Step activity monitoring in lumbar stenosis patients undergoing decompressive surgery

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Abstract Symptomatic degenerative central lumbar spinal stenosis (LSS) is a frequent indication for decompressive spinal surgery, to reduce spinal claudication. No data are as yet available on the effect of surgery on the level of activity measured with objective long-term monitoring. The aim of this prospective, controlled study was to objectively quantify the level of activity in central LSS patients before and after surgery, using a continuous measurement device. The objective data were correlated with subjective clinical results and the radiographic degree of stenosis. Forty-seven patients with central LSS and typical spinal claudication scheduled for surgery were included. The level of activity (number of gait cycles) was quantified for 7 consecutive days using the StepWatch Activity Monitor (SAM). Visual analogue scales (VAS) for back and leg pain, Oswestry disability index and Roland–Morris score were used to assess the patients’ clinical status. The patients were investigated before surgery and 3 and 12 months after surgery. In addition, the radiographic extent of central LSS was measured digitally on preoperative magnetic resonance imaging or computed tomography. The following results were found preoperatively:

3,578 gait cycles/day, VAS for back pain 5.7 and for leg pain 6.5. Three months after surgery, the patients showed improvement: 4,145 gait cycles/day, VAS for back pain 4.0 and for leg pain 3.0. Twelve months after surgery, the improvement continued: 4,335 gait cycles/day, VAS for back pain 4.1 and for leg pain 3.3. The clinical results and SAM results showed significant improvement when pre-operative data were compared with data 3 and 12 months after surgery. The results 12 months after surgery did not differ significantly from those 3 months after surgery. The level of activity correlated significantly with the degree of leg pain. The mean cross-sectional area of the spinal canal at the central LSS was 94 mm². The radiographic results did not correlate either with objective SAM results or with clinical outcome parameters. In conclusion, this study is the first to present objective data on continuous activity monitoring/measurements in patients with central LSS. The SAM could be an adequate tool for performing these measurements in spine patients. Except for leg pain, the objective SAM results did not correlate with the clinical results or with the radiographic extent of central LSS.

Keywords Step activity monitor (SAM) · Lumbar spinal stenosis · Decompression · Level of activity · Mobility

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Introduction

Symptomatic degenerative central lumbar spinal stenosis (LSS) is one of the most frequent indications for spinal decompressive surgery [25, 29]. Spinal claudication is the main symptom in these patients, who are usually older [33, 39]. As walking is a well-accepted parameter for most physical activities of daily living [31, 32], spinal

claudication ultimately leads to progressive immobility and inactivity. The inactivity affects not only the patients' walking distance but also various aspects of life, including their social, psychological and physical status. In patients who do not benefit from conservative treatment, surgical decompression may be indicated in order to alleviate spinal claudication and improve the activity level in daily life.

Magnetic resonance imaging (MRI) and computed tomography (CT) precisely reveal the degree of central LSS. However, the extent to which the amount of LSS correlates with the patients' clinical symptoms, particularly restriction of mobility, is not at present clear. A review of the literature shows that only a few investigations have independently and objectively measured improvements in functional activity among these patients following decompressive surgery [13, 28, 39]. Several investigations have examined the preoperative situation, but without evaluating the course and development during the follow-up period after surgery [3, 35, 40]. Gait analyses on a treadmill or in a movement laboratory have only been carried out on patients in a laboratory setting and for very limited periods of time, usually only with a few minutes of measurement. These techniques are time-consuming and do not allow any conclusions to be drawn regarding the patients' everyday activity outside of the laboratory.

The aim of the present prospective study was to independently and objectively quantify the patients' functional activity for several consecutive days using a new technique in normal living conditions both before and after lumbar decompressive surgery. The data were correlated with the clinical results, as well as with the radiologically assessed amount of central LSS.

Materials and methods

A prospective, controlled study design was chosen. Patients with symptomatic degenerative central LSS with relevant spinal claudication who did not improve after intensive conservative treatment in accordance with international guidelines and recommendations [21, 25, 34] for at least 3 months were included consecutively. Conservative multimodal treatment comprised physiotherapy (including flexion exercises and traction), physical therapies, strengthening exercises, back schools, braces, medication, infiltration therapies (e.g., epidural steroid injections), patient information about the characteristics and course of the disease, cognitive behavioural therapy and electrical stimulation therapy on an individual basis. The indication for decompressive surgery was established independently of the study. All of the patients underwent surgical decompression of the stenotic segments. Patients with additional segmental instability (up to a maximum of grade

1 spondylolisthesis) requiring stabilizing instrumentation in addition to decompression were also included. Patients requiring treatment for the following diseases within the previous 2 years were excluded: peripheral arterial disease, rheumatic diseases, systemic muscular diseases, fractures of the lower extremities, deformities and severe degenerative diseases of the lower extremities, cardiac, pulmonary and circulatory diseases severely affecting the patients' mobility, and surgery of the lower extremities (e.g., arthroplasty). All of the patients were examined before surgery and 3 and 12 months after surgery. The study was approved by the institution's ethics committee.

The level of activity was assessed using the StepWatch 3 Activity Monitor (SAM) device (Orthocare Innovations, Seattle, WA, USA) (Fig. 1). This robust, small (75 × 50 × 20 mm), lightweight (38 g), unobtrusive, ankle-worn uni-axial piezoelectric accelerometer continuously measures the number of gait cycles per day. Data are stored at 1-min intervals. The sum of one left and one right step is equivalent to one gait cycle. As gait is an accumulation of steps and gait cycles, it is an indicator for the individual activity level [31, 32], and many gait cycles are equivalent to a high level of activity. The patients were asked to wear the SAM for 7 consecutive days from getting up in the morning until bed rest in the evening and to document individual wearing times in a log list. Only days with a minimum wearing time of 8 h were included in the analysis. In order to minimize the patients' distorting impact (bias) on their activity—with conscious or subconscious behavioural changes due to the awareness of being monitored—a relatively long observation period of 7 days including weekdays and the weekend was chosen, as recommended in the literature [7, 10, 30]. Even if the patients' behaviour was influenced by the measurement itself, the bias would be present at all three data recording times and the development of activity would therefore not be influenced. The device does not have a display or any switches, so that patient bias or interference with it is not possible. Manipulation of data—e.g. by shaking or moving the device—is hardly possible. The device includes an internal clock, not visible to the patient, that allows data to be displayed relative to the exact date and time. Before measurement, the SAM was adjusted to the patient's individual body parameters (body height) using its telemetric infrared interface. After data acquisition for 7 days, the data were downloaded to a computer via an infrared interface and the software identified and provided the number of gait cycles as the primary output. Gait intensities were measured as gait cycles per minute. It has been shown that measurement of ambulatory activity using the SAM device was 99.87% accurate [19], and its validity has been proven [4, 20]. The device has been used in several investigations in other medical applications [5–7, 9, 12, 27,

Fig. 1 The StepWatch 3 Activity Monitor (SAM)

38], but has not previously been used to study degenerative spine diseases.

Average gait cycles per day, gait cycles per hour and gait intensities above 40 gait cycles per minute, which are considered to be indicative of continuous walking, were evaluated.

The clinical outcome (using self-reporting instruments and therefore termed “subjective” in contrast to the “objective” SAM data) was measured using visual analogue scales (VAS) for back and leg pain, the Oswestry disability index (ODI) [17, 18] and the Roland–Morris score (RMS) [36]. In addition, patients underwent a clinical orthopaedic and neurological examination. The prevalence of back pain, leg pain, motor deficits and sensory deficits was documented. The existence of back pain, leg pain, motor deficits, or sensory deficits was assessed as either present or not present in this general outcome measure, without differentiating between various grades of pain and deficits. Overall satisfaction was graded as excellent, good, fair, or poor.

The degree of lumbar canal stenosis was assessed using preoperative CT or MRI scans in neutral position. The images were digitized and analysed using the Image-Pro Plus programme (Media Cybernetics, Bethesda, MD, USA). Axial images presenting the most severe degree of stenosis were investigated in a standardized way (Fig. 2). The following parameters were measured: median sagittal diameter of the spinal canal, maximum thickness of the yellow ligament on the right and left sides, cross-sectional area of the spinal canal and circumference of the cross-sectional area of the spinal canal. These radiographic data were correlated with the SAM measurements and with the clinical results.

Statistical analysis was performed using SPSS 11.0 (SPSS Inc., Chicago, IL, USA). In addition to descriptive analyses, the following tests were applied: Mann–Whitney *U* test, Wilcoxon test, Spearman correlation coefficient, McNemar test, 1-sample *t* test and Kruskal–Wallis test. Differences were considered significant at $P < 0.05$. Power

Fig. 2 Axial view of the spinal canal. *a* Thickness of the right yellow ligament. *b* Thickness of the left yellow ligament. *c* Maximum sagittal diameter; dark grey: cross-sectional area of the spinal canal

analyses revealed that with a sample size of $n = 50$ patients, mean differences between preoperative and post-operative measurements of any continuous parameter can be detected with a power of 80%, if they amount to more than 0.4–0.5 multiples of the standard deviation of measurements at a fixed time point. In the case of gait cycles per day (primary outcome parameter), this means that differences of 800–1,000 units can be expected to be significantly detected. With regard to VAS for back and leg pain (secondary outcome parameters), differences of 1.2–1.5 units can be detected. (Existing mean differences below these thresholds are therefore not detected with high probability. In the case of nonsignificant *P* values, one should not draw the conclusion that there are definitely no

differences. Instead, it can only be concluded that potentially existing differences are expressed below the aforementioned thresholds.)

To minimize any potential bias, the different parts of the research investigations were performed independently by different subgroups of the authors (clinical examination and patients' instruction for questionnaires: TLS, VB; surgery: LH, HW; SAM analyses: CW, MB, DR; radiological studies: TS; statistics: TS, DL).

Results

Patient characteristics

A total of 60 consecutive patients who met the inclusion criteria were asked to participate in the study. Ten declined to participate, and 50 patients were therefore included at the beginning of the study. Three patients did not appear for follow-up after surgery and were thus not included in the statistical analyses. Forty-seven patients finally completed the study (24 women, 23 men), with a mean age of 69.3 ± 7.5 years at surgery and a mean BMI of 28.7 ± 4.4 kg/m². In nine patients, grade 1 degenerative spondylolisthesis was found in addition to the central LSS. Thirteen patients had undergone surgical decompression prior to the study, in the same segments in which the recurrent LSS had now developed.

Twenty-seven patients underwent standardized undercutting decompression without any additional instrumentation, including bilateral posterior undercutting decompression of the spinal canal with transection of the supraspinous and interspinous ligaments, as well as the yellow ligaments. Three millimetres of the cranial and caudal lamina were resected. Medial hypertrophic parts of the zygapophysial joints were partially resected until 'normal' anatomy was restored. The joint space was not opened, and the stabilizing capsules were kept intact. The stability of the articular processes was strictly maintained.

In 20 patients, stabilization of the decompressed segment was carried out in addition to decompression, due to spondylolisthesis or instability. Six patients underwent transforaminal lumbar interbody fusion (TLIF); five had a Dynesys[®] stabilization system placed (Zimmer Ltd., Winterthur, Switzerland); four had a Wallis[®] device placed (Abbott Spine, Bordeaux, France); four had a Coflex[®] device placed (Paradigm Spine Ltd., Wurmlingen, Germany); and one underwent TLIF as well as having a Wallis[®] device placed.

A single segment was decompressed in 21 patients; two adjacent segments were decompressed in 20 patients; three adjacent segments in four patients; and four adjacent segments were decompressed in two patients. A total of 81

segments were decompressed: $2 \times \text{L1/2}$, $5 \times \text{L2/3}$, $29 \times \text{L3/4}$, $35 \times \text{L4/5}$ and $10 \times \text{L5/S1}$.

Three patients (6.4%) underwent additional lumbar surgery during the follow-up period. One patient required stabilization of the initially decompressed segment with Dynesys[®], due to symptomatic segmental instability; one patient underwent repeat decompression of the initially decompressed segment, due to symptomatic recurrent central LSS; and one patient was treated with vertebroplasty, due to a lumbar osteoporotic compression fracture. With regard to complications, one patient had an incidental intraoperative durotomy, which was closed successfully intraoperatively, and three patients developed delayed superficial wound healing, which was treated surgically a few days after the initial operation. These complications did not influence the clinical results or SAM results.

Step activity monitoring results

Figure 3 presents an example of a SAM measurement in one patient before and 3 months after decompression and shows that gait cycles per minute increased after surgery and that periods of continuous activity were longer after surgery than before surgery.

None of the patients reported any difficulties in using the SAM device, and none of the measurements failed due to technical errors or errors due to incorrect application of the device by the patient. The wearing times registered by the SAM device corresponded to the patients' documented wearing times.

The overall results for the SAM measurements are presented in Fig. 4, showing mean gait cycles per day. The data for gait cycles per hour showed an average of 277 ± 127 gait cycles before surgery, 323 ± 144 gait cycles after 3 months' follow-up (significant improvement in comparison with the situation before surgery, $P = 0.006$) and 336 ± 137 gait cycles after 12 months' follow-up (significant improvement in comparison with the situation before surgery, $P < 0.001$). There were no significant differences between the 3- and 12-month follow-up data.

Statistical analysis showed significant increases in gait intensity of more than 40 gait cycles per minute between the situation before surgery ($3.2 \pm 3.8\%$) and the 3-month follow-up ($5.9 \pm 6.4\%$; $P < 0.001$) and between the situation before surgery and the 12-month follow-up ($4.9 \pm 3.9\%$; $P < 0.001$). However, there were no significant differences between the 3- and 12-month follow-up data.

Statistical analysis did not show any significant influence of gender, BMI, age at surgery, number of operated segments, history of prior lumbar surgery, or type of surgery (decompression alone vs. decompression and

Fig. 3 Example of a StepWatch 3 Activity Monitor (SAM) measurement over 24 h in a selected patient. *Top* the situation before surgery, with 2,856 gait cycles per day. *Bottom* the situation 3 months after decompression, with 5,339 gait cycles per day

Fig. 4 Gait cycles per day (mean, standard deviation). *n.s.* not significant, *FU* follow-up, *Mo* months

additional stabilizing instrumentation) on the number of gait cycles per day at the three different measurement times, or on the relative changes in gait cycles between the different measurement times.

Patients with a grade 1 preoperative spondylolisthesis had significantly delayed improvement in activity (gait cycles per day; $P = 0.018$). The relative change in their gait cycles per day deteriorated by 9% when data before surgery were compared with data after 3 months' follow-up, whereas patients without spondylolisthesis had an improvement of 31.4%. Between the 3- and 12-month follow-up examinations, patients with spondylolisthesis improved by 34.2% and those without by 3.5% ($P = 0.034$). When data before surgery were compared with data after 12 months' follow-up, there were no significant differences between the two groups of patients.

The three patients who underwent additional lumbar surgery during the follow-up period did not show poorer levels of activity than other patients (with mean gait cycles per day ranging between 4,720 and 5,897 at 12 months after surgery).

Clinical results, outcome questionnaires and radiological results

The clinical results and the results of the outcome questionnaires used are presented in Table 1. When the patients' status after 3 and 12 months of follow-up was compared with the preoperative data, significant improvements were seen in the prevalence of leg pain ($P < 0.001$ for both follow-up examinations). The values for the prevalence of back pain, motor deficits and sensory deficits did not change significantly. The VAS, ODI and RMS values also improved significantly during the follow-up period in comparison with the preoperative data ($P \leq 0.001$).

There were no significant differences between women and men in the values for VAS, ODI, or RMS. Age at surgery did not correlate with clinical outcome parameters.

Overall patient satisfaction at the 12-month follow-up examination was excellent in 29.8%, good in 53.2%, fair in 14.9% and poor in 2.1%.

The number of operated lumbar segments and the BMI did not have a significant influence on the clinical outcome parameters (VAS, ODI, RMS). No significant differences were found between patients who underwent stabilizing procedures in addition to decompression and those who did not. Patients who had previously undergone lumbar surgery had poorer clinical results in some respects than those without prior surgery (before surgery, RMS $P = 0.041$; after 3 months' follow-up, RMS $P = 0.022$, VAS back pain $P = 0.011$, VAS leg pain $P = 0.044$; after 12 months' follow-up, RMS $P = 0.005$, VAS back pain $P = 0.003$).

Patients with grade 1 spondylolisthesis had poorer clinical results than those without, for the following

parameters: before surgery, RMS $P = 0.009$, VAS back pain $P = 0.018$. All of these patients had undergone stabilization with TLIF or Dynesys® in addition to decompression.

The percentage relative improvement in all of the outcome parameters (Fig. 5) showed that the gait cycles increased less during the follow-up period than the clinical parameters did.

The Oswestry score explicitly assesses the subjective restriction on walking distance. Statistical analysis showed a significant correlation between the patients' subjective rating and the objective number of gait cycles per day after 3 months' follow-up ($r = -0.375$; $P = 0.017$) and after 12 months' follow-up ($r = -0.444$; $P = 0.004$), but not with the data prior to surgery. Correlations between the SAM results and clinical results are shown in Table 2.

Analysis of the axial preoperative scans showed a mean cross-sectional area of the spinal canal, at the narrowest stenosis, of $93.6 \pm 44.8 \text{ mm}^2$; a mean thickness of the yellow ligament of $5.4 \pm 1.1 \text{ mm}$ on the right and $5.5 \pm 1.2 \text{ mm}$ on the left; a mean sagittal diameter of the spinal canal of $13.5 \pm 4.5 \text{ mm}$; and a mean circumference of the axial cross-section of $62.8 \pm 15.6 \text{ mm}$. These radiological data correlated neither with the SAM results nor with the clinical data, particularly the VAS for leg pain.

Discussion

As far as the authors are aware, this is the first study that has objectively investigated the level of activity in patients with a degenerative lumbar spine disease using the SAM device. The study showed that even in these relatively old patients, with severe symptoms such as spinal claudication,

Table 1 Prevalence of clinical symptoms in % and results of the visual analogue scales (VAS) for back and leg pain, Oswestry disability index (ODI) and Roland–Morris score (RMS)

	Before surgery	3-month follow-up	12-month follow-up
Prevalence			
Back pain	78.3%	69.6% (n.s.)	73.9% (n.s.)
Leg pain	91.3%	54.3% ($P < 0.001$)	54.3% ($P < 0.001$)
Motor deficit	13.5%	8.1% (n.s.)	10.8% (n.s.)
Sensory deficit	29.7%	32.4% (n.s.)	37.8% (n.s.)
VAS			
Back pain	5.7 ± 2.8	4.0 ± 2.6 ($P < 0.001$)	4.1 ± 2.5 ($P = 0.001$)
Leg pain	6.5 ± 2.7	3.0 ± 2.8 ($P < 0.001$)	3.3 ± 2.6 ($P < 0.001$)
ODI	51.6 ± 17.9	32.4 ± 21.9 ($P < 0.001$)	34.6 ± 17.7 ($P < 0.001$)
RMS	13.2 ± 4.9	7.5 ± 5.9 ($P < 0.001$)	8.8 ± 5.7 ($P < 0.001$)

Significances were calculated by comparing data at follow-up with data from before surgery. Between 3 and 12 months of follow-up, no significant differences were observed for symptom prevalences, VAS, ODI or RMS

n.s. not significant

Fig. 5 Relative changes (percentage improvements in means) in objective gait cycles per day, compared with the relative changes in subjective clinical results. *FU* follow-up, *Mo* months, *VAS* visual analogue scale, *ODI* Oswestry disability index, *RMS* Roland–Morris score

Table 2 Correlation (*r*) between the StepWatch 3 Activity Monitor (SAM) results and the clinical results

	Visual analogue scales		ODI	RMS
	Back pain	Leg pain		
Gait cycles/day				
Before surgery	0.137	−0.489**	−0.075	−0.064
3-month follow-up	−0.142	−0.227	−0.284	−0.134
12-month follow-up	−0.242	−0.259	−0.287	−0.238
Gait cycles/h				
Before surgery	0.041	−0.426**	−0.046	−0.089
3-month follow-up	−0.109	−0.278	−0.214	−0.062
12-month follow-up	−0.266	−0.341*	−0.278	−0.219
Gait intensities >40 gait cycles/min				
Before surgery	0.192	−0.267	−0.121	−0.125
3-month follow-up	−0.088	−0.351*	−0.223	−0.090
12-month follow-up	−0.255	−0.229	−0.289*	−0.250

ODI Oswestry disability index, *RMS*, Roland–Morris score

* $P < 0.05$ for $r > 0.288$

** $P < 0.01$ for $r > 0.372$

SAM measurements were practicable and feasible. The measurement technique proved to be simple to use and was not subject to error. It should be emphasized that, in contrast to laboratory-based investigations, the SAM device allows continuous recording of daily activity over a long period of time in the patient's private environment. The first conclusion of this investigation is therefore that SAM measurements could be recommended for further studies in patients undergoing spine surgery, even at advanced age.

Overall, 83% of the patients included had excellent or good clinical results 1 year after surgery. The study shows that leg pain in particular improved after surgery. The greatest improvement in the subjective clinical scores, as well as in the objective SAM measurements, was seen after

3 months of follow-up. No further relevant improvements occurred between 3 and 12 months of follow-up: subjective clinical scores slightly deteriorated, objective SAM measurements minimally improved, both not statistically significant. This indicates that the main therapeutic effect, clinically and with regard to the level of activity, appears to be achieved by decompressive surgery and occurs shortly after surgery. The present clinical results are similar to those of other studies investigating comparable patients [8, 15, 34, 39].

There were no differences between women and men with regard to the clinical outcome parameters investigated, as was also reported in other studies [1].

This study did not find any significant effect of the number of decompressed segments, BMI, or type of surgery (decompression alone vs. decompression and additional stabilization) on the clinical and SAM results. Patients with previous lumbar surgery had slightly lower clinical scores in comparison with patients without prior lumbar surgery; however, the SAM measurements did not differ significantly between these groups.

The age of the patients at surgery did not have an effect on the clinical outcome or SAM results. This is an important observation, in view of the increasing numbers of older patients. Advanced age per se should not be a contraindication to decompressive surgery in patients with LSS. This finding is in agreement with other recent reports in the literature [1].

Patients with spondylolisthesis had slightly poorer clinical scores before surgery in comparison with patients without spondylolisthesis. Increased back pain in particular may be interpreted as being due to instability. The improvement in gait cycles was slightly delayed in patients with spondylolisthesis in comparison with those without. Increased morbidity associated with the stabilizing surgery (TLIF, Dynesys®) might be a reason for the

delayed mobilization. However, patients with additional stabilization procedures did not generally have poorer clinical performance or SAM measurements in comparison with patients who only underwent a decompression procedure.

An important result of this study is the finding that gait cycles correlate only with leg pain and not with other clinical scores. In addition, the Oswestry sub-item assessing the subjective restriction of walking distance only correlated with the number of gait cycles after surgery, not prior to surgery. Subjective scores showed more pronounced improvement in comparison with objective measurements of the level of activity—corresponding to the findings in the literature [3]. There is evidently a substantial difference between subjective and objective outcome assessments. The overall outcome depends on many different factors. The objective level of activity is only one aspect, and probably not even the most important one. It is possible that subjective clinical improvement does not necessarily lead to the same degree of improvement in the activity level. Whether this is due to symptoms preventing patients from being more active, or whether it is a matter of motivation, is unclear. One possible implication for treatment might be that attempts could be made to motivate patients to become more active after surgery, taking advantage of the improvement in their subjective clinical parameters.

Other research groups have found a negative correlation between increased BMI and mobility in patients with LSS [14]. This was not confirmed in the present study.

The pathophysiology of spinal stenosis is very complex, with specific effects of the reduced cross-sectional area in the spinal canal on nerve roots [11, 22, 23]. Measurement of the spinal canal showed results similar to those of other studies [3, 14, 24, 39]. Although it is known that the degree of LSS is posture-dependent [37], it is justifiable to use conventional supine MRI and CT, as has been done in comparable investigations [3, 14, 39, 40], particularly as these techniques are recommended by international guidelines [34] and applied in daily clinical practice. Functional MRI would have been desirable, but was not available in this study. The use of either MRI or CT scans for spinal canal measurements was warranted, as measurements with these two techniques are fairly comparable [16, 26]. For ethical reasons, patients did not undergo both types of investigation. Several patients were not able to undergo MRI scans due to implants and thus required CT scans. The absence of correlation observed between the clinical parameters, radiographic extent of spinal canal stenosis, and objective level of activity corresponds well to the literature findings [2, 14, 39, 40]. Recently, Barz et al. [3] found a positive correlation between the cross-sectional

area at the stenosis and the measured walking distance, with clinical symptoms occurring earlier. However, the treadmill test they used only allowed measurements at a single time point, not over a long period as in the present investigation. Neither treadmill tests nor tests in a laboratory are able to reflect the patient's level of activity on a continuous day-to-day basis.

One limitation of the present study is the heterogeneity of the study population. It should also be emphasized that the level of activity depends on many different factors, controlling for all which is not possible in clinical studies. The number of patients, the relatively long period of the SAM measurements (7 days) and the exclusion criteria improved the reliability of the current findings. However, the authors are aware that additional, uncontrolled factors might have influenced the results.

Conclusion

1. Objective measurement of the level of activity using the SAM device in patients with central LSS is possible and could be recommended for further studies. After surgical decompression, patients improved significantly in terms of their level of activity (mean gait cycles per day before surgery 3,578; 3 months after surgery 4,145; and 12 months after surgery 4,335). The greatest improvement was detected within 3 months after surgery. During the later follow-up—i.e., between 3 and 12 months after surgery—only minor additional improvement can be expected.
2. In addition, clinical scores improved. Leg pain in particular was reduced. No clear risk factors were identified as correlating with inadequate clinical results and levels of activity. The values for subjective improvement, assessed with commonly used scoring systems and questionnaires, did not correlate with the objective amount of improvement in the SAM measurements. The subjective results showed greater improvement than the objective ones. The positive correlation between leg pain and gait cycles supports the fact that spinal claudication in particular, rather than other factors such as low back pain, restricts patients' mobility.
3. The radiographic extent of central LSS did not correlate with the patients' clinical subjective situation or with their objective level of activity.

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