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Pedicle Subtraction Osteotomy in the Revision *Versus* Primary Adult Spinal Deformity Patient

Is There a Difference in Correction and Complications?

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Study Design. Multicenter, prospective study of consecutive adult spinal deformity (ASD) patients.

Objective. To compare alignment correction and perioperative complications after pedicle subtraction osteotomies (PSO) in the primary *versus* revision surgery setting for ASD.

Summary of Background Data. PSO are performed to correct sagittal plane deformity; however, these are difficult procedures that have potential for large blood loss and risk for intraoperative and postoperative complications.

Methods. Inclusion criteria were age at least 18 years, lumbar PSO, and available data on perioperative (up to 6 weeks after surgery) complication data. Patients were classified according to SRS-Schwab sagittal modifiers: PT (pelvic tilt), SVA (sagittal vertical axis), and lumbo-pelvic mismatch (pelvic incidence−lumbar lordosis). Patients were divided into primary (P; no previous spine fusion surgery) or revision (R; previous fusion). Baseline and 1-year demographic, radiographic parameters, complications and revision rates were analyzed.

Results. A total of 421 patients were included. P (n = 70) and R (n = 351) were similar for age, body mass index, sex, mean total Posterior Spinal Fusion (PSF) levels (P = 10.0; R = 10.5), PSO angle (P = 27°; R = 25°), estimated blood loss (P = 2.76L; R = 2.92L), and operative time (P = 437 min; R = 434 min). The most common osteotomy site was L3 for both primary (31.8%) and revision groups (43.6%). Both groups demonstrated improvement in sagittal spinopelvic parameters from baseline to 1 year, with similar changes in sagittal modifiers except for the pelvic mismatch that improved to a grade 0 (*i.e.*, less than 10°) more often for primary PSO group (83%) than revision PSO group (57%; $P = 0.004$). Complication rates were similar ($P > 0.05$) for the following: new motor deficit (P = 4.2%, R = 9.4%), bowel/bladder deficit (P = 1.4%, R = 2.8%), 1-year revision rate (P = 4.3%, R = 7.4%), and pseudarthrosis rate (P = 1.4%; R = 2.5%; $P < 0.05$).

Conclusion. PSO may be performed in primary or revision ASD patient with similar sagittal deformity correction and similar complication rates; however, primary PSO patients were more likely to achieve better lumbo-pelvic mismatch correction.

Key words: adult spinal deformity, complication, motor deficit, pedicle subtraction osteotomy, pelvic tilt, primary surgery, revision, revision surgery, sagittal alignment, SRS-Schwab classification.

Level of Evidence: 3

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Pedicle subtraction osteotomies (PSO) originally were described to attain correction of sagittal plane deformities in ankylosing spondylitis patients[1,2]; however, currently, PSOs are most often performed to correct sagittal plane deformity in patients with adult spinal deformity (ASD). PSO has become a widely used tool for

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correction of adult deformities and is done most commonly in the lumbar, rather than thoracic, spine. The osteotomy is used to correct a variety of sagittal deformities, ranging from degenerative disorders resulting in loss of lumbar lordosis and flat lumbar spine to multioperated spinal deformities with severe thoracic and lumbar kyphosis.[3–6] PSOs are challenging procedures that have the potential for substantial intraoperative blood loss and risk for intraoperative and postoperative complications.[4,7–9]

Pedicle subtraction osteotomies become even more complex when the patient has had previous surgical procedures. The removal of previous instrumentation and the dissection of the spine, scarred dura, and neural elements add additional operative time and risk for complications. Similar complication rates were observed in revision and primary surgeries for patients undergoing ASD correction[10]; however, there is no such comparison that has been published for PSO in primary *versus* revision procedures. Most PSOs are done in revision surgeries for patients that have had multiple previous spinal procedures. More recently, surgeons have begun to employ PSO in primary deformity corrections, as an alternative to a formal anterior release and fusion to decrease morbidity in the adult population.[3] The purpose of this study is to evaluate the differences in the clinical and radiographic outcomes for patients undergoing PSO as a primary *versus* revision spine procedure at 1-year follow-up, and compare the complication rates between the two groups.

MATERIALS AND METHODS

Patient Study Group

A retrospective review of a large, multicenter, prospective database of 626 patients who underwent surgical correction of ASD was performed. The inclusion criteria for the database were as follows: age more than 18 years with either SVA more than 5 cm, pelvic tilt (PT) more than 25 degrees. or thoracic kyphosis more than 60°.

Only patients who underwent a PSO in the lumbar spine with complete perioperative complications data (minimum 6 weeks) and had at least 1-year follow-up for radiographic and clinical data were included in the study.

Radiographic Analysis

Measurements of all radiographs were performed in a standard manner at one institution to minimize error. SpineView software (ENSAM, Laboratory of Biomechanics, Paris, France) was used to measure radiographs sent from the different centers.[11,12] Preoperative, postoperative, and final follow-up standing 36'' scoliosis radiographs were analyzed. The sagittal measurements included the following pelvic parameters: sacral slope (SS), PT, and pelvic incidence (PI).[13] Measured global sagittal spinal parameters included the following: sagittal vertical axis (SVA), T1 spinopelvic inclination (T1SPi, angle between the center of T1 vertebral body and the center of the bicoxo-femoral axis with the vertical reference line, thoracic kyphosis, thoracolumbar kyphosis, and lumbar lordosis were also measured.[14]

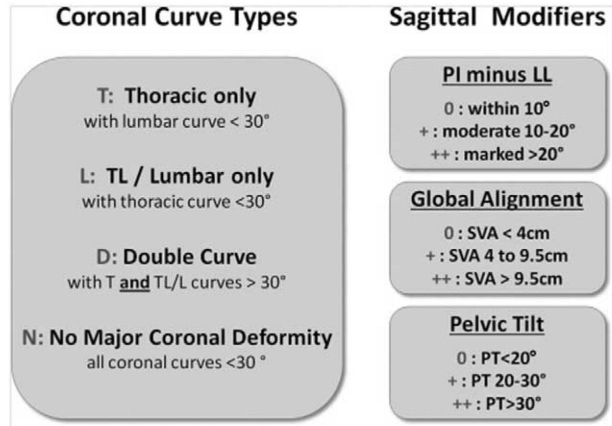

Figure 1. The SRS-Schwab Adult Spinal Deformity Classification, updated from the earlier Schwab classification to include pelvic parameters.

The patients' radiographs were also classified by the SRS-Schwab classification. The classification includes the sagittal and pelvic modifiers such as PT, SVA, and PI-LL mismatch (Fig. 1).

Clinical Data

The two groups studied were the primary and revision PSO group (Figs. 2 and 3). Revision surgery group at baseline included patients with previous lumbar fusion. Demographic data were compiled for primary and revision

Figure 2. Example of primary case. At baseline, the patient had PT 59°, PI−LL 88°, and SVA 239 mm (all SRS-Schwab grade ++), which improved to PT 14°, PI−LL −23°, and SVA 20 mm (all SRS-Schwab grade 0) at 1 year postoperatively. LL indicates lumbar lordosis; PI, pelvic incidence; PT, pelvic tilt; SVA, sagittal vertical axis.

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Figure 3. Example of revision case. At baseline, the patient had PT 39°, PI−LL 62°, and SVA 165 mm (all SRS-Schwab grade ++), which improved to PT 14°, PI−LL -16°, and SVA -49 mm at 1 year postoperatively. LL indicates lumbar lordosis; PI, pelvic incidence; PT, pelvic tilt; SVA, sagittal vertical axis.

groups. The perioperative major and minor complications, as previously defined by Carreon *et al*,[15] were noted and analyzed. The 1-year clinical results in terms of residual neurologic deficits, pseudarthrosis, and failure of instrumentation were noted. The patients who underwent revision surgery after the PSO surgery were evaluated for reasons for revision and their final clinical and radiographic disposition was reviewed.

Statistical Analysis

Mean and standard deviation were used to describe continuous variables, and frequency analyses were used for categorical variables. The groups were compared demographically and radiographically utilizing the chi-squared test for categorical variables and unpaired t test for continuous variables. All analyses were performed with Stata Software 13.1 (StataCorp, College Station, TX) with a level of significance set at 0.05.

RESULTS

Demographic Results

A total of 421 patients (67%) of the 626 patients in the database met the inclusion criteria. There were 70 patients who underwent a primary PSO and 351 patients who underwent a revision PSO. The primary and revision PSO groups were similar in age, body mass index, and gender distribution (Table 1). The mean total PSF levels were similar as follows: 10.0 levels for the primary PSO group and 10.5 levels for the revision PSO group ($P = 0.392$). Mean previous posterior spinal fusion levels for revision PSO group was 5.5 segments.

The most common osteotomy site was L3 for both the primary (31.8%) and the revision PSO groups (43.6%). PSO angle measurement for the primary PSO group was 27° and the revision PSO group was 25°, without significant differences ($P = 0.515$). The operating room time and estimated blood loss were also similar between the primary PSO and revision PSO groups (Table 1).

Radiographic Results

The distribution of patients in each sagittal SRS-Schwab modifier group was similar for primary and revision PSO groups. Both groups demonstrated improvement in all sagittal spinopelvic parameters from baseline to 1 year, with significant changes in sagittal modifiers (Tables 2 and 3). The comparison of radiographic improvement between groups revealed that the pelvic mismatch improved to a grade 0 (*i.e.*, less than 10°) more often for the primary PSO group 83% than the revision PSO group 57% ($P < 0.005$), without significant differences for SVA improvement to grade 0 (*i.e.*, less than 4 cm; no previous spine fusion surgery

TABLE 1. Comparison of Preoperative Demographic Parameters and Surgical Data

	Primary		Revision		
	Mean	SD	Mean	SD	P
Age (yrs)	61.1	12.7	59.8	10.8	0.36
BMI (kg/m^2)	28.4	10.7	28.2	6.6	0.831
Gender (women, %)	61%	—	71%	—	0.098
No. of levels fused at baseline	0	0	5.5	4.7	0
OR time (mn)	437	159	434	147	0.897
Blood loss (mL)	2756	2034	2922	1972	0.573
No. of levels fused postoperatively	10	3.9	10.5	3.7	0.392

BMI indicates body mass index; OR, operating room; SD, standard deviation.

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TABLE 2. Analysis of the Changes in Radiographic Parameters From Preoperative to Postoperative (Paired *t* Test) for the Primary Group

	Preoperative		Postoperative		Δ Pre- to Postoperative		
	Mean	SD	Mean	SD	Mean	SD	*P*
Thoracic kyphosis T2-T12	30.9	25.5	50.3	16.5	19.3	18.3	<0.001
Thoracic kyphosis T4-T12	29.2	24.2	44.1	14.8	14.9	19.7	<0.001
LL L1-S1	−25.7	24.1	−53.4	14.8	−27.7	24.4	<0.001
SVA	128.4	70.6	38.8	58.4	−89.5	72.6	<0.001
T1 spinopelvic inclination	3.1	6.3	-3.8	5	−6.9	6.6	<0.001
PT	31.9	11.8	24	10.3	−7.9	10.1	<0.001
PI−LL	31.0	23.9	3.7	15.7	−27.3	24	<0.001

Δ pre- to postoperative indicates difference between pre- and postoperative value; LL, lumbar lordosis; PI, pelvic incidence; PT, pelvic tilt; SD, standard deviation; SVA, sagittal vertical axis.

[P] = 54%, previous fusion [R] = 47%, *P* = 0.397), neither PT improvement to grade 0 (*i.e.*, less than 20°; P = 26%, R = 32%, *P* = 0.131).

Complications and Revision Surgery

The analysis of major complications (intraoperative or immediate postoperative up to 6 weeks after the index osteotomy) revealed no significant differences between the primary and revision PSO groups: 24.3% *versus* 31.9%, respectively, *P* = 0.207. Overall, the rate of intraoperative major complications was 15.7% for the primary PSO group and 23.6% for the revision PSO group, when counting excessive blood loss (*i.e.*, more than 4 L) as a major complication. The rate of intraoperative complications was less than 5% for both primary and revision PSO groups when excluding excessive blood loss as major complication (P = 2.8%, R = 4.5%). The rate of postoperative major complications was 27.1% for the primary PSO group and 48.4% for the revision PSO group (*P* = 0.69).

Neurologic complication rates were similar in both primary and revision groups. The motor deficit rate (*i.e.*, motor response inferior to 3/5) in the primary PSO group was 4.2% and in the revision PSO group was 9.4% (*P* = 0.163). The rate of patients that suffered from bowel or bladder deficit in the primary PSO group was 1.4% and in the revision PSO group was 2.8% (*P* = 0.498). Furthermore, the deep infection rate was 4.3% in the primary PSO group and 4.3% in the revision PSO group (*P* = 0.996) (Table 4).

Revisions Surgery: Incidence and Reasons

The overall rate of revision surgery within the first year was 4.3% for the primary PSO group and 7.4% for the revision PSO group (*P* = 0.396). The main indications for revision surgery are summarized in Table 5. The revision rate for implant failure was similar in both the primary PSO and revision PSO groups (P = 4.29%, R = 2.56%); there was no statistical difference in terms of revision rate for nonunion (P = 1.42%, R = 2.56%). The main difference between the

TABLE 3. Analysis of the Changes in Radiographic Parameters From preoperative to postoperative (paired *t* test) for the Revision Group

	Preoperative		Postoperative		Δ Pre- to Postoperative		
	Mean	SD	Mean	SD	Mean	SD	*P*
Thoracic kyphosis T2-T12	30.6	20.8	45.4	19	14.8	15.4	<0.001
Thoracic kyphosis T4-T12	27.3	18.7	38.1	17.3	10.8	15.3	<0.001
LL L1-S1	−23.7	20.6	−53	15.4	−29.9	16.6	<0.001
SVA	145.3	79.5	42.3	63.2	−103	74.6	<0.001
T1 spinopelvic inclination	4.5	7.5	−3.5	5.8	−8	6.8	<0.001
PT	32.9	11	25.1	11.5	−7.8	8.8	<0.001
PI−LL	36.8	19.8	7.3	18.3	−29.4	16.8	<0.001

Δ pre- to postoperative indicates difference between pre- and postoperative value; LL, lumbar lordosis; PI, pelvic incidence; PT, pelvic tilt; SD, standard deviation; SVA, sagittal vertical axis.

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TABLE 4. Incidence of Major Complications

Complications	All (%)	Primary (%)	Revision (%)	*P*
Intraoperative bleeding > 4L	17.30	12.80	18.20	0.28
Intraoperative cardiac arrest	0.50	0.00	0.50	0.53
Intraoperative cord deficit	1.20	1.40	1.10	0.84
Intraoperative unplanned stage	1.00	0.00	1.10	0.37
Intraoperative vessel/organ injury	1.40	1.40	1.40	1.00
Postoperative acute respiratory failure	1.40	0.00	1.70	2.71
Postoperative arrhythmia	0.70	0.00	0.90	0.44
Postoperative bowel/bladder deficit	2.60	1.40	2.80	0.00
Postoperative cauda equina deficit	0.70	0.00	0.90	0.44
Postoperative deep infection	4.30	4.30	4.30	1.00
Postoperative DVT	1.90	1.40	2.00	0.75
Postoperative motor deficit paralysis	8.60	4.20	9.40	0.16
Postoperative optic deficit	0.20	1.40	0.00	0.03
Postoperative PE	1.70	1.40	1.70	0.87
Postoperative pneumonia	1.20	1.40	1.10	0.84
Postoperative reintubation	0.50	0.00	0.60	0.53
Postoperative sepsis	0.50	0.00	0.60	0.53
Postoperative tracheotomy	0.20	0.00	0.30	0.66
Postoperative unplanned return OR	11.40	8.60	12.00	0.42

DVT indicates deep venous thrombosis; PE: pulmonary embolism.

two groups related to the revision rate within the first 3 months after the surgery (R = 14.0%, P = 8.5%) but was not significant ($P = 0.273$). Similarly, between 3 months and 1 year there were no significant differences in the revision rate (P = 4.3%, R = 7.4%, $P = 0.39$).

DISCUSSION

PSO is an extremely valuable tool in correcting sagittal plane deformity, especially in revision spine fusion cases. Commonly, these patients have had a previous spinal fusion that resulted in inadequate lumbar lordosis or flat back posture. The patient attempts to stand erect; however, with inadequate lumbar lordosis, the patient compensates by extending the hips and retroverting the pelvis in addition to posterior pelvic translation.[16] When hip extension reaches its limits, the patient tends to lean forward; to compensate for this hip extension, the patient flexes the knees in an attempt to look straight ahead; however, this leads to fatigue in the quadriceps muscles, hamstrings muscles, and the lumbar erector muscles. This clinical posture of a patient and his or her accompanied complaints of pain in the lower limbs and back is the presentation of a flat back condition. A PSO is a useful tool for the surgical management of these patients to restore lumbar lordosis and optimal global sagittal alignment.

PSOs are commonly used procedures to correct flat back deformity; however, PSOs performed in patients who have had previous spinal surgery can be complex. The dissection of the scar tissue to expose the instrumentation and the posterior spinal elements and the frequent need to remove previous instrumentation is challenging. Furthermore, placing new instrumentation can be difficult because the posterior element anatomy is variable due to the previous fusion attempt. Revision decompression and the dissection

TABLE 5. Reasons for Revision Surgery

	Primary (%)	Revision (%)	*P*
Implant failure	4.29	2.56	0.431
Other	0.00	0.56	0.528
PJK	0.00	2.28	0.300
Pseudo	1.42	2.56	0.570
Sagittal imbalance	0.00	1.70	0.342
Neurologic deficit	0.00	0.00	-
Painful instrumentation	0.00	0.29	0.656
Infection	0.00	0.57	0.528
Unknown	0.00	0.28	0.656

PJK indicates proximal junctional kyphosis.

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of the scarred dura pose additional risks, as higher rate of dural tears with revision lumbar surgery may occur. Patients with flat back posture also develop hip flexion contractures, which make patient positioning on the operating table more difficult.

The use of PSO in patients with coronal and sagittal plane deformities without any previous surgery is relatively new and a recent trend has shown an increasing use of posterior-only procedures that include posterior interbody fusion. The reasons for this trend may be a desire to avoid the morbidity of the anterior approach, which has been described to include vascular injury, sympathectomy effect, chyle leak, ureteral injury, ileus, abdominal wall protrusion, hernia, and prolonged hospital stay.[8,17–19] Furthermore, PSO may be performed in an asymmetric manner, and thus allow correction of the coronal and sagittal plane simultaneously. PSO for the surgical treatment for primary lumbar degenerative scoliosis has also been reported by Hedlund.[3]

In this study, we found that the majority of the patients undergoing a PSO in a revision setting were patients with primarily a sagittal plane deformity. The osteotomy site was similar in both groups, with most osteotomies performed at L3. The PSO correction achieved was statistically similar, and was found to be 25° in the revision PSO group and 27° in the primary PSO group. The angular correction is consistent with the literature reports of PSO correction in the 25° to 30° range in most series.[6,20–22]

The sagittal plane measurements preoperatively were similar in both groups suggesting that the surgeons utilized similar thresholds of SVA for operative correction in primary and revision settings. The preoperative pelvic parameters in both groups were similar as well. At baseline, both groups had inadequate lordosis for the amount of pelvic incidence (PI−LL more than 31.0°) as well as a high PT (more than 32.9°). Postoperatively, the primary PSO group had significantly greater success in improving the pelvic mismatch, achieving SRS-Schwab modifier grade 0 in 83% of cases, whereas the revision PSO group attained it in only 57% of cases ($P = 0.004$). The patient undergoing a primary PSO can have correction of the lumbosacral junction, in addition to the lumbar PSO. In a revision situation, however, the lumbosacral junction may be fused in a flat contour and performing the lumbar PSO is insufficient to obtain the harmonious lordosis of the lumbar spine; thus, other tools and osteotomy types (Smith-Petersen) may be useful.[23]

The neurologic complication rates were similar for both groups. The rates of new motor deficits were 4.2% in the primary PSO group and 9.4% in the revision PSO group, but the difference did not reach statistical significance. Similarly, there were no differences between groups in dural tear rate. Patients who underwent primary PSO had significantly lower incidence of bowel or bladder deficit than those with revision PSO (1.4% and 2.8%, $P = 0.00$). The neurologic complication rate for PSO has been reported to be 11% by Buchowski et al.[9] The overall neurologic injury rate in the present study is similar to what has been reported in the literature and did not differ significantly between the primary and revision PSO groups.[7,9]

The revision rate after PSO surgery was higher in the revision PSO group (7.4%) compared with that of the primary PSO group (4.3%), although this did not reach statistical significance. When comparing the indication for revision between the primary and revision PSO groups, the rate of implant failures was similar in the revision PSO group (2.56%) and the primary PSO group (4.29%); however, revision rates for nonunion were different between groups. The nonunion rate was 1.42% in the primary PSO group and 2.56% in the revision PSO group ($P > 0.05$). In revision spinal surgery, due to multiple prior operations, the paraspinal muscles are atrophied and abundant scar tissue surrounds the bone graft. Therefore, there may be less of a chance of the surrounding tissue providing the neovascularization to the bone graft needed for the bone graft to achieve a successful spinal fusion .[24] Infection rate was greater in revision PSO than primary PSO, but not significantly so. Given the apparently higher operative time and higher blood loss, we would have expected the revision PSO group to have a higher infection rate; however, although the operative time and estimated blood loss were modestly higher in the revision PSO group, these differences were not statistically significant.

The strengths of this study include the large number of patients and the extensive amount of demographic, radiographic, clinical, and complication data that were recorded and analyzed. One limitation of this study is that it is retrospective in design. Future studies on this topic should include a prospective enrollment of consecutive cases of patients undergoing PSO for both revision and primary procedures. This study is also limited by the lack of patient-based health-related quality-of-life measures, such as the Oswestry Disability Index, Scoliosis Research Society-22 questionnaire, and the Short Form-36 survey. Future studies would benefit from including these measures, especially when considering the magnitude of PSO in both primary and revision settings. Whereas this study included a large cohort of several hundred patients with 1-year follow-up, longer follow-up would allow for better determination of the consequences of complications and ultimate radiographic changes. Finally, this study is limited in the asymmetry in the group sizes, thus posing a risk for underpowered comparisons of complication rates between the groups; however, due to the substantial correction with PSO, they are less commonly performed in primary patients. Moreover, the primary and revision groups were similar in all key baseline demographics, providing more confidence in the comparisons.

CONCLUSION

PSO may be performed for the surgical correction of both primary and revision ASD cases, yielding similar sagittal correction and major complication rates. Overall, PSO performed in both primary and revision surgeries are

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