Clinical value of motor evoked potentials with transcranial magnetic stimulation in the assessment of lumbar spinal stenosis

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Abstract The objective of this study was to evaluate the clinical usefulness of assessing motor evoked potentials (MEP) in lumbar spinal stenosis (LSS). Twenty-three LSS patients were enrolled. The preoperative data of MEP latency (MEPLT), clinical symptoms, Japanese Orthopaedic Association (JOA) scores for low back pain, visual analogue scale (VAS) for back pain, leg pain and numbness, walking distance and the minimal cross-sectional area (mCSA) of the dural sac were evaluated. The mean MEPLT was 42.1 ± 2.8 ms. Fourteen patients had bilateral leg symptoms. The mean walking distance and mCSA were 302.1 ± 302.8 m and 0.4 ± 0.2 cm², respectively. The mean JOA score and VAS scores for back pain, leg pain and numbness were 15.9 ± 4.8 , 6.0 ± 2.9 , 7.7 ± 1.9 and 7.3 ± 3.0 , respectively. MEPLT was related to the walking distance, limb symptoms and the VAS for numbness. MEPLT was significantly delayed in patients who showed a walking distance less than 500 m. MEP is useful in LSS assessment. It can reflect the subjective severity of motor disturbance and predict the neurological deficit prior to appearance.

Résumé L'objectif de cette étude est d'évaluer l'utilité des potentiels évoqués majeurs dans les canaux lombaires étroits. Méthode: 23 patients présentant un canal lombaire étroit (12 hommes et 11 femmes) ont été évalués. L'âge

moyen était de $67,9 \pm 8,5$ années. L'évaluation des potentiels évoqués moteurs pré-op ainsi que la symptomatologie, le score JOA, le score douleur ainsi que la douleur des deux membres inférieurs, la distance de marche avec claudication intermittente NIC et la surface de la section du sac dural ont été évalués, la largeur du sac dural MCSA étant évalué par IRM. Résultats: le temps de latence des potentiels évoqués moteurs était de $42,1 \pm 2,8$ ms avec une symptomatologie moyenne ayant évolué pendant $31,5 \pm 31,8$ mois. 12 patients présentaient un spondylolisthésis dégénératif associé. 14 patients avaient des signes bilatéraux et 9 unilatéraux. La claudication intermittente moyenne était de $302,1 \pm 302,8$ mètres et la surface de section moyenne du cul-de-sac de $0,4 \pm 0,2$ cm². Le score moyen JOA, le score douleur VAS, les douleurs des membres inférieurs étaient respectivement de $15,9 \pm 4,8$, $6 \pm 2,9$, $7,7 \pm 1,9$ et $7,3 \pm 3,0$, avec un seul disque lésé dans 15 cas, deux dans 7 cas et trois dans un cas. Le temps moyen d'intermittence des potentiels évoqués rapporté au périmètre de marche à la symptomatologie douloureuse des membres inférieurs, au score JOA au nombre de disques, à la durée moyenne de la symptomatologie, au score douleur et au temps de latence des potentiels évoqués était significativement plus important chez les patients qui avaient un périmètre de marche inférieur à 500 mètres. En conclusion, les potentiels évoqués moteur sont utiles pour l'évaluation des canaux lombaires étroits et sont le reflet exact de la sévérité des lésions motrices. Ils permettent de prédire le déficit neurologique avant que celui-ci n'apparaisse.

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Introduction

Lumbar spinal stenosis (LSS) is a very common degenerative disease of the spine, especially in the elderly. Typical

symptoms include back and/or leg pain, numbness/tingling, muscular weakness and neurogenic intermittent claudication (NIC). It has been proven that electrophysiological methods are able to reveal neurological deficits in LSS even in patients who do not demonstrate an anomaly on physical examination. Several methods, such as electromyogram (EMG), F waves, H waves, somatosensory evoked potential (SEP) and motor evoked potential (MEP), have been used widely in clinical research of LSS [2, 3, 5–7, 9, 10, 12, 16, 24].

MEP elicited by magnetic stimulation is a painless and non-invasive examination. It can effectively evaluate patients' motor function by stimulating the motor cortex or spinal nerve roots. Lazzaro et al. [9] reported that MEP recording is an accurate and easily applicable test for the diagnosis of lumbosacral spinal cord lesions. As the abnormality ratio of MEP elicited by lumbosacral stimulation is low, Leinonen et al. [16] recommended the use of transcranial stimulation for assessing motor conduction deficits in LSS. There are few papers reporting the association between MEP and clinical factors. This study evaluated the clinical usefulness of assessing MEP in LSS patients by investigating whether MEP correlates with clinical symptoms, signs, image findings and subjective or objective outcome measures.

Materials and methods

Inclusion and exclusion criteria

The subjects of this study were LSS patients, with or without degenerative spondylolisthesis, excluding patients with:

1. A history of lumbar surgery
2. Pure lumbar disc herniation without bony spinal canal stenosis
3. Any other neurological lesions (such as those resulting from diabetes mellitus)
4. Any other diseases that might affect precise clinical assessments or physical examinations

MEP recording method

In all patients, the latencies of MEP (MEPLT) were measured by the same doctor who did not know the results of clinical examinations, assessment scores or image findings. MEP was elicited by transcranial magnetic stimulation with a 120-mm diameter circular coil (MagPro stimulator, MC125, Dantec, Skovlunde, Denmark) and recorded by electromyographic equipment (Nihon Kohden, Neuropack, Tokyo, Japan). The centre of the stimulator was

2 cm in front of the vertex with a clockwise-inducing current flow for the right motor cortex and counterclockwise for the left. The intensity was 30% above motor threshold. Surface recording electrodes were placed at both sides of the abductor hallucis (AH). The electrode impedance was maintained at <5 k Ω and the bandpass filter was set to 20 Hz~3 kHz. Five stimulations were performed and MEPLT was measured from the response with the shortest latency. The longest MEPLT recorded at the bilateral AH was chosen for statistical analysis.

Assessment methods

All patients were diagnosed and assessed by experienced spine specialists who did not know the results of electrophysiological examinations. Patient ages, gender, stature, duration of symptoms, limb symptoms (unilateral or bilateral), affected disc levels and walking distance of NIC were collected from the clinical records and/or patient self-assessment reports.

The Japanese Orthopaedic Association (JOA) score was used for clinical evaluation, which contains subjective symptoms (low back pain, leg pain and gait), clinical signs [straight leg raising (SLR) test, sensory and motor disturbances], restriction of activities of daily living (ADL) and urinary bladder function. A 10 point visual analogue scale (VAS) was used to assess back pain, leg pain and leg numbness (0 indicates complete absence of pain/numbness and 10 represents the worst level of pain/numbness) at the same time as all other clinical data were obtained.

For radiographic assessment, roentgenograms were used to assess whether the patients demonstrated degenerative spondylolisthesis. The minimal cross-sectional area (mCSA) of the cauda equina at the involved level(s) on magnetic resonance imaging (MRI) was measured using imaging software (Adobe® Photoshop® 7.0). In patients with multiple affected levels, the CSA at the narrowest level was chosen for evaluation in this study.

Statistical analysis

SPSS® 12.0 J for Windows (SPSS Inc., Chicago, IL, USA) was used for statistical analysis. As it was reported that MEPLT has a significant relationship with height [22], a correction for height was used to standardise the data to the average stature (157 cm) of our group for statistical comparison according to the following formula: corrected MEPLT=MEPLT $\times$ stature/157.

To determine significant differences, an unpaired *t*-test was performed and correlation analysis between parameters was evaluated by Pearson's correlation coefficients and partial correlation coefficients. The level of significance was set at *p*<0.05.

Results

A total of 23 cases of LSS patients, consisting of 12 men and 11 women, met the criteria described above. Twelve patients had degenerative spondylolisthesis. Fourteen patients had bilateral and nine cases had unilateral leg symptoms. The number of involved disc levels was one in 15 cases, two in seven cases and three in one case, and the affected levels were L2–3 in three, L3–4 in seven, L4–5 in 21 and L5–S1 in one case.

The average latencies of MEP, age, stature, duration of symptoms, walking distance, JOA score, VAS and mCSA are shown in Table 1.

Walking distance was less than 100 m in five, less than 500 m but more than 100 m in 12 and more than 500 m in six cases, while mCSA was less than 0.4 cm² in 11, less than 0.7 cm² but more than 0.4 cm² in ten and more than 0.7 cm² in two cases. The VAS was divided into four groups: absent (0–1), moderate (2–4), strong (5–7) and very severe pain or numbness (8–10). The JOA scores of clinical signs (SLR test, sensory and motor disturbances) and VAS scores for back pain, leg pain and leg numbness are shown in Figs. 1 and 2.

Analysis of factors

The MEPLT was significantly delayed in patients with a walking distance less than 500 m ($p=0.003$). The MEPLT tended to be delayed in patients with bilateral symptoms ($p=0.097$) or a VAS score for numbness more than 8 ($p=0.047$). We did not find any significant difference in MEPLT in relation to gender, with or without degenerative spondylolisthesis, involved disc levels (multilevel or single-

Table 1 Characteristics of the subjects

	Mean±SD	Max.	Min.
MEPLT (ms)	42.1±2.8	47.5	37.7
Age (years)	67.9±8.5	83	52
Stature (cm)	157.2±8.2	173	145
Affected disc levels	1.4±0.6	3	1
Duration of symptoms (months)	31.5±31.8	120	3
Walking distance of NIC (m)	302.1±302.8	1,000	3
JOA score (29 patients)	15.9±4.8	23	4
Subjective symptoms (9 patients)	3.9±1.5	7	2
Clinical signs (6 patients)	4.8±1.4	6	1
Sensory disturbance (2 patients)	1.6±0.7	2	0
Motor disturbance (2 patients)	1.5±0.6	2	0
SLR (2 patients)	1.8±0.5	2	0
ADL (14 patients)	7.5±2.4	13	3
VAS for low back pain	6.0±2.9	10	0
VAS for leg pain	7.7±1.9	10	3
VAS for numbness	7.3±3.0	10	0
mCSA (cm ²)	0.4±0.2	0.9	0.1

Fig. 1 Distribution of neurological findings

level), duration of symptoms (more than or less than 33 months) [18] and degrees of motor or sensory disturbances (Tables 2 and 3).

Correlation analysis

Partial correlation coefficients were calculated to exclude the effect of stature. MEPLT was related to walking distance ($p=0.034$), limb symptoms (unilateral or bilateral limb, $p=0.009$) and the VAS for numbness ($p=0.005$), but did not show any relationship with diagnosis, involved disc levels, duration of symptoms, total JOA scores or any of its components, the VAS for back pain, the VAS for leg pain or mCSA (Table 4).

Discussion

Most LSS patients demonstrated severe symptoms without obvious neurological deficits. In our group, only patients

Fig. 2 Distribution of VAS scores

Table 2 Association between MEPLT and clinical factors

	Walking distance		<i>p</i> value
	<500 m (<i>N</i> =17)	≥500 m (<i>N</i> =6)	
MEPLT (ms)	42.9±2.8	39.7±1.5	0.003*
Symptoms	3.6±1.5	4.8±1.3	0.142
Clinical signs	4.8±1.4	5.0±1.4	0.741
ADL	7.6±2.7	7.0±0.8	0.440
Diagnosis			
	LSS (<i>N</i> =11)	LSS + DS (<i>N</i> =12)	
MEPLT (ms)	41.7±2.8	42.5±3.0	0.497
Limb symptoms			
	Unilateral (<i>N</i> =9)	Bilateral (<i>N</i> =14)	
MEPLT (ms)	41.0±1.6	42.8±3.3	0.097
Involved levels			
	Single level (<i>N</i> =15)	Multiple levels (<i>N</i> =8)	
MEPLT (ms)	42.4±3.4	41.5±1.3	0.376
Duration of symptoms			
	<33 months (<i>N</i> =13)	≥33 months (<i>N</i> =10)	
MEPLT (ms)	41.9±2.0	42.5±4.1	0.685
Gender			
	Female (<i>N</i> =11)	Male (<i>N</i> =12)	
MEPLT (ms)	41.7±3.0	42.5±2.6	0.507

**p*<0.01

LSS lumbar spinal stenosis, DS degenerative spondylolisthesis

one and two respectively, demonstrated severe sensory and/or motor disturbance on neurological examination, while most of them had severe symptoms and walking difficulty as shown in Figs. 1 and 2. Although MEP has been proven to be useful in assessing the neural function of the descending motor pathway, we did not find a correlation between MEPLT and JOA scores of motor disturbance. MEPLT was only relatively delayed in patients showing motor deficit (MMT<2) on physical examinations, but there was no significant difference shown in Table 2. Thus, subjective assessment might be a more reliable reflection of the real severity of neurological conditions than findings on physical examina-

Table 3 Association between MEPLT with JOA scores of motor disturbance and VAS for numbness

	Motor disturbance		<i>p</i> value
	<2 (<i>N</i> =10)	≥2 (<i>N</i> =13)	
MEPLT (ms)	42.4±2.5	41.8±3.2	0.634
VAS for numbness			
	<8 (<i>N</i> =9)	≥8 (<i>N</i> =14)	
MEPLT (ms)	41.0±1.5	43.1±3.2	0.047

Table 4 Correlation of MEPLT with clinical factors and assessment scores (partial correlation coefficients)

	MEPLT	<i>p</i> value
Diagnosis	0.029	0.898
Limb symptoms	0.545	0.009**
Involved levels	-0.202	0.367
Duration of symptoms	0.291	0.188
Gender	-0.233	0.297
Walking distance	-0.455	0.034*
JOA score	-0.219	0.368
Subjective symptoms	-0.401	0.079
Clinical signs	-0.191	0.420
Sensory	-0.322	0.144
Motor	-0.181	0.419
SLR	0.105	0.463
ADL	-0.049	0.841
VAS for back pain	0.242	0.305
VAS for leg pain	0.245	0.299
VAS for numbness	0.605	0.005**
mCSA	-0.233	0.297

p*<0.05 ; *p*<0.01

tions [13]. In our research, MEPLT showed some significant relationships with subjective assessment data, including walking distance of NIC, limb symptoms (bilateral or unilateral) and the VAS for numbness.

NIC is one of the characteristic symptoms of LSS. Patients develop progressive symptoms of radicular pain, paraesthesias, numbness and/or motor weakness initiated or worsened by walking and released by sitting. The pathological reasons are thought to be reversible nerve root ischaemia and venous congestion. Walking ability has been widely studied and is considered a useful assessment method and prognostic predictor in LSS patients. Greater walking ability, milder symptoms and better self-rated health may predict a better prognosis [1, 14]. Walking ability can be assessed by a walking test [8] or self-assessment [17]. In our study, walking distance was defined as how long the patient could walk without resting as assessed by the patients themselves. According to our results, MEPLT showed a negative relationship with walking distance. Although MEPLT was significantly delayed in patients whose walking distance was less than 500 m, there was no significant difference in JOA scores of clinical symptoms, signs or ADL compared to those of patients whose walking distance was more than 500 m, as shown in Table 2. This finding demonstrated that MEP can predict a neurological deficit prior to its appearance and reflects subjective severity of motor dysfunction in LSS.

Some authors have reported that preoperative leg pain may predict neurological function and leg symptom outcomes. Atlas et al. [4] reported unilateral symptoms as an independent predictor of satisfaction after a four-year

follow-up of 119 patients. Yamashita et al. [23] followed up 181 cases for two years after surgery and reported that patients with unilateral leg pain showed significantly greater improvement in function and leg symptoms than patients with bilateral leg pain after surgery. In our research, we found a positive correlation between MEPLT and limb symptoms. Patients with bilateral pain or numbness showed more prolonged MEPLT than those with only unilateral limb symptoms. These findings may indicate that patients with bilateral symptoms have a more severe neurological deficit and may be one explanation of the findings reported by Atlas et al. and Yamashita et al. However, no postoperative MEP data were examined in this study, and both the neurological condition of patients and outcome measures in our study differed from those of the previous reports. Further study of postoperative MEP data are still needed in order to verify this hypothesis.

Our research also showed a positive relationship between MEPLT and the VAS for numbness. Many studies have reported that the VAS score for low back pain and leg pain improved markedly after surgery and that the VAS can be used to describe the intensity of symptoms and assess the results of clinical treatment during follow-up [25]. However, the VAS for leg numbness has mostly been used by Japanese authors [23] and seldom performed in many studies. Actually, limb numbness is one of the main symptoms in LSS patients. Goh et al. [11] investigated the clinical symptoms associated with LSS and reported that 66.6% of the patients experienced numbness or tingling of the legs. Since numbness is usually associated with a feeling of muscular weakness in most of LSS patients, the VAS for numbness may also reflect a subjective assessment of the severity of motor weakness in the lower limbs. Moreover, the VAS for numbness is also related to limb symptoms in our study. These findings may indicate the clinical value of the VAS for numbness in assessing LSS, and it may appropriate to use the VAS for numbness as a routine evaluation of LSS patients.

Some clinical factors might be related to the severity of neurological deficit or prognosis of LSS, such as gender, duration of symptoms [18], multilevel involvement [20], association with degenerative spondylolisthesis and imaging findings. We could not find any relationship between MEPLT and these factors. Concerning imaging assessment, some authors [19] have reported that patients may not achieve a good recovery if the mCSA is less than 70 mm²; however, in our series mCSA was larger than 70 mm² in only two cases, and there was also no correlation between MEPLT and mCSA. The duration of symptoms has been considered to be an important factor [18], but we could not find a significant relationship between MEPLT and the duration of symptoms. The reason may be the difference in the inclusion criteria between our study and those of other

researchers. As all of our patients had associated NIC and were scheduled for surgical treatment because of severe symptoms, data from patients with mild symptoms were not included in our research.

Several authors have investigated the sensitivity of MEP in LSS or lumbosacral cord lesions and reported that the rate of abnormal MEP was increased after exercise [3, 6, 9, 15, 16]. Baramki et al. [6] reported that MEPLT was significantly prolonged after walking a certain distance and concluded that exercise significantly increased the sensitivity of MEP in detecting roots under functional compression in LSS. In that research, the ratio of patients showing MEPLT abnormality was 66% before exercise and 76% after exercise. Adamova et al. [3] found a similar tendency, but did not recognise significant differences between pre- and post-exercise values of MEPLT. It was reported that graded compression of the cauda equina can cause progressive reduction of nerve conduction velocity [21]. As pressure in the spinal canal may be increased by venous congestion after walking, a dynamic technique may be able to induce the prolongation of MEPLT and be useful for diagnosing LSS in the early stage. Although MEPLT assessment was useful at rest in this study, more meaningful results may be recognised using a dynamic method in any future study.

All our findings indicate that MEP can reflect the subjective severity of LSS and may be able to predict the prognosis of LSS patients. As no postoperative MEP data were examined this issue warrants further investigation of changes in MEPLT after surgery.

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