functioning of the corticospinal tract in patients with cervical compressive myelopathy, and it has been widely reported as a non-invasive and objective method for evaluating the central motor pathway.^{13,14} However, the central motor conduction time in abductor digit minim tended to be less prolonged in patients with C6–7 myelopathy, with the central motor conduction time in abductor hallucis more obviously prolonged. We previously reported that central motor conduction time in abductor digit minim can be a useful examination tool for the screening of cervical compressive myelopathy that is rostral to the C5–6 level.¹⁴ Nakanishi *et al.*¹⁵ reported that low central motor conduction time in abductor digit minim/central motor conduction time in abductor hallucis ratios provide complementary information for the screening of patients with thoracic myelopathy. In fact, however, the sensitivity of central motor conduction time in abductor hallucis for C6–7 myelopathy could be high, and the sensitivity of central motor conduction time in abductor digit minim could be very low. Diagnosis of the patients with myelopathy caudal C6–7 should include assessment of central motor conduction time in abductor hallucis.

Differential diagnosis of C6–7 myelopathy

The neurological findings were consistent with the involvement of segment and long tracts. Involvement of long tracts would be consistent with numbness, sensory disturbance,^{2,16} clumsiness of hands¹⁷ and prolongation of central motor conduction time.^{18,19}

Hand symptoms tend to be obvious in more proximal levels than C6–7. Both segment and long tracts correlated with hands became damaged in more upper levels than C6–7, but only segment correlated with hands in C6–7. It is also possible to explain negative Hoffmann sign and the absence of hand symptoms in patients with C6–7 myelopathy. The explanation could be that the anatomical features that compressed the spinal cord at the C6–7 could lead to involvement of the C8 segment and the long tract caudal to T1, or to involvement of the T1 segment and long tract caudal to T2. Therefore, the neurological and electrophysiological findings in C6–7 were characteristic.

Thoracic myelopathy and lumbar stenosis diseases must be considered in the differential diagnosis of C6–7 myelopathy, as patients with this condition would not be detected by neurological abnormalities in their hands.

Some authors^{7,20} reported that sensory disturbance in the little finger with or without involvement of the ring finger was accurate for the diagnosis of C6–7 myelopathy. If the patients' major complaint is gait disturbance, it is important to carefully examine the clinical findings from their hand and assess diagnostic imaging including the cervicothoracic junction. The characteristic symptoms make diagnosis challenging and could potentially lead to misdiagnosis and the subsequent progression of myelopathy, thus resulting in poor outcomes.

CONCLUSION

We assessed neurological examination and electrophysiological findings for the diagnosis of C6–7 myelopathy. Almost half of the patients could not be detected by neurological abnormalities in their hands, and central motor conduction time in abductor digit minim tended to be less prolonged.

Surgeons should bear in mind possible disorders of caudal C6–7 when they encounter patients with no or few symptoms in the hands and with leg weakness or numbness.

DATA ARCHIVING

There were no data to deposit.

CONFLICT OF INTEREST

The authors declare no conflict of interest.

DISCLAIMER

The manuscript submitted does not contain information about medical device (s)/drug(s). No benefits in any form have been received or will be received by a commercial party related directly or indirectly to the subject of this article.

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