Correction of severe spinopelvic mismatch: decreased blood loss with lateral hyperlordotic interbody grafts as compared with pedicle subtraction osteotomy

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OBJECTIVE Pedicle subtraction osteotomy (PSO) provides extensive correction in patients with fixed sagittal plane imbalance but is associated with high estimated blood loss (EBL). Anterior column realignment (ACR) with lateral graft placement and sectioning of the anterior longitudinal ligament allows restoration of lumbar lordosis (LL). The authors compare peri- and postoperative measures in 2 groups of patients undergoing correction of a sagittal plane imbalance, either through PSO or the use of lateral lumbar fusion and ACR with hyperlordotic (20°–30°) interbody cages, with stabilization through standard posterior instrumentation in all cases.

METHODS The authors performed a retrospective chart review of cases involving a lumbar PSO or lateral lumbar interbody fusion and ACR (LLIF-ACR) between 2010 and 2015 at the authors' institution. Patients who had a PSO in the setting of a preexisting fusion that spanned more than 4 levels were excluded. Demographic characteristics, spinopelvic parameters, EBL, operative time, and LOS were analyzed and compared between patients treated with PSO and those treated with LLIF-ACR.

RESULTS The PSO group included 14 patients and the LLIF-ACR group included 13 patients. The mean follow-up was 13 months in the LLIF-ACR group and 26 months in the PSO group. The mean EBL was significantly lower in the LLIF-ACR group, measuring approximately 50% of the mean EBL in the PSO group (1466 vs 2910 ml, $p < 0.01$). Total LL correction was equivalent between the 2 groups (35° in the PSO group, 31° in the LLIF-ACR group, $p > 0.05$), as was the preoperative PI-LL mismatch (33° in each group, $p > 0.05$) and the postoperative PI-LL mismatch ($< 1^\circ$ in each group, $p = 0.05$). The fusion rate as assessed by the need for reoperation due to pseudarthrosis was lower in the LLIF-ACR group but not significantly so (3 revisions in the PSO group due to pseudarthrosis vs 0 in the LLIF-ACR group, $p > 0.5$). The total operative time and LOS were not significantly different in the 2 groups.

CONCLUSIONS This is the first direct comparison of the LLIF-ACR technique with the PSO in adult spinal deformity correction. The study demonstrates that the LLIF-ACR provides equivalent deformity correction with significantly reduced blood loss in patients with a previously unfused spine compared with the PSO. This technique provides a powerful means to avoid PSO in selected patients who require spinal deformity correction.

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KEY WORDS pedicle subtraction osteotomy; adult deformity; minimally invasive surgery; lateral interbody; estimated blood loss

SAGITTAL imbalance is the primary predictor of disability in adult spinal deformity (ASD), and restoration of sagittal alignment and creation of spinopelvic harmony with matched pelvic incidence (PI) and lumbar lordosis (LL) is known to lead to the best long-

term outcomes in ASD patients who undergo surgical correction.^{4,18,33,34,63–65} The traditional surgical approach for lordosis restoration in patients with severe spinopelvic mismatch has involved the use of the 3-column pedicle subtraction osteotomy (PSO).^{9,12,18,19,21,76} While

ABBREVIATIONS ACR = anterior column realignment; ALIF = anterior lumbar interbody fusion; ALL = anterior longitudinal ligament; ASD = adult spinal deformity; BMP = bone morphogenetic protein; EBL = estimated blood loss; LL = lumbar lordosis; LLIF = lateral lumbar interbody fusion; LOS = length of stay; OR = operating room; PI = pelvic incidence; PSO = pedicle subtraction osteotomy; TLIF = transforaminal lumbar interbody fusion.

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successful in restoring spinopelvic harmony, this approach is associated with high surgical and postoperative morbidity.^{3,9,13,26,31,66,72}

The minimally invasive lateral lumbar interbody fusion (LLIF)¹⁷ first popularized by Pimenta in 2001⁵⁴ based on earlier case series^{16,36,42} has been used as an alternative to anterior lumbar interbody fusion and transforaminal lumbar interbody fusion (TLIF).^{17,27,68,81} A number of studies have demonstrated the use of standard LLIF in the correction of mild sagittal- and coronal-plane deformities.^{1,2,7,15,23,24,27,37,48,56,57,62} More advanced techniques involving the use of hyperlordotic cages with anterior longitudinal ligament (ALL) release and anterior column realignment (ACR) via a lateral technique allow for a significant gain in LL with the added benefit of coronal balance restoration and indirect neuroforaminal decompression at multiple levels in a single procedure.^{11,14,41,46,47,52,71,75}

Here we compare our series of patients undergoing PSO or multiple-level LLIF with ACR for the correction of ASD and examine intraoperative estimated blood loss (EBL), operative time, length of stay (LOS), and change in spinopelvic parameters as well as perioperative and postoperative complications.

Methods

This study was approved by the institutional review board of Virginia Mason Medical Center. All patients were treated at Virginia Mason Hospital. We performed a retrospective chart review of all ASD correction cases involving a lumbar PSO and/or LLIF-ACR between 2010 and 2015 that qualified for inclusion based on the following criteria. Inclusion criteria were 1) a surgical procedure including either the use of a PSO or the use of hyperlordotic (20° or 30°) laterally placed interbody cages (NuVasive); and 2) standing lateral preoperative and postoperative films that included the lumbar spine and femoral heads. Patients who had a PSO in the setting of a preexisting lumbar fusion that spanned more than 4 levels were excluded, as were patients who had a PSO that also included the placement of hyperlordotic lateral implants (any graft with angulation > 15°). Patients were excluded if they had received any antifibrinolytics preoperatively or intraoperatively, which became a part of our systematic operative protocol in mid-2015, in order to prevent confounding of the data between patients who had or had not received antifibrinolytics. Demographic information, spinopelvic parameters (LL and PI), level of graft placement, angulation of each LLIF graft, intraoperative EBL, operative time, and LOS were gathered from this chart analysis. Full spinopelvic parameters (e.g., sagittal vertical axis [SVA] and T1 spinopelvic angle) were not gathered for these patients as some earlier patients who underwent surgery before 2012 did not have reliable full-length scoliosis radiographs and our focus in this study was on correction of LL primarily. For staged procedures, intraoperative EBL and operating room (OR) time were combined to yield the sum that covered the entire operative intervention. All images were loaded into Surgimap software (Nemaris, Inc.) for measurement. A total of 27 patients who met the criteria for inclusion in the study were identified. The patients were separated into

TABLE 1. Summary of demographic and preoperative clinical characteristics

Characteristic	Group		p Value
	PSO (n = 14)	LLIF-ACR (n = 13)	
Male, n (%)	7 (50.0)	7 (53.85)	>0.999
Age in yrs			0.207
Median	65.9	62.3	
IQR	62.8–68.8	58.9–68.1	
BMI in kg/m ²			0.207
Median	26.6	30.9	
IQR	21.8–33.2	27.1–31.9	
Preop LL (°)			0.63
Mean	20.2	23.0	
Range	1–53	–16 to 40	
Preop PI (°)			0.41
Mean	52.6	26.1	
Range	36–81	45–74	
Preop PI-LL (°)			0.90
Mean	32.4	33.1	
Range	12–55	16–77	

BMI = body mass index; IQR = interquartile range.

2 groups (the PSO group and the LLIF-ACR group) for data analysis depending on the primary means of lumbar lordosis correction. Summary statistics were generated for all demographic and operative parameters and compared between the 2 groups using 2-tailed t-tests (see Tables 1 and 2); $p < 0.05$ was considered statistically significant.

Results

The PSO group consisted of 14 patients (mean age 65.4 years, range 54–78 years, SD 6.3 years) who had a PSO and posterior fusion. Table 3 summarizes the operative characteristics of this group, including fixation and PSO levels. The total procedure was a single-stage operation in 3 (21%) of 14 patients while the majority had a staged procedure with pedicle screw instrumentation placement on one day followed by the PSO and correction 2–3 days later (11 patients, 79%). L5–S1 interbody fusion via TLIF was completed as part of the posterior procedure in 13/14 patients (93%) with 1 patient having an L5–S1 anterior lumbar interbody fusion (ALIF) (7%). Interbody fusion above and below the PSO location was completed via either posterior TLIF and/or via a lateral approach in 6/14 patients. In the patients who had a lateral interbody fusion at the levels above and below the PSO, the graft angulation was either 0° or 10°. Bone morphogenetic protein (BMP) was used in 12 of these 14 patients. Our general practice during this time period was to use BMP in any TLIF cages, typically one-half of a sponge, and to lay the remaining 3.5 sponges of a medium kit (Medtronic) along the posterolateral arthrodesed segments of the lumbar spine. BMP was not used in patients with a prior history of any cancer or a strong family history of cancer. Figure 1 provides an example of a patient with PSO correction (PSO Case 1).

The LLIF-ACR group consisted of 13 patients (mean

TABLE 2. Operative parameters

Parameter	Group		p Value
	PSO (n = 14)	LLIF-ACR (n = 13)	
LOS in days (from 1st stage)			0.750
Mean	8.9	9.5	
Range	7–12	7–10	
LOS in days (from PSO or XLH portion)			0.099
Mean	7	7	
Range	5–7	7–10	
EBL in ml (for PSO or XLH stage)			0.003
Mean	2500	800	
Range	1100–2800	250–1200	
EBL in ml (for all stages)			0.007
Mean	2910	1466	
Range	1800–3600	1000–1800	
Postop complications, n (%)	8 (57.1)	2 (15.4)	0.046
Reoperations w/in 30 days, n (%)	2 (14.3)	0 (0.0)	0.481
Reoperation beyond 30 days			0.596
No. of operations	4	2	
No. of pts involved (%)	3 (21.4)	1 (7.7)	
Reoperation for pseudarthrosis			
No. of operations	3	0	
No. of pts involved (%)	2 (14.3)	0 (0.0)	0.522
Length of follow-up in mos			
Median	25.5	13.2	0.091
IQR	5.0–73.6	4.3–25.3	
No. of cases w/ BMP utilized (%)	12 (86)	11 (85)	0.939

Pts = patients; XLH = CoRoent XL-H, NuVasive.

age 62.5 years, range 52–73 years, SD 6.3 years) who had a lateral approach initially with hyperlordotic interbody graft placement. Table 4 summarizes the demographic and operative characteristics of this group, including fixation and interbody levels. This lateral plus posterior procedure was completed in a single day (in 5 patients, 38%) or as a staged procedure with lateral graft placement on 1 day followed by the placement of posterior instrumentation 2–3 days later (8 patients, 62%). Since the lateral approach is unable to supply interbody fusion at L5–S1, all of these patients had an L5–S1 TLIF graft placed as part of the posterior procedure. Most patients had multiple hyperlordotic grafts placed, with total angulation of grafts implanted ranging from 30° to 90°. BMP was used in 11 of 13 patients, in the fashion described above with similar exclusions. Figure 2 provides an example of an LLIF-ACR case with interbody placement at L2–3, L3–4, and L4–5 (LLIF-ACR Case 8).

The mean value for total intraoperative EBL was significantly lower in the LLIF-ACR group, approximately 50% mean EBL in the PSO group (1466 vs 2910 ml, $p < 0.01$). The total correction in LL was equivalent between the 2 groups (35° in the PSO group, 31° in the LLIF-ACR group, $p > 0.05$). The mean preoperative PI-LL mismatch was equivalent at 33° in each group ($p > 0.05$; range 12°–55° in the PSO group and 16°–77° in the LLIF-ACR group). The postoperative PI-LL mismatch was likewise equivalent in the 2 groups ($p > 0.05$) with an average of –0.6° in the PSO group (range –12° to 24°, SD 10.7°) and 0.8° in the LLIF-ACR group (range –11° to 22°, SD 10.22°). The total operative time and LOS did not differ significantly between the 2 groups (mean 9 hours 43 minutes vs 9 hours 22 minutes, $p > 0.05$; and 8.85 days vs 9.5 days, $p > 0.05$). The total number of levels fused did not differ significantly between groups (a mean of 9.3 levels in the PSO group

TABLE 3. Clinical summary: PSO group

Case No.	Age (yrs), Sex	Fixation Levels	Implanted Grafts (°)				PSO Level	Preop		Postop		LL Corr
			L1–2	L2–3	L3–4	L4–5		LL	PI-LL	LL	PI-LL	
1	65, M	T10–pelvis					L-3	21	23	56	–12	35
2	68, M	T10–pelvis	10	10	10	10	L-2	19	24	58	–12	39
3	71, F	T4–pelvis		0	0		L-3	30	38	67	5	37
4	78, F	T10–pelvis			0		L-3	1	35	40	–6	39
5	55, F	T10–pelvis				10	L-5	17	42	61	6	44
6	67, F	T9–pelvis		10	10	10	L-3	53	28	77	4	24
7	69, F	T10–pelvis		10	10	10	L-3	16	33	62	–11	46
8	70, F	T10–pelvis		0	0	0	L-3	28	28	48	8	20
9	63, M	T10–pelvis					L-3	3	48	42	9	39
10	67, M	L2–pelvis					L-4	32	19	54	–2	22
11	64, F	T10–pelvis					L-3	28	12	51	–11	23
12	61, M	T10–pelvis					L-3	1	55	32	24	31
13	63, M	T10–pelvis					L-3	2	46	47	1	45
14	54, M	T10–pelvis		10	10		L-3	32	22	60	–11	28

Corr = correction.

Clinical summary of 14 cases involving patients with ASD treated using a PSO at L-2, L-3, L-4, or L-5 along with, in some cases, lateral interbody fusion with 0° or 10° grafts; 13 of 14 patients underwent an L5–S1 TLIF in addition to the above-mentioned grafts, with 1 patient having L5–S1 ALIF.

FIG. 1. Case 1 from the PSO Group. Preoperative (**A and B**) and postoperative (**C and D**) standing scoliosis radiographs of a patient who underwent L3 PSO with T10–pelvis posterior fixation with L4–5, L5–S1 TLIF for flat-back deformity. The preoperative coronal radiograph (**A**) demonstrates a 30° thoracolumbar curve with a 35° lumbosacral curve, while the preoperative sagittal radiograph (**B**) demonstrates an LL of 3° and a PI of 41°, for a mismatch of 38°. The postoperative coronal radiograph (**C**) demonstrates that both curves have been reduced to 16°, and the postoperative sagittal radiograph (**D**) demonstrates appropriate PI–LL matching. Cobb = Cobb angle; L Lordo = lumbar lordosis; PT = pelvic tilt.

vs 11 levels in the LLIF-ACR group, $p = 0.22$). Within the LLIF-ACR group, the most common total cage angle of inserted lateral grafts was 50° (range 30°–90°, average 61°), and the average number of lateral grafts inserted was 3 (range 1–4). The lordosis correction reported as a percentage of total implanted cage angle ranged from 12% to 164%, with an average of 54%, suggesting that in most patients the amount of lordosis gained was approximately half of the inserted cage angle.

Complications were collected as perioperative (within

30 days of surgery) and postoperative beyond 30 days after surgery (Tables 5 and 6). Eight patients in the PSO group had a perioperative complication, with 2 of these complications likely representing direct surgical issues, including a wound infection requiring washout in one patient and postoperative quadriceps weakness in another patient, requiring a return to the OR for relaxation of the correction at the PSO site. This patient subsequently saw an improvement back to normal function over the next 4 months. Two patients in the LLIF-ACR group had perioperative complications, although there were no direct approach-related injuries, such as iliac injury, lumbar plexus injury, or bowel perforation. Three of 14 patients in the PSO group required reoperation beyond 30 days, with 2 patients having a fracture at the PSO site requiring revision and 1 patient undergoing removal of a painful iliac bolt. One of the patients who had a rod fracture patients subsequently had a second rod fracture requiring revision. In the LLIF-ACR group, 1 patient required reoperation due to proximal junctional failure shortly after the index procedure and subsequently required an additional procedure for revision of a nonhealing wound. There were no rod fractures or pseudarthroses in the LLIF-ACR group, although the overall duration of follow-up for this group was lower, which constitutes a potential source of bias in our results.

Discussion

The PSO remains a mainstay of fixed sagittal balance correction for deformity surgeons, especially when approaching patients with a flat-back⁷⁹ or kyphotic deformity.^{9,12} There are numerous disadvantages associated with the PSO, however, including increases in operative time and blood loss, as well as an increase in risk of neurological dysfunction, morbidity, and mortality.^{9,20} Although institutional protocols involving staged surgery,⁵⁹ a dual deformity surgeon approach,^{3,67} hybrid techniques encompassing open and percutaneous pedicle screw placement,^{4,25,40,49–51} the use of preoperative medications such as tranexamic acid (TXA) to reduce blood loss,³² and intraoperative neuromonitoring have reduced the morbidity of the PSO, perioperative complication rates remain high. Less invasive PSO techniques have been developed, but they have also not substantially reduced these risks.²²

Moreover, the PSO technique does not restore LL in a harmonious manner, instead relying on achieving the majority of the deformity correction across a single segment of the spine.^{10,13} The significant focal curvature may increase the risk of neurological injury due to dural bucking and the risk of hardware failure due to rod fracture and may be associated with higher rates of proximal junctional kyphosis due to nonharmonious realignment.^{10,13,21,30,38,44,45,55,61,80} Techniques utilizing bridging rods or novel rod constructs have decreased but not eliminated this risk.^{10,38,44,45,55,61}

The anterior column resection (ACR) technique was first described in 2011 as a means of increasing the lordosis that could be obtained by lateral interbody grafts, more similar in correction to an anteriorly placed graft than the conventional lateral grafts that had been used up until that point in time.^{14,58,75} Parallel and mildly lordotic

TABLE 4. Clinical summary: LLIF-ACR group

Case No.	Age (yrs), Sex	Fixation Levels	Implanted Grafts (°)				Total	Preop		Postop		LL Corr
			L1–2	L2–3	L3–4	L4–5		LL	PI-LL	LL	PI-LL	
1	63, F	T10–pelvis	30	20	30	10	90	24	37	55	4	31
2	73, M	L2–5		20	30	10	60	32	16	41	5	9
3	52, M	T10–pelvis		20	30		50	33	24	61	–4	28
4	62, M	T9–pelvis		30	20	30	80	14	31	48	–9	34
5	68, F	T3–pelvis		20	30	30	80	30	29	61	6	21
6	54, F	T4–pelvis	30				30	20	26	51	–8	31
7	58, M	L1–5		20	30		50	–16	77	66	–7	82
8	70, M	T4–pelvis		20	20	30	70	23	29	56	–7	33
9	59, F	T4–pelvis	20			30	60	11	34	55	–11	44
10	60, F	T4–pelvis	15	20	30		65	22	52	57	14	35
11	60, F	T2–pelvis		15	15	30	60	32	25	47	10	15
12	71, M	T10–pelvis		15	20	20	55	26	20	46	–5	20
13	63, M	T10–pelvis		20	20	15	55	38	30	45	22	7

Clinical summary of 13 cases involving patients with ASD treated using hyperlordotic lateral interbody grafts. All 20° and 30° grafts were performed with an ACR technique with ALL release; 10° and 15° grafts were placed without ALL release. All patients underwent an L5–S1 TLIF in addition to the above-mentioned grafts.

(5°–10°) lateral grafts have been used to treat scoliotic curvatures with reasonable results, but these corrections are typically much more impressive in the coronal plane than the sagittal plane, suggesting that lateral techniques may apply primarily to treatment of patients with minimal or no sagittal imbalance.^{27–29} Typical lordosis restoration with these standard lateral grafts without sectioning of the ALL ranges from 4°–9° at each level, allowing for modest correction of a sagittal plane deformity.^{1,2,23,35,53,57,62,69,74,77,78}

With the advent of lateral grafts with 20°–30° of angulation and sectioning of the ALL,²⁹ however, much more profound focal and regional curvature can be obtained, typically averaging about 50% of the inserted graft angle (10°–17°).^{11,14,41,71,73,75} Case series have demonstrated that the procedure can be performed safely, with blood loss ranging from 40 to 150 ml and with a complication rate similar to that observed with standard lateral transposas approaches.^{11,29,58} This technique does have some limitations, however, as it generally cannot be used in cases of previous posterior fusion without some form of release, and almost never in cases of a previous interbody fusion unless a pseudarthrosis is present. Its primary use, therefore, is in patients with no prior fusion or a limited-segment lumbar fusion who are presenting with spinopelvic mismatch.

Our current study primarily attempts to compare the intraoperative and pre- and postoperative radiographic parameters of patients undergoing correction of a spinopelvic mismatch with either a PSO or with the use of lateral ACR with hyperlordotic cage placement (LLIF-ACR). The average spinopelvic mismatch between LL and PI was greater than 30° in each group preoperatively. As noted in *Methods*, we excluded patients from the PSO group who had an extensive preexisting fusion; these patients would not be candidates for LLIF-ACR and would generally require a PSO for correction. This strict inclusion criterion limits the overall number of patients in the study, but hopefully provides a greater degree of clinical equipoise

between the 2 groups, as we are comparing parameters between patients who theoretically could have had either procedure as a means of sagittal plane correction.

We find that PSO and multilevel LLIF-ACR generate equivalent lordosis and restoration of spinopelvic matching. Both groups had 30°–35° of lumbar lordosis correction. However, patients undergoing LLIF-ACR had significantly less operative blood loss without any significant increase in perioperative/postoperative complications or need for reoperation. This study represents the first direct comparison between PSO and LLIF-ACR, as previous case series have typically described the results of LLIF-ACR and compared results to literature reports of outcomes after PSO, and it demonstrates that LLIF-ACR is able to provide the correction needed even for patients with profound spinopelvic mismatch. We did not find any substantial difference in operative time between the 2 groups, likely because the LLIF-ACR portion of the procedure does necessitate a separate positioning, opening, and closing, as compared with a PSO, in which instrumentation placement and the osteotomy can be performed through a single incision. In addition, we did not see any difference in total LOS. With the increase in the use of preoperative antifibrinolytics, the high EBL reported in our PSO group and by others describing PSOs may be reduced, making this difference between the 2 groups less clinically significant.

One notable limitation of this study is the lack of long-term follow-up for all patients beyond 1 year. Another limitation is the lack of information regarding functional outcomes.⁷⁰ While we do currently gather these data clinically, some patients within the PSO group did not have these data available for review, so they are not reported here. Likewise, there is a lack of data regarding minor adverse outcomes, although we can report that no patients in either group experienced a major complication of bowel injury,⁸ hardware failure within 30 days, or death. There have been 2 recent studies suggesting that neurological

FIG. 2. Case 8 from the LLIF-ACR Group. Preoperative (**A** and **B**) and postoperative (**C** and **D**) standing scoliosis radiographs of a patient who underwent L2–3, L3–4, and L4–5 LLIF-ACR with T10–pelvis posterior fixation for flat-back deformity. The preoperative coronal radiograph (**A**) demonstrates a 48° thoracolumbar curve with a 29° fractional lumbosacral curve, while the preoperative sagittal radiograph (**B**) demonstrates an LL of 11° and a PI of 56°, for a mismatch of 45°. The postoperative coronal radiograph (**C**) demonstrates that the curves have been reduced to 25° and 17° respectively, and the postoperative sagittal radiograph (**D**) demonstrates appropriate PI-LL matching.

complications with LLIF-ACR are less than with PSO,^{52,60} and this is supported by our data from the present study, although further studies will be needed to substantiate this assertion.

Another clinical limitation is the current general challenge of creating a detailed preoperative plan for ACR correction. It is important to note that even with the PSO, exact correction may be hard to determine preoperatively, and we have recently demonstrated that correction changes from intraoperative films to postoperative films by 13°.⁴³ Although surgical planning software^{6,39} can make preop-

TABLE 5. Perioperative complications

Group & Case No.	Complication	Reoperation Required?	Reoperation (procedure)
PSO Group			
Case 3	Wound infection	Yes	Washout
Case 4	Trochanteric bursitis	No	
Case 7	UTI	No	
Case 8	Delirium, ileus	No	
Case 9	Quadriceps weakness	Yes	Slight relaxation of correction at PSO
Case 10	Fever	No	
Case 11	Neuritis	No	
Case 14	Delirium, ileus	No	
LLIF-ACR Group			
Case 10	Costochondritis	No	
Case 12	Fever, DVT	No	

UTI = urinary tract infection.

erative planning more exact, it cannot fully account for the intraoperative state. Our experience with LLIF-ACR presented here resembles that described by other groups, in that the degree of lordosis created at a particular level can vary substantially independent of the graft angulation inserted. We reported on the increase in focal lordosis as a percentage of the graft angulation inserted, such that a patient who had an increase of 15° in segmental lordosis after insertion of a 30° lordotic graft would have a 50% correction. Our average lordosis gain was 54% of total cage angle, but the results were variable. In patients with a focal kyphosis, we generally observed a correction greater than 50%, in one instance up to 164%, while in other cases, lordosis gain was more modest, typically reduced by subsidence during cage insertion.⁴⁷ In cases of intraoperative graft subsidence, we typically adjusted the cage angle that was planned for adjacent levels or considered adding another level of interbody graft. This intraoperative modification of the surgical plan has allowed us to achieve the desired correction in almost all cases. Continued development of preoperative planning software to account for these intraoperative factors will improve the reliability of this technique for deformity correction.

We do not envision that the LLIF-ACR will completely replace the PSO, but rather that it can serve as a useful alternative with less risk for patients with unfused disc levels. Current ACR techniques may also allow for the future development of minimally invasive scoliosis correction techniques even in patients with sagittal plane imbalance who remain some of the more difficult patients to treat via minimally invasive approaches.

Conclusions

This is the first single-institution direct comparison of the LLIF-ACR technique with the PSO in ASD correction. We have demonstrated that the LLIF-ACR provides

TABLE 6. Reoperation at more than 30 days after the index procedure

Group & Case No.	Reason for Reoperation	Reoperation	Time After Index Op (mos)
PSO Group			
Case 11	Symptomatic left iliac bolt	Iliac bolt removal	10.8
Case 12	Rod fracture at L4–5	Revision fusion at L4–5	4.8
Case 13	Rod fracture at PSO site	Revision fusion at PSO	19.3
Case 13	Unilateral rod fracture L1–2	Lateral interbody graft T12–L1 & L1–2	63.3
LLIF-ACR Group			
Case 2	Proximal junctional failure	Extension of fusion up to T-10 w/ pelvic fixation	1.5
Case 2	Nonhealing wound	Revision of wound	3

equivalent deformity correction compared with the PSO in patients with significant spinopelvic mismatch and a previously unfused spine, with significantly reduced blood loss. This technique provides a powerful means to avoid the PSO in selected patients who require spinal deformity correction and may make spinal deformity surgery accessible to a broader range of patients. Future studies of LLIF-ACR will be necessary to elucidate the long-term outcomes of this technique compared with the PSO.

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Disclosures

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Author Contributions

Conception and design: Leveque, Sethi. Acquisition of data: Leveque. Analysis and interpretation of data: Leveque, Yanamadala, Buchlak. Drafting the article: Leveque, Yanamadala, Sethi. Critically revising the article: Yanamadala, Buchlak, Sethi. Reviewed submitted version of manuscript: Yanamadala, Buchlak, Sethi. Approved the final version of the manuscript on behalf of all authors: Leveque. Administrative/technical/material support: Leveque, Sethi.

Supplemental Information

Previous Presentations

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