

Pedicle subtraction osteotomy: a comprehensive analysis in 104 patients. Does the cause of deformity influence the outcome?

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OBJECTIVE The clinical outcomes and complications of patients who underwent pedicle subtraction osteotomy (PSO) for various diagnoses were compared. More specifically, the purpose was to identify if outcomes differed between patients with flat-back syndrome after lumbar fusion (FBS-LF) versus patients who underwent surgery for adult spinal deformity (ASD).

METHODS A retrospective analysis of 104 patients who underwent a PSO for sagittal plane imbalance was performed. There were 28 patients with FBS-LF and 76 patients with various forms of ASD. Outcome was measured using visual analog scale (VAS)-back, VAS-leg, Oswestry Disability Index (ODI) (range 0–100 for all scales), and EQ-5D scores (range 0–1). Patients also rated their global outcomes as much better, better, unchanged, or worse at follow-up. The minimum follow-up was 1 year (range 1–4 years). Clinical outcomes and complications were compared between the 2 groups of patients.

RESULTS The most common level of PSO was L-3 and L-2; 100 single and 4 double PSOs were performed. The average local correction by PSO itself was 27.2°. The sagittal vertical axis (SVA) improved from a mean preoperative value of 74 ± 23 mm to 49 ± 20 mm at the final follow-up. The VAS-back, ODI, and EQ-5D scores improved significantly for the entire group by 33, 16, and 0.31 points, respectively. In total, 57% of patients reported that they were “much better” or “better” than before surgery. Preoperatively, as well as postoperatively, the FBS-LF patients reported significantly worse VAS scores. According to VAS-back results, the ASD group improved by 34 points compared with 29 points in FBS-LF patients. ODI scores were similar between the 2 groups preoperatively but improved significantly more in the ASD group (18 points) compared with the FBS-LF group (13 points). The EQ-5D scores improved from 0.07 to 0.35 in FBS-LF patients, and from 0.21 to 0.56 on average in ASD patients. Similarly, a “much better” or “better” outcome compared with before surgery was reported by 72% of patients in the ASD group compared with 24% of patients in the FBS-LF group ($p < 0.001$). The overall reoperation rate was 31%: 46% of patients in the FBS-LF group compared with 25% of patients in the ASD group. There were 19 (18%) dural tears, 14 (13.5%) surgical site infections, 12 (11.5%) instances of pseudarthrosis, 15 (14%) proximal junctional failures, and 2 distal junctional failures. The 12 (11%) neurological complications were dominated by partial weakness of hip flexion and knee extension, and all but 2 of these were temporary.

CONCLUSIONS PSO is a safe and effective method for correcting sagittal plane imbalance due to multiple etiologies. The authors found patient satisfaction to be high, and health-related quality of life was greatly improved by the procedure in patients with ASD. In contrast, in FBS-LF patients, a suboptimal outcome was observed and the cautious use of PSO seems warranted in this subset of patients.

<https://thejns.org/doi/abs/10.3171/2016.12.SPINE16585>

KEY WORDS pedicle subtraction osteotomy; adult spine deformity; vertebral osteotomy; lumbar flat back; kyphotic deformity

ABBREVIATIONS ASD = adult spinal deformity; FBS-LF = flat-back syndrome after lumbar fusion; ODI = Oswestry Disability Index; PJF = proximal junctional failure; PSO = pedicle subtraction osteotomy; SVA = sagittal vertical axis; VAS = visual analog scale.

SUBMITTED May 23, 2016. **ACCEPTED** December 15, 2016.

INCLUDE WHEN CITING Published online May 5, 2017; DOI: 10.3171/2016.12.SPINE16585.

SAGITTAL plane spinal deformity has been increasingly recognized as an important cause of low health-related quality of life. It is commonly related to adult spinal deformity (ASD), i.e., degenerative scoliosis and adult idiopathic scoliosis, and also to various etiologies such as posttraumatic kyphosis and iatrogenic flat back after lumbar fusion. The clinical picture is characterized by back pain and often severe functional disability. Nonoperative treatment options fail in most patients. Surgical interventions, which are typically accomplished by extensive fusion with or without osteotomies, are aimed at restoring sagittal balance; perhaps the most common of these interventions is pedicle subtraction osteotomy (PSO).^{3,13}

Originally, PSO was used in the ankylosed spine, particularly for ankylosing spondylitis, replacing open-up osteotomies or combined front and back surgery.¹³ Although it is a technically challenging method, satisfactory clinical outcomes have been reported.^{6,9,10} The indications for PSO currently include any kyphotic spinal disorder, such as degenerative scoliosis, posttraumatic kyphosis, neuromuscular scoliosis, congenital kyphoscoliosis, flat-back syndrome after previous scoliosis surgery, and flat-back syndrome after lumbar spine fusion (FBS-LF).^{9,14,15} The purpose of this study was to compare the clinical outcomes and complications in patients who underwent PSO for various spinal disorders and to identify possible differences in outcomes and complications between patients with a primary diagnosis of ASD compared with patients with FBS-LF for degenerative conditions.

Methods

A retrospective analysis of 104 consecutive patients who had undergone PSO between 2007 and 2012 at Sahlgrenska University Hospital in Gothenburg, Sweden, was performed. We obtained informed consent from all the patients and also approval from the ethics committee of Gothenburg University. The medical records were reviewed to extract demographic data (age, sex, height, and weight) and the preoperative diagnosis. The presence of any previous osteoporotic fracture and the history and nature of

any previous spine surgery were also noted. Surgical data were extracted, including the level of PSO, proximal and distal level of instrumentation, operative time, estimated blood loss (including drainage), transfusions, and length of the hospital stay. The complications and their time of occurrence were recorded and classified as minor or major.

Before surgery, as part of our routine documentation, and at the final follow-up, the patients were asked to fill out validated questionnaires. Patients who did not send back the questionnaires were contacted by telephone and reminded to submit their questionnaires. Preoperative scores were available for all except 4 patients. The final follow-up scores were available for 90 (87%) patients.

Pain was assessed using the visual analog scale (VAS) on a scale of 1–100 for back and leg pain separately, functional disability was assessed by the Oswestry Disability Index (ODI), and quality of life was assessed by EQ-5D. The global outcome⁸ as reported by the patients was classified as much better, better, unchanged, or worse at the final follow-up.

All patients underwent radiographic evaluation preoperatively, postoperatively, and at the final follow-up using Surgimap spine software.¹ Full-length standing radiographs were obtained with documentation of the sagittal spinopelvic parameters, including sagittal vertical axis (SVA), thoracic kyphosis measured from T-4 to T-12, lumbar lordosis measured from L-1 to S-1, pelvic incidence, sacral slope, and pelvic tilt. All included patients were either in overt clinical sagittal imbalance (SVA > 5 cm) or in compensating sagittal imbalance (pelvic tilt/sacral slope not corresponding to pelvic incidence, indicating pelvic retroversion or other types of compensatory changes¹²). The pedicle subtraction angle was defined as the change of the angle formed by the lower vertebral endplate of the adjacent cephalic vertebra to the upper vertebral endplate of the adjacent caudal vertebra.

The patients were grouped according to their diagnoses (Table 1). The 28 patients with FBS-LF were defined as the degenerative group (Fig. 1), and the 76 patients with a primary diagnosis of ASD were defined as the deformity group (Fig. 2). Among the patients with ASD, there were 20 patients with posttraumatic kyphosis, 16 patients

TABLE 1. Demographic data of 104 patients with multiple etiologies who underwent PSO

Diagnosis	No. of Patients	Median Age at Op in Yrs (IQR)	% Female	Median Body Mass Index (IQR)
Degenerative group				
FBS-LF	28	66 (56–71)	57	27 (24–28)
Deformity group				
Total	76			
Degenerative scoliosis	21	63 (58–70)	76	24 (22–29)
Posttraumatic kyphosis	20	63 (56–68)	70	26 (23–29)
Flat-back syndrome after scoliosis surgery	16	49 (25–56)	75	25 (24–28)
Adolescent idiopathic scoliosis op as adult	9	50 (44–56)	100	26 (23–30)
Neuromuscular scoliosis	6	22 (17–29)	33	23 (20–24)
Congenital scoliosis	3	24 (18–46)	33	26 (24–26)
Ankylosing spondylitis	2	40 (37–42)	0	22 (12–33)
Total	104	55 (48–67)	67	25 (23–29)

with flat-back syndrome following scoliosis surgery during adolescence using Harrington instrumentation, 21 patients with degenerative scoliosis, 9 patients with idiopathic scoliosis presenting in adulthood, 6 patients with neuromuscular scoliosis, 3 patients with congenital scoliosis, and 2 patients with ankylosing spondylitis. All patients had a kyphotic deformity assessed as severely affecting daily function.

Statistical Analysis

All statistical analyses were performed using SPSS (version 21, IBM SPSS, Inc.). Normally distributed variables were described using the mean \pm standard deviation, while variables not normally distributed were described using the median and interquartile range. The clinical outcomes and complication rates between the degenerative group and deformity group were analyzed for statistical significance using the t-test and chi-square tests. Statistical significance was set at $p < 0.05$.

Results

There were 33 (32%) male and 71 (68%) female patients, with a mean age of 55 ± 16 years. Seventy-five patients (72%) had undergone previous spine surgery. The mean operative time was 336 ± 89 minutes (Table 2).

There were 100 single and 4 double PSOs. The most common PSO levels were L-3 (42%) and L-2 (23%). For PSOs at L-3, the most frequent instrumentation levels were T12–S1 (18%), T4–S1 (16%), and L1–5 (16%). For PSOs at L-2, the most common instrumentation levels were T11–L5 (42%) and T11–S1 (13%). All patients had only 2 stabilizing rods across the PSO site. The mean (minimum–maximum) number of instrumented levels was 9 (5–17), mean intraoperative bleeding was 2600 ml (500 ml to 10 L), and mean postoperative drain collection was 900 ml (100–2500 ml). Cell salvage with autologous transfusion was used in all patients. Perioperative blood transfusion was used in 72% (75 of 104) of patients, and postoperatively it was used in 32% (33 of 104) of patients. The mean (minimum–maximum) length of hospitalization was 12 days (range 6–54). Patients with a flat-back diagnosis had on average a 7-level fusion compared with 10 levels in deformity patients.

All patients had a significant improvement in their clinical scores after PSO (Table 3). The average local correction by PSO itself was 27.2° , and the mean improvement in lumbar lordosis was from 29° to 42° . SVA improved from a mean preoperative value of 74 mm to 49 mm at the follow-up ($p < 0.001$).

The mean preoperative and postoperative pain scores were significantly higher in the degenerative group (Table 4). The ODI scores were similar in the 2 groups preoperatively. However, after surgery, the improvement in ODI scores in the deformity group was significantly better (18%) compared with the degenerative group (13%). Similarly, the deformity group had significantly more improvement in the EQ-5D scores than the degenerative group (Table 4). On the global assessment scale, 72% of patients in the deformity group rated their status as “much better” or “better” (satisfactory outcome), whereas in the degen-

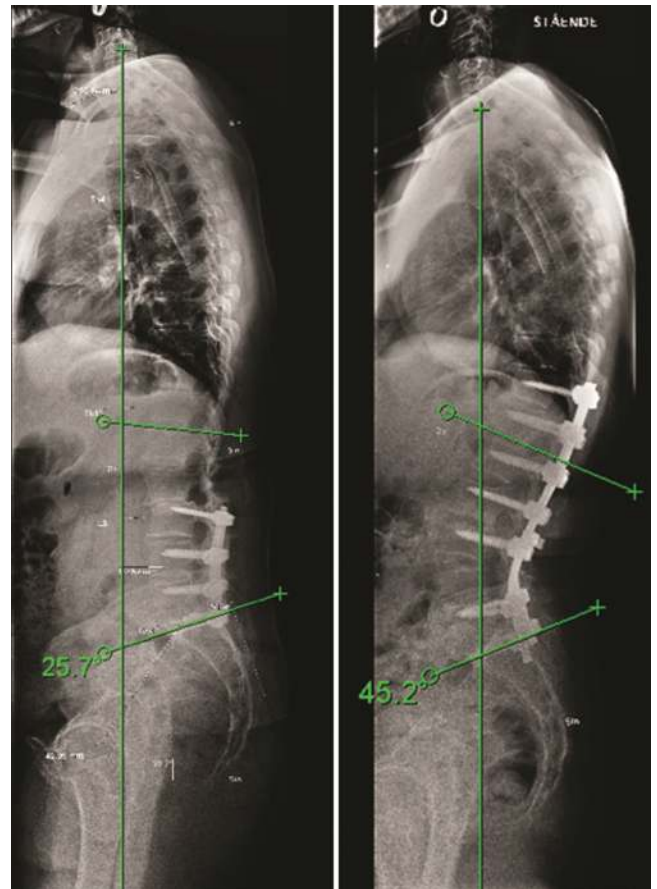


FIG. 1. Preoperative and postoperative radiographs of a 56-year-old male patient who had previously undergone decompression and fusion at L3–S1. The patient developed flat-back syndrome and sagittal imbalance, an SVA of 8 cm, and pelvic retroversion. He underwent reoperation 4 years later with PSO at L-4 and fusion at T11–S1. A normalized sagittal profile of the thoracic and lumbar spine as well as pelvic retroversion are shown. Figure is available in color online only.

erative group only 24% of patients reported a satisfactory outcome ($p < 0.001$) (Table 5).

Overall, there were 19 (18%) intraoperative dural tears. Of 16 (15.3%) surgical site infections, 10 (9%) were deep and 6 (5%) were superficial. The most common organism isolated was *Staphylococcus aureus* (8 patients), followed by *Proteus mirabilis* and *Propionibacterium acnes* in 2 patients each. There were 12 (11.5%) instances of pseudarthrosis with rod breakage or implant failure. Pseudarthrosis occurred significantly more often in the degenerative group (8 of 28 patients; 28.5%) than in the deformity group (4 of 76 patients; 5.3%). If pseudarthrosis occurred after PSO, the revision included repairing pseudarthrosis by compression over the pseudarthrotic cleft, which often allowed some concomitant improvement in sagittal imbalance. Extension of fusion, typically superiorly, was performed if sagittal imbalance was not fully corrected. There were 15 (14%) proximal junctional failures (PJFs) and 2 (2%) distal junctional failures that required revision surgery in all of these patients, which involved extension of the instrumentation. PJF occurred



FIG. 2. Preoperative (A and B) and postoperative (C and D) clinical photographs and radiographs obtained in a 42-year-old male patient who was severely disabled and used a wheelchair outdoors due to ankylosing spondylitis and severe rigid kyphosis. He underwent double PSO at T-12 and L-3 and achieved an excellent clinical outcome. Figure is available in color online only.

significantly more frequently in the degenerative group (10 of 28 patients; 35.7%) compared with the deformity group (5 of 76 patients; 6.5%). Neurological complications occurred in 11% of the patients. The most common complication was weakness in hip flexion or knee extension. All but 2 patients recovered completely by the end of 1 year (Table 6).

The overall reoperation rate was 31% (32 of 104 patients). In the degenerative group, the reoperation rate was 46% (13 of 28 patients), which was significantly higher than in the deformity group (19 of 76 patients; 25%). Reoperations in the deformity group were mostly performed on patients with adolescent idiopathic scoliosis who had undergone surgery as a child. These patients did as well or better than adults who underwent primary surgeries, and

better than patients who underwent previous lumbar fusion as adults.

Discussion

We observed a striking difference in clinical outcomes between patients with various deformity diagnoses compared with the outcomes of patients with FBS-LF for degenerative lumbar disorders. Thus, the findings showed that outcome, to a large extent, was affected by the primary diagnosis. The most important finding was the strikingly poor outcome in FBS-LF patients, with only 24% of these patients demonstrating a satisfactory outcome and a mean change of only 0.27 on the EQ-5D index at the final follow-up. In contrast, 72% of patients with

TABLE 2. Surgical details and length of stay for the patients with different etiologies

Diagnosis	Median No. of Instrumented Levels (IQR)	Mean Op Time in Mins	Median Blood Loss in ml	Median Length of Stay in Days (IQR)
FBS-LF	7 (6–8)	320	3600	11 (9–17)
Degenerative scoliosis	8 (7–9)	322	2700	10 (8–11)
Posttraumatic kyphosis	6 (5–7)	245	2300	9 (8–12)
FBS after scoliosis surgery	15 (8–15)	377	3200	9 (8–11)
Adolescent idiopathic scoliosis op as adult	13 (8–14)	391	3300	14 (12–14)
Neuromuscular scoliosis	12 (7–18)	339	3000	12 (10–14)
Congenital scoliosis	12 (9–13)	494	2400	11 (10–17)
Ankylosing spondylitis*	11 (9–13)	391	8500	30 (10–50)

* Includes only 2 patients.

TABLE 3. Preoperative and postoperative outcome scores for all patients

Questionnaire	No. of Patients	Mean Preop	Mean Postop	p Value
VAS-back	90	70	37	0.005*
VAS-leg	86	50	31	0.004*
ODI	90	55	39	0.000*
EQ-5D index	89	0.18	0.49	0.001*

* The mean difference was significant at $p < 0.05$

various classic spinal deformity diagnoses showed a satisfactory outcome and a mean change of 0.35 on EQ-5D. Also, compared with the ASD patients, the FBS-LF patients scored poorly on all of the clinical scores at the final follow-up, including VAS, ODI, EQ-5D, and the global assessment scale. Furthermore, the reoperation rate was almost double (46%) in patients with previous lumbar fusion compared with the rate in patients with a primary deformity diagnosis (25%). Thus, the findings show a much worse outcome in FBS-LF patients compared with ASD patients, who showed an overall satisfactory outcome in three-quarters of patients.

The reason for this outcome discrepancy is most likely multifactorial. Although they were all patients with sagittal imbalance, those undergoing PSO for the correction of FBS-LF differed considerably from the patients in whom the primary diagnosis was a spinal deformity. The difference is not only in the basic pathology, but also in the patient profiles between the 2 groups. FBS-LF patients, by definition, had previously undergone surgery for low-back pain, and it is likely that the selection of low-back-pain patients whose surgeries had failed and who were in need of a reoperation results in a suboptimal outcome. A subgroup of patients in the deformity group—the patients who underwent surgery for adolescent idiopathic scoliosis as children also constitutes a reoperation group—did not undergo surgery initially for pain but for deformity. Thus,

TABLE 4. Difference in the clinical scores between the degenerative group and deformity group

Outcome Variable	Degenerative (n = 28)	Deformity (n = 76)	p Value
VAS-back			
Preop	77	68	0.021*
At last follow-up	48	32	0.036*
Difference	29	34	0.517
ODI			
Preop	59	54	0.211
At last follow-up	46	36	0.002*
Difference	13	18	0.039*
EQ-5D			
Preop	0.07	0.21	0.027*
At last follow-up	0.35	0.56	0.004*
Difference	0.28	0.35	0.024*

* The mean difference was significant at $p < 0.05$.

TABLE 5. Differences in global assessment between groups

Global Outcome	No. of Patients (%)	
	Degenerative	Deformity
Much better	5 (17)	18 (25)
Better	2 (7)	34 (47)
No change	8 (28)	14 (19)
Worse	14 (48)	7 (9)
Total no. of patients	29	77

they were not preselected pain patients, and most likely had a better chance of a satisfactory outcome.

Another reason for the major difference in outcome between the degenerative and deformity patients may be that the degenerative patients were predominantly fused up to the T10–L1 region, in contrast to the deformity patients who mostly underwent high thoracic fusion. The observed, much higher risk of PJF in the degenerative group (35%) compared with PJF in the deformity group (7%) strongly suggests that not only the diagnosis but also the length of fusion may affect the outcome. Furthermore, the

TABLE 6. Early and late major and minor complications

Complications	No. of Patients
Major complications	
Intraop & before discharge	
Deep infection	2
Motor deficit	10
Pneumonia	2
Pulmonary embolism	1
Cervical fracture	1
Iliac fracture	1
Hematoma	2
At final follow-up	
Hematemesis	1
Deep infection	8
Implant failure	15
Proximal junctional kyphosis	15
Distal junctional kyphosis	2
Sagittal imbalance	3
Pseudarthrosis	12
Total no. of major complications	76
Minor complications	
Intraop & before discharge	
Apathy	1
CSF leak	19
Superficial infection	1
Excessive bleeding >5 L	20
Sensory deficit	11
At final follow-up	
Superficial infection	5
Total no. of minor complications	56

degenerative patients were on average older (mean age 64 years) than the patients in the deformity group (mean age 52 years), with probably weaker musculature and poorer bone quality. This was reflected by the fact that 39% of the patients in the degenerative group had a history of osteoporotic vertebral fractures in contrast to only 18% of the patients in the deformity group. Also, the presence of other comorbidities in these older patients may have had an impact on their clinical outcomes.

Also, pseudarthrosis occurred more often in the patients with preoperative flat backs. Of the 12 total cases of pseudoarthrosis, 8 were seen in the degenerative group and 4 in the deformity group. Of these, 6 were at the level of the osteotomy. All patients with pseudoarthrosis underwent revision and fusion was accomplished. In the present study, PSO was a part of the learning curve for some surgeons, particularly in the degenerative group, which possibly influenced the results.

There are no previous comparisons between the outcomes of PSO in patients with FBS-LF and patients with more traditional ASD. Somewhat in contrast to our study, Kim et al.⁹ in their retrospective review of 140 patients who underwent PSO for various etiologies, reported no significant differences in the clinical outcomes or complications between various subgroups. However, 61% (86 of 140) of their patients had ankylosing spondylitis, thereby rendering comparison difficult. Gupta et al.⁷ in a multicentric study comparing outcomes after PSO as a primary versus revision surgery in patients with ASD, demonstrated similar correction and complication rates in both groups, except for pseudarthrosis, which was seen more commonly in a revision setting. They, however, did not make a distinction between the various etiological diagnoses and also did not report patient-based, health-related quality of life measures. In the present study, we did not compare primary versus revision surgery in ASD patients due to the limited number of revisions for ASD.

Similar to the published literature,^{3,5,7,9,10} we noted a high rate of complications. Neurological complications were seen in 11% patients, which is comparable to that in previous studies.⁵ Most complications were mild and reversible. There were no deaths related to the surgical procedure. Intraoperative blood loss was highly variable, with excessive bleeding (> 5000 ml) occurring in 19% of patients. The median bleeding of 2000 ml is similar to other studies⁹ and can be considered large, but was tolerable for the great majority of patients with only 1 patient with a complication that could be attributed to blood loss. Other than pseudarthrosis and PJF, there were no significant differences in the complication rates between the 2 groups.

Largely in agreement with our study, most authors^{7,9,10} have reported that PSO is a safe and effective method for correcting sagittal malalignment. The average observed local correction obtained by PSO (27°) is similar to a previously reported study.⁴ The mean preoperative lumbar lordosis was increased by only 13°. The much smaller increase in lumbar lordosis than the local correction obtained by PSO is explained by the fact that some of the PSOs were performed at the thoracic level, and if local midlumbar lordosis were corrected by PSO then the compensatory low lumbar lordosis actually was reduced in

some patients because the need for compensatory changes below the PSO was no longer required. This resulted in a more harmonious sagittal profile. In contrast to previous studies that reported mainly radiographic results, the present study focused on clinical outcome and complications according to diagnosis. Although extensive radiographic analyses were performed with quantification of the spinopelvic variables, we decided not to include these data because of the risk of obscuring the major findings, i.e., the variation in clinical outcomes between different diagnoses. A detailed analysis of sagittal balance is presented separately.

The strength of our study is the large sample size and the extent of the data that were collected on the demographics, clinical evaluations, complications, and patient-based, health-related quality of life. The presence of consistent findings across multiple validated outcome tools increases the statistical confidence and clinical relevance of the findings. However, apart from the retrospective study design, there are several limitations. The relatively shorter follow-up period ranged from 1 to 4 years and may not be adequate for estimating outcomes and the complication rate. This is particularly true for pseudarthrosis; it is reported that 40%–50% of cases may present later than 2 years postoperatively.^{10,11} However, the maximum improvement in the health-related quality of life of a patient is reported to occur during the first 6 months following surgery, even in the presence of complications.² Thus, a longer follow-up period may not yield significantly different clinical outcomes than those achieved at the end of 1 year. An additional limitation is the limited number of patients in some subgroups. The similar outcomes observed in the different types of deformity patients, however, justify the combined analysis of this group to some extent. A separate analysis of each diagnostic subgroup would have been preferable because they do differ in many important aspects. However, the limited number of patients in the different subgroups does not allow any conclusion from such an analysis. It may of course be that such differences exist, but a much larger series of patients is needed to study this possibility.

Conclusions

PSO is a safe and effective method for correcting sagittal plane imbalance due to multiple etiologies. We found patient satisfaction to be high, and health-related quality of life was greatly improved by the procedure in patients with ASD. In contrast, a suboptimal outcome was observed in patients with FBS-LF, and the cautious use of the PSO seems warranted in this subset of patients.

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Disclosures

Dr. Hedlund reports that he receives research funds from Zimmer and DePuy Synthes and is on the speakers' bureau for Zimmer, Globus, K2M, and DePuy Synthes.

Author Contributions

Conception and design: Hedlund. Acquisition of data: Eskilsson, Johansson. Analysis and interpretation of data: Sharma, Eskilsson, Hedlund. Drafting the article: Sharma, Eskilsson, Hedlund. Critically revising the article: Sharma, Hedlund. Reviewed submitted version of manuscript: Sharma. Approved the final version of the manuscript on behalf of all authors: Sharma. Statistical analysis: Sharma, Eskilsson, Johansson. Study supervision: Hedlund.

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