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Long-term Clinical and Radiographic Outcomes of Pedicle Subtraction Osteotomy for Fixed Sagittal Imbalance: Does Level of Proximal Fusion Affect the Outcome? Minimum 5-Year Follow-up

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Abstract

Study Design: Retrospective case series of surgically treated adult patients with fixed sagittal imbalance.
Objective: To assess clinical and radiographic changes after pedicle subtraction osteotomy (PSO) to treat adult fixed sagittal imbalance.
Background: Although recent reports have shown favorable clinical outcomes for PSO, few reports have published long-term follow-up outcomes. It is also unknown whether long-term outcomes are correlated with the level of proximal fusion and the radiographic changes that are observed after PSO.
Materials and Methods: We reviewed the charts, X-rays, and postoperative SRS-22 and Oswestry Disability Index (ODI) scores of 32 adult patients who presented with fixed sagittal imbalance and were treated with lumbar PSO. Long fusions were defined as those proximal to T6, and short fusions were defined as those below T8. Measured radiographic parameters included thoracic kyphosis, lumbar lordosis (LL), sacral slope, pelvic incidence, and sagittal balance (SVA). Statistical analysis included Student *t* test and chi-square test. A p value of $< .05$ and a confidence interval of 95% were considered statistically significant.
Results: Among the reviewed cases were 23 women and 9 men, with a mean age of 50.9 years (range, 33−76 years) and a mean follow-up 8.6 years (range, 5−16 years). The LL increased from −16.0° preoperatively to −52.1° postoperatively. This metric decreased to −51.0° at final follow-up. The SVA decreased from 10.4 cm preoperatively to 3.6 cm postoperatively. The SVA increased to 5.4 cm at the final follow-up visit. There were 17 long fusions and 15 short fusions. The SRS scores at the final follow-up time point were: total, 3.63; function, 3.59; pain, 3.68; self-image, 3.46; mental health, 3.56; satisfaction, 4.26. A total of 16 patients exhibited minimal disability, 11 exhibited moderate disability, and 2 exhibited severe disability in ODI scores at the final follow-up visit (average, 28.2%). The SRS and ODI scores were not significantly different between groups ($p = .64$ for SRS; $p = .59$ for ODI). We observed no significant differences between groups with respect to the LL, sacral slope, or pelvic incidence. The observed increase in SVA at the final follow-up visit was significantly larger in the short fusion group compared with the increase we observed in the long fusion group ($p = .03$). The thoracic kyphosis (T5−T12) and proximal junctional angle at the final follow-up visit also significantly increased in patients who underwent a short fusion ($p < .001$). A total of 14 major complications occurred in 12 patients (8 in the short fusion group and 6 in the long fusion group) ($p = .43$). Eight patients required additional surgery to treat these complications.
Conclusions: In a group of adults presenting with fixed sagittal imbalance, PSO provided good sagittal balance and maintained favorable clinical outcomes in both the short and long fusion groups despite a slight decrease in the SVA and a high complication rate. The data suggest that the loss of sagittal balance may be attributed to increase global and junctional kyphosis in short fusion groups, and should be monitored for long-term outcomes. Particular attention should be paid to the long-term deterioration of the SVA in adults who present with fixed sagittal imbalance after PSO.

Keywords: Pedicle subtraction osteotomy; Complication; Fixed sagittal imbalance

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Introduction

A symptomatic fixed crouching posture resulting from the loss of lumbar lordosis after posterior spinal fusion for scoliosis was first described by Doherty [1] in 1973. Cummine et al. [2] named this condition "flatback syndrome" and reported their early results after the treatment of this condition. Booth et al. [3] classified their patients with flatback into 2 groups. Type 1 describes the loss of lumbar lordosis with normal sagittal balance and type 2 describes a fixed positive sagittal imbalance. Patients with type 2 were more significantly affected structurally and symptomatically by the deformity than were those with type 1. The etiology of flatback syndrome, which is also referred to as "fixed sagittal imbalance," may be multifactorial, but the most commonly reported cause of this condition is the iatrogenic loss of lumbar lordosis as a result of Harrington distraction instrumentation [4-8], and Ohlén [9] reported lumbar lordosis at 38° when the Harrington instrumentation stopped at T12, only 21° when the fusion extended beyond the thoracolumbar junction and down to L4, and 16° when the fusion extended to L5. Kostuik et al. [10] reported that 22 of 45 adult patients with scoliosis with a previous fusion that extended to the sacrum and distraction instrumentation had substantial loss of lumbar lordosis; 13 patients required additional corrective procedures because of adjacent-level degeneration and fixed positive sagittal imbalance. Recently, another important cause of flatback syndrome has been identified. Failure to maintain lumbar lordosis during the fusion of a degenerated spine can result in an inability to compensate locally, resulting in accelerated adjacent level degeneration and the loss of sagittal balance [11,12,13]. Pedicle subtraction osteotomy (PSO) for ankylosis spondylitis was first described by Thomasen [14] in 1985 and has been used increasingly frequently for the surgical correction of fixed sagittal imbalance. Berven et al. [15] used this procedure to treat 13 primary adult patients with sagittal imbalance. Those authors reported 30° of restored lordosis at the 2-year follow-up visit. Although most other recent reports have demonstrated favorable restoration of lumbar lordosis and maintenance of sagittal balance, few reports have been published regarding the long-term follow-up of these patients [16-20]. To the best of our knowledge, only Kim et al. [21] reported the outcomes of these cases, observing their patients for a minimum of 5 years after PSO for fixed sagittal imbalance. In their analysis of 35 patients, the authors reported a mean Oswestry Disability Index (ODI) score of 24.1 at the final follow-up visit. In the present study, we present the long-term clinical and radiographic outcomes of PSO to treat fixed sagittal imbalance.

Materials and Methods

Inclusion criteria

The Institutional Review Board at the Hospital for Special Surgery approved this study. We conducted a retrospective review of the charts and radiographs and identified 41 consecutive adult patients from a single institution. All patients underwent a PSO for fixed sagittal imbalance by the senior author between 1994 and 2005. All patients exhibited symptoms that may have resulted from the postural deformity and radiographic appearance, thereby qualifying them for a diagnosis of flatback syndrome. Symptoms included intolerable pain and disability. All patients had received a minimum of 1 year of conservative treatment but had failed a prolonged course of conservative management (physical therapy, nonsteroidal anti-inflammatory drugs, and narcotics). All were observed for a minimum of 5 years. An independent senior spine surgeon who was not involved in the surgical treatment retrospectively performed the data collection. We evaluated the preoperative and postoperative radiographic measurements, age, sex, bone mineral density, upper instrumentation vertebra (UIV) level, surgery type, lower instrumentation vertebra level, complications and clinical outcomes. We determined the density of the femoral neck using dual-energy X-ray absorptiometry. We performed the radiography prospectively and reviewed it retrospectively. The complete radiographic review required adequate preoperative, immediate postoperative (8−12 weeks postoperative) 36-inch-long cassette radiographs. Also required were the anteroposterior and lateral standing 36-inch-long radiographs obtained at the most recent follow-up. We excluded 2 patients because of poor radiograph quality. Seven patients were either lost to follow-up or had incomplete radiographs. A subset of international patients left the geographic area after receiving surgical treatment. Therefore, a study population of 32 patients met all of the inclusion criteria (retrieval rate, 78.0%; 32 of 41 patients). As a surgical note, we collected data regarding the operative time and the estimated blood loss (EBL). We combined EBL with the postoperative suction drainage to determine the total estimated perioperative blood loss. We calculated estimated blood volume by the formula: weight (kg) $\times$ 65. Additional clinical data were collected regarding intraoperative and postoperative major complications and reoperations.

Patient outcomes

We used the Scoliosis Research Society Patient Questionnaire (SRS-22r) and the Oswestry Disability Index (ODI) to evaluate patient outcomes at the final follow-up [22,23]. The completed questionnaires were available for 29 of 32 patients (91%). Given our patient enrollment period (1994−2005), preoperative SRS-22r and ODI data were not applicable.

Radiographic measurements

We measured the sagittal vertical axis (SVA) on the lateral radiographs as the distance from the C7 plumb line to a perpendicular line from the superior posterior end plate of the S1 vertebral body. We measured thoracic kyphosis (TK) from the upper end plate of T5 to the lower end plate of T12, and lumbar lordosis (LL) from the lower end plate of T12 to the upper end plate of S1. The sacral slope (SS) was defined as the angle between a horizontal line and the sacral end plate line. The pelvic incidence (PI) was defined as the angle subtended by a perpendicular line from the cephalad end plate of S1 and a line between the center of the femoral head and the center of the cephalad endplate of S1 [24-26]. The proximal junction (PJ) was defined as the caudal end plate of the UIV to the cephalad endplate of 2 vertebrae proximal. Abnormal PJ fracture (PJK) was defined by a PJ angle greater than 10° and at least 10° greater than the corresponding preoperative measurement [26,27]. The presence of both criteria was necessary to be considered abnormal. Pseudoarthrosis was defined as implant failure consisting of halo around a fixation point, pullout of a fixation point, failure of a rod, loss of correction of _10%, or what appeared to be nonunion based on coned-down coronal, sagittal, and oblique radiographs of the fusion mass.

Surgical procedure and surgical decision making

All of the patients underwent a single-level lumbar transpedicular closing wedge osteotomy. Details regarding the procedure and surgical decision making have been previously described [16]. To achieve bone-on-bone contact in posterior lamina, we preferred to achieve complete bone apposition centrally and laterally on closure of the osteotomy site. Autografts and allografts were placed over the laminae, facet joints, and transverse processes.

We chose the level of the osteotomy based on the region of kyphosis and the requirement for fixation distally while preserving motion segments. Anteroposterior combined fusions were performed on patients who were judged to be at high risk for pseudoarthrosis at the most distal fusion level. These risks included the following factors: the UIV was at T8 or above; large and stiff coronal or sagittal deformities were present; and the level of the PSO was at L4 or below. We used titanium mesh interbody cages with morselized autogenous or femoral ring structural allografts at the distal lumbar segments, where there was no prior fusion. The choice of the proximal fusion level was based in part on the patient's bone quality, the magnitude of the coronal curve, the shoulder balance, the coronal imbalance, and the local sagittal alignment. The choice of the distal fusion level was based in part on the status of the lumbar spine curve and the disc. If spinal stenosis, degenerative listhesis, significant obliquity, or disc degeneration were present based on the SRS adult scoliosis classification, we extended the arthrodesis to the sacrum [28]. We augmented the posterior instrumentation construct using iliac screw fixation and an anterior column support at L5–S1, in addition to bilateral or unilateral S1 screws.

Statistical analysis

We used the Student *t* test for continuous variables and chi-square tests for ordinal and nominal data for which more than 5 observations were expected in each category. p values less than .05 and with a confidence interval of 95% were considered statistically significant. We performed all analyses using the Statistical Package for the Social Sciences (SPSS, Chicago, IL).

Results

Patient population

Among the reviewed cases, there were 23 women and 9 men. The mean age of the population was 50.9 years (range, 33–76 years), and the mean follow-up period was 8.6 years (range, 5–16 years). The etiology of the flatback syndrome in our population was previous scoliosis treatment extending to the lumbar spine with Harrington rod distraction instrumentation, isolated instrumented lumbar fusion (n = 23), ankylosing spondylitis (n = 3), congenital kyphoscoliosis (n = 2), posttraumatic deformity (n = 2), or severe degenerative lumbar spondylosis with decompensation (n = 2). One patient presented with type 1 segmental sagittal imbalance (Table 1), and 31 patients presented with a type 2 deformity. Pedicle subtraction osteotomy was performed at L2 in 4 patients, at L3 in 23, and at L4 in 5. Additional Ponte osteotomies and Smith-Petersen osteotomies were performed in 12 patients who exhibited severe fixed and rigid sagittal imbalance. Anteroposterior combined fusions were performed on 12 patients who were judged to be at high risk for pseudoarthrosis. We divided the patients into 2 groups for the analysis based on the proximal fusion level. We classified 11 patients who had previously received a proximal fusion above T5, 3 who had a proximal fusion level above T6, and 3 with ankylosing spondylitis as belonging to the long fusion group, based on the nature of the disease. We classified 15 patients who had a proximal fusion level below the sagittal apex (T8) as belonging to the short fusion group (Figs. 1 and 2). One patient had a distal fusion level of L4, 2 had a distal fusion level of L5, and 29 had a distal fusion level of S1. We observed no significant difference between the long and short fusion groups with respect to age, sex, follow-up period, bone mineral density, TK, LL, or PI (Table 1).

Radiographic outcomes

Lumbar lordosis significantly increased from −16.0° preoperatively to −52.1° immediately postoperatively. This metric was −51.0° at the final follow-up visit (Table 2). We observed no significant loss of the restoration of LL until the final follow-up in both the long and short fusion groups. Thoracic kyphosis was not significantly altered at the immediate postoperative time point, but significantly increased at the final follow-up time point in both of the groups (Table 2). We observed a significant increase in TK in

Table 1
Characteristic comparison between long fusion and short fusion groups.

	Total	Long fusion	Short fusion	p
Patients, n	32	17	15	.78
Mean follow-up, years	8.6 (5−16)	9.4 (5−16)	7.9 (5−12)	.22
Age at surgery, years	50.4 (33−76)	48.7 (33−73)	53.7 (33−76)	.31
Gender				
Male	9	3	6	.39
Female	23	14	9	.41
Bone mineral density (g/cm^2)	0.806±0.183	0.816±0.143	0.779±0.186	.34
Type of sagittal imbalance				
Type 1 segmental sagittal imbalance	1	0	1	
Type 2 global sagittal imbalance	31	17	14	
Preoperative thoracic kyphosis (°)	24.9 (0−54)	21.0 (2−48)	29.7 (0−54)	.19
Preoperative lumbar lordosis (°)	16.0 (−33−33)	20.1 (−5−30)	11.1 (−33−33)	.18
Preoperative pelvic incidence (°)	51.3 (38−70)	53.1 (38−66)	47.4 (41−70)	.41
Preoperative sacral slope (°)	24.3 (6−35)	21.2 (6−29)	27.8 (13−35)	.11
Preoperative sagittal balance (SVA) (mm)	103.8 (40−200)	97.5 (40−200)	111.5 (55−190)	.42

SVA, sagittal vertical axis.
Range is in parentheses. We compared the values of the short fusion group with the corresponding values of the long fusion group.

the short fusion group compared with the long fusion group during the follow-up period (9.9° vs. 1.9°). The SVA significantly decreased from 10.4 cm preoperatively to 3.6 cm at the immediate postoperative time point. This metric was 5.4 cm at the final follow-up time point. We noted a significant increase in the SVA from 3.7 cm at the immediate postoperative time point to 6.7 cm at final follow-up in the short fusion group (Table 2). A significant difference in SVA resulting from a postoperative loss of SVA was observed in the short fusion group compared with the long fusion group at the final follow-up time point (Table 3). There was no significant difference in the restoration of LL between the long and the short fusion groups until the final follow-up time point. The SS improved from 24.3° preoperatively to 30.1° postoperatively and was well maintained in both groups until the final follow-up. The lumbosacral alignment (ie, PI + LL) was 35.2° preoperatively and improved to −5.3° at the immediate postoperative time point. For the total population, this metric was −4.4° at the final follow-up. We observed no difference in lumbosacral alignment between the long and the short fusion groups until the final follow-up time point (Table 3).

Clinical outcome

The SRS scores at the final follow-up visit were as follows: total, 3.63; function, 3.59; pain, 3.68; self-image,

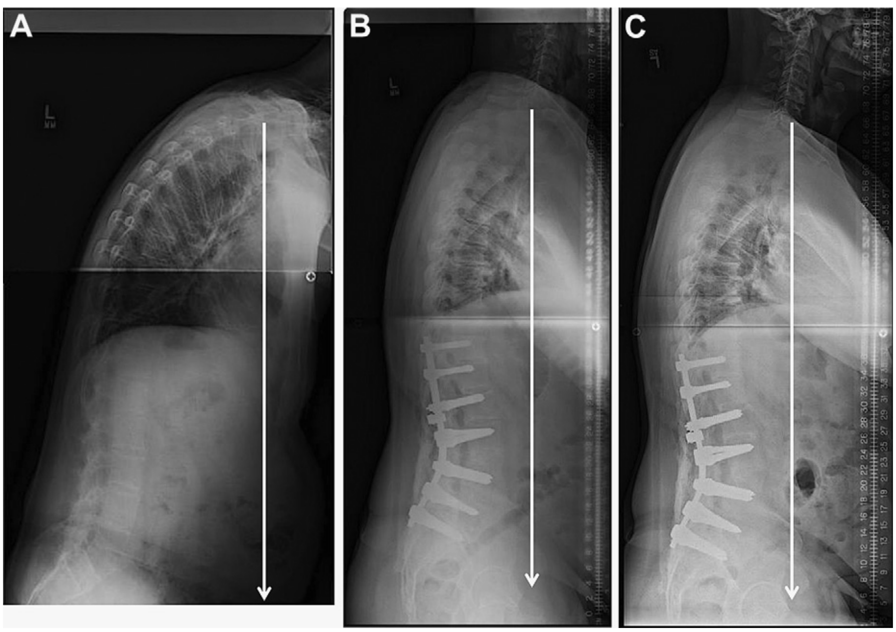

Fig. 1. A 44-year-old male with type 2 fixed sagittal imbalance pts had previous decompression from L2 to L4. PSF from T11 to Sacrum with PSO at L3 was done (short fusion group). A, preoperative lateral view: Lumbar lordosis 4°, SVA +24 cm; B, immediate postoperative lateral view: Lumbarlordosis 36, SVA +6.6 cm; C, Five-year postoperative lateral view: Lumbar lordosis 37, SVA +7.2 cm.

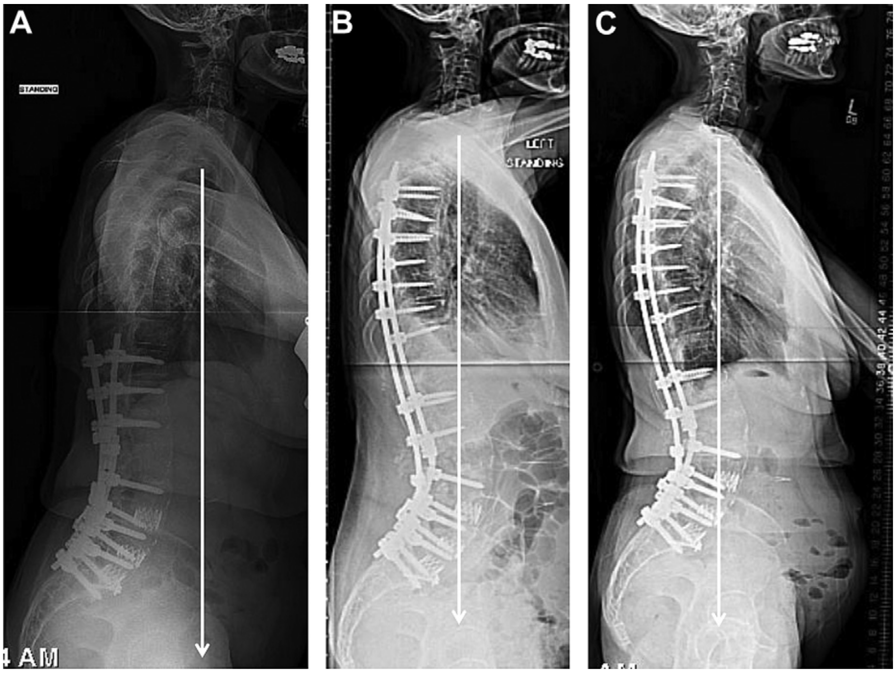

Fig. 2. A 49-year-old woman with type 2 fixed sagittal imbalance pts had previous fusion from T10 to L5. PSF from T4 to Sacrum with PSO at L1 was done (long fusion group). A, preoperative lateral view: Lumbar lordosis 32°, SVA +11 cm; B, immediate postoperative lateral view: Lumbar lordosis 70°, SVA +3.4 cm; C, Five-year postoperative lateral view: Lumbar lordosis 70°, SVA +4 cm.

3.46; mental health, 3.56; and satisfaction, 4.26. Based on the ODI scores, 16 patients exhibited minimal disability (ODI, 0%−20%), 11 exhibited moderate disability (ODI, 21%−40%), and 2 exhibited severe disability (ODI, 41% −60%). Overall ODI was an average of 28.2%, and the average ODI of 2 patients who were classified with severe disability was 42.3%. The 2 patients had residual low back pain and showed a low pain intensity domain score while they had solid fusion and good sagittal balance at the final follow-up time point. We noted no significant difference in total clinical outcomes between the long and short fusion groups at the final follow-up time point (p = .64; p = .59) (Table 4).

Surgical time and blood loss

The surgical time was not significantly different between groups in the perioperative period (5.4 ± 1.5 hours vs. 4.9 ± 1.1 hours; p = .22). Similarly, EBL and %EBL/estimated blood volume was not significantly less in the short fusion group (3,081 ± 1,111 mL vs. 2,792 ± 2,032 mL; p = .63). We found no significant difference for time of surgery and

Table 2
Radiographic outcomes of pedicle subtraction osteotomy procedure.

	Total			Long fusion			Short fusion		
	Value	P1	P2	Value	P1	P2	Value	P1	P2
Thoracic kyphosis									
Preoperative (°)	24.9			21			29.7		
Immediately postoperative (°)	27.1			25.5			29.1		
Final follow-up (°)	33.5	<.001*	<.001*	29	.008*	.021*	39	.011*	<.001*
Lumbar lordosis									
Preoperative (°)	16			20.1			11.8		
Immediately postoperative (°)	52.1			53.4			50.3		
Final follow-up (°)	51	<.001*	.063	51.6	<.001*	.051	49.8	<.001*	.85
Sagittal balance (SVA)									
Preoperative (mm)	103.8			97.5			104.9		
Immediately postoperative (mm)	36.3			35.7			37		
Final follow-up (mm)	54.1	<.001*	.002*	42.1	<.001*	.07	67.1	.002*	.007*

SVA, sagittal vertical axis.
P1: We compared the values of final follow-up with the corresponding values preoperatively.
P2: We compared the values of final follow-up with the corresponding values immediately postoperatively.
* Statistically significant.

Table 3
Comparison of radiographic outcomes of pedicle subtraction osteotomy procedure.

	Total	Long fusion	Short fusion	p
Thoracic kyphosis				
Preoperatively (°)	24.9	21.0	29.7	.56
Immediately postoperative (°)	27.1	25.5	29.1	.47
Final follow-up (°)	33.5	29.0	39.0	.06
Immediately postoperative–preoperative (°)	2.2	5.0	−0.7	.08
Final follow-up–immediately postoperative (°)	6.4	1.9	9.9	.001*
Lumbar lordosis				
Preoperatively (°)	−16.0	−20.1	−11.8	.11
Immediately postoperative (°)	−52.1	−53.4	−50.3	.51
Final follow-up (°)	−51.0	−51.6	−49.8	.77
Immediately postoperative–preoperative (°)	−36.1	−33.4	−39.4	.40
Final follow-up–immediately postoperative (°)	−1.1	−1.8	−0.1	.13
Pelvic incidence + lumbar lordosis				
Preoperatively(°)	35.2	34.4	36.1	.68
Immediately postoperative (°)	−5.3	−4.0	−6.8	.32
Final follow-up (°)	−4.4	−2.6	−6.6	.11
Sacral slope				
Preoperatively(°)	24.3	21.2	27.8	.11
Immediately postoperative (°)	30.1	30.0	30.2	.55
Final follow-up (°)	30.1	29.8	30.5	.59
Sagittal balance (SVA)				
Preoperatively(mm)	103.8	97.5	104.9	.96
Immediately postoperative (mm)	36.3	35.7	37.0	.91
Final follow-up (mm)	54.1	42.1	67.1	.04*
Immediately postoperative–preoperative (mm)	−67.5	−61.8	−71.4	.48
Final follow-up–immediately postoperative (mm)	17.9	6.4	31.8	.03*
Proximal junctional angle				
Preoperatively(°)	4.9	6.4	3.4	.33
Immediately postoperative (°)	6.8	6.8	6.8	.91
Final follow-up (°)	9.3	7.8	11.3	.04

SVA, sagittal vertical axis.
We compared the values of the short fusion group with the corresponding values of the long fusion group.
* Statistically significant.

intraoperative blood loss between the first 16 and last 16 cases (5.2 ± 1.4 hours vs. 5.2 ± 1.6 hours, p = .52; 3,021 ± 1,681 mL vs. 2,802 ± 1,713 mL, p = .61). On average, 15.1 motion sections were fused in the long fusion group, compared with 8.4 motion segments in the short fusion group (p < .001) (Table 4).

Complications

There were 2 intraoperative complications and 12 postoperative complications in 12 of 32 patients (37.5%) (Table 5). Both intraoperative complications were dural tears and were repaired by applying direct sutures to the tear during the surgery. No associated neurologic deficits were observed in these patients. Postoperative complications in both of the groups included 3 pseudoarthroses, 2 superficial wound infections, 1 deep wound infection, 1 painful PJK resulting from adjacent-level vertebral fracture, 1 coronal decompensation, 1 broken iliac screw, 1 dislodgement of the proximal hook construct, 1 prominent instrumentation, and 1 radiculopathy. Eight revision surgeries were required to treat these postoperative complications (Table 5). Four postoperative complications developed within 6 months after surgery, 6 postoperative complications developed within

Table 4
Clinical outcomes of patients who had pedicle subtraction osteotomy surgery.

	SRS22r total	Function	Pain	Self-image	Mental health	Satisfaction	ODI	Operative time (hours)	EBL (mL)	%EBL/EBV	No. of fused vertebra
Total	3.63±0.76	3.59±0.81	3.68±0.96	3.46±0.96	3.56±0.97	4.26±0.93	28.2±23.2	5.2±1.2	2901±1403	46.1	11.8±3.9
Long fusion	3.69±0.72	3.65±0.95	3.61±0.91	3.61±0.63	3.63±0.73	4.47±0.79	25.6±25.4	5.4±1.2	3081±1111	49.3	15.1±1.4
Short fusion	3.55±0.79	3.52±0.59	3.77±0.76	3.25±0.91	3.48±1.12	3.98±1.03	30.3±20.6	4.9±1.1	2792±2032	42.2	8.4±1.7
p	.64	.67	.68	.23	.71	.23	.59	.22	.63	.23	<.001*

SRS22r, Scoliosis Research Society Patient Questionnaire; ODI, Oswestry Disability Index; EBL, estimated blood loss; EBV, estimated blood volume.
We compared the values of the short fusion group with the corresponding values of the long fusion group.
* Statistically significant.

Table 5
Complications of patients who had pedicle subtraction osteotomy surgery.

	Intraoperative complication		Early postoperative complication		Middle postoperative complication		Late postoperative complication		Total
Short fusion (n=15)	Dural tear	1	Deep wound infection	1	Broken iliac screw	1	PJK	1	8
			Radiculopathy	1	Decompensation	1			
			Superficial wound infection	1	Pseudoarthrosis	1			
Long fusion (n=17)	Dural tear	1	Superficial wound infection	1	Dislodgement of Hook	1	Pseudarthrosis	2	6
					Prominent instrument	1			
Total		2		4		5		3	14
p		NA		NA		NA		NA	0.43

NA, not applicable.

We compared the values of the short fusion group with the corresponding values of the long fusion group. Early complications developed within 6 months after surgery; middle complications developed from 6 months to 5 years after surgery; late complications developed later than 5 years after surgery.

2 years after surgery, and 3 developed more than 5 years postoperatively. The late postoperative complications consisted of 2 pseudoarthroses and 1 PJK; both of these complications were successfully treated by revision fusion surgery. Two pseudoarthroses developed at the thoracolumbar junction, and 1 developed at the proximal end. No pseudoarthrosis developed at the PSO site. Other additional surgeries were performed for patients with coronal decompensation, deep wound infection, PJK resulting from a proximal vertebral fracture, and a broken iliac screw. Patients who exhibited PJK because of a proximal vertebral fracture required a revision extension posterior spinal fusion 2 years after the PSO. One superficial wound infection was successfully treated with antibiotics, and the other was treated with a single irrigation and debridement. One patient who had a prolonged radiculopathy postoperatively was treated by extensive conservative treatment. There were 1 intraoperative and 5 postoperative complications in the long fusion group. There were 1 intraoperative and 8 postoperative complications in the short fusion group. The complication rate was not significantly different between groups ($p = .43$; 6 of 17 patients [35%] in long fusion group vs. 8 of 15 [44%] in short fusion group).

Discussion

Since Glassman et al. [29,30] reported the impact of sagittal positive imbalance for the surgical treatment of adult spinal deformities, maintaining sagittal balance has become the most important factor for establishing favorable clinical outcomes after the surgical treatment of adult spinal deformities. To achieve the appropriate sagittal balance, the surgical correction of lumbar lordosis is critical. Pedicle subtraction osteotomy is widely accepted as a useful tool for obtaining the restoration of LL through all 3 columns from a posterior approach. This technique does not lengthen the anterior column and maximizes the bone fusion potential by maintaining the 3 columns and bone-to-bone contact [31-34]. In the present study, the incidence of neurologic deficits was 3.1%; we note no permanent deficits. We observed surgical complications in 12 of 32 patients. Despite the high complication rate, the overall clinical outcomes in the ODI and SRS scores were favorable, including among patients who experienced complications. Several studies have previously reported complications after a PSO procedure. Bridwell et al. [15] recently described a series of 33 consecutive patients in which 5 patients experienced a transient neurologic deficit; no patients exhibited permanent deficits in this previous series. The present study substantiates and expands upon these previous studies. During the perioperative period, surgical time and blood loss were not significantly different between groups, despite the significant difference in the number of the fused vertebra. It is likely that the vast majority of intraoperative blood loss and the duration of surgery resulted from the performance of the PSO, which may have increased the technical difficulty in achieving a satisfactory result of the PSO of the lumbar vertebra. Most patients in the short fusion group had previously undergone lumbar decompression or lumbar interbody fusion surgery at the level of the PSO site. The dura and the scar tissue made the surgery more technically challenging. Alternatively, most patients in the long fusion group had fixed sagittal imbalance because of distal adjacent disc degeneration or the loss of LL as a result of Harrington distraction instrumentation. This dissimilarity between groups may explain why we did not see a significant difference.

This study reveals that PSO can aid in the long-term maintenance of sagittal balance. The length of the construct has been proposed to be important for achieving effective bone fusion but not for maintaining sagittal balance [15-17,36]. In the present study, we focused on the impact of the UIV level of the construct for maintaining sagittal balance and on the achievement of good clinical outcomes. Overall, SVA was well maintained until the final follow-up time point. Despite the good restoration of LL, the SVA increased slightly from 3.7 cm immediately postoperatively to 6.7 cm at the final follow-up time point in the short fusion group, an effect for which we do not have a clear explanation. The loss of LL is most responsible for maintaining a sagittal balance in healthy aged volunteers [26,37-39]. Based on the alignment ranges observed in a normative population and clinical outcomes, Schwab et al. [36] also proposed an optimal sagittal lumbosacral alignment for achieving good clinical outcomes ($LL = PI + 9°$). In the present study, postoperative sagittal lumbosacral alignment was well maintained until the final follow-up visit in both the short and long fusion groups. The change in TK in the short fusion group during the follow-up period suggests that the loss of sagittal balance can be attributed to increased TK. Rose et al. [40] reported the importance of maintaining TK as well as pelvic incidence for patient with fixed sagittal imbalance undergoing PSO. They reported that patients with shorter fusions are more likely to lose correction with time because of increased TK. They reported that the formula $PI + LL + TK < 45°$ showed high sensitivity for predicting ideal sagittal balance. Age-related differences in TK are still controversial. Gelb et al. [35] reported that TK is not correlated with age in healthy aged volunteers despite a significant loss of LL and SVA. Alternatively, Schwab et al. [36] reported an age-dependent progression of TK among asymptomatic adult volunteers. Although only 20% (3 of 15) of short group met PJK criteria, the mean PJ angle in this group increased significantly during a follow-up period. We have previously reported the progression of PJK in adult idiopathic scoliosis patients after long instrumented spinal fusion without 3-column osteotomy in a mean 9 years' follow-up [26,27]. The PJ angle increased a mean 13° postoperatively in adult patients with long instrumented fusion in the long term [27]. In the present study, all patients had PSO; this angular sagittal corrective osteotomy within short segments may have an on for the posterior ligamentous complex in a long-term period. Theoretically, progression of junctional kyphosis in the thoracolumbar lesion has more effect on sagittal malalignment than that which occurs in the proximal thoracic lesion. Taken together, it strongly suggests that slight deterioration of sagittal balance in the short fusion group may reflect both the progression of junctional kyphosis and the natural aging of the spine. Despite the significant loss of SVA at final follow-up, the ODI and SRS scores exhibited no deterioration in the short fusion group compared with the long fusion group. This finding suggests that a 6.7-cm positive SVA in the short fusion group is still sufficient to maintain the health of these patients. The report from Vedantam et al. [41] supports the present study's findings: The report revealed a wide range of sagittal balance in asymptomatic adults (3.2 ± 3.2 cm behind the front of the sacrum). However, the deterioration of SVA because of increasing global and junctional kyphosis in the short fusion group may result in the requirement for additional revision surgery. Kim et al. [21] reported poorer clinical outcomes in patients whose SVA was greater than 8 cm after PSO. Taken together, the present study suggests that global and junctional kyphosis may participate in the maintenance of sagittal balance in patients who undergo PSO for fixed sagittal imbalance. In addition, the loss of sagittal balance should be monitored carefully in the long term, especially in patients who receive a short fusion procedure.

The limitations of the present study include a low retrieval rate (78%) and a small sample size (32 patients). However, our patients came from across the globe, and many patients returned to their countries before the final follow-up. A low retrieval rate and a small sample size negatively affect the power of the statistical analysis.

Conclusions

Despite a slightly increased SVA and a high complication rate, good sagittal balance was achieved with PSO, and favorable clinical outcomes were maintained in both the short and long fusion groups. The patients were observed for a mean of 8.6 years. Careful attention should be paid to the long-term deterioration of SVA in adult fixed sagittal imbalance after PSO. This study will guide spine surgeons in preoperative planning and surgical management of adult patients with fixed sagittal imbalance, and reduce poor clinical outcomes. Additional multicenter studies with long-term follow-up is required to improve understanding of the effect of the loss of sagittal balance and the outcomes of patients with this defect.

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