JIMA Vol. 73, No. 4 (Oct. 2021) pp. 177-188.

Original

Gait analysis of patients with lumbar spinal stenosis using a wearable tri-axial acceleration sensor

Dachi KINNO [1], Hideki MURAKAMI [1], Hirooki ENDO [1], Daisuke YAMABE [1], Yusuke CHIBA [1], Yuichiro ABE [1], Shuntaro WADA [1], Yasushi CHIDA [2] and Minoru DOITA [1]

[1] Department of Orthopedic Surgery, School of Medicine, Iwate Medical University, Yahaba, Japan
[2] Bycen Inc., Kobe, Japan

(Received on January 20 2021 & Accepted on February 12, 2021)

Abstract

Lumbar spinal stenosis (LSS) is one of the most common causes of gait disturbance. However, most gait analyses in patients with LSS require a laboratory and do not yield results instantly. Lissajous index (LI) is a method that represents the gait asymmetry visually and numerically based on trunk acceleration data. We investigated the effect of surgery on gait disturbance and assessed whether LI can be useful for the quantitative analysis of gait in patients with LSS. Thirty-two patients were evaluated during a 6-minute walking test with a wearable tri-axial acceleration sensor, preoperatively and at 3 months postoperatively. The distance walked significantly increased from 395.1 ± 60.8 m preoperatively to 455.4 ± 64.4 m postoperatively ($p < 0.001$). The preoperative LI value increased over time ($p < 0.001$) and showed a tendency to postoperative improvement. The postoperative LI value was significantly lower than the preoperative value at 1–4 min ($p < 0.05$) and was much lower at 4–6 min ($p < 0.01$). Preoperative and postoperative LI changes correlated with clinical scores ($p < 0.05$). Thus, surgery improves gait symmetry, and LI values can be useful for evaluating gait in patients with LSS.

Key words : gait analysis, gait asymmetry, Lissajous index, lumbar spinal stenosis, wearable tri-axial acceleration sensor

I. Introduction

Patients with lumbar spinal stenosis (LSS) have low back pain and leg symptoms from compression of the cauda equina nerve bundle and nerve roots, as a result of narrowing of the lumbar spinal canal caused by disc degeneration, osteophyte formation, facet joint hyperplasia, yellow ligament thickness, and age-related degeneration [1]. The reported prevalence rates of LSS are 1.7–13.1% and 7.7–11.3% in the United States and Japan, respectively [2, 3]. Most patients with LSS have gait disturbance caused by leg pain, burning, numbness and paresthesia aggravated by walking, that is, intermittent claudication [4]. Surgical treatment is currently regarded as an appropriate management strategy for patients with LSS that do not respond to conservative therapy [5]. Although several effective surgical

Corresponding author: Daichi Kinno
eureka_orag@yahoo.co.jp

treatments for patients with LSS have been reported, most of the surgical outcomes were evaluated using only questionnaires, which may be affected by subjective patient viewpoints and influenced by their psychological status. Appropriate objective quantitative assessment of gait is important to evaluate quality of life in LSS patients, and the findings will serve as indicators for post-treatment evaluation decisions [6, 7]. However, objective assessment of gait quality in daily life has not been established yet because most gait analyses require large scale laboratory environments. Therefore, we used a small, lightweight, wearable tri-axial acceleration sensor that can analyze gait quality in conditions close to daily life. Moreover, to visually and numerically analyze gait quality, we used the Lissajous figure (LF) that represents the movements of the body mass center to calculate the Lissajous index (LI) and evaluate gait asymmetry. The LI value visually and numerically evaluates the left-right asymmetry of LF using a simple formula and has the advantage of allowing visual recognition of the lateral deviations of the trunk during gait [8]. The higher the LI values obtained from gait analysis, the larger the gait asymmetry. The purpose of the present study was to evaluate whether LI values derived from a wearable tri-axial acceleration sensor could be useful for objective preoperative and postoperative assessment of gait characterization in patients with LSS. We hypothesized that the LI value would change as gait reflected changes in symptoms, and that LI value would improve postoperatively. We further expected that changes in LI value would correlate with changes observed using a clinical scoring system including questionnaires.

II. Materials and methods

1. Participants

Patients were considered for enrollment when they were diagnosed with LSS, had gait disturbance, and were scheduled for surgical treatment. The diagnosis was made by three spine specialist surgeons based on patient history, physical examination, and imaging findings. Patients with a significant condition that could limit their gait, such as cervical myelopathy, cardiopulmonary disease, or severe osteoarthritis of lower extremities, and those who were unable to complete a 6–minute walk were excluded; ultimately, 47 patients (male, 20; female, 27; mean age, 69.3 ± 10.1 years) were enrolled. Patients with symptoms, such as low back pain, caused by spinal instability underwent surgery for decompression and interbody fusion. Instability was defined as vertebral translation >3 mm on flexion/extension radiographs. Several patients underwent surgery using the lateral approach; however, patients with a history of retroperitoneal inflammatory disease (e.g., diverticulitis) or extensive retroperitoneal surgery (e.g., renal surgery) underwent surgery using the posterior approach. All patients were examined 1 week prior to the scheduled surgery and 3 months postoperatively.

This study was approved by the Ethics Committee of Iwate Medical University School of Medicine (IRB: MH2018-067), and written informed consent was obtained from all patients.

2. Protocol

For gait analysis, we used a single wearable

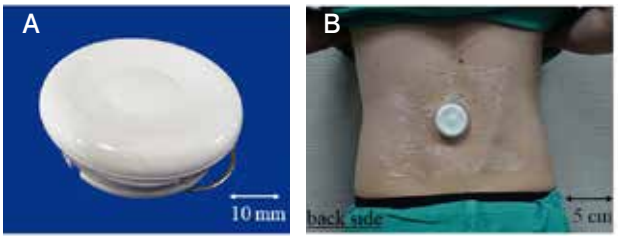
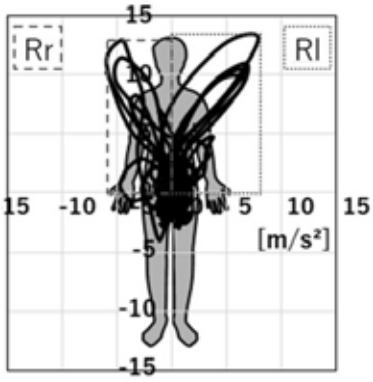


Fig 1. Wearable tri-axial acceleration sensor.
A: Image of a wearable tri-axial acceleration sensor (weight, 15 g; diameter, 41 mm; thickness, 15 mm).
B: Image of the sensor directly on the skin on top of the spinous process of L3.



$$LI = \left| \frac{2(R_r - R_l)}{R_r + R_l} \times 100 \right|$$

Fig 2. An example of LF and method for calculating the LI value.
LF reflects the movements of the body mass center and gives a visual recognition of trunk sway. LI value is calculated from LF by a simple formula as an index for gait symmetry.
LF, Lissajous figure; LI, Lissajous index; Rr, right rectangular area within the blue solid line; Rl, left rectangular area within the red dotted line.

tri-axial acceleration sensor (Q'z TAG Research: Sumitomo Electric Industries, Osaka, Japan), with 15 g weight, 41 mm diameter, and 15 mm thickness (Fig. 1A). All data collected during the walking test were transmitted to a laptop via Bluetooth (transmission distance: approximately 30 m). The acceleration sensor sampling rate was set to 200 Hz [9, 10]. After affixing the sensor directly to the skin on top of the spinous process of L3 [11] with a dressing material (Fig. 1B), the patient underwent the 6-minute walking test (6MWT), according to the method advocated by the American Thoracic Medical Society (ATS) [12]. All participants were instructed to walk as fast as possible along a 25 m horizontal pathway for 6 minutes [13], and return to the starting point after reaching the cone indicating the end of the course. In addition, the patients' walking distance was measured during the 6MWT.

3. Data analysis

All acceleration data in three axes (CSV format) were divided into sections every minute. Then, the stable 2048-point data excluding the turning point were extracted every minute to transmit the data of the turning point. The LF was created from two-axis data from each extracted 2048-point data (Fig. 2); the LI value was calculated from each LF as an index of gait asymmetry (Fig. 2).

The LI calculation method was as follows: the rectangle with a solid line in Figure 2 represented the rectangular area of the right side (Rr); the rectangle with a dotted line represented the rectangular area of the left side (Rl).

The methods for finding the area of Rr and Rl were as follows:

a) Vertical length of the rectangle: maximum acceleration in a vertical direction

b) Horizontal length of the rectangle: an absolute value of the maximum acceleration in a left-to-right direction.

c) The area was calculated from the vertical height × horizontal length to determine Rr and Rl.

The LI value was calculated as follows:

$LI = [2 \times (Rr - Rl) / (Rr + Rl)] \times 100$

The lower the LI numeric value, the greater the gait symmetry, whereas the higher the numeric value, the greater the walking asymmetry.

4. Clinical scoring system

The Japanese Orthopedic Association (JOA) score and the Oswestry Disability Index (ODI) were used to examine the correlation between the LI values and clinical symptoms. The JOA score evaluates pain and disability based on a 29-point scale, constituting four domains related to lower back pain: subjective and objective symptoms, activities of daily living, and bladder function. The recovery rate was calculated based on Hirabayashi et al. [14] as follows:

Recovery rate of JOA score (%) = (postoperative JOA score − preoperative JOA score) × 100 / (29 − preoperative JOA score)

The ODI is one of the principal condition-specific outcome measures used in the management of spinal disorders, constituting the following 10 items: pain intensity, personal care, lifting, walking, sitting, standing, sleeping, sexual life, social life, and traveling. ODI ranges from 0% to 100%, with higher ODI scores indicating more severe disability. The Japanese translation published in 2003 was used in this study [15]. The change in ODI was calculated using the following formula:

Change in ODI (%) = postoperative ODI score (%) − preoperative ODI score (%).

The correlation between the recovery rate of JOA score and the change in the LI value, and the correlation between changes in ODI and changes in LI value were examined to compare gait characterization pre- and postoperatively.

5. Statistical analysis

The changes in JOA score, ODI, 6MWT distance and LI value pre- and postoperatively were assessed by paired t test. In addition, the correlation between the LI value and clinical scoring system was evaluated using Pearson's correlation coefficient. SPSS version 21.0 (IBM Corp., Armonk, NY) was used for the statistical analysis, with $p < 0.01$ as the significance level. Continuous variables were expressed as mean ± standard deviation (SD).

III. Results

1. Participants

In total, 32 of 47 patients (male, 15; female, 17; mean age, 68.7 ± 9.7 years) participated in the preoperative and postoperative measurements. Six patients were unable to complete the 6MWT in the preoperative assessment, while 9 patients dropped out from the study postoperatively (3 withdrew from the study; 4 missed the follow-up examination; 2 had an exacerbation of the underlying disease).

2. Surgical procedures

Clinical information and surgical procedures of the patients are shown in Table 1 and Table 2. Of the 32 patients, 24 had LSS with spondylolisthesis and 1 had LSS with adjacent level degeneration. Moreover, 18 had cauda equina type, 9 had nerve root type, and 5 had combined type with regard to neuropathy type. Seven patients underwent direct decompression without fusion, 17 patients underwent indirect decompression with lateral lumbar interbody fusions (LLIF) and 8 patients underwent direct decompression with posterior lumbar interbody fusion (PLIF).

Table 1. Basic information and clinical data of 32 patients with LSS

Age (yr)	Sex	BMI (kg/m^2)	Diagnosis	Neuropathy type
68	M	24.2	LSS L2-5	cauda equina
75	F	25.7	LSS L2-5	cauda equina
78	M	21.2	LSS with spondylolisthesis L4-5	cauda equina
59	F	23.8	LSS with spondylolisthesis L3-5	cauda equina
76	F	23.5	LSS with spondylolisthesis L3-5	cauda equina
70	F	28.1	LSS with spondylolisthesis L4-5	nerve root
81	F	25.1	LSS with spondylolisthesis L3-5	combined
54	M	27.7	LSS with spondylolisthesis L4-5	cauda equina
69	F	24.1	LSS with spondylolisthesis L3-5	nerve root
47	F	24.1	LSS with spondylolisthesis L4-5	cauda equina
63	M	22.9	LSS L3-5	nerve root
67	M	22.8	LSS L2-5	nerve root
76	F	22.5	LSS with spondylolisthesis L3-5	cauda equina
69	M	28.0	LSS with spondylolisthesis L4-5	cauda equina
76	M	28.9	LSS with spondylolisthesis L3-5	cauda equina
56	M	32.5	LSS with spondylolisthesis L4-5	combined
62	M	23.2	LSS with spondylolisthesis L3-5	cauda equina
77	F	18.4	LSS with spondylolisthesis L4-5	nerve root
55	F	24.2	LSS with spondylolisthesis L4-5	cauda equina
65	F	28.5	LSS with spondylolisthesis L4-5	nerve root
75	F	23.3	LSS with spondylolisthesis L4-5	cauda equina
78	F	22.1	LSS with spondylolisthesis L3-5	combined
80	F	29.5	LSS with spondylolisthesis L4-5	cauda equina
80	M	25.9	LSS with spondylolisthesis L4-5	combined
56	M	26.0	LSS with spondylolisthesis L3-5	nerve root
72	M	22.8	LSS with spondylolisthesis L4-5	combined
78	M	19.9	LSS L3-5	cauda equina
75	M	25.4	LSS L3-5	cauda equina
66	F	20.5	LSS with spondylolisthesis L4-5	nerve root
68	F	28.8	LSS L3-5	cauda equina
69	M	27.0	LSS with spondylolisthesis L3-5	cauda equina
60	F	19.5	Adjacent level degeneration with LSS L2-3	nerve root

F, female; M, male; LSS, lumbar spinal stenosis; BMI, body mass index.

Table 2. Surgical procedure of the patients with LSS

Surgery	Level	N
Decompression	L2-5	3
	L3-5	4
PLIF	L2-3	1
	L3-5	2
	L4-5	5
LLIF+PPS	L3-5	8
	L4-5	9

Procedure of decompression indicates decompression of the neural elements alone while preserving stability. Procedure of PLIF indicates direct decompression and interbody fusion with posterior instrumentation using open posterior approaches. LLIF procedure indicates indirect decompression followed by interbody fusion using minimum invasive lateral approaches with percutaneous pedicle screws.
LLS, lumbar spinal stenosis; PLIF, posterior lumbar interbody fusion; LLIF, lumbar lateral interbody fusion.

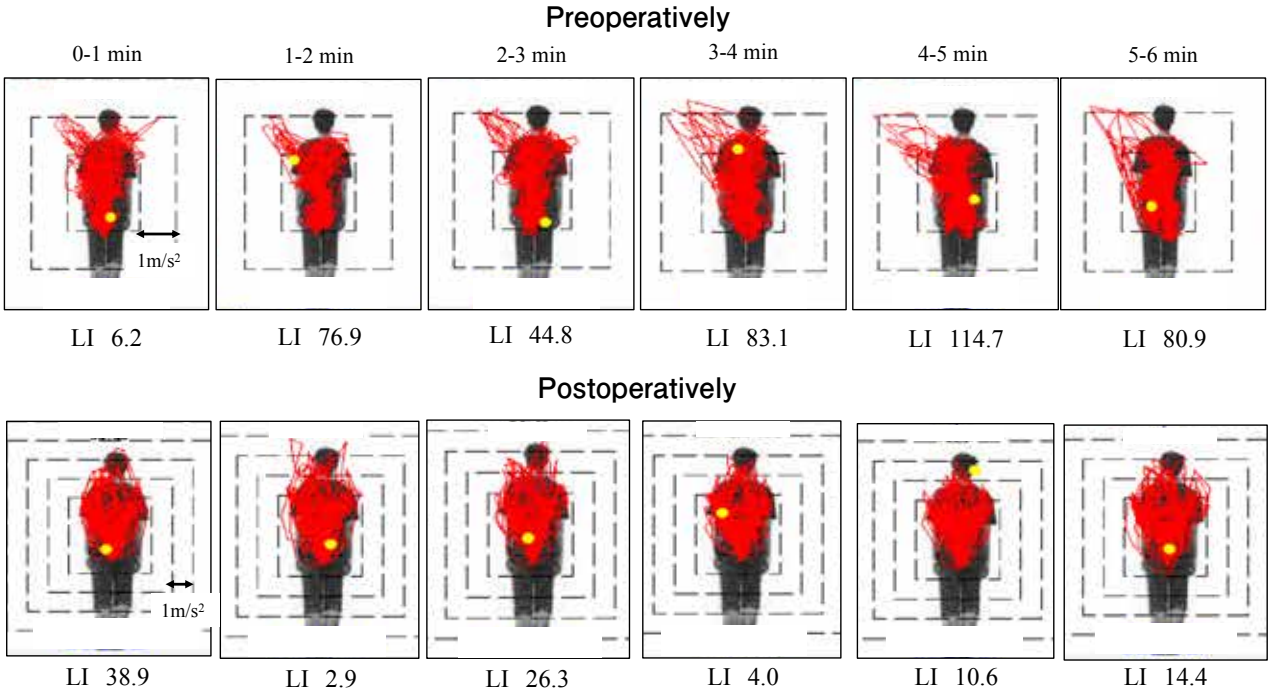


Fig 3. An example of LF and LI value pre- and 3 months postoperatively during the 6-minute walking test. Preoperatively, the LF of the coronal plane became asymmetric and the LI value increased over time. Symmetry of the LF and plateau in the LI value from the start is observed postoperatively.
LF, Lissajous figure; LI, Lissajous index; LSS, lumbar spinal stenosis.

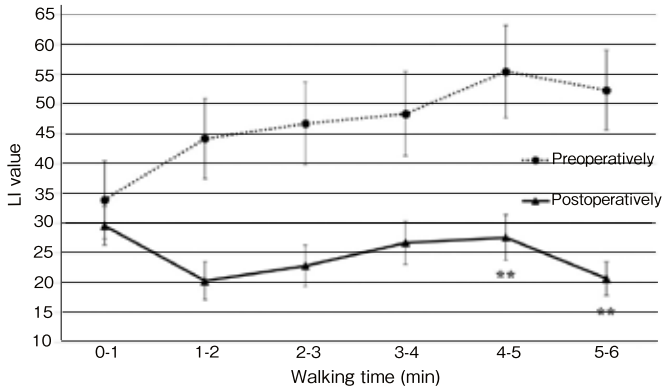


Fig 4. Changes in the LI value pre- and postoperatively.
The LI value gradually increased over time preoperatively. On the other hand, this value did not increase postoperatively and was significantly lower when compared with preoperative value.
pre- versus postoperatively, paired t-test, **p <0.01.

3. Clinical scoring systems

The preoperative and postoperative JOA scores were 15.6 ± 3.3 and 21.1 ± 3.8, respectively (p <0.001). The recovery rate of the JOA score was 40.3 ± 26.6%. The preoperative and postoperative ODI values were 39.1 ± 17.4% and 25.0 ± 15.0%, respectively (p <0.001). The change in ODI was -14.1 ± 12.3%.

Table 3. Correlation between LI value and clinical scoring system

Clinical scoring	Min	Correlation Coefficient	p value
Recovery rate of JOA score	0-1	0.301	0.173
	1-2	− 0.007	0.576
	2-3	− 0.114	0.432
	3-4	− 0.191	0.194
	4-5	− 0.189	0.198
	5-6	− 0.524	0.002
Change in ODI	0-1	− 0.031	0.331
	1-2	0.109	0.282
	2-3	0.205	0.189
	3-4	0.081	0.289
	4-5	0.107	0.269
	5-6	0.361	0.038

A significant correlation was noted between LI value and clinical scores of JOA at 5-6 min (Pearson's correlation coefficient).
LI, Lissajous index; JOA, Japanese orthopedic association; ODI, Oswestry disability index.

4. Gait parameters

Walkable distance during 6MWT was significantly different between the preoperative (395.1 ± 60.8 m) and postoperative measurements (455.4 ± 64.4 m) ($p < 0.001$). An example of preoperative and postoperative LFs is shown in Figure 3. The preoperative LF was asymmetric in the coronal plane, and the asymmetry was remarkable over time. Conversely, the postoperative LF was symmetrical, with improved left-to-right balance. Changes in the LI value during the 6MWT pre- and postoperatively are shown in Figure 4. The respective preoperative and postoperative LI values in the group of the patients with LSS were: 33.9 ± 35.8 and 29.6 ± 17.7 (0–1 min, $p = 0.48$); 44.3 ± 37.1 and 20.3 ± 17.6 (1–2 min, $p = 0.02$); 46.8 ± 38.1 and 22.9 ± 18.9 (2–3 min, $p = 0.02$); 48.4 ± 38.8 and 26.7 ± 19.8 (3–4 min, $p = 0.04$); 55.5 ± 42.6 and 27.6 ± 17.0 (4–5 min, $p = 0.004$); and 52.4 ± 36.9 and 20.7 ± 15.4 (5–6 min, $p < 0.001$). The preoperative LI value gradually increased over time, but plateaued from the start postoperatively. Furthermore, the postoperative LI value was significant lower than the preoperative one at 4–6 min ($p = 0.004$ at 4–5 min and $p < 0.001$ at 5–6 min).

5. Correlation between LI value and clinical scoring system

Correlation between LI value and clinical scoring system is shown in Table 3. A negative significant correlation was found with a recovery rate of the JOA score at 5–6 min ($r = -0.52$, $p = 0.002$).

IV. Discussion

Functional neuropathies in patients with LSS can be classified into 3 types based on the compressed neural elements: cauda equina type, nerve root type and combined type; these 3 types of patients were included in this study as shown in Table 1. Most patients with LSS have gait disturbance caused by leg pain, burning, numbness and paresthesia increased by walking, that is,

intermittent claudication. Therefore, surgical treatment such as procedures of lumbar decompression with or without fusion are currently regarded as an appropriate management strategy when conservative therapies fail. Although the aim of lumbar decompression surgery is to decompress the neural elements, an instrumented fusion is performed in addition to improve low back pain caused by instability if the lumbar spine is unstable from spondylolisthesis, which is defined as the slipping forward of one lumbar vertebra on another with an intact neural arch [16]. Open posterior approaches for fusion and supplemental internal fixation have been widely used traditionally to manage low back pain and neurological symptoms. Recently, less invasive approaches for lumbar interbody fusion have gained in popularity, because of muscle damage and excessive bleeding associated with the posterior approach. One such less invasive surgery for lumbar decompression with fusion is LLIF with posterior instrumentation using percutaneous pedicle screws (PPS), reportedly resulting in the preservation of back muscles, and bony and ligamentous structures [17].

Several surgical procedures have been established and developed in this way. Many studies on the severity of gait disturbance aggravated by walking and surgery outcomes in patients with LSS have been performed, but most are based on patient-reported information or questionnaires, which may be subjective, inaccurate, or incomplete [18, 19]. Appropriate objective evaluation is mandatory to diagnose the severity of gait disturbance in LSS patients. The gait analysis of these patients is a promising avenue to provide objective measurements compared with analysis based on patients' questionnaire responses [6, 7]. Suda et al. [20] reported that gait analysis using a force plate can provide objective quantitative evaluation of gait characteristics of patients with LSS pre- and postoperatively. However, this gait analysis may not be feasible in daily practice for diagnosing of gait disturbance, as it requires a laboratory environment for the force plate and/or several items of analytical equipment. Conversely, the tri-axial acceleration sensor is small, light-weight, and useful in measuring gait in various conditions, and can analyze gait quality in conditions close to daily life because it does not require a laboratory environment. Furthermore, the use of a tri-axial acceleration sensor to evaluate gait has been regarded as an effective objective quantitative tool compared with laboratory-based gait assessment [21, 22]. The wearable tri-axial acceleration sensor that we used in this study showed high test-retest reliability ($r = 0.77 - 0.96$) in walking assessed in 20 healthy individuals, and correlation with the force plate ($r = 0.73$, $p < 0.0001$) in the measurement of gait asymmetry [23, 24]. Papadakis et al.[9, 10] and Nagai et al. [25] quantified the changes in gait quality in patients with LSS using a wearable tri-axial acceleration sensor. However, several studies pointed out that the parameters calculated from the acceleration data, such as the root mean square and harmonic ratio, may not be instantly analyzed or easily visualized [8, 26]. The LI value advocated by Yamaguchi et al. 8) is calculated from the LF using a simple formula, and the left-right balance during gait in the LF can be instantly quantified to visually and numerically

determine the acceleration data. In patients with cerebral palsy, chronic obstructive pulmonary disease, and stroke, gait ability has been evaluated using LI values [26-28].

We previously reported that the LI value of patients with LSS is significantly higher than that of healthy subjects during walking [29]. To the best of our knowledge, the present study is the first to evaluate the postoperative improvement of gait disturbance in patients with LSS using LI value measured by a wearable tri-axial acceleration sensor. We confirmed that the gait asymmetry indicated by LI value significantly increased over time during the preoperative 6MWT, and they provided postoperative improvement especially at 4–6 min. Furthermore, they had significant correlations with the clinical scores of JOA at 5–6 min, the last minute of the 6MWT. We considered that these results were related objectively to the effectiveness of surgical treatment in improving trunk sway by decreasing low back pain and neurological leg symptoms that become remarkable when gait distance gets longer.

This study has several limitations. First, the postoperative changes of gait characteristics may be overestimated because of the small sample size and the relatively high dropout rate (19.1%). Second, we assessed gait characteristics 3 months postoperatively because a previous study on gait analysis in patients with LSS reported that visual analogue scale (VAS) at the post-gait load test improved 3 months after surgery and was maintained until the final follow up [30]. Finally, We focused on postoperative improvement of neurological symptoms and low back pain, which are typical symptoms of LSS in this study. Therefore, three types of surgical procedures existed because several neuropathy types and LSS with or without spondylolisthesis coexist in participants. Further long term follow-up studies where we increase the number of patients with consisted LSS type for certain evaluation of gait disturbance may be necessary.

Overall, this study found that gait analysis using an LI value derived from a wearable tri-axial acceleration sensor could provide an appropriate objective quantitative assessment for patients with LSS. It could also be useful for postoperative objective evaluations of gait improvement without the need for large scale laboratory environments.

Acknowledgments

The authors would like to express their appreciation to Bycen Inc. for their advice on experimental design. The submitted manuscript does not contain information regarding medical device(s)/drug(s).

No funds were received in support of this work. No relevant financial activities took place outside the submitted work.

IRB approval: This study was approved by the ethical committees of Iwate Medical University School of Medicine.

Conflict of interest: The authors have no conflict of interest to declare.

References

1) **Tomita K**: Diagnosis and treatment of lumbar spinal canal stenosis. JMAJ **46**, 439–444, 2003.
2) **Kalichman L, Cole R, Kim DH, et al.**: Spinal stenosis prevalence and association with symptoms: the Framingham Study. Spine J **9**, 545-550, 2019.
3) **Ishimoto Y, Yoshimura N, Muraki S, et al.**: Prevalence of symptomatic lumbar spinal stenosis and its association with physical performance in a population-based cohort in Japan: the Wakayama Spine Study. Osteoarthr Cartil **20**, 1103-1108, 2012.
4) **Konno S, Kikuchi S, Tanaka Y, et al.**: A diagnostic support tool for lumbar spinal stenosis: a self-administered, self-reported history questionnaire. BMC Muscloskelet Disord **8**, 102, 2007.
5) **Ahmed SI, Javed G, Bareeqa SB, et al.**: Comparison of decompression alone versus decompression with fusion for stenotic lumbar spine: a systematic review and meta-analysis. Cureus **10**, e3135, 2002.
6) **Pratt RK, Fairbank JC** and **Virr A**: The reliability of the shuttle walking test, the Swiss spinal stenosis questionnaire, the Oxford spinal stenosis score, and the Oswestry disability index in the assessment of patients with lumbar spinal stenosis. Spine (Phila Pa 1976) **27**, 84-91, 2002.
7) **Tomkins CC, Battié MC, Rogers T, et al.**: A criterion measure of walking capacity in lumbar spinal stenosis and its comparison with a treadmill protocol. Spine (Phila Pa 1976) **34**, 2444-2449, 2009.
8) **Yamaguchi R, Hirata S, Doi T, et al.**: The usefulness of a new gait symmetry parameter derived from Lissajous figures of tri-axial acceleration signals of the trunk. J Phys Ther Sci **24**, 405–408, 2012.
9) **Papadakis NC, Christakis DG, Tzagarakis GN, et al.**: Gait variability measurements in lumbar spinal stenosis patients: part A. Comparison with healthy subjects. Physiol Meas **30**, 1171-1186, 2009.
10) **Papadakis NC, Christakis DG, Tzagarakis GN, et al.**: Gait variability measurements in lumbar spinal stenosis patients: part B. Comparison with healthy subjects. Physiol Meas **30**, 1171-1186, 2009.
11) **Kavanagh JJ, Morrison S, James DA, et al.**: Reliability of segmental accelerations measured using a new wireless gait analysis system. J Biomech **39**, 2863-2872, 2006.
12) ATS Committee on Proficiency Standards for Clinical Pulmonary Function Laboratories: ATS statement: guidelines for the six-minute walk test. Am J Respir Crit Care Med **166**, 111-117, 2002.
13) **Weir NA, Brown AW, Shlobin OA, et al.**: The influence of alternative instruction on 6-min walk test distance. Chest **144**, 1900-1905, 2013.
14) **Hirabayashi K, Miyakawa J, Satomi K, et al.**: Operative results and postoperative progression of ossification among patients with ossification of cervical posterior longitudinal ligament. Spine (Phila Pa 1976) **6**, 354-364, 1981.
15) **Fujiwara A, Kobayashi N, Saiki K, et al.**: Association of the Japanese Orthopaedic Association score with the Oswestry Disability Index, Roland-Morris Disability Questionnaire, and short-form 36. Spine (Phila Pa 1976) **28**, 1601-1607, 2003.
16) **Kalff R, Ewald C, Waschke A, et al.**: Degenerative lumbar spinal stenosis in older people. Dtsch Arztebl Int **110**, 613-624, 2013.
17) **Blizzard DJ, Hills CP, Isaacs RE, et al.**: Extreme lateral interbody fusion with posterior instrumentation for spondylodiscitis. J Clin Neurosci **22**, 1758-1761, 2015.
18) **Carragee EJ** and **Cheng I**: Minimum acceptable outcomes after lumbar spinal fusion. Spine J **10**, 313-320, 2010.
19) **Carragee EJ**: The rise and fall of the "minimum clinically important difference". Spine J **10**, 283-284, 2010.
20) **Suda Y, Saitou M, Shibasaki K, et al.**: Gait analysis of patients with neurogenic intermittent claudication. Spine (Phila Pa 1976) **27**, 2509-2513, 2002.
21) **Rao PJ, Phan K, Maharaj MM, et al.**: Accelerometers for objective evaluation of physical activity following spine surgery. J Clin Neurosci **26**, 14-18, 2016.
22) **Chakravorty A, Mobbs RJ, Anderson DB, et al.**: The role of wearable devices and objective gait analysis for the assessment and monitoring of patients with lumbar spinal stenosis: systematic review. BMC Musculoskelet Disord **20**, 288, 2019.
23) **Henriksen M, Lund H, Moe-Nilssen R, et al.**: Test-retest reliability of trunk accelerometric gait analysis. Gait Posture **19**, 288-297, 2004.
24) **Karimpour R, Krupenevich RL, Miller RH, et al.**: Evaluation of gait asymmetry using force plates versus accelerometer. J Mech Med Biol **18**, 1850015, 2018.

25) **Nagai K, Aoyama T, Yamada M, et al.**: Quantification of changes in gait characteristics associated with intermittent claudication in patients with lumbar spinal stenosis. J Spinal Disord Tech **27**, E136-E142, 2014.
26) **Mutoh T, Mutoh T, Tsubone H, et al.**: Effect of hippotherapy on gait symmetry in children with cerebral palsy: a pilot study. Clin Exp Pharmacol Physiol **46**, 506-509, 2019.
27) **Terui Y, Iwakura M, Suto E, et al.**: New evaluation of trunk movement and balance during walking in COPD patients by a triaxial accelerometer. Int J Chron Obstruct Pulmon Dis **13**, 3957-3962, 2018.
28) **Terui Y, Suto E, Konno Y, et al.**: Evaluation of gait symmetry using a tri-axial accelerometer in stroke patients. NeuroRehabilitation **42**, 173-180, 2018.
29) **Abe Y, Murakami H, Endo H, et al.**: Quantification of gait features in patients with lumbar spinal stenosis using an acceleration sensor. JIMA **72**, 133-144, 2020.
30) **Kim Y, Park S, Oh I, et al.**: The clinical effect of gait load test in two level lumbar spinal stenosis. Asian Spine J **3**, 96–100, 2009.

岩手医誌 73 巻，4 号（令和 3 年 10 月）177-188 頁.

ウエアラブル 3 軸加速度センサを用いた 腰部脊柱管狭窄症患者の歩行解析

金野大地[1)]，村上秀樹[1)]，
遠藤寛興[1)]，山部大輔[1)]，千葉佑介[1)]，
安部悠一郎[1)]，和田俊太郎[1)]，千田　康[2)]，土井田稔[1)]

[1)] 岩手医科大学医学部，整形外科学講座
[2)] バイセン株式会社

(Received on January 20 2021 & Accepted on February 12, 2021)

要旨

腰部脊柱管狭窄症（LSS）患者の歩行能力を簡便に視覚化したパラメーターは確立されていない．我々は歩行非対称性を簡便に視覚的・数値的に捉えることができる Lissajous Index（LI）値を使用した．本研究の目的は LI 値術前後での歩容変化を前向きに捉え，LSS 患者の術後評価が可能かを検討した．当院にて手術を施行した LSS 患者 32 名を対象とした．歩行試験は術直前と，術後 3 ヵ月時に施行した．加速度センサを貼付し最大歩行速度で直線 25m を往復して 6 分間歩行試験を行った．加えて術前後の LI 値と JOA score・ODI との関係を統計学的に検討した．歩行距離は術前 395.1 ± 60.8m，術後 455.4 ± 64.4m と有意に延長していた．術前は時系列的に LI 値の増大傾向を認めていたが，術後は増大傾向が緩徐となり，1 分以降は有意に術前より低値を示した．また，5-6 分において LI 値と臨床スコアの間に相関関係を認めた．これらの結果から LI 値を用いた歩行試験は LSS 患者の術後評価として実臨床応用が期待できる．