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Dynamic electrophysiological examination in patients with lumbar spinal stenosis: Is it useful in clinical practice?

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Abstract Neurogenic claudication (NC) is typical of lumbar spinal stenosis (LSS). One suspected pathophysiological mechanism underlying NC is intermittent hypoxia of cauda equina fibres resulting from venous pooling, which may lead to ischaemic nerve conduction failure and to transient clinical and electrophysiological changes after exercise. The aim of this study was to evaluate the appearance of significant transient electrophysiological abnormalities after walking exercise in patients with LSS and to establish the contribution of dynamic electrophysiological examination in the differential diagnostics of patients with LSS. The study participants were 36 consecutive patients with LSS demonstrated by computed tomography (CT). The control groups included, respectively, 28 patients with diabetes mellitus and clinically manifested polyneuropathy, and 32 healthy volunteers. The LSS patients were divided into four subgroups based on the clinical severity of the disease (with respect to the presence or absence of NC in the history and pareses on neurological examination). Soleus H-reflex, tibial F-wave and motor evoked potentials (MEPs) to abductor hallucis muscle were examined in all groups, before and after quantified walking on a treadmill. The electrophysiological parameters measured after an ex-

ercise treadmill test (ETT) in LSS patients and in both control groups were compared with the same parameters obtained before ETT. The study shows that the electrophysiological parameters reveal minimal but statistically significant changes after walk loading in patients with LSS (a prolongation of the minimal latency of the tibial F-wave and of the latency of the soleus H-reflex). The changes in these parameters were demonstrated not only in patients with NC but also in patients without NC. More pronounced changes were found in LSS patients exhibiting chronic lower extremity pareses. Conclusions: From among a large battery of electrophysiological tests, only the minimal latency of the tibial F-wave and the latency of the soleus H-reflex exhibit changes after walk loading in patients with LSS. These are minimal but statistically significant. Dynamic electrophysiological examination can illustrate the pathophysiology of NC in LSS, but from a practical point of view its contribution to the differential diagnostics of LSS or diabetic polyneuropathy is limited by an absence of established cut-off values.

Keywords Lumbar spinal stenosis · Dynamic electrophysiological examination · Neurogenic claudication · Exercise treadmill test

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Introduction

Lumbar spinal stenosis (LSS) is defined as any type of narrowing of the spinal canal, nerve root canals, or intervertebral foramina [7]. In the pathogenesis of LSS, the degenerative process in the lumbar spine is the main component producing compression of neural tissue in the spinal and/or nerve root canal [5]. Such stenosis is classified as central or lateral, congenital or acquired; combinations are common. Central stenosis implies narrowing in the spinal canal, lateral stenosis in the nerve root canal.

LSS can give rise to several clinical syndromes: neurogenic claudication (NC), low back pain and/or radiculopathy, or chronic cauda equina syndrome. Postural dependency is a hallmark of the symptoms of LSS. Spinal extension narrows the spinal canal and exacerbates symptoms, whereas spinal flexion increases the dimensions of the spinal canal and reduces symptoms [16, 19, 20]. NC is typical of LSS and is characterised by intermittent pain and paresthesia of the leg(s), most often in a lumbosacral root distribution, followed by weakness apparent on walking or standing [10, 12]. Patients usually describe walking downhill as worse than walking uphill, and cycling is no problem. These signs are a useful discriminator between neurogenic and vascular claudication [17]. The incidence of NC is reported at 11–100% in patients with LSS; a mean calculated from 32 studies is 62% [22]. Symptoms usually affect men aged more than 50 years [17]. LSS is currently the most common diagnosis for individuals over the age of 65 undergoing spinal surgery [22]. One suspected pathophysiological mechanism underlying NC is intermittent hypoxia of cauda equina fibres resulting from venous pooling, which may lead to ischaemic nerve conduction failure and to transient clinical and electrophysiological changes after exercise [8, 15, 17]. The pain is explained by the ischaemia-related activation of pain receptors, and weakness would be caused by a partial conduction block at root level [14, 15]. At least two levels of cauda equina fibre compression are necessary for the development of NC (at least one level of central stenosis) [18].

The use of dynamic electrophysiological examination in patients with LSS and NC to verify transient changes of electrophysiological parameters after walking or standing is described in the literature. Few studies have evaluated the effects of NC on the parameters of the F-waves [12, 13, 15, 21], soleus H-reflex [15], motor evoked potentials (MEPs) [8] and somatosensory evoked potentials (SEPs) from the lower extremities [11]. Reversibility of changed electrophysiological parameters is described over 7–30 minutes [15, 11]. However, our own experience and our previous study have demonstrated that the changes in electrophysiological parameters were minimal in patients with mild LSS after load on a treadmill [3].

Diabetic polyneuropathy and LSS are common ailments of advancing age. Many people suffer from LSS and diabetic polyneuropathy at the same time. Differentiation may

sometimes be difficult in such patients, if the cause of signs and symptoms described by patients is LSS or polyneuropathy [4]. Both diseases may present with numbness and tingling of the feet, and helpful clinical clues such as back pain, proximal weakness, or radiating pain into the legs may be absent [9]. In such a situation, electrophysiological examination can be useful.

The aim of this study was to evaluate the appearance of significant transient electrophysiological abnormalities after walking exercise in patients with LSS and to establish the contribution of dynamic electrophysiological examination in the differential diagnostics of patients with LSS.

Materials and methods

Patients with LSS

Thirty-six patients (21 men, 15 women) were recruited consecutively from a total of 132 patients with LSS who had been treated and observed in the Department of Neurology, University Hospital, Brno, between 1998 and 2001. They were divided into four subgroups with respect to (1) the presence or absence of NC in the history and (2) pareses of the lower limbs on neurological examination (Table 1, Table 2).

In a previous study we established that the presence of NC and pareses was the only statistically significant parameter to influence walking ability in these patients [1]. Walking capacity was evaluated by a walking test (an evaluation of the ability to cover a distance of 10 m and the time needed to do so, walking without help as quickly as possible), which is proven to be an acceptable endpoint for risk stratification of LSS patients. It was confirmed that the risk status of LSS patients increased in the following order: $L_1 < L_2 < L_3 < L_4$. The risk status of LSS patients expresses the risk of decreased walking ability (10-m walking test performed in a time of more than 15 s). The presence of pareses was more of a risk factor for clinical severity of LSS than was the presence of NC.

Inclusion criteria for the selected patients with LSS

The following inclusion criteria were used:

- Clinically symptomatic LSS (NC and/or low back pain)
- At least one-level central LSS documented by computed tomography (CT)
- Age between 25 and 70 years
- Absence of hip- and/or knee-joint arthrosis that would limit walking
- Absence of arteriosclerotic peripheral vascular disease of the lower extremity that would limit walking

Table 1 Subgroups of patients with lumbar spinal stenosis (LSS) by presence or absence of neurogenic claudication (NC) and pareses of the lower extremities

Subgroup of LSS patients	Sample size	NC	Pareses of the lower extremities
L ₁	12	Absent	Absent
L ₂	14	Present	Absent
L ₃	4	Absent	Present
L ₄	6	Present	Present

Table 2 Basic characteristics of the groups compared. Quantitative parameters are expressed as median estimates with 10%–90% quantiles in parentheses (LSS lumbar spinal stenosis, AP anteroposterior)

Parameter	Healthy controls		Diabetic patients		LSS patients			
					Subgroup L_{1+2}		Subgroup L_{3+4}	
Sample size	32		28		26		10	
Age (years)	48	(33; 60) ^a	48	(27; 68) ^a	52	(38; 65) ^a	56	(40; 67) ^a
Height (cm)	170	(160; 184) ^a	175	(163; 183) ^a	168	(159; 182) ^a	176	(163; 184) ^a
Sex (% M/F)	34.4/65.6 ^a		64.3/35.7 ^b		53.9/46.2 ^{ab}		70.0/30.0 ^b	
Radiological parameters – spinal canal diameter (mm)								
Smallest AP diameter			14.5	(13.0; 18.0) ^a	11.0	(8.1; 12.7) ^b	10.2	(7.4; 12.8) ^b
Smallest transverse diameter			23.5	(20.0; 27.0) ^a	15.20	(7.4; 17.8) ^b	12.7	(6.5; 18.1) ^b

^{a-b}Letters indicate statistical significance within one row; groups marked with the same letter are not significantly different ($p > 0.05$; Mann–Whitney U-test for quantitative parameters, binomial test for relative frequencies)

- Absence of diabetes mellitus
- No serious cardiac disease
- Ability to undergo exercise treadmill test (ETT)
- Absence of pacemaker and no epileptic seizures in the history (capacity to undergo MEPs)

Control groups

Two control groups were assessed. One was a group with diabetic polyneuropathy; the other was a group of healthy volunteers. The individuals for control groups were selected for comparability with the LSS patients with respect to age and height.

There were 28 patients with diabetic polyneuropathy (18 men, 10 women) in the first control group (Table 2). The criteria for inclusion in this group were:

- Diabetes mellitus type I or II
- Signs of polyneuropathy (numbness and/or tingling of feet)
- No low back pain or NC
- Normal diameters of the lumbar spinal canal
- Absence of arteriosclerotic, peripheral vascular disease of the lower extremity that would limit walking
- No serious cardiac disease
- Ability to undergo exercise treadmill test (ETT)
- Absence of pacemaker and no epileptic seizures in the history (capacity to undergo MEPs)

The second control group comprised 32 healthy volunteers (11 men, 21 women) without low back pain or NC in their history, without diabetes mellitus, with no complaints and normal clinical findings from the lower extremities (Table 2).

Radiological examination

The patients were examined radiologically according to the following protocol: (1) A plain radiograph of the lumbar spine was taken in the LSS patients, with assessment of the presence of spondylarthrosis, scoliosis and degenerative or isthmic spondylolisthesis; (2) CT axial scans at three levels (L3–S1) were performed in LSS patients and in patients with diabetic polyneuropathy. The following standard parameters of the spinal canal were measured:

- The anteroposterior (AP) diameter of the spinal canal at the level of the middle of the L3, L4, and L5 vertebrae
- The transverse interarticular (IA) diameter (between ventral margins of facet joints) at the level of the upper margins of the L3/4, L4/5 and L5/S1 discs
- The lateral recess diameter, bilaterally, at the same level as the transverse diameter

CT criteria for spinal stenosis were based on our own normal data [2]:

- Central stenosis: anteroposterior diameter < 11.7 mm and/or transverse diameter < 16.0 mm
- Lateral stenosis: lateral recess diameter < 5.2 mm

The lowest anteroposterior and transverse diameters at L3–S1 levels were evaluated.

Exercise treadmill test

Quantified walking (speed for the first 3 min, 1.6 km/h; next 3 min, 2.4 km/h; following 3 min, 3.2 km/h; and final 3 min, 4.0 km/h) on a treadmill was performed in all groups. In the event of patient discomfort during walking (e.g., NC, dyspnea, etc.), the exercise was aborted.

Electrophysiological examination

In all groups the following parameters were examined before and after ETT:

- Soleus H-reflex (determination of latency and amplitude); sub-maximal stimuli with increasing voltage were delivered to provide maximum H-reflex amplitude
- Tibial F-wave (determination of minimal latency, chronodispersion)
- Motor evoked potentials (MEPs) to abductor hallucis (AH) muscle (determination of spinal latency, cortical latency, central motor conduction time, amplitude of cortical response)

In patients with LSS and diabetic patients, electrophysiological examination was extended by motor and sensory conduction studies from the lower extremities and needle EMG from L4–S1 myotomes.

To ensure that the placement of electrodes before ETT was identical to the placement of electrodes after ETT, the positions of recording and stimulating electrodes during electrophysiological examination before ETT were drawn on the skin of the individuals examined.

Clinical examination in LSS patients

Patients with LSS also underwent a clinical examination according to the following protocol:

- Walking test: evaluation of the ability to cover a distance of 10 m, and the time needed to do so, walking without help as quickly as possible

Table 3 Identification of two subgroups of patients with lumbar spinal stenosis (LSS) with respect to the presence of pareses (NC neurogenic claudication, P pareses, L_{1+2} LSS patients without pareses, L_{3+4} LSS patients with pareses)

Subgroup of LSS patients	Sample size	NC/P (%) ¹	10-m walking test ² (time in s)	10-m running test ²		More than 1 central stenotic level ² (% of cases)	The smallest diameter of spinal canal (mm) ²	
				ability (%)	time in s ³		Transverse	Antero-posterior
L_{1+2}	26	53.8/0	9.2 ^a (7.8; 10.6)	88.5	4.4 ^a (3.9; 4.9)	76.9	14.5 ^a (13.0; 16.0)	10.6 ^a (9.9; 11.2)
L_{3+4}	10	60.0/100	10.1 ^a (7.7; 12.4)	80.0	5.1 ^a (4.1; 5.9)	80.0	11.2 ^b (8.2; 12.7)	10.5 ^a (9.3; 11.6)
All LSS patients	36	55.6/27.8	9.7 (8.3; 11.2)	86.1	4.7 (4.0; 5.4)	77.8	13.1 (11.2; 14.2)	10.5 (9.6; 11.5)

¹The presence (in %) of pareses and neurogenic claudication²Quantitative parameters are expressed as geometrical mean estimates supplied with appropriate 95% confidence limits (in parentheses)³Only patients able to perform 10-m running test^{a-b}Letters indicating statistically significant differences between compared subgroups: subgroups marked with the same letter are not significantly different ($p > 0.05$; Mann-Whitney U-test for quantitative parameters, binomial test for relative frequencies)

- Running test: evaluation of the ability to cover a distance of 10 m, and the time needed to do so, running without help as quickly as possible
- Evaluation of the presence of NC in the patient's history
- Evaluation of the presence of pareses of the lower extremities

Statistical methods

A value $p < 0.05$ was taken as a universal indicative limit for statistical significance in all univariate analyses.

Initial quantitative diagnostic data were descriptively summarised using common robust statistics (i.e., median estimate with 10% and 90% quantiles) and then compared among groups on the basis of the Mann-Whitney U-test. Standard descriptive statistics were used to express the mean differences among subgroups of cases (arithmetic mean for electrophysiological parameters; geometrical mean for study endpoints – i.e., time for 10-m walking test and running test). Differences in the values of electrophysiological parameters before and after ETT were expressed as the arithmetical mean supplied with 95% confidence limits and tested for statistical significance using the pairwise t -test [6, 23].

Results

Patients with LSS were divided into four subgroups with respect to the presence or absence of NC in the history and weakness (pareses) of the lower limbs on physical examination (Table 1). Evaluation of electrophysiological parameters before and after ETT were performed from two points of view: (1) the population of LSS patients was analysed with respect to the presence of weakness of the lower extremities. We fused subgroups L_1 and L_2 (subgroups without pareses) and subgroups L_3 and L_4 (patients with chronic weakness) (Table 3); (2) patients with LSS were analysed with respect to the presence of NC. We fused subgroups L_1 and L_3 (patients without NC) and subgroups L_2 and L_4 (with NC).

1. Dynamic electrophysiological examination with respect to the presence of pareses in patients with LSS

We compared the changes in selected electrophysiological parameters after ETT in healthy volunteers, patients with diabetic polyneuropathy and two subgroups of LSS patients (L_{1+2} and L_{3+4}) (Fig. 1). Significant changes were found only in the minimal latency of the tibial F-wave (in both subgroups of LSS patients) and in the latency of the soleus H-reflex (only in subgroup L_{3+4}). We also discriminated on the basis of the frequency distribution of changes in the minimal latency of the tibial F-wave and the latency of the soleus H-reflex (Fig. 2). The frequency histograms show that it is not possible to establish cut-off values for electrophysiological parameters of LSS patients and control groups. Therefore, dynamic examinations are limited from the practical electrophysiological point of view.

2. Dynamic electrophysiological examination with respect to the presence of NC in patients with LSS

We established a group of 16 patients without NC (subgroups L_1+L_3) and a group of 20 patients with NC (subgroups L_2+L_4). The changes in selected electrophysiological parameters after ETT in healthy volunteers, patients with diabetic polyneuropathy and two subgroups of LSS patients (L_{1+3} and L_{2+4}) were compared (Fig. 3). Minimal changes after ETT were found only in the minimal latency of the tibial F-wave in LSS patients. Changes in the latency of the soleus H-reflex in LSS patients with NC were not statistically significant in comparison with the two control groups and the subgroup of LSS patients without NC.

These results document that changes in electrophysiological parameters (a prolongation of the minimal latency

Fig. 1 Pairwise comparison of changes in electrophysiological parameters influenced by exercise treadmill test in healthy volunteers, patients with diabetic polyneuropathy and two subgroups of lumbar spinal stenosis (LSS) patients. (HV healthy volunteers, DM patients with diabetic polyneuropathy, LS1–2 LSS patients without paresis, LS3–4 LSS patients with paresis). Data are expressed as arithmetical mean supplied with 95% confidence limit. P-level: significance level of pairwise *t*-test. A: differences are not statistically significant. B: differences are statistically significant in specified parameter ($p < 0.05$)

of the tibial F-wave and of the latency of the soleus H-reflex) were found in patients with LSS after ETT. The changes were, however, minimal and were more influenced by the presence of lower extremity weakness than by the presence of NC.

Discussion

Changes in various electrophysiological parameters after walk loading or standing in patients with LSS and NC are described in the literature. Authors have reported changes in the F-wave parameters (non-elicitability, increase in minimal latency or chronodispersion) [12, 13, 15, 21], soleus H-reflex (changes in the recruitment curve of the soleus H-reflex) [15], motor evoked potentials (prolongation of

the motor evoked potential latency time (cortical latency) and/or the peripheral motor conduction time) [8] and somatosensory evoked potentials from the lower extremities [11]. Pastor noted change in the recruitment curve of the soleus H-reflex after walking in LSS patients with NC. The H-reflex showed a transient increase in its threshold intensity with respect to that of the M wave in seven patients (70%) [15].

Baramki et al. demonstrated that clinical examination was positive in about 30% of patients with LSS, while MEPs were prolonged in 66% of patients before exercise, increasing to 76% following exercise. They concluded that exercise increases the sensitivity of MEPs in the detection of roots under functional compression in LSS [8]. Kondo et al. studied the effect of NC on nerve conduction along the sensory pathway. They evaluated 37 patients with acquired LSS and described the abnormality of stress-SEPs after walking (decrease of amplitude and prolongation of latency) in 31 patients. In seven of nine patients operated on, SEPs after walking remained unchanged postoperatively [11]. It is assumed that the presence of these transient changes in electrophysiological parameters can explain the aetiology of neurogenic claudication.

In our study, significant changes after walk loading (after ETT) were demonstrated in the minimal latency of the

Fig. 2 Frequency histogram of differences between post- and pre-exercise values of latency of the tibial F-wave and latency of the soleus H-reflex. (*LSS patients*: patients with lumbar spinal stenosis, *L₃₊₄* patients with lumbar spinal stenosis with pareses)

tibial F-wave and the latency of the soleus H-reflex. Both parameters exhibited a mild prolongation of latencies after ETT. Changes in these parameters were recorded not only in patients with NC but also in patients without NC. One possible explanation is that the walking also evokes an asymptomatic ischaemic conduction block of cauda equina fibres, with subsequent influence on the electrophysiological parameters; however, patients did not experience claudication. This hypothesis cannot be supported by the literature, since subclinical changes of electrophysiological parameters in patients with LSS without NC still remain to be evaluated. In our study, more pronounced changes were found in LSS patients with permanent weakness. This finding is in accordance with the results of another study in which significant differences between the values of electrophysiological parameters, measured be-

fore and after exercise, occurred in patients with signs of neurological deficit (motor and/or sensitive deficit) [8]. This difference was not found to be significant in patients without neurological deficits. The changes in MEP latencies described by Baramki were relatively small. The most frequent change in the MEP-latency time was found to be between 5% and 8% of the baseline value in patients with neurological deficit, while it was 5% or less in the patients without neurological deficit.

In our study we found no significant difference between pre- and post-exercise values of chronodispersion of the tibial F-wave and MEP parameters in LSS patients.

Manganotti et al. reported that chronodispersion of F-waves showed a significant decrease for both the peroneal and tibial nerve after walking in healthy subjects. They assume that F-wave changes observed in dynamic conditions probably reflect a synchronisation of motor-neuron firing requiring a certain amount of descending facilitation [13].

We are not able to confirm this finding. No significant changes in the electrophysiological parameters evaluated

Fig. 3 Pairwise comparison of changes in electrophysiological parameters influenced by exercise treadmill test in healthy volunteers, patients with diabetic polyneuropathy and two subgroups of lumbar spinal stenosis (LSS) patients. (HV healthy volunteers, DM patients with diabetic polyneuropathy, LS1–3 LSS patients without NC, LS2–4 LSS patients with NC). Data are expressed as arithmetical mean supplied with 95% confidence limit. P-level: significance level of pairwise *t*-test. A: differences are not statistically significant. B: differences are statistically significant in specified parameter ($p < 0.05$)

were found in patients with diabetic polyneuropathy and healthy volunteers after ETT.

Conclusions

From among an extensive battery of electrophysiological tests, only the minimal latency of the tibial F-wave and

the latency of the soleus H-reflex reveal changes after walk loading in patients with LSS. These are minimal but statistically significant. No significant changes in electrophysiological examination after walk loading were found among healthy volunteers and patients with diabetic neuropathy. Dynamic electrophysiological examination can illustrate the pathophysiology of NC in LSS, but from a practical point of view its contribution to the differential diagnostics of LSS or diabetic polyneuropathy is limited by an absence of established cut-off values.

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