

Clinical Study

# Predictors of walking ability after surgery for lumbar spinal canal stenosis: a prospective study

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## Abstract

**BACKGROUND CONTEXT:** Few studies have investigated predictors of objective walking distance in patients with lumbar spinal stenosis (LSS).

**PURPOSE:** This study aimed to clarify objective predictors of postoperative 6-minute walk distance (6MWD) in patients with LSS and to develop prediction equations.

**STUDY DESIGN:** This was a prospective study. Data were analyzed by multiple linear regression analyses.

**PATIENT SAMPLE:** Patients with LSS were enrolled.

**OUTCOME MEASURES:** Predictors of 6MWD after surgery were evaluated, including patient characteristics (sex, age, height, and body weight), pain (visual analog scale; low back pain, lower limb pain, and lower limb numbness), surgical factors (number of operation segments [1 or  $\geq 2$ ], surgery type [fusion or decompression], and minimum area of the dural sac), and objective physical function (6MWD and trunk muscle strength).

**METHODS:** Patients with LSS were consecutively included and assessed preoperatively (n=113) and 6 months postoperatively (n=78). Simple and multiple linear regression analyses were performed with 6MWD at 6 months postoperation as the dependent variable. We have study funding sources (Nagano Medical Foundation) and no study-specific conflicts of interest-associated biases.

**RESULTS:** At 6-month follow-up, 6MWD ( $457.7 \pm 105.5$  m) improved significantly compared with preoperative 6MWD ( $275.0 \pm 157.2$  m;  $p < .01$ ). Trunk muscle strength and pain improved significantly compared with the preoperative score ( $p < .01$ ). The predictors of postoperative 6MWD were age, body weight, number of operation segments (1 or  $\geq 2$ ), surgery type (fusion or decompression), preoperative trunk extensor strength, and preoperative 6MWD (adjusted  $R^2 = 0.65$ ,  $p < .01$ ). The proposed prediction equation was as follows: postoperative 6MWD (m) =  $549.5 - 5.3 \times \text{age (years)} - 1.8 \times \text{body weight (kg)} - 68.3 \times \text{surgery type (0: decompression, 1: fusion)} - 58.6 \times \text{operation segment (0: one segment, 1: } \geq 2 \text{ segments)} + 3.5 \times \text{trunk extensor strength (kg)} + 0.2 \times \text{preoperative 6MWD (m)}$ .

FDA device/drug status: The FDA approved ARMADA™ (NuVasive Inc, San Diego, CA, USA), medications (prostaglandin E1, nonsteroidal anti-inflammatory drug, pregabalin, tramadol). The FDA did not approve multi-slice CT (Alexion, Canon Medical Systems Corporation, Otawara-shi, Tochigi, Japan), strain-gauge dynamometer (Mobic®, SAKAI Medical, Tokyo, Japan).

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**CONCLUSIONS:** Younger age, lower body weight, one level operative segment, decompression surgery, and better preoperative scores for trunk extensor strength and 6MWD predicted better scores for 6 months postoperative 6MWD. Preoperative reduction in body weight and increase of trunk extensor strength might be associated with improved postoperative 6MWD scores. © 2019 Elsevier Inc. All rights reserved.

*Keywords:* Decompression; Lumbar fusion; Lumbar spinal canal stenosis; Prognostic indicator; Walking ability; 6-minute walk distance

## Introduction

Patients with lumbar spinal stenosis (LSS) experience symptoms such as lower limb pain, numbness, intermittent claudication, and difficulties with activities of daily living [1]. The LSS is incident in almost 3.6 million people older than 40 years of age in Japan and has a prevalence rate of approximately 10% in Japanese people in their 70s [2]. When conservative therapy is ineffective, decompression surgery or fusion surgery is used to treat severe symptoms [3].

Walking ability is the main outcome measure for patients with LSS. Self-reported walking distance is recognized as a major factor for evaluation [4]. Ogikubo et al. found that self-reported walking distance for patients with LSS was associated with age, low back pain, lower limb pain, and minimum area of the dural sac [5]. In a longitudinal study, Katz et al. documented that predictors of self-reported walking distance for 2 years after surgery were self-reported health before surgery, self-reported walking distance before surgery, union failure of fixed objects (noninstrumented fusion), and higher income [6]. In these previous studies, self-reported walking distances of patients with LSS have been clarified to correlate with patient characteristics, pain, radiologic parameters, and self-reported walking distance before surgery.

The self-paced walking test, treadmill walking test, and 6-minute walk distance (6MWD) have been used for the objective evaluation of walking distance in patients with LSS [4,7,8]. Few studies have investigated predictors of objective walking distance. Tomkins-Lane and Battie [9] reported that predictors of the self-paced walking test at 12 months after surgery were preoperative self-reported lumbar spine dysfunction, preoperative self-reported balance disorder, and lower limb pain at 12 months after surgery. However, these predictors were evaluated by subjective measures, not objective measures. A disadvantage of the self-paced walking test is that it requires 13 minutes on average and 30 minutes maximum, and is thus not considered a useful method [7]. In contrast, the 6MWD requires only a maximum of 6 minutes to evaluate exercise capacity [10]. It is simple to perform and correlates well with more sophisticated tests requiring a treadmill [8]. Nevertheless, the predictors of postoperative 6MWD for patients with LSS have not been reported.

It is important to clarify the predictors of postoperative 6MWD in order to plan preoperative intervention strategies. Therefore, in the present study, we investigated

patient characteristics (sex, age, height, and body weight), pain (low back pain, lower limb pain, and lower limb numbness), surgical-related factors (operation segments, surgery type: decompression or fusion, minimum area of the dural sac), and objective physical function (6MWD and trunk muscle strength). The purpose of this study was to clarify objective predictors of postoperative 6MWD in patients with LSS, and to develop prediction equations from objective predictors.

## Materials and methods

### *Study design, participants, and ethics*

This was a prospective study performed at a single hospital. Patients were enrolled from June 2013 to December 2017. Patients were assessed before surgery and 6 months after surgery. Inclusion criteria were as follows: (1) severe neurogenic claudication as defined by leg pain or/and numbness; (2) availability of magnetic resonance imaging, computed tomography myelography, and radiological findings; and (3) ineffective nonoperative therapy. The options for nonoperative therapy include medications (prostaglandin E1, nonsteroidal anti-inflammatory drug, pregabalin), epidural steroid injection, or selective nerve root injection [11–13]. Exclusion criteria were as follows: (1) severe osteoarthritis of the knee and hip, (2) history of central nervous system disorder, (3) vertebral fracture, (4) patients treated with lateral lumbar interbody fusion, (5) nerve paralysis (score of 2 or less on the manual muscle test), (6) patients who previously underwent spinal surgery, and (7) insufficient understanding of the questionnaire. The study was approved by the research ethics committee of our institute, and informed consent was obtained from each participant.

### *Surgical procedure and rehabilitation management*

Patients underwent decompression surgery and/or fusion surgery by open methods. The indications for fusion surgery were slip greater than 3 mm, greater than 15° instability on lateral view of the lumbar functional x-ray scan, or greater than 5° local kyphosis angle on lateral view of the lumbar flexion x-ray scan [14]. Fusion surgery was performed by the conventional open approach (eg, total facetectomy) using carbon-polyetheretherketone interbody cages and pedicle screw systems (ARMADA, NuVasive Inc, San Diego, CA,

USA) [15]. Decompression surgery was performed via a split spinous process, and the stenotic part of the lumbar spine was decompressed by partial medial facetectomy [16].

All patients received daily physical therapy only during hospitalization. Patients who underwent decompression surgery began rehabilitation on postoperative day 3 and were discharged on postoperative day 5. The mean number of days of hospitalization for the decompression surgery group was approximately 7 days. Patients who underwent fusion surgery began rehabilitation on postoperative day 3 and were discharged on postoperative day 12. The mean number of days of hospitalization for the fusion surgery group was approximately 14 days. Patient started walking using a walker. Physical therapy of approximately 40 min/d continued until discharge. A physical therapist advised patients to avoid excessive flexion of the trunk and lifting of heavy objects, encouraged light exercise (walking every day, heel up, toe lift, standing on one foot, half standing upright squat, drawing, dorsal position buttock raising), and encouraged stretching (hip flexion, abduction, hamstrings, triceps surae muscle). Patients who underwent fusion surgery used a hard corset for 3 months; patients treated with decompression surgery did not.

#### Outcome

As the primary outcome variable, we evaluated 6MWD, which was assessed according to established guidelines [17]. Pain and numbness scores were also assessed using a Numerical Rating Scale (NRS) during 6MWD tests. The NRS scores ranged from 0 to 10, with higher scores indicating an increased severity of symptoms.

#### Predictors

In developing the prediction formula, parameters for patient characteristics, surgical-related factors, patient-reported outcomes, and physical function were examined.

#### Patient characteristics and surgery-related factors

Age, height, and body weight were assessed to evaluate patient characteristics. We also assessed the following: duration of symptoms, comorbidity (diabetes mellitus, heart disease, depression, renal disease, anxiety, history of stroke), current smoking status, and medication. Comorbidities were defined based on the whether they took medication or no. Surgery-related factors included surgery time, blood loss volume, surgical type (fusion or decompression), number of surgery segments, and minimum area of the dural sac. Surgical type was selected based on lumbar spine slip greater than 3 mm and/or greater than 15° instability. Operative segments included the decompressed or fixed vertebrae. Dural sac area was preoperatively evaluated by myelography and multislice computed tomography (Alexion, Canon Medical Systems Corporation, Otawara-shi, Tochigi, Japan). Images were taken from the L1–L2 to L5–S1 intervertebral levels;

the surgical segment dura sac area was measured, and the minimum value was adopted.

#### Patients' reported outcome

Disease-specific measures include the physical function and symptom severity scales, the Roland-Morris Disability Questionnaire (RDQ) [18]. The RDQ assesses degree of back pain-related disability. The RDQ consists of 24 yes/no statements, where higher scores indicate greater symptom severity (range 0–24).

#### Physical function and pain

Strength of the trunk muscles was measured using a strain-gauge dynamometer (Mobie, SAKAI Medical, Tokyo, Japan). Isometric extension and flexion strength of the trunk muscles were measured in the sitting position on a chair with the patient's hip and knee joints at 90°. Two maximal effort attempts were performed. If the measured strength level increased by more than 10% from the first attempt, patients were asked to perform one additional attempt.

A visual analog scale (VAS; 0–100, with 100 being the worst pain or numbness) was used to assess maximal low back pain, lower extremity pain, and numbness over the previous week.

#### Sample size calculation

Sample sizes were calculated using the G\*Power [19] software (version 3.1; Faul, University Kiel, Germany) to ensure a power=80%,  $\alpha=0.05$ , effect size  $f=0.33$  (based on a previous study [9]), and number of predictors=15 with a minimum total sample size of 71 patients. Therefore, more than 71 patients were recruited 6 months after surgery.

#### Statistical analysis

We used descriptive statistics to describe the study sample and used completed case analysis of the 78 patients with complete data. Statistical analyses were performed using EZR (Saitama Medical Center, Jichi Medical University, Shimotsuke, Tochigi, Japan) [20]. Differences were considered statistically significant at  $p<.05$ .

The comparison of physical function and pain before and after surgery were analyzed using the Mann-Whitney *U* test. Cohen's *r* was used to evaluate the magnitude of the effect size, with  $r\geq 0.1$  to  $0.3$ =small effect size,  $r\geq 0.3$  to  $0.5$ =medium effect size, and  $r\geq 0.5$ =large effect size [21].

The compared postoperative 6MWD between comorbidities (eg, heart disease and diabetes mellitus) yes and no; current smoking status smoker and nonsmoker using the Mann-Whitney *U* test. The associations between the predictors and the 6MWD at 6 months postoperation were analyzed using Pearson correlation analysis. Simple and multiple linear regression analyses were performed with

6MWD at 6 months postoperation as the dependent variable. Akaike Information Criterion-based stepwise regression was performed both backward/forward. Parameters for the regression analysis were sex, surgery type, number of operated segments, the variables that showed significant differences in comorbidities, current smoking status, and correlations with 6MWD at 6 months ( $p < .05$ ). Multicollinearity was evaluated by the value of variance inflation factor. If the value of variance inflation factor is less than 10, there is multicollinearity.

## Results

### Patient clinical characteristics

A total of 113 patients were assessed before surgery. Twenty-two patients were excluded for the following reasons: appointment cancellation after surgery ( $n=12$ ), reoperation ( $n=1$ ), severe knee osteoarthritis ( $n=1$ ), need for nursing care ( $n=1$ ), femoral neck fracture due to fall ( $n=1$ ), development of dementia ( $n=1$ ), and unknown reasons ( $n=5$ ). Thirteen patients were excluded because of missing data at the 6-month follow-up time point. Thus, we analyzed 78 patients who had completed the evaluation both preoperatively and at 6 months after surgery. Patient characteristics are shown in Table 1. The patients were predominantly male (56.4%; 44 of 78), treated with decompression surgery (60.3%; 47 of 78), and with one operation segment (56.4%; 44 of 78). The average duration of symptoms was  $1.6 \pm 2.2$  years. Comorbidities were diabetes mellitus (nine patients, 11.5%), heart disease (six patients, 7.7%), and depression (one patient, 1.3%). Patients with diabetes mellitus had hemoglobin A1c  $< 7.5\%$ . Twelve patients (15.4%) were current smokers.

### Recovery of physical function, patients reported outcome, and pain

Table 2 reports data on the recovery of physical function and pain to preoperative levels. The postoperative 6MWD at 6 months ( $275.0 \pm 157.2$  m) increased significantly compared with preoperative 6MWD ( $457.7 \pm 105.5$  m;  $p < .01$ ). The 6MWD showed good improvement with a large effect size (Cohen's  $r > 0.5$ ). Pain and numbness NRS during the 6MWD test showed improvement (Cohen's  $r > 0.5$ ). The postoperative RDQ showed large improvements ( $p < .01$ , Cohen's  $r = 0.7$ ). The postoperative strength of the trunk muscle extensor and flexor muscles showed small improvements ( $p < .01$ ; extensor, Cohen's  $r = 0.2$ ; flexor, Cohen's  $r = 0.1$ ). The VAS for low back pain, lower extremity pain, and numbness significantly improved with a large effect size ( $p < .01$ , Cohen's  $r > 0.5$ ).

### Predictors of postoperative 6MWD

The correlation matrix was described in Table 3. The postoperative 6MWD significantly correlated with age, height,

Table 1  
Patients characteristics (n=78)

Sex, n (%)	
women	34 (43.6)
men	44 (56.4)
Age (y)	69.7 (8.9)
Height (cm)	160.0 (10.3)
Body weight (kg)	61.2 (12.1)
BMI (kg/m <sup>2</sup> )	23.8 (3.1)
Duration of symptoms (y)	1.6 (2.2)
Comorbidity	
No, n (%)	63 (80.8)
Yes, n (%)	15 (19.2)
Diabetes mellitus, n (%)	9 (11.5)
Heart disease, n (%)	6 (7.7)
Depression, n (%)	1 (1.3)
Current smoker, n (%)	12 (15.4)
Pharmacological treatment	
No, n (%)	13 (16.7)
Yes, n (%)	65 (83.3)
Pregabalin, n (%)	47 (60.3)
NSAIDs, n (%)	40 (51.3)
Tramadol, n (%)	4 (5.1)
Surgical-related factors	
Blood loss (mL)	159.8 (196.8)
Operation time (min)	99.2 (41.1)
Surgery, n (%)	
Fusion	31 (39.7)
Decompression	47 (60.3)
Operation segments, n (%)	
1	44 (56.4)
$\geq 2$	34 (43.6)
Minimum area of the dural sac (mm <sup>2</sup> )	36.2 (34.2)

BMI, body mass index; NSAIDs, nonsteroidal anti-inflammatory drugs.

Comorbidity was defined as treated with medication.

Data are expressed as mean (SD) or number of patients (%).

body weight, minimum dural sac area, lower extremity pain and numbness, strength of trunk muscle flexors and extensors, and preoperative 6MWD ( $p < .01$ ). There were significant differences between the current smoking status, smoker ( $513.8 \pm 81.8$  m) and nonsmoker ( $447.5 \pm 106.6$  m) in postoperative 6MWD ( $p < .04$ ). Based on these analyses, 14 predictive variables were included in the multiple linear regression analyses.

Preoperative 6MWD, sex, age, height, body weight, current smoking status, surgery type, number of operation segments, minimum area of the dural sac, lower limb pain, lower limb numbness, trunk extensor strength, and trunk flexor strength were included in the simple and multiple linear regression analyses as predictive variables (Table 4). Age (standardized partial regression coefficient beta:  $\beta = -0.45$ ), body weight ( $\beta = -0.20$ ), surgery type (0: decompression or 1: fusion,  $\beta = -0.32$ ), operation segments (0: 1 segment or 1:  $\geq 2$  segments,  $\beta = -0.28$ ), preoperative trunk extensor strength ( $\beta = 0.26$ ), and preoperative 6MWD ( $\beta = 0.31$ ) were associated with 6MWD at 6 months ( $p < .001$ ; Table 4). Total adjusted models explained 65% of the variance (adjusted  $R^2 = 0.65$ ,  $p < .001$ ). Therefore, the proposed prediction equation is: postoperative 6MWD (m) =  $549.5 - 5.3 \times \text{age (years)} - 1.8 \times \text{body weight (kg)} - 68.3 \times \text{surgery type (0: decompression, 1:$

Table 2  
Recovery of physical function and pain at baseline and at 6 months postoperatively

	Preoperative Mean (SD)	Postoperative at 6 months Mean (SD)	p Value	Effect size r
Patients reported outcome				
RDQ	8.8 (4.9)	2.1 (3.2)	<.001	0.7
Physical function				
6MWD (m)	275.0 (157.2)	457.7 (105.5)	<.001	0.5
Gait time (s)	264.3 (119.3)	354.9 (32)	<.001	0.4
Trunk extensor strength (kg)	19.6 (8)	23.2 (7.5)	<.01	0.2
Trunk flexor strength (kg)	14.9 (5)	16.6 (5)	<.01	0.1
Pain or numbness NRS during 6MWD (0–10)	5.8 (2.7)	1.1 (2.2)	<.001	0.5
Pain or numbness VAS (0–100; mm)				
LBP	57.5 (30.5)	22.8 (21.9)	<.001	0.5
Leg pain	66.8 (27)	19.4 (22.4)	<.001	0.6
Leg numbness	59.7 (32.5)	16.6 (23.2)	<.001	0.6

RDQ, Roland-Morris Disability Questionnaire; 6MWD, 6 minutes walking distance, NRS; Numerical Rating Scale, LBP; low back pain.

Cohen's r was also used to evaluate the magnitude of the effect size, with  $r \geq 0.1$  to  $0.3$ =small effect size,  $r \geq 0.3$  to  $0.5$ =medium effect size and  $r \geq 0.5$ =large effect size [19].

fusion)–58.6×operation segment (0: 1 segment, 1:  $\geq 2$  segment)+3.5×trunk extensor strength (kg)+0.2×preoperative 6MWD (m).

## Discussion

We investigated subjective and objective variables in order to identify predictors of postoperative 6MWD. Younger age, lower body weight, one level operative segment, decompression surgery, better scores for trunk extensor strength, and 6MWD before surgery predicted better scores for postoperative 6MWD at 6 months. The total adjusted models explained 65% of the variance. Moreover, we developed a prediction equation.

In the present study, age and body weight predicted a better score on postoperative 6MWD at 6 months. In a previous study, age, height, and body weight were associated with 6MWD in healthy adults [22]. In a national survey of the

Japanese elderly, 6MWD decreased with age [23]. These results support the findings of the present study. It is possible that 6MWD decreases because an increase in body weight leads to increased exercise load. Age is not a changeable variable before surgery, but weight is changeable. Therefore, preoperative body weight is important as a predictor of postoperative walking distance.

Our finding was that the correlation coefficient between postoperative 6MWD and duration of symptoms was not significant. However, there were some reports that the duration of symptoms affects postoperative patient-reported outcomes [24,25]. In another previous study, duration of symptoms was not the selected predictor of objectively measured walking capacity [9]. Prolonged duration of symptoms can cause chronic pain, which may lead to patient bias. The impact of preoperative duration of symptoms may be different for subjective and objective outcomes.

Table 3  
Correlation matrix between the postoperative 6MWD at 6 month and the preoperative predictive variables in patients with LSS (n=78)

Variables	1	2	3	4	5	6	7	8	9	10	11	12	13
1 6 mo 6MWD	1												
2 Preoperative 6MWD	0.60*	1											
3 Age	–0.57*	–0.40*	1										
4 Height	0.51*	0.45*	–0.47*	1									
5 Body weight	0.34*	0.33*	–0.44*	0.72*	1								
6 Minimum area of the dural sac	0.43*	0.24*	–0.29*	0.18	0.07	1							
7 Duration of symptoms	–0.13	–0.05	0.13	–0.15	–0.14	–0.10	1						
8 LBP VAS	–0.07	–0.19	0.03	0.11	–0.09	–0.11	0.18	1					
9 Leg numbness VAS	–0.27*	–0.37*	0.15	–0.09	–0.20	–0.26*	0.07	0.44*	1				
10 Leg pain VAS	–0.26*	–0.44*	0.11	–0.39*	–0.38*	–0.06	0.27	0.32*	0.42*	1			
11 Trunk flexor strength	0.43*	0.40*	–0.27*	0.69*	0.72*	0.32*	–0.21*	–0.07	–0.15	–0.43	1		
12 Trunk extensor strength	0.36*	0.37*	–0.23	0.67*	0.65*	0.20	–0.06	–0.03	–0.23	–0.39*	0.81*	1	
13 RDQ	–0.13	–0.52*	0.16	–0.11	–0.16	–0.10	0.003	0.27*	0.28*	0.38*	–0.29*	0.11	1

6MWD, 6-minute walk distance; LBP, low back pain; VAS, visual analog scale; RDQ, Roland-Morris Disability Questionnaire.

\*  $p < .05$ .

Table 4  
Preoperative predictors of postoperative 6-month 6MWD

	Crude estimates			Adjusted estimates			VIF
	$\beta$	SE	p Value	$\beta$	SE	p Value	
Sex (0: women, 1: men)	0.35	0.11	<.01				2.9
Age (y)	−0.61	0.09	<.001	−0.45	0.09	<.001	2.0
Height (cm)	0.53	0.10	<.001				5.1
Body weight (kg)	0.36	0.11	<.01	−0.20	0.10	<.05	3.5
Current smoking (0: no, 1: yes)	0.23	0.12	.04				1.3
Surgery type (0: decompression, 1: fusion)	−0.33	0.11	<.01	−0.32	0.07	<.001	1.4
Operation segments (0: 1, 1: $\geq 2$ )	−0.37	0.11	<.001	−0.28	0.07	<.001	1.3
Minimum area of the dural sac (mm <sup>2</sup> )	0.43	0.11	<.001				1.7
LBP VAS (0–100; mm)	−0.10	0.12	.42				1.4
Leg numbness VAS (0–100) (mm)	−0.21	0.11	.08				1.7
Leg pain VAS (0–100; mm)	−0.27	0.11	<.05				1.8
Preoperative 6MWD (m)	0.61	0.09	<.001	0.31	0.08	<.001	1.6
Trunk flexor strength (kg)	0.44	0.10	<.001				4.8
Trunk extensor strength (kg)	0.40	0.11	<.001	0.26	0.11	<.05	3.8

VIF, variance inflation factor; LBP, low back pain.

Prediction equation is: postoperative 6MWD (m)=549.5−5.3×age (years)−1.8×body weight (kg)−68.3×surgery type (0: decompression, 1: fusion)−58.6×operation segment (0: one segment, 1:  $\geq 2$  segments)+3.5×trunk extensor strength (kg)+0.2×preoperative 6MWD (m).

Standardized partial regression coefficient beta ( $\beta$ ), standard error (SE), and p value are given for crude and adjusted estimates in the multiple regression analyses. The total model explained 65% of variance at 6MWD at 6-month follow-up (adjusted R<sup>2</sup>=0.65).

Concerning surgery-related factors, surgery type (fusion or decompression) and operation segments (1 segment or  $\geq 2$  segments) were predictors of postoperative 6MWD at 6 months. It has been reported that patients who undergo multisegment surgery and fusion surgery experienced more extensive back muscle damage compared with those who undergo one-segment surgery and decompression surgery [26]. Furthermore, in the present study, patients who underwent fusion surgery used a hard corset to ensure bone healing for 3 months postoperatively. Based on these findings, recovery of postoperative 6MWD at 6 months may have been delayed in cases of fusion surgery and/or multisegment surgery. In contrast, two previous studies reported that there was no difference in self-reported clinical outcome at 24 months after surgery when comparing decompression surgery and fusion surgery [26,27]. Therefore, if the follow-up period is greater than 6 months after surgery, the surgical type and number of surgery segments might not be predictors of postoperative 6MWD. A long-term follow-up study is required.

Concerning physical function, preoperative trunk extensor muscle strength and preoperative 6MWD were identified as predictors of postoperative 6MWD at 6 months. Katz et al. [6] reported that preoperative self-reported walking distance was a predictor of postoperative self-reported walking distance at 6 months (Table 5). This previous study and our research suggest that preoperative walking ability predicts postoperative walking ability. In contrast, Takahashi et al. [28] reported that standing and trunk extension increase pain because of higher epidural pressure. Therefore, patients with LSS may have decreased preoperative trunk extensor strength because of avoidance of trunk extension. Whitman et al. [29] reported that physical therapy, such as manual therapy to the spine and lower extremities, trunk muscle strength exercise, and body-weight supported treadmill walking, influenced functional disability and walking ability in patients with LSS. Therefore, a future study will be necessary to investigate whether preoperative physical therapy may affect postoperative walking function.

Table 5  
Comparison of previous study and the present study

Author	Mean age (y)	No. of patients	Outcome measures	Related factors	Adjusted R <sup>2</sup>
Katz et al. [6]	68.6	199	Questionnaire scales measuring walking ability	Better self-rated health, less cardiovascular comorbidity, before better walking ability, no instrumented fusion, higher income	0.33
Tomkins-Lane and Battie [9]	65.8	49	Self-paced walking test	ODI, self-report balance problems, postwalking leg pain	0.33
The present study	69.7	78	6MWD	Age, body weight, surgery type (0: decompression, 1: fusion), operation segments (0: 1, 1: $\geq 2$ ), preoperative 6MWD, trunk extensor strength	0.65

ODI, Oswestry Disability Index; 6MWD, 6-minute walk distance.

The strengths of this study include its ability to clarify predictive factors of postoperative 6MWD at 6 months based on objective measures. In previous studies, walking ability and predictive factors were assessed based on subjective measures, and the total adjusted models explained 33% and 38% of the variance, respectively (Table 5). It is likely that subjective measures may be distorted because of pain or recall bias. In the present study, we evaluated objective measures, such as 6MWD, surgery-related factors, and physical function. The total adjusted models explained 65% of the postoperative 6MWD, and the adjusted R-squared was higher than previously reported values [6,9]. Furthermore, we defined a prediction formula for postoperative 6MWD at 6 months. This prediction formula could be useful in planning the preoperative intervention strategy.

### Study limitations

This study has several limitations. First, trunk muscle strength was assessed using an isometric method. Currently, there is no gold standard for assessing trunk muscle strength; only one study assessed postoperative trunk muscle strength using an isometric method in the standing position [30]. The standing position increases leg pain in patients with LSS [28]. Therefore, we used the isometric method in the sitting position to minimize pain. Second, the results of this study apply only to short-term outcomes of approximately 6 months. However, it was reported that great improvement at 3 months after LSS surgery can be seen [31]. Thus, we evaluated the recovery of physical function at 6 months. Third, we did not compare types of surgery. In the present study, surgical type was identified as a predictor of postoperative 6MWD at 6 months. Conversely, two previous studies reported that surgery type was not a predictor of disability at 24 months after surgery [26,27]. As surgery type was selected based on a lumbar spine slip greater than 3 mm and/or greater than 15° instability, the stenotic area of the lumbar spine might be different in patients treated with different surgical techniques. More research is needed to examine how different surgery types may predict postoperative 6MWD. Lastly, there were 35 patients (31%) who dropped out during the 6 months follow-up. The patients in this study may have attrition bias, and 6MWD after surgery may be overestimated. Therefore, the results of our study may have limited generalization for LSS postoperative patients.

### Conclusions

We evaluated patient characteristics, pain, surgery-related factors, and objective physical function parameters in order to clarify the predictors of postoperative 6MWD in patients with LSS and to develop prediction equations. Younger age, lower body weight, one-level operative segment, decompression surgery, and better scores for trunk extensor strength and 6MWD before surgery predicted better scores for postoperative 6MWD at 6 months. Preoperative body weight, trunk extensor strength, and 6MWD are changeable factors.

Therefore, preoperative reduction in body weight and increase of trunk extensor strength might be associated with improved postoperative 6MWD scores.

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### Reference

- [1] Lurie J, Tomkins-Lane C. Management of lumbar spinal stenosis. *BMJ* 2016;352:h6234. <https://doi.org/10.1136/bmj.h6234>.
- [2] Yabuki S, Fukumori N, Takegami M, Onishi Y, Otani K, Sekiguchi M, et al. Prevalence of lumbar spinal stenosis, using the diagnostic support tool, and correlated factors in Japan: a population-based study. *J Orthop Sci* 2013;18:893–900. <https://doi.org/10.1007/s00776-013-0455-5>.
- [3] Weinstein JN, Tosteson TTD, Lurie JD, Tosteson ANA, Blood E, Hanscom B, et al. Surgical versus nonsurgical therapy for lumbar spinal stenosis. *N Engl J Med* 2008;358:794–810. <https://doi.org/10.1056/NEJMoa0707136.Surgical>.
- [4] Aalto TJ, Malmivaara A, Kovacs F, Herno A, Alen M, Salmi L, et al. Preoperative predictors for postoperative clinical outcome in lumbar spinal stenosis. *Spine* 2006;31:E648–63. <https://doi.org/10.1097/01.brs.0000231727.88477.da>.
- [5] Ogikubo O, Forsberg L, Hansson T. The relationship between the cross-sectional area of the cauda equina and the preoperative symptoms in central lumbar spinal stenosis. *Spine* 2007;32:1423–8 discussion 1429. <https://doi.org/10.1097/BRS.0b013e318060a5f5>.
- [6] Katz JN, Stucki G, Lipson SJ, Fossel AH, Grobler LJ, Weinstein JN. Predictors of surgical outcome in degenerative lumbar spinal stenosis. *Spine* 1999;24:2229–33. <https://doi.org/10.1097/00007632-199911010-00010>.
- [7] Rainville J, Childs LA, Peña EB, Suri P, Limke JC, Jouve C, et al. Quantification of walking ability in subjects with neurogenic claudication from lumbar spinal stenosis—a comparative study. *Spine J* 2012;12:101–9. <https://doi.org/10.1016/j.spinee.2011.12.006>.
- [8] Suzuki W, Mamizuka N, Imoo Y. Evaluation and validity verification of the Japanese version of Zurich Claudication Questionnaire and six-minute walking test for lumbar spinal canal stenosis. *J Spine Res* 2013;4:63–7.
- [9] Tomkins-Lane CC, Battie MC. Predictors of objectively measured walking capacity in people with degenerative lumbar spinal stenosis. *J Back Musculoskelet Rehabil* 2013;26:345–52. <https://doi.org/10.3233/BMR-130390>.
- [10] ATS Committee on Proficiency Standards for Clinical Pulmonary Function Laboratories. ATS statement. *Am J Respir Crit Care Med* 2002;166:111–7. <https://doi.org/10.1164/ajrccm.166.1.at1102>.
- [11] Matsudaira K, Seichi A, Kunogi J, Yamazaki T, Kobayashi A, Anamizu Y, et al. The efficacy of prostaglandin E1 derivative in patients with lumbar spinal stenosis. *Spine* 2009. <https://doi.org/10.1097/BRS.0b013e31818f924d>.
- [12] Orita S, Yamashita M, Eguchi Y, Suzuki M, Inoue G, Miyagi M, et al. Pregabalin for refractory radicular leg pain due to lumbar spinal stenosis: a preliminary prospective study. *Pain Res Manag* 2016;2016:5079675. <https://doi.org/10.1155/2016/5079675>.
- [13] Chou R, Hashimoto R, Friedly J, Fu R, Bougatsos C, Dana T, et al. Epidural corticosteroid injections for radiculopathy and spinal stenosis: a systematic review and meta-analysis. *Ann Intern Med* 2015. <https://doi.org/10.7326/M15-0934>.
- [14] Ito Z, Matsuyama Y, Sakai Y, Imagama S, Wakao N, Ando K, et al. Bone union rate with autologous iliac bone versus local bone graft in

- posterior lumbar interbody fusion. *Spine* 2010;35. <https://doi.org/10.1097/BRS.0b013e3181de4f2e>.
- [15] Makino T, Kaito T, Fujiwara H, Honda H, Sakai Y, Takenaka S, et al. Risk factors for poor patient-reported quality of life outcomes after posterior lumbar interbody fusion. *Spine* 2017;42:1502–10. <https://doi.org/10.1097/BRS.0000000000002137>.
- [16] Kawakami M, Nakao S, Fukui D, Kadosaka Y, Matsuoka T, Yamada H. Modified Marmot operation versus spinous process transverse cutting laminectomy for lumbar spinal stenosis. *Spine* 2013;38:E1461–8. <https://doi.org/10.1097/BRS.0b013e31829f-f4ae>.
- [17] Crapo RO, Casaburi R, Coates AL, Enright PL, MacIntyre NR, McKay RT, et al. ATS statement: guidelines for the six-minute walk test. *Am J Respir Crit Care Med* 2002;166:111–7. <https://doi.org/10.1164/rccm.166/1/111>.
- [18] Suzukamo Y. Outcome assessment by Roland-Morris Disability Questionnaire (RDQ). *J Japanese Soc Lumbar Spine Disord* 2009;15:17–22. <https://doi.org/10.3753/yotsu.15.17>.
- [19] Faul F, Erdfelder E, Lang A-G, Buchner A. G\*Power 3: a flexible statistical power analysis program for the social, behavioral, and biomedical sciences. *Behav Res Methods* 2007;39:175–91.
- [20] Kanda Y. Investigation of the freely available easy-to-use software 'EZ' for medical statistics. *Bone Marrow Transplant* 2013;48:452–8. <https://doi.org/10.1038/bmt.2012.244>.
- [21] Cohen J. *Statistical power analysis for the behavioral sciences*. 2nd ed.. L. Erlbaum Associates; 1988.
- [22] Enrichi PL, Sherrill DL. Reference equations for the six-minute walk in healthy adults. *Am J Respir Crit Care Med* 1998;158:1384–7. <https://doi.org/10.1164/ajrccm.161.4.16147a>.
- [23] Japan Sport Agency. Physical fitness exercise capacity survey result. Available at: [https://www.e-stat.go.jp/stat-search/files?page=1&layout=datalist&toukei=00402102&tstat=000001088875&cycle=0&tclass1=000001107355&tstat\\_infid=000031632191](https://www.e-stat.go.jp/stat-search/files?page=1&layout=datalist&toukei=00402102&tstat=000001088875&cycle=0&tclass1=000001107355&tstat_infid=000031632191). Accessed November 2018 [In Japanese].
- [24] Aalto T, Sinikallio S, Kröger H, Viinamäki H, Herno A, Leinonen V, et al. Preoperative predictors for good postoperative satisfaction and functional outcome in lumbar spinal stenosis surgery—a prospective observational study with a two-year follow-up. *Scand J Surg* 2012. <https://doi.org/10.1177/145749691210100406>.
- [25] Sigmundsson FG, Kang XP, Jönsson B, Strömqvist B. Prognostic factors in lumbar spinal stenosis surgery. *Acta Orthop* 2012. <https://doi.org/10.3109/17453674.2012.733915>.
- [26] Chang W, Yuwen P, Zhu Y, Wei N, Feng C, Zhang Y, et al. Effectiveness of decompression alone versus decompression plus fusion for lumbar spinal stenosis: a systematic review and meta-analysis. *Arch Orthop Trauma Surg* 2017;137:637–50. <https://doi.org/10.1007/s00402-017-2685-z>.
- [27] Försth P, Michaëlsson K, Sandén B. Does fusion improve the outcome after decompressive surgery for lumbar spinal stenosis? A two-year follow-up study involving 5390 patients. *Bone Jt J* 2013;95B:960–5. <https://doi.org/10.1302/0301-620X.95B7.30776>.
- [28] Takahashi K, Miyazaki T, Takino T, Matsui T, Tornita K. Epidural pressure measurements: relationship between epidural pressure and posture in patients with lumbar spinal stenosis. *Spine* 1995;20:650–3. <https://doi.org/10.1097/00007632-199503150-00003>.
- [29] Whitman JM, Flynn TW, Childs JD, Wainner RS, Gill HE, Ryder MG, et al. A comparison between two physical therapy treatment programs for patients with lumbar spinal stenosis: a randomized clinical trial. *Spine* 2006;31:2541–9. <https://doi.org/10.1097/01.brs.0000241136.98159.8c>.
- [30] Tarnanen S, Neva MH, Kautiainen H, Ylinen J, Pekkanen L, Kaistila T, et al. The early changes in trunk muscle strength and disability following lumbar spine fusion. *Disabil Rehabil* 2013;35:134–9. <https://doi.org/10.3109/09638288.2012.690496>.
- [31] Fritsch CG, Ferreira ML, Maher CG, Herbert RD, Pinto RZ, Koes B, et al. The clinical course of pain and disability following surgery for spinal stenosis: a systematic review and meta-analysis of cohort studies. *Eur Spine J* 2016;1–12. <https://doi.org/10.1007/s00586-016-4668-0>.