Neurological impairment score in lumbar spinal stenosis

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Abstract

Background and aim The Oswestry Disability Index (ODI) is an interview-based instrument generally accepted as a measure of disability in patients with lumbar spinal stenosis (LSS). There is, however, no generally accepted measure for neurological impairment in LSS. We therefore developed a scoring system [neurological impairment score in lumbar spinal stenosis (NIS-LSS)] for the assessment of neurological impairment in the lower limbs of patients with LSS, then performed a validation study to facilitate its implementation in the routine clinical evaluation of patients with LSS.

Methods The NIS-LSS is based on the combined evaluation of tendon reflexes, tactile and vibratory sensation, pareses, and the ability to walk and run; the total score ranges from 0 (inability to walk) to 33 points (no impairment). A group of 117 patients with LSS and a control group of 63 age- and sex-matched healthy volunteers were assessed with the NIS-LSS to evaluate capacity to discriminate between LSS patients and controls. A correlation with the ODI was performed for assessment of construct validity.

Results The median NIS-LSS was 27 points in LSS patients compared with 33 points in controls. The NIS-LSS discriminated LSS patients from healthy controls to a high degree of significance: the optimum NIS-LSS cut-off value was 32 points with a sensitivity of 85.5 % and a specificity of 81.3 % ($p < 0.001$). Overall NIS-LSS correlated significantly with the ODI score ($p < 0.001$). Vibratory sensation ($p = 0.04$), presence of paresis ($p = 0.01$) and especially the ability to walk and run ($p < 0.001$) were the NIS-LSS elements that correlated most closely with the degree of disability assessed by the ODI.

Conclusions The NIS-LSS is a simple and valid measure of neurological impairment in the lower limbs of patients with LSS (without comorbidity), discriminating them from healthy controls to a high degree of sensitivity and specificity and correlating closely with the degree of disability. It extends our ability to quantify neurological status and to follow changes arising out of the natural course of the disease or the effects of treatment.

Keywords Oswestry Disability Index · Lumbar spinal stenosis · Neuromuscular impairment · Neurogenic claudication

Abbreviations

AUC	Area under the curve
CI	Confidence interval
CT	Computed tomography
JOA	Japanese Orthopaedic Association
LSS	Lumbar spinal stenosis
MRI	Magnetic resonance imaging
NC	Neurogenic claudication
NIS-LSS	Neurological impairment score in lumbar spinal stenosis
NMI	Neuromuscular impairment index

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ODI	Oswestry disability index
ROC	Receiver operating characteristic
SIP	Sickness impact profile
VAS	Visual analogue scale

Introduction

Various scores and scales are used both in research and routine clinical practice to assess patient status as exactly and quantifiably as possible and to evaluate therapeutic effects in patients with spinal disorders, including those with LSS. A summary of the most commonly used scales, questionnaires and quantified examinations for LSS patients appears in Table 1 [1–13].

Table 1 The most commonly used scales, questionnaires and quantified examinations for LSS patients (modified by Fritz) [1]

Type of examination or evaluation	Scale, questionnaire, parameter
History	Visual analogue scale (VAS) Pain intensity numerical rating scale (PI-NRS)
Radiological examination	Diameters of the spinal canal, dural sac cross-sectional area (CT, MRI and/or myelo-CT)
Neurological examination	Neurological impairment score in lumbar spinal stenosis (NIS-LSS) [2] Neuromuscular impairment index (NMI) [3] Straight leg raising Spinal range of motion Treadmill walking test
Generic self-reported level of health status	Sickness Impact Profile (SIP) [4] Medical Outcomes Survey 36-item short form (SF-36) [5]
Disease-specific self-reported level of health status (for patients with low back pain)	Oswestry Disability Index (ODI) [6] Roland Morris Disability Questionnaire (RDQ) [7] General Function Score (GFS) [8] Quebec Back Pain Disability Scale [9] Waddell Disability Index [10]
Condition-specific self-reported level of health status (for patients with LSS)	Swiss Spinal Stenosis Questionnaire [11] Beaujon Scoring System [12] Oxford Claudication Score [13]
Self-reported satisfaction with treatment	Swiss Spinal Stenosis Questionnaire – patient satisfaction scale [11]

A visual analogue scale (VAS) for pain, with the patient expressing the intensity of pain in the graphic form of variations in a 10-cm horizontal line, is often used in our department. Another means of pain quantification is a pain intensity numerical rating scale (PI-NRS), an 11-point subjective scale from 0 (no pain) to 10 (the worst possible pain).

The Oswestry Disability Index (ODI) evaluates disturbance to the common activities of daily living attributable to low back pain, quantifies the subjective problems of patients and reports the level of their disability [6, 14–16]. It consists of ten questions, each of which may be answered by one of six different statements. The result is expressed as a percentage (percentage of disability) with 0 % for no disability and 100 % for maximum disability.

To assess patient satisfaction with treatment, we use the patient satisfaction scale provided by the Swiss Spinal Stenosis (SSS) Questionnaire, which consists of six questions about satisfaction with treatment [11].

As a part of routine clinical examination of patients with LSS we test walking on a treadmill to objectify neurogenic claudication and to measure the distance covered before the onset of difficulty. It has been recorded that subjective distance perception is poor by patients and increasing distress appears to have a negative impact on the accuracy of distance perception [17]. The need for objective measurement of the level of activity in patients with LSS is emphasized [18].

Although there exists a generally accepted measure of disability in patients with low back pain, including LSS patients—the ODI—there is no such widely used measure of neurological impairment in LSS patients. To remedy this lack, we developed a score for clinical assessment of the lower limbs (neurological impairment score in LSS) derived from our practical experience with LSS patients (Table 2). The NIS-LSS was originally described as the Ada-Vo score, an abbreviation derived from the first letters of its authors' names (Adamova, Vohanka). The parameters evaluated for the NIS-LSS were selected as the most frequently described objective clinical features in patients with LSS. The total score includes assessment of tendon reflexes, tactile and vibration sensation in the lower limbs, presence of paresis (stand on tiptoe, on heel, squat) and ability to walk and run. The score ranges from 0 to 33 points, with the full number of points (33) representing normal neurological findings in the lower limbs, and 0 points inability to walk [2]. Testing for the score is very simple and may be included after routine neurological examination of the lower limbs. However, practical application of the score is hindered by the fact that it has not yet been validated. Stucki et al. [3] created the neuromuscular impairment index (NMI) to summarize neuromuscular findings in the lower limbs of patients with LSS. This

included assessment of pain perception, vibration, muscle strength and deep tendon reflexes. To the best of our knowledge, this index has not been extended or validated and is not commonly used in practice.

The aim of this study was, therefore, to standardize and validate the NIS-LSS as a measure of neurological impairment in LSS patients.

Methods

Design

The NIS-LSS and the ODI were evaluated in patients with LSS and in an age- and sex-matched group of healthy volunteers. To examine the influence of age, both LSS patients and controls were further divided into four age categories: ≤ 55 , 56–65, 66–75 and $76 \leq$ years. The diagnostic validity of the NIS-LSS in discrimination between LSS patients and controls was evaluated using receiver operating characteristics (ROC) curve analysis with determination of an optimum cut-off value. To evaluate construct convergent validity (the degree of disability as a

construct) we correlated the NIS-LSS and its parameters and the ODI.

This study was reviewed and approved by the local research ethics committee.

Neurological impairment score in lumbar spinal stenosis

The evaluation of both the LSS group and the controls was performed by skilled neurologist. Both lower limbs are tested and five parameters are assessed:

1. *Tendon (myotatic) reflexes in lower limbs*, that is, patellar reflex and Achilles tendon reflex. For each reflex evoked (using facilitating manoeuvres), the person examined is given 1 point, potential score 0–4 points.
2. *Tactile sensation* in lower limbs using a cotton swab. If there is a dysfunction of tactile sensation in both lower limbs, the person examined receives 0 points. If there is a dysfunction of tactile sensation in only one lower limb then the score is 2 points. If tactile sensation is bilaterally normal, the score is 4 points. In our LSS group, 4 patients out of 117 received 3 points, with dysfunction of tactile sensation vague in one lower limb (patient was not completely sure whether a dysfunction of tactile sensation was present).
3. *Vibration sensation* in the lower limbs was assessed using a 128-Hz graduated tuning fork for optimum accuracy. The vibration threshold is recorded on a scale from 0 to 8, with the maximum expressed as 8/8 and minimum 0/8. Vibration sensation was recorded at the external ankle. The threshold for vibration increases with age, so we employed two threshold limits: for those younger than 40 years, the limit was 6/8, for those over 40, the limit was 4/8 [19, 20].
4. *Presence of paresis* of lower limbs was assessed by asking the subject to stand on tiptoe, stand on the heels, and squat. Each exercise successfully performed scored 1.5 points (giving a total range of 0–9 points). Squatting was considered as the ability to stand from a full squatting position. Wherever the results of these tests were in doubt (e.g., where the influence of pain or joint arthrosis appeared possible), the presence of paresis was verified by isometric muscle testing.
5. *Evaluation of ability to walk and run*. If the subject was able to run at least 10 m, 12 points were awarded. If the person was able to walk this distance without support he/she received 9 points. Walk with one crutch scored 6 points, walk with the aid of two crutches earned 3 points. If the subject was unable to walk, the score was 0.

Table 2 Neurological impairment score in lumbar spinal stenosis (NIS-LSS)

Tendon reflexes	
Patellar reflex, Achilles tendon reflex, each evoked reflex 1 point	(0–4 points)
Tactile sensation in lower limbs	
Bilaterally normal 4 points	
Unilateral abnormal 2 points	
Bilaterally abnormal 0 point	(0–4 points)
Vibration sensation in lower limbs (external ankle)	
Bilaterally normal 4 points	
Unilateral abnormal 2 points	
Bilaterally abnormal 0 point	(0–4 points)
Presence of paresis—stand on tiptoe, stand on heels, squat	
Every exercise in one lower limb 1.5 points	(0–9 points)
Walk + run	
Ability to run 12 points	
Walk without support 9 points	
Walk with support of one crutch 6 points	
Walk with support of two crutches 3 points	
Inability to walk 0 point	(0–12 points)
Total	(0–33 points)

The result of the NIS-LSS is the total number of points for all of the above, thus within a range of 0–33 points.

The Oswestry Disability Index

The Czech version of the ODI (version 1.0) was given to the LSS patient group and to the healthy volunteers. The ODI was completed in writing. Patients and controls were told how to complete the questionnaire correctly, and the result expressed as a percentage (thus, per-cent disability). We used the ODI version 1.0 rather than the recently recommended version 2.1a because no other Czech-language version of the ODI was available at the time.

Healthy volunteers

There were 63 people in the group of healthy volunteers. Medical history and clinical neurological examination were scrutinised for exclusion criteria.

Exclusion criteria:

1. Current presence of low back pain
2. Attack of radicular lumbosacral syndrome in medical history
3. Presence of neurogenic claudication or diagnosis of LSS
4. Presence of diabetes mellitus or other disease involving polyneuropathy (e.g. abuse of alcohol, chemotherapy treatment—to eliminate influence of polyneuropathy on the results of the NIS-LSS and the ODI)
5. Presence of hip and/or knee joint arthrosis limiting walking or running
6. Presence of arteriosclerotic peripheral vascular disease of the lower limbs limiting walking
7. Presence of any other serious comorbidity that could influence the results of the NIS-LSS or the ODI (e.g. central paresis of lower limbs, myopathy).

Patients with LSS

There were 117 patients in the clinically symptomatic LSS group.

Inclusion criteria:

1. Clinically symptomatic LSS (presence of neurogenic claudication and/or low back pain radiating below the knee to one or both limbs).
2. Presence of central LSS (an osteoligamentous narrowing of the lumbar spinal canal) at one level at least, established by CT or MRI of lumbar spine.

The CT criteria for central stenosis have been described in detail in a previous study of ours [21]. Anteroposterior and transverse interarticular diameters were measured at

Table 3 Basic characteristics of the groups examined (healthy volunteers and patients with LSS)

	Patients with LSS	Healthy controls	<i>p</i> ^b
Sample size, <i>n</i>	117	63	–
Sex—males, <i>n</i> (%)	57 (48.7)	32 (50.8)	0.788
Age ^a			
Total	64 (42–80)	65 (44–83)	0.954
Males	61 (42–77)	65 (43–79)	0.611
Females	66 (42–80)	67 (46–85)	0.793
Age categories—total, <i>n</i> (%)			
≤55	41 (35.0)	17 (27.0)	0.109
56–65	23 (19.7)	15 (23.8)	
66–75	41 (35.0)	17 (27.0)	
76≤	12 (10.3)	14 (22.2)	
Age categories—males, <i>n</i> (%)			
≤55	19 (33.3)	7 (21.9)	0.251
56–65	15 (26.3)	12 (37.5)	
66–75	18 (31.6)	7 (21.9)	
76≤	5 (8.8)	6 (18.8)	
Age categories—females, <i>n</i> (%)			
≤55	22 (36.7)	10 (32.3)	0.388
56–65	8 (13.3)	3 (9.7)	
66–75	23 (38.3)	10 (32.3)	
76≤	7 (11.7)	8 (25.8)	
Oswestry Disability Index (1.0) ^a	44 (12–71)	0 (0–13)	<0.001
NIS-LSS ^a	27 (14–33)	33 (29–33)	<0.001

^a Categorical data are described by absolute number and percentage of patients in the given category; continuous variables are described by median and 5th–95th percentile

^b Statistical significance of difference between groups is tested by ML- χ^2 test for categorical data and by Mann–Whitney *U* test for continuous parameters

three levels (L3–S1) and a morphological evaluation was also carried out (presence of spondylosis, facet joint arthrosis and hypertrophy of the ligamenta compromising the nervous structures). The presence of central stenosis on MRI of the lumbar spine was considered in morphological terms as encroachment on the thecal sac with compression of nervous structures. Correlation between clinical and radiological findings was essential.

Exclusion criteria:

1. Presence of diabetes mellitus or other disease involving polyneuropathy (e.g. abuse of alcohol, chemotherapy treatment—to eliminate the influence of polyneuropathy on the results of the NIS-LSS and the ODI)

2. Presence of hip and/or knee joint arthrosis limiting walking or running
3. Presence of arteriosclerotic peripheral vascular disease of the lower limbs limiting walking
4. Presence of any other serious comorbidity that could influence the results of the NIS-LSS and the ODI score (e.g. central paresis of lower limbs, myopathy).

Statistical approaches

Standard robust summary statistics were used to describe primary data (age, the ODI score and the NIS-LSS): relative and absolute frequencies, median supplied with the 5th–95th percentile range. The ML- χ^2 test was employed to compare experimental variants in categorical variables and the non-parametric Mann–Whitney U test and Kruskal–Wallis test were used for comparison of variants on the basis of continuous variables. The correlation between the NIS-LSS and the ODI was quantified using Spearman's rank correlation coefficient (r_s). The diagnostic power of the score examined was assessed on the basis of ROC

curves supplemented by estimates of sensitivity and specificity. A value $\alpha = 0.05$ was used as the limit of statistical significance in all analyses performed. The SPSS for Windows statistical package (Rel. 12.0.1, 2003, Chicago; SPSS Inc) was employed.

Results

The basic characteristics of the two groups are given in Table 3; they did not differ in age and sex. The median NIS-LSS for patients with LSS was 27 points, for healthy volunteers 33; the median ODI for patients with LSS was 44 %, for healthy volunteers 0 % (Table 3). The NIS-LSS and the ODI values for each age category and gender are shown in Table 4. The NIS-LSS values are significantly different in patients with LSS when compared with healthy volunteers, for all age and sex categories. Furthermore, it is interesting to note a trend towards decreasing NIS-LSS in older patients with LSS that is not present in the healthy controls.

Table 4 Comparison of the Oswestry Disability Index (1.0) and the NIS-LSS between patients with LSS and healthy controls

	Oswestry Disability Index (1.0)			NIS-LSS		
	Patients with LSS ^a (<i>N</i> = 117)	Healthy controls ^a (<i>N</i> = 63)	<i>p</i> value ^b	Patients with LSS ^a (<i>N</i> = 117)	Healthy controls ^a (<i>N</i> = 63)	<i>p</i> value ^b
Total	44 (12–71)	0 (0–13)	<0.001	27 (14–33)	33 (29–33)	<0.001
Sex						
Males	40 (10–62)	0 (0–13)	<0.001	27 (17–33)	33 (29–33)	<0.001
Females	49 (18–71)	0 (0–16)	<0.001	27 (13–33)	33 (28–33)	<0.001
Age categories—total						
≤55	40 (16–71)	0 (0–7)	<0.001	30 (22–33)	33 (33–33)	<0.001
56–65	46 (12–68)	2 (0–11)	<0.001	27 (19–32)	33 (31–33)	<0.001
66–75	40 (13–64)	0 (0–24)	<0.001	25 (13–32)	33 (28–33)	<0.001
76≤	64 (26–71)	0 (0–16)	<0.001	22 (13–29)	32 (27–33)	<0.001
Age categories—males						
≤55	36 (0–76)	0 (0–4)	<0.001	30 (20–33)	33 (33–33)	0.001
56–65	46 (6–60)	2 (0–7)	<0.001	25 (17–32)	33 (31–33)	<0.001
66–75	39 (10–62)	0 (0–16)	<0.001	24 (14–33)	33 (29–33)	0.001
76≤	47 (26–64)	0 (0–13)	0.005	22 (19–29)	32 (27–33)	0.010
Age categories—females						
≤55	54 (22–71)	0 (0–7)	<0.001	31 (22–33)	33 (33–33)	<0.001
56–65	44 (22–70)	4 (2–11)	0.014	29 (23–32)	33 (33–33)	0.013
66–75	42 (13–71)	0 (0–24)	<0.001	25 (12–32)	33 (28–33)	<0.001
76≤	66 (56–71)	0 (0–16)	0.001	21 (13–28)	32 (28–33)	0.001

^a The Oswestry Disability Index and the NIS-LSS are summarized as the median supplied with 5th–95th percentile range

^b Mann–Whitney U test: *p* value

Correlation with the ODI was performed in order to validate the NIS-LSS (assessment of convergent construct validity). This demonstrated that the two scores correlate very well (Spearman's correlation coefficient = -0.739 , $p < 0.001$), holding true for all age categories and both sex categories (Table 5).

The NIS-LSS values obtained were also assessed in terms of the ODI categories of disability level, in which the ODI 0–20 % is equivalent to minimal disability, 21–40 % moderate disability, 41–60 % severe disability, 61–80 % crippled, and 81–100 % represents patients who are either bed-bound or exaggerating their symptoms. No ODI was higher than 80 % in this study, leaving the remaining four categories to be assessed. It was confirmed once more that the NIS-LSS correlates with the ODI; it significantly discriminates out the first and second ODI categories but differences did not achieve significance for the third and fourth ODI categories (Table 6, Fig. 1).

Each parameter of the NIS-LSS in healthy volunteers and in patients with LSS was analysed. At least one tendon reflex in the lower limbs was absent in 76.9 % of LSS patients (19 % of controls). Failure of tactile sensation in at least one lower limb was disclosed in 55.6 % of LSS patients (0 % of controls). Failure of vibratory sensation in at least one lower limb was observed in 24.8 % of LSS patients (9.5 % of controls). Paresis was present in 41 % of LSS patients (0 % of controls), while 47 % of LSS patients were able to run the 10 m compared to 95.2 % of healthy controls (Table 7).

The correlation of each NIS-LSS parameter with the ODI categories in LSS patients was examined and some statistically significant correlations emerged: vibratory sensation ($p = 0.04$), presence of paresis ($p = 0.01$) and especially the ability to walk and run ($p < 0.001$) (Table 8).

An ROC analysis for the NIS-LSS as a potential predictor of LSS was performed (Fig. 2) and an optimum cut-off value established at 32 points, to a sensitivity of 85.5 % and specificity of 81.3 % ($p < 0.001$) (Table 9).

Discussion

This study introduces a new score for the assessment of neurological findings in the lower limbs of patients with LSS. To the best of our knowledge, a similar validated score has not been yet described in the literature. It was felt that a simple quantification of neurological findings in LSS patients would be a useful addition to diagnostic, prognostic and follow-up procedures. The study also demonstrates very good correlation between the results of the NIS-LSS and disability evaluated by the ODI.

Table 5 Correlation between the NIS-LSS and the Oswestry Disability Index (1.0)

	Total	
	N	Spearman's correlation coefficient
Total	180	$r_s = -0.739$ (<0.001)
Sex		
Males	89	$r_s = -0.729$ (<0.001)
Females	91	$r_s = -0.770$ (<0.001)
Age categories—total		
≤ 55	58	$r_s = -0.745$ (<0.001)
56–65	38	$r_s = -0.782$ (<0.001)
66–75	58	$r_s = -0.775$ (<0.001)
76 $\leq$	26	$r_s = -0.807$ (<0.001)
Age categories—males		
≤ 55	26	$r_s = -0.622$ (<0.001)
56–65	27	$r_s = -0.807$ (<0.001)
66–75	25	$r_s = -0.787$ (<0.001)
76 $\leq$	11	$r_s = -0.727$ (0.011)
Age categories—females		
≤ 55	32	$r_s = -0.854$ (<0.001)
56–65	11	$r_s = -0.809$ (0.003)
66–75	33	$r_s = -0.777$ (<0.001)
76 $\leq$	15	$r_s = -0.856$ (<0.001)

Table 6 Values of the NIS-LSS in the Oswestry Disability Index (1.0) categories

Oswestry Disability Index 1.0 (%)	NIS-LSS					
	Total (N = 180)		Patients with LSS (N = 117)		Healthy controls (N = 63)	
	N	Median (5–95 %)	N	Median (5–95 %)	N	Median (5–95 %)
0–20	74	33 (25–33)	12	29 (20–33)	62	33 (30–33)
21–40	42	30 (21–33)	41	30 (21–33)	1	28 (28–28)
41–60	43	27 (14–32)	43	27 (14–32)	0	–
61–80	21	21 (13–29)	21	21 (13–29)	0	–
81–100	0		0		0	

Stucki et al. [3] developed a NMI to assess neurological findings in patients with LSS, but their approach has not been extended into common practice. The NIS-LSS, like the NMI, evaluates tendon reflexes in the lower limbs, vibratory sensation and muscle strength. However, in contrast to the NMI, the NIS-LSS evaluates tactile sensation rather than painful sensation and, furthermore, the locomotive ability (walking and running). Stucki et al. [3] examined the association between neuromuscular impairment (expressed by the NMI) and physical functional status, which was assessed with the physical dimension of the

Fig. 1 The NIS-LSS in the Oswestry Disability Index (1.0) categories. ¹Comparison of the NIS-LSS among the ODI categories was performed by Kruskal–Wallis test. Multiple comparisons of mean ranks method was used to determine the difference between individual groups. *a, b, c*—Same letters denote homogeneous groups

Sickness Impact Profile (P-SIP), which consists of three subscales measuring mobility, ambulation and body care and management. The neuromuscular index was significantly but weakly related to P-SIP.

Some authors use the Japanese Orthopaedic Association (JOA) score for lumbar diseases to assess the severity of neurological impairment. This comprises four categories: subjective symptoms, clinical signs, restriction of activities of daily living and urinary bladder function [22, 23]. The clinical signs evaluated to establish this score include assessments of straight leg raising test, sensory disturbance and motor disturbance. In our opinion, the drawbacks of this score include its combination of subjective and objective evaluation and insufficiently detailed assessment of the objective neurological impairment.

Several NIS-LSS parameters exhibited statistically significant correlations with the ODI in the current study: vibration sensation, presence of paresis and ability to walk and run. Among the components of the NMI, patellar tendon reflexes and vibration sensation had a significant relationship with the P-SIP. Reduced ankle reflex, muscle weakness and painful sensation in the lower extremities were not related to physical function status (P-SIP) [3].

Several reasons may be suggested for the different degree of correlation between these two scales (the NIS-LSS and the NMI) and their parameters and disability, or rather with physical functional status. Firstly, the NIS-LSS

Table 7 NIS-LSS parameters—description

NIS-LSS	Total (<i>N</i> = 180)	Patients with LSS (<i>N</i> = 117)	Healthy controls (<i>N</i> = 63)
Tendon reflexes, <i>n</i> (%)			
0 point	17 (9.4 %)	17 (14.5 %)	0 (0 %)
1 point	14 (7.8 %)	13 (11.1 %)	1 (1.6 %)
2 points	33 (18.3 %)	28 (23.9 %)	5 (7.9 %)
3 points	38 (21.1 %)	32 (27.4 %)	6 (9.5 %)
4 points	78 (43.3 %)	27 (23.1 %)	51 (81 %)
Tactile sensation, <i>n</i> (%)			
0 point	9 (5 %)	9 (7.7 %)	0 (0 %)
2 points	52 (28.9 %)	52 (44.4 %)	0 (0 %)
3 points	4 (2.2 %)	4 (3.4 %)	0 (0 %)
4 points	115 (63.9 %)	52 (44.4 %)	63 (100 %)
Vibration sensation, <i>n</i> (%)			
0 point	15 (8.3 %)	14 (12 %)	1 (1.6 %)
2 points	20 (11.1 %)	15 (12.8 %)	5 (7.9 %)
4 points	145 (80.6 %)	88 (75.2 %)	57 (90.5 %)
Presence of paresis, <i>n</i> (%)			
3 points	4 (2.2 %)	4 (3.4 %)	0 (0 %)
4.5 points	5 (2.8 %)	5 (4.3 %)	0 (0 %)
6 points	17 (9.4 %)	17 (14.5 %)	0 (0 %)
7.5 points	22 (12.2 %)	22 (18.8 %)	0 (0 %)
9 points	132 (73.3 %)	69 (59 %)	63 (100 %)
Walk + run, <i>n</i> (%)			
3 points	10 (5.6 %)	10 (8.5 %)	0 (0 %)
6 points	12 (6.7 %)	12 (10.3 %)	0 (0 %)
9 points	43 (23.9 %)	40 (34.2 %)	3 (4.8 %)
12 points	115 (63.9 %)	55 (47 %)	60 (95.2 %)

Table 8 Correlation of the NIS-LSS parameters with the ODI categories in patients with LSS

NIS-LSS	Oswestry Disability Index (1.0)				Spearman's correlation
	0–20	21–40	41–60	61–80	
Tendon reflexes, <i>n</i> (%)					
0 point	1 (5.9)	3 (17.6)	9 (52.9)	4 (23.5)	−0.163 (<i>p</i> = 0.079)
1 point	1 (7.7)	6 (46.2)	3 (23.1)	3 (23.1)	
2 points	4 (14.3)	8 (28.6)	11 (39.3)	5 (17.9)	
3 points	3 (9.4)	11 (34.4)	11 (34.4)	7 (21.9)	
4 points	3 (11.1)	13 (48.1)	9 (33.3)	2 (7.4)	
Tactile sensation, <i>n</i> (%)					
0 point	0 (0)	2 (22.2)	4 (44.4)	3 (33.3)	−0.170 (<i>p</i> = 0.068)
2 points	5 (9.6)	17 (32.7)	19 (36.5)	11 (21.2)	
3 points	2 (50.0)	0 (0)	1 (25.0)	1 (25.0)	
4 points	5 (9.6)	22 (42.3)	19 (36.5)	6 (11.5)	
Vibration sensation, <i>n</i> (%)					
0 point	3 (21.4)	2 (14.3)	5 (35.7)	4 (28.6)	−0.191 (<i>p</i> = 0.040)
2 points	0 (0)	3 (20)	7 (46.7)	5 (33.3)	
4 points	9 (10.2)	36 (40.9)	31 (35.2)	12 (13.6)	
Presence of paresis, <i>n</i> (%)					
3 points	0 (0)	0 (0)	3 (75.0)	1 (25.0)	−0.238 (<i>p</i> = 0.010)
4.5 points	0 (0)	0 (0)	3 (60.0)	2 (40.0)	
6 points	4 (23.5)	5 (29.4)	3 (17.6)	5 (29.4)	
7.5 points	0 (0)	7 (31.8)	9 (40.9)	6 (27.3)	
9 points	8 (11.6)	29 (42.0)	25 (36.2)	7 (10.1)	
Walk + run, <i>n</i> (%)					
3 points	0 (0)	0 (0)	4 (40.0)	6 (60.0)	−0.575 (<i>p</i> < 0.001)
6 points	0 (0)	2 (16.7)	5 (41.7)	5 (41.7)	
9 points	3 (7.5)	9 (22.5)	18 (45.0)	10 (25.0)	
12 points	9 (16.4)	30 (54.5)	16 (29.1)	0 (0)	

includes evaluation of the ability of walk and run and this parameter features strongly in the score (12 points available out of 33); we assume that this parameter reflects physical functional status clearly and expresses the degree of disability.

Furthermore, we consider that the ODI is more convenient for the assessment of LSS patient condition. The ODI focuses on patients with low back pain unlike the SIP, which is more general and less specific.

Another limitation of the NMI study performed by Stucki et al. is the fact that their neuromuscular findings in lower limbs were evaluated by surgeons rather than neurologists and that the NMI was a calculated secondary value—data were collected by chart abstraction using physician notes.

Various studies demonstrate that variability of clinical features in patients with LSS is wide. In meta-analysis of 74 studies, objective weakness of the lower limbs emerged

Fig. 2 ROC curve for the NIS-LSS as potential predictor of LSS

Table 9 ROC curve for the NIS-LSS as potential predictor of LSS

Parameter	AUC (95 % CI) ^a	p ^a	Optimal cut-off ^b	Sensitivity ^c (95 % CI)	Specificity ^c (95 % CI)
NIS-LSS	0.90 (0.85; 0.94)	<0.001	<32	85.5 % (77.8–91.3)	81.3 % (69.5–89.9)

^a Area under the curve supplemented by 95 % confidence interval and statistical significance

^b Optimal cut-off for diagnostically relevant binary coding of the parameter

^c Sensitivity and specificity for given cut-off

in 14–100 % of patients (average 51 %) [24]. In a previous study, we demonstrated paresis in 29 % of patients with LSS [25]. Stucki et al. [3] described paresis in 29 % of LSS patients. In the current study, paresis was disclosed by neurological examination in 41 % of patients with LSS. The differences between studies may arise out of selection of patients with LSS (e.g., whether a study includes patients with mild LSS for conservative treatment and/or patients with severe LSS intended for surgery). Evaluation of weakness in the lower extremities may also vary. It is important to differentiate between weakness objectified by neurological examination and that described subjectively by patients. Self-perceived weakness, which measures subjective weakness with exertion, was reported by 87 % of LSS patients although examination disclosed it in only 29 %. Objective sensory deficit was described by an average of 52 % of LSS patients (range 15–91 %) [24]. In this study, deficit of tactile sensation in at least one lower limb was disclosed in 55.6 % of patients with LSS.

It was noted that loss of vibratory sensation in LSS patients was strongly correlated with self-reported balance disturbance and had a significant relationship with physical functional status in patients with LSS [3]. Impairment of vibratory sensation in at least one lower limb was present in 24.8 % of patients with LSS in this study, in contrast to that of Stucki and al., who recorded these deficits in 86.9 % of LSS subjects. The difference between the two studies may derive from the methods used to evaluate vibratory sensation; in this study, patients were examined by a neurologist using a graduated tuning fork and results were categorized with respect to age-related normative data, while the examination was not described in detail in the Stucki study.

In this study, a trend was observed towards a decrease in the NIS-LSS with age of LSS patients, which was not paralleled by healthy controls. This trend could be probably explained by the fact that elderly patients have longer duration of LSS and some deterioration of neurological status may also be dependent on duration of the disease. Stucki et al. also noted a statistically significant correlation between age and the NMI.

The NIS-LSS has several limitations, particularly in that it is not suitable for patients with polymorbidity. In such

patients, the NIS-LSS may be influenced by other diseases, e.g. the presence of polyneuropathy, hip or knee joint arthrosis limiting locomotive ability (walking and running) or diseases that result in muscle weakness or gait disturbance. A further limitation of the NIS-LSS is possible incorrect assessment of NIS-LSS parameters, especially in less co-operative patients. Finally, the choice of patients with respect to severity was not proportional, since patients with a mild-to-moderate degree of involvement predominated.

The outstanding advantage of the NIS-LSS is its simplicity and ease of realization. A routine neurological examination is sufficient for calculation of the score. We anticipate its use for long-term follow-up of neurological status and for evaluation of treatment effect in patients with LSS.

Conclusions

The NIS-LSS quantifies neurological findings in the lower limbs.

The NIS-LSS significantly discriminated between patients with LSS and healthy controls and correlation between this score and disability was demonstrated in patients with LSS.

The applicability of the NIS-LSS to patients with LSS (without comorbidity) was confirmed.

We anticipate that the main contribution of this score will be in the long-term follow-up of neurological status and for assessment of treatment effect in patients with LSS.

Conflict of interest None.

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