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Correction of Spinal Sagittal Alignment after Posterior Lumbar Decompression: Does Severity of Central Canal Stenosis Matter?

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Study Design: This study adopted a retrospective study design.

Purpose: Our study aimed to investigate the impact of central canal stenosis severity on surgical outcomes and lumbar sagittal correction after lumbar decompression.

Overview of Literature: Studies have evaluated sagittal correction in patients with central canal stenosis after lumbar decompression and the association of stenosis severity with worse preoperative sagittal alignment. However, none have evaluated the impact of spinal stenosis severity on sagittal correction.

Methods: Patients undergoing posterior lumbar decompression (PLD) of ≤4 levels were divided into severe and non-severe central canal stenosis groups based on the Lee magnetic resonance imaging (MRI) grading system. Patients without preoperative MRI or inadequate visualization on radiographs were excluded. Surgical characteristics, clinical outcomes, and sagittal measurements were compared. Multivariate logistic regression was performed to determine the predictors of pelvic tilt (PT), sacral slope (SS), lumbar lordosis (LL), and pelvic incidence minus lumbar lordosis (PI–LL).

Results: Of the 142 patients included, 39 had severe stenosis, and 103 had non-severe stenosis. The mean follow-up duration for the cohort was 4.72 months. Patients with severe stenosis were older, had higher comorbidity indices and levels decompressed, and longer lengths of stay and operative times ($p<0.001$). Although those with severe stenosis had lower lordosis, lower SS, and higher PI–LL mismatch preoperatively, no differences in Delta LL, SS, PT, or PI–LL were observed between the two groups ($p>0.05$). On multivariate regression, severe stenosis was a significant predictor of a lower preoperative LL (estimate=–5.243, $p=0.045$) and a higher preoperative PI–LL mismatch (estimate=6.192, $p=0.039$). No differences in surgical or clinical outcomes were observed ($p>0.05$).

Conclusion: Severe central lumbar stenosis was associated with greater spinopelvic mismatch preoperatively. Sagittal balance improved in both patients with severe and non-severe stenosis after PLD to a similar degree, with differences in sagittal parameters remaining after surgery. We also found no differences in postoperative outcomes associated with stenosis severity.

Keywords: Spinal stenosis; Central canal stenosis; Sagittal balance; Lumbar lordosis; Lumbar decompression

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Introduction

An estimated 1.2 million primary care visits in the United States are related to symptoms of lumbar spinal stenosis, which has become the most frequent cause of spinal surgery in patients aged >65 years [1,2]. Although its etiology can be due to varying types of spinal disease, spinal stenosis is commonly caused by a combination of posterior compression from ligamentum flavum hypertrophy and anterior compression from disk bulges into the central canal with consequent thecal sac compression [3]. Spinal stenosis can lead to neurogenic claudication, which presents as heaviness or pain in the lower extremities while standing or walking and is associated with diminished function and impaired quality of life [4]. Lumbar decompression remains the gold standard treatment for this condition because it has been shown to be superior to nonsurgical treatment for improving pain and function [5].

Magnetic resonance imaging (MRI) is essential in determining the necessity of surgical intervention and the requirements for adequate neural element decompression. Although several MRI grading classification systems have been proposed for lumbar central canal stenosis, interestingly, no clear consensus has been reached. However, the Schizas system, a 7-grade classification based on the morphology of the dural sac and the ratio of the rootlet to cerebrospinal fluid (CSF), and the Lee system, a 4-grade classification system based on the obliteration of CSF space in front of the cauda equina in the dural sac and the separation degree of the cauda equina, are two classification systems that have been proven to be reproducible among clinicians and radiologists [6-8].

Understanding sagittal alignment is also essential in examining lumbar degenerative conditions and plays a significant role in surgical decision-making and postoperative outcomes [9,10]. It has been well-reported in the literature that surgical decompression for spinal stenosis can lead to reactive improvements in lumbar and global sagittal alignment. Studies have shown increases in lumbar lordosis (LL) and decreases in pelvic incidence minus lumbar lordosis (PI–LL) postoperatively [11,12]. However, few studies have analyzed the relationship between spinal stenosis severity and sagittal alignment. A study explored correlations between spinal stenosis severity and baseline sagittal alignment measurements but did not analyze postoperative changes [13]. Therefore, this study aimed to explore sagittal correction stratified by spinal stenosis severity, which can be valuable to spine surgeons due to associations between sagittal parameters and clinical outcomes [14]. Additionally, we analyzed differences in surgical and clinical outcomes as secondary outcomes.

Materials and Methods

Upon obtaining approval of the Thomas Jefferson University Institutional Review Board (IRB approval no., control #19D.508), all patients aged ≥18 years who underwent one- to four-level posterior lumbar decompression (PLD) from 2018 to 2022 were retrospectively identified from a single academic institution. The following current procedural terminology codes were used for an inclusive list of patients undergoing PLD: 63047 and 63048. Indications for surgery included myelopathy, myeloradiculopathy, or radiculopathy resistant to nonoperative management. The exclusion criteria were as follows: patients with decompression of more than four levels or a surgical indication of infection, malignancy, or trauma; those who had inadequate visualization of the femoral head and lumbar spine on lateral radiographs at the preoperative and postoperative time points; those whose preoperative MRI was not identified through chart review. Informed consent was waived because of the retrospective nature of the study.

1. Data extraction

Patient demographics and surgical characteristics were collected through a Structured Query Language search and manual chart review of the electronic medical records. Patient age, sex, body mass index (BMI), smoking status (i.e., nonsmoker, current smoker, or former smoker), Charlson comorbidity index (CCI), and preoperative MRI grade (i.e., 0–3) were collected for each patient. MRI grade was determined using the classification system described by Lee et al. [7], where stenosis severity is graded from 0 to 3. In our study, grades 0–2 were classified as non-severe stenosis and grade 3 as severe stenosis. For multilevel decompression, each level was graded, and the highest grade was assigned to that patient. Additionally, surgical characteristics were collected, including operative length (minutes), length of stay (days), 90-day readmissions, and reason for readmission.

Radiographic measurements were collected via our institution's picture archiving and communication system

(Sectra AB, Linköping, Sweden). Preoperative lateral lumbar spine radiographs and those obtained from 3 months to 1 year after surgery were reviewed for each patient, and LL, pelvic incidence (PI), sacral slope (SS), and pelvic tilt (PT) were measured for each patient. PI–LL mismatch was calculated for each patient as well. LL was measured using the Cobb method from the superior end plate of L1 to the superior endplate of S1. PI was measured as the angle between a line orthogonal to the sacral endplate and the line between the center of the femoral head to the midpoint of the sacral endplate. PT was measured as the angle formed between a vertical line and the line between the middle of the sacral endplate to the center of the femoral head. SS was measured as the angle between a horizontal line and the line tangential to the superior endplate of S1 [15]. Changes in LL, SS, and PT were defined as Delta (Δ) and were calculated by subtracting the preoperative measurements from the postoperative values.

Patient-reported outcome measures were collected through the institution's prospectively managed outcome database (OBERD, Columbia, MO, USA). These measures included the Visual Analog Scale for back (VAS-back) and leg (VAS-leg) pain, the Oswestry Disability Index (ODI), and the mental and physical component scores (MCS-12 and PCS-12) of the Short Form-12 survey. A Delta score was calculated by subtracting the preoperative score from the postoperative score.

2. Statistical analysis

The patients were grouped to compare those with severe stenosis (grade 3) with those with non-severe stenosis (grades 0–2). Descriptive statistics, including means with standard deviations, were reported for patient demographics, surgical characteristics, and patient outcomes. The Shapiro-Wilk test was used to analyze the normality of each continuous variable, and parametric data were compared using the independent *t*-test, whereas nonparametric data were compared using the Mann-Whitney *U* test. Dichotomous variables were compared using Pearson's chi-square test. Bivariate analyses were performed to compare differences in outcomes between the groups. The paired *t*-test was also performed to determine significant differences in preoperative and postoperative LL, SS, PT, and PI–LL. A multivariable logistic regression model accounting for age, sex, BMI, and CCI was developed to measure the effect of preoperative grade 3 stenosis on preoperative, postoperative, and Δ radiographic measurements. *p*-values <0.05 were used to denote statistical significance. All statistical analyses were performed using RStudio ver. 4.0.2 (RStudio, Boston, MA, USA).

Results

1. Patient demographics

Of the 142 patients included, 39 had severe stenosis and 103 had non-severe stenosis. Patients with severe stenosis were significantly older (66.7±13.0 versus 54.7±13.5, *p*<0.001) and had significantly greater CCI (2.95±1.52 versus 1.44±1.39, *p*<0.001). No significant differences in sex (*p*=0.289), race (*p*=1.00), BMI (*p*=0.445), and smoking status (*p*=0.944) were observed between patients with severe stenosis and those with non-severe stenosis. Patients with severe stenosis had an average preoperative MRI grade of 3±0.00, whereas those with non-severe stenosis had an average preoperative MRI grade of 1.24±0.65 (Table 1).

Table 1. Demographics by severity of central stenosis

Characteristic	Non-severe stenosis (grades 0–2)	Severe stenosis (grade 3)	*p*-value[a]
No. of patients	103	39	
Age (yr)	54.7±13.5	66.7±13.0	<0.001*
Sex			0.289
Female	54 (52.4)	25 (64.1)	
Male	49 (47.6)	14 (35.9)	
Race			1.000
White	83 (80.6)	33 (84.6)	
Black	15 (14.6)	5 (12.8)	
Other	5 (4.85)	1 (2.56)	
Body mass index (kg/m^2)	28.9±7.50	29.9±7.51	0.445
Charlson comorbidity index	1.44±1.39	2.95±1.52	<0.001*
Smoking status			0.944
Non-smoker	66 (64.1)	26 (66.7)	
Current smoker	21 (20.4)	7 (17.9)	
Former smoker	16 (15.5)	6 (15.4)	
Average properative MRI grade	1.24±0.65	3.00±0.00	<0.001*

Values are presented as number, mean±standard deviation, or number (%).
MRI, magnetic resonance imaging.
*p<0.05 (statistical significance). [a]By independent *t*-test, Mann-Whitney *U* test, or Pearson's chi-square test.

2. Surgical characteristics

Patients with severe stenosis demonstrated longer operative times (122±39.7 minutes versus 90.9±32.9 minutes, $p<0.001$), length of stay (1.67±1.56 days versus 0.65±0.95 days, $p<0.001$), and more total levels decompressed (2.38±1.11 versus 1.43±0.77, $p<0.001$) (Table 2).

Table 2. Surgical characteristics by severity of central stenosis

Variable	Non-severe stenosis (grades 0–2)	Severe stenosis (grade 3)	p-value[a]
No. of patients	103	39	
Operative time (min)	90.9±32.9	122±39.7	<0.001*
Length of stay (day)	0.65±0.95	1.67±1.56	<0.001*
Total levels decompressed	1.43±0.77	2.38±1.11	<0.001*

Values are presented as number, mean±standard deviation, or number (%).
*$p<0.05$ (statistical significance). [a]By independent t-test, Mann-Whitney U test, or Pearson's chi-square test.

3. Surgical outcomes

No significant differences in 90-day readmissions, complications, and revisions were observed between the severe and non-severe stenosis groups (all $p>0.05$) (Table 3).

Table 3. Surgical outcomes by severity of central stenosis

Variable	Non-severe stenosis (grades 0–2)	Severe stenosis (grade 3)	p-value[a]
No. of patients	103	39	
Intraoperative durotomy			0.556
No	93 (90.3)	34 (87.2)	
Yes	10 (9.71)	5 (12.8)	
90-Day all-cause readmissions			1.000
No	94 (91.3)	35 (92.1)	
Yes	9 (8.74)	3 (7.89)	
Etiology for readmission			
Deep vein thrombosis			0.475
No	102 (99.0)	38 (97.4)	
Yes	1 (0.97)	1 (2.56)	
Reoperation for cerebrospinal fluid leak			1.000
No	102 (99.0)	39 (100.0)	
Yes	1 (0.97)	0	
Wound dehiscence			0.475
No	102 (99.0)	38 (97.4)	
Yes	1 (0.97)	1 (2.56)	
I&D for surgical site infection			0.475
No	102 (99.0)	38 (97.4)	
Yes	1 (0.97)	1 (2.56)	
I&D for hematoma/seroma			1.000
No	101 (98.1)	38 (100.0)	
Yes	2 (1.94)	0	
Revisions			1.000
No	100 (97.1)	38 (97.4)	
Repeat decompression	2 (1.94)	1 (2.56)	
Fusion	1 (0.97)	0	

Values are presented as number or number (%).
I&D, incision and drainage.
[a]By independent t-test, Mann-Whitney U test, or Pearson's chi-square test.

4. Radiographic outcomes

The severe stenosis group demonstrated significantly less preoperative LL (42.0°±12.8° versus 49.1°±12.0°, $p=0.004$) and SS (29.7°±7.79° versus 33.1°±8.64°, $p=0.026$) but higher PI–LL mismatch (11.1°±13.7° versus 5.74°±12.6°, $p=0.037$). Postoperatively, LL (44.5°±13.3° versus 50.7°±11.2°, $p=0.012$) and SS (30.8°±7.22° versus 34.3°±7.93°, $p=0.014$) remained lower in patients with severe stenosis. Both the severe and non-severe stenosis groups showed significant improvement in LL and SS (all $p<0.05$). However, no significant differences in the changes in LL (2.44°±6.75° versus 1.60°±7.41°, $p=0.52$), SS (1.09°±5.44° versus 1.18°±4.69°, $p=0.933$), PT (0.68°±7.65° versus −0.14°±6.06°, $p=0.545$), and PI–LL (−2.44°±6.75° versus −1.60°±7.41°, $p=0.520$) were observed between the groups. Moreover, no significant difference in preoperative to postoperative PT or PI–LL was observed between the two groups (all $p>0.05$) (Table 4).

5. Clinical outcomes

No significant differences in any patient-reported outcome measures, including VAS-back, VAS-leg, ODI, MCS-12, and PCS-12, were identified between the groups (Table 5).

6. Multivariate linear regression analysis

Multivariate linear regression analysis showed that severe stenosis was not a significant predictor of the degree of improvement in LL, SS, PT, or PI–LL; however, it was a significant predictor of a lower preoperative LL

Table 4. Radiographic outcomes by severity of central stenosis

Variable	Non-severe stenosis (grades 0–2)	Severe stenosis (grade 3)	p-value$^{a)}$
No. of patients	103	39	
Lumbar lordosis			
Preop	49.1±12.0	42.0±12.8	0.004*
Postop	50.7±11.2)	44.5±13.3	0.012*
Δ	1.60±7.41	2.44±6.75	0.520
p-value$^{b)}$	0.028*	0.041*	
Sacral slope			
Preop	33.1±8.64	29.7±7.79	0.026*
Postop	34.3±7.93	30.8±7.22	0.014*
Δ	1.18±4.69	1.09±5.44	0.933
p-value$^{b)}$	0.011*	0.048*	
Pelvic tilt			
Preop	22.2±8.54	24.0±10.3	0.319
Postop	22.0±8.39	24.7±8.61	0.100
Δ	-0.14±6.06	0.68±7.65	0.545
p-value$^{b)}$	0.657	0.696	
Pelvic incidence-lumbar lordosis			
Preop	5.74±12.6	11.1±13.7	0.037*
Postop	4.14±12.6	8.68±15.2	0.102
Δ	-1.60±7.41	-2.44±6.75	0.520
p-value$^{b)}$	0.218	0.278	0.520

Values are presented as number, mean±standard deviation, or number (%).
Preop, preoperative; Postop, postoperative; Δ, Delta.
*p<0.05 (statistical significance). $^{a)}$By independent t-test, Mann-Whitney U test, or Pearson's chi-square test. $^{b)}$By paired t-test.

Table 5. One-year patient-reported outcomes

Variable	Non-severe stenosis (grades 0–2)	Severe stenosis (grade 3)	p-value
Preoperative VAS-back	5.52±3.43	5.73±2.48	0.789
Postoperative VAS-back	3.86±3.19	3.38±2.47	0.496
Delta VAS-back	-1.78±3.18	-2.07±2.36	0.762
Preoperative VAS-leg	5.19±3.70	5.51±3.13	0.751
Postoperative VAS-leg	2.47±2.95	2.21±2.27	0.733
Delta VAS-leg	-3.00±4.36	-3.48±2.49	0.661
Preoperative ODI	47.3±19.4	44.1±17.5	0.570
Postoperative ODI	25.4±23.6	27.3±19.1	0.771
Delta ODI	-22.7±19.9	-16.8±15.1	0.360
Preoperative MCS-12	48.3±12.0	50.4±9.47	0.474
Postoperative MCS-12	49.8±11.9	54.9±8.21	0.063
Delta MCS-12	1.24±13.0	3.37±6.40	0.456
Preoperative PCS-12	32.5±8.05	34.5±8.59	0.181
Postoperative PCS-12	37.2±9.21	38.2±9.80	0.356
Delta PCS-12	4.98±12.1	4.98±8.77	0.337

Values are presented as mean±standard deviation.
VAS, Visual Analog Scale; ODI, Oswestry Disability Index; MCS, mental component score; PCS, physical component score.

(estimate=−5.338, p=0.045) and a higher preoperative PI–LL (estimate=6.192, p=0.039). The number of levels decompressed was a significant predictor of postoperative LL (estimate=−2.635, p=0.025), PI–LL (estimate=3.267, p=0.008), and change in LL (estimate=−1.764, p=0.017), PT (estimate=1.863, p=0.005), and PI–LL (estimate=3.120, p<0.001). BMI was predictive of preoperative LL (estimate=−0.281, p=0.041). Age was predictive of the degree of improvement in PT (estimate=−0.137, p=0.049) and PI–LL (estimate=−0.233, p=0.016) (Table 6).

Discussion

Sagittal alignment of the lumbar spine is the keystone to understanding the biomechanics underlying spinal diseases, particularly in the elderly population. The driving force of sagittal alignment is typically the relationship between PI and LL [16]. In patients with sagittal alignment mismatch, a decrease in LL reduces anterior truncal inclination, necessitating compensatory sagittal changes, such as an increase in PT and knee flexion and a decrease in SS, to maintain the "gravity line" close to the hip center and over the center of the ankles [17,18]. Proper sagittal balance is correlated with increased function, physical performance, and quality of life [19]. However, studies on the impact of central canal stenosis severity on spinopelvic balance correction after lumbar decompression surgery are limited [20].

We identified several significant differences in preoperative and surgical characteristics between patients with severe stenosis and those with non-severe stenosis. Patients with severe stenosis were likely to be older with higher comorbidity indices. Additionally, they had more levels decompressed during surgery, which coincides with the longer operative times and lengths of stay found in this study. However, these findings were expected considering the population and the natural history and progression of lumbar spinal stenosis severity.

Patients with severe stenosis were more likely to have worse sagittal alignment preoperatively than those with non-severe stenosis. Moreover, they had lower LL and SS

Table 6. Multivariable linear regression analysis of radiographic measures

Variable	LL		SS		PT		PI–LL	
	Estimate	*p*-value	Estimate	*p*-value	Estimate	*p*-value	Estimate	*p*-value
Preoperative								
Age	-0.088	0.493	-0.059	0.503	0.026	0.794	0.062	0.657
Female sex	1.466	0.488	1.649	0.255	-1.1.77	0.471	-1.227	0.595
BMI	-0.281	0.041*	-0.159	0.090	-0.043	0.684	0.080	0.591
CCI	0.025	0.835	-0.402	0.624	-0.489	0.596	-0.941	0.472
Stenosis grade 3	-5.243	0.045*	-1.506	0.419	3.041	0.149	6.192	0.039*
Levels decompressed	-0.871	0.470	-0.444	0.519	-0.552	0.553	0.118	0.929
Postoperative								
Age	0.050	0.691	0.008	0.920	-0.111	0.213	-0.170	0.194
Female sex	2.201	0.284	3.265	0.020*	-0.232	0.874	0.913	0.669
BMI	-0.210	0.113	-0.136	0.131	0.015	0.871	0.068	0.602
CCI	-0.785	0.499	-0.318	0.687	0.431	0.603	1.154	0.341
Stenosis grade 3	-2.643	0.318	-1.087	0.546	1.173	0.534	2.900	0.293
Levels decompressed	-2.635	0.025*	-0.726	0.362	1.310	0.118	3.267	0.008*
Δ								
Age	0.138	0.079	0.068	0.231	-0.137	0.049*	-0.233	0.016*
Female sex	0.735	0.567	1.616	0.082	0.945	0.206	2.083	0.187
BMI	0.070	0.395	0.023	0.703	0.058	0.429	-0.006	0.954
CCI	-0.810	0.265	0.084	0.873	0.920	0.154	2.118	0.019*
Stenosis grade 3	2.600	0.117	0.420	0.725	-1.868	0.203	-3.337	0.102
Levels decompressed	-1.764	0.017*	-0.282	0.593	1.863	0.005*	3.120	<0.001*

LL, lumbar lordosis; SS, sacral slope; PT, pelvic tilt; PI, pelvic incidence; BMI, body mass index; CCI, Charlson comorbidity index.
*$p<0.05$ (statistical significance).

and higher PI–LL mismatch. Additionally, multivariate analysis identified severe stenosis as a significant predictor of preoperative malalignment through lower LLs and higher PI–LLs. Our findings agree with those of a study by Buckland et al. [13] who have examined the effects of stenosis severity, using the Lee classification system, on sagittal alignment. They showed that severe central canal stenosis (grade 3) was associated with greater malalignment in PI–LL; however, no significant differences in PT were observed when compared with non-severe (grades 1–2) central canal stenosis preoperatively [13]. These findings may be because patients with increased stenosis flex their lumbar spine (leading to a lower LL) to decrease the compression of the nerves as a mechanism for reducing pain.

Several studies have shown that patients with lumbar spinal stenosis with preoperative sagittal malalignment improve their sagittal balance after lumbar decompression surgery. Ogura et al. [11] showed that patients had a significant decrease in PI–LL and a concomitant improvement in back and leg pain. However, no significant differences in PT and SS were found [11]. Fujii et al. [21] showed significant changes in PT, LL, and PI–LL after lumbar decompression. Recent data published by Jeon et al. [22] also suggested that laminectomy increased LL and decreased PI–LL and PT. However, their study did not analyze clinical outcomes [22]. Our study showed significant improvements in LL and SS parameters in both groups; however, no significant differences in PT and PI–LL were found. Our findings indicate that there is some degree of sagittal correction after lumbar decompression, regardless of the severity of central canal stenosis.

Although studies have explored the impact of preoperative malalignment on sagittal correction postoperatively, none have investigated the effects of stenosis severity on postoperative sagittal correction. Patients with lumbar central canal stenosis improved their sagittal correction after lumbar decompression, despite the severity of stenosis; however, no significant differences in the degree of correction were observed. We found significant preoperative and postoperative differences in LL and SS but no significant differences in the change in LL or SS, indicating that correction was similar across the groups. We hypothesized that severe stenosis leads to greater correction after lumbar decompression because of greater preoperative sagittal mismatch. However, we found that correction was limited. This could be because of unaccounted factors involving posture and other components of the musculoskeletal system [23]. Additionally, sagittal parameters may be influenced by patients' symptoms and can be better contextualized when correlated with clinical outcomes.

Contextualizing radiographic findings with clinical outcomes is crucial when interpreting clinical relevance. Fujii et al. [21] did not find any correlation between pain scores and radiographic parameters. This premise remains true in our study. Although patients with severe stenosis had greater sagittal misalignment preoperatively, no differences in preoperative patient-reported outcomes were observed. Similar to our findings regarding radiographic outcomes, both groups showed postoperative improvements in clinical outcomes. No differences in the degree of improvement were found. These findings align with those of a study by Buckland et al. [13] that did not show a relationship between the severity of lumbar stenosis and quality of life outcomes, as they found no significant differences in ODI, EuroQol-5 Dimension, or VAS scores. Notably, a study did show that preoperative severe central stenosis was predictive of reduced lower leg and back pain postoperatively. However, radiographic outcomes were not analyzed in that study [24].

Exploring factors that could impact surgical outcomes after lumbar decompression is important because such events can increase healthcare costs and are associated with poor patient satisfaction [25]. Studies have shown that increased age and comorbidity indices lead to greater complication rates after lumbar decompression [26-28]. Meanwhile, Nolte et al. [29] showed no differences in surgical outcomes between patients who underwent decompression for more than three levels and those who underwent decompression for less than three levels. Research investigating the effects of stenosis severity on surgical outcomes is lacking. To the best of our knowledge, only one other retrospective study has attempted to evaluate this. The authors concluded that complication rates are not correlated with stenosis severity, categorized by the Schizas grading system, after lumbar decompression [30]. Our study showed that stenosis severity does not impact the rates of revisions, complications, and readmissions.

Our study has several limitations, including those inherent to a retrospective cohort study. This study is subject to the bias inherent to retrospective patient identification through query and chart review. Our cohort was limited by patients with accessible imaging through chart review. Because our health system has many different imaging services, some of which the research team does not have access to, our query was substantially limited. Furthermore, if the images were present, the radiographs should have the femoral head present for all sagittal measurements to be made. As a retrospective study, we only had access to routine lumbar radiographs and were unable to obtain full-standing spine radiographs, which would have helped assess global alignment. Additionally, the follow-up duration for the patients in our study may not have been sufficient for ideal measures of postoperative outcomes radiographically or clinically. Our study did not analyze foraminal stenosis severity, which could be another driver of these sagittal parameter findings. Additionally, radiographic measurements have variations and observer error, which could result in inaccurate findings.

Conclusions

Patients with severe central canal stenosis have more sagittal imbalance preoperatively, likely because of increased compensatory mechanisms. Although sagittal correction was significantly improved postoperatively in patients with severe and non-severe central canal stenosis after decompression, the degree of correction between the two groups was similar, resulting in continued postoperative differences in sagittal parameters. Moreover, no differences in clinical or surgical outcomes were observed between the groups.

Conflict of Interest

No potential conflict of interest relevant to this article was reported.

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Author Contributions

ML, ND, CK, and GS contributed to the conception and design of the manuscript. DT, YL, and JH contributed to writing the original draft of the manuscript. JP and SS contributed to data curation. YL, MK, KR, MK, DK, JC, AH, AV, CK, and GS supervised and contributed to critical revision and editing of the final version to be published.

References

1. Hart LG, Deyo RA, Cherkin DC. Physician office visits for low back pain: frequency, clinical evaluation, and treatment patterns from a U.S. national survey. Spine (Phila Pa 1976) 1995;20:11-9.
2. Deyo RA, Gray DT, Kreuter W, Mirza S, Martin BI. United States trends in lumbar fusion surgery for degenerative conditions. Spine (Phila Pa 1976) 2005;30:1441-7.
3. Bolender NF, Schonstrom NS, Spengler DM. Role of computed tomography and myelography in the diagnosis of central spinal stenosis. J Bone Joint Surg Am 1985;67:240-6.
4. Otani K, Kikuchi S, Yabuki S, et al. Lumbar spinal stenosis has a negative impact on quality of life compared with other comorbidities: an epidemiological cross-sectional study of 1862 community-dwelling individuals. ScientificWorldJournal 2013;2013:590652.
5. Phan K, Teng I, Schultz K, Mobbs RJ. Treatment of lumbar spinal stenosis by microscopic unilateral laminectomy for bilateral decompression: a technical note. Orthop Surg 2017;9:241-6.
6. Schizas C, Theumann N, Burn A, et al. Qualitative grading of severity of lumbar spinal stenosis based on the morphology of the dural sac on magnetic resonance images. Spine (Phila Pa 1976) 2010;35:1919-24.
7. Lee GY, Lee JW, Choi HS, Oh KJ, Kang HS. A new grading system of lumbar central canal stenosis on MRI: an easy and reliable method. Skeletal Radiol 2011;40:1033-9.
8. Ko YJ, Lee E, Lee JW, et al. Clinical validity of two different grading systems for lumbar central canal stenosis: Schizas and Lee classification systems. PLoS One 2020;15:e0233633.
9. Jang JS, Lee SH, Kim JM, Min JH, Han KM, Maeng DH. Can patients with sagittally well-compensated lumbar degenerative kyphosis benefit from surgical treatment for intractable back pain? Neurosurgery 2009;64:115-21.
10. Barrey C, Jund J, Noseda O, Roussouly P. Sagittal balance of the pelvis-spine complex and lumbar degenerative diseases: a comparative study about 85 cases. Eur Spine J 2007;16:1459-67.
11. Ogura Y, Shinozaki Y, Kobayashi Y, et al. Impact of decompression surgery without fusion for lumbar spinal stenosis on sagittal spinopelvic alignment: minimum 2-year follow-up. J Neurosurg Spine 2019;30:743-9.
12. Madkouri R, Brauge D, Vidon-Buthion A, et al. Improvement in sagittal balance after decompression surgery without fusion in patients with degenerative lumbar stenosis: clinical and radiographic results at 1 year. World Neurosurg 2018;114:e417-24.
13. Buckland AJ, Ramchandran S, Day L, et al. Radiological lumbar stenosis severity predicts worsening sagittal malalignment on full-body standing stereoradiographs. Spine J 2017;17:1601-10.
14. Kim MK, Lee SH, Kim ES, Eoh W, Chung SS, Lee CS. The impact of sagittal balance on clinical results after posterior interbody fusion for patients with degenerative spondylolisthesis: a pilot study. BMC Musculoskelet Disord 2011;12:69.
15. Celestre PC, Dimar JR 2nd, Glassman SD. Spinopel-

vic parameters: lumbar lordosis, pelvic incidence, pelvic tilt, and sacral slope: what does a spine surgeon need to know to plan a lumbar deformity correction? Neurosurg Clin N Am 2018;29:323-9.

16. Suzuki H, Endo K, Kobayashi H, Tanaka H, Yamamoto K. Total sagittal spinal alignment in patients with lumbar canal stenosis accompanied by intermittent claudication. Spine (Phila Pa 1976) 2010;35:E344-6.
17. Barrey C, Roussouly P, Le Huec JC, D'Acunzi G, Perrin G. Compensatory mechanisms contributing to keep the sagittal balance of the spine. Eur Spine J 2013;22(Suppl 6):S834-41.
18. Le Huec JC, Saddiki R, Franke J, Rigal J, Aunoble S. Equilibrium of the human body and the gravity line: the basics. Eur Spine J 2011;20(Suppl 5):558-63.
19. Glassman SD, Bridwell K, Dimar JR, Horton W, Berven S, Schwab F. The impact of positive sagittal balance in adult spinal deformity. Spine (Phila Pa 1976) 2005;30:2024-9.
20. Ogura Y, Shinozaki Y, Kobayashi Y, et al. Impact of sagittal spinopelvic alignment on clinical outcomes and health-related quality of life after decompression surgery without fusion for lumbar spinal stenosis. J Neurosurg Spine 2019;30:470-5.
21. Fujii K, Kawamura N, Ikegami M, Niitsuma G, Kunogi J. Radiological improvements in global sagittal alignment after lumbar decompression without fusion. Spine (Phila Pa 1976) 2015;40:703-9.
22. Jeon CH, Lee HD, Lee YS, Seo HS, Chung NS. Change in sagittal profiles after decompressive laminectomy in patients with lumbar spinal canal stenosis: a 2-year preliminary report. Spine (Phila Pa 1976) 2015;40:E279-85.
23. Pumberger M, Schmidt H, Putzier M. Spinal deformity surgery: a critical review of alignment and balance. Asian Spine J 2018;12:775-83.
24. Kuittinen P, Sipola P, Leinonen V, et al. Preoperative MRI findings predict two-year postoperative clinical outcome in lumbar spinal stenosis. PLoS One 2014;9:e106404.
25. Malik AT, Deiparine S, Khan SN, Kim J, Yu E. Costs associated with a 90-day episode of care after single-level anterior lumbar interbody fusion. World Neurosurg 2020;135:e716-22.
26. Bays A, Stieger A, Held U, et al. The influence of comorbidities on the treatment outcome in symptomatic lumbar spinal stenosis: a systematic review and meta-analysis. N Am Spine Soc J 2021;6:100072.
27. Li G, Patil CG, Lad SP, Ho C, Tian W, Boakye M. Effects of age and comorbidities on complication rates and adverse outcomes after lumbar laminectomy in elderly patients. Spine (Phila Pa 1976) 2008;33:1250-5.
28. Cassinelli EH, Eubanks J, Vogt M, Furey C, Yoo J, Bohlman HH. Risk factors for the development of perioperative complications in elderly patients undergoing lumbar decompression and arthrodesis for spinal stenosis: an analysis of 166 patients. Spine (Phila Pa 1976) 2007;32:230-5.
29. Nolte MT, Parrish JM, Jenkins NW, et al. The influence of comorbidity on postoperative outcomes following lumbar decompression. Clin Spine Surg 2021;34:E390-6.
30. Weber C, Giannadakis C, Rao V, et al. Is there an association between radiological severity of lumbar spinal stenosis and disability, pain, or surgical outcome?: a multicenter observational study. Spine (Phila Pa 1976) 2016;41:E78-83.