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Clinical Case Studies

# Short-segment minimally disruptive anterior column release for focal sagittal deformity correction of the thoracolumbar spine ☆

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ABSTRACT

*Background:* Sagittal malalignment is associated with poor quality of life. Correction of lumbar lordosis through anterior column release (ACR) has been shown to improve overall sagittal alignment, however typically in combination with long posterior constructs and associated morbidity. The technical feasibility and radiographic outcomes of short-segment anterior or lateral minimally invasive surgery (MIS) ACR techniques in moderate to severe lumbar sagittal deformity were evaluated.

*Methods:* Consecutive patients treated with short-segment MIS ACR techniques for moderate to severe lumbar sagittal deformity correction were retrospectively analyzed from a prospectively collected database. Clinical outcomes included perioperative measures of invasiveness, including operative time, blood loss, complications, and average length of stay. Radiographic outcomes included measurement of preoperative, immediate postoperative, and long-term follow-up radiographic parameters including coronal Cobb angle, lumbar lordosis (LL), pelvic incidence (PI), PI-LL mismatch, pelvic tilt (PT), T1 pelvic angle (TPA), T1 spino-pelvic inclination (T1SPI), proximal junctional angle (PJA), and sagittal vertical axis (SVA).

*Results:* The cohort included 34 patients (mean age 63) who were treated at an average 2.5 interbody levels (range 1-4) through a lateral or anterior approach (LLIF or ALIF). Of 89 total interbody levels treated, 63 (71%) were ACR levels. Posterior fixation was across an average of 3.2 levels (range 1-5). Mean total operative time and blood loss were 362 minutes and 621 mL. Surgical complications occurred in 2 (5.9%). Average hospital stay was 5.5 days (including staging). At last follow-up (average 25.4 months; range 0.5-7 years), all patients (100%) demonstrated successful achievement of one or more alignment goal, with significant improvements in coronal Cobb, LL, PI-LL mismatch, PT, and TPA. No patient was revised for PJK.

*Conclusions:* These data show that short-segment MIS ACR correction of moderate to severe lumbar sagittal deformity is feasible and effective at achieving overall alignment goals with low procedural morbidity and risk of proximal junctional issues.

Informed Consent Statement:

This study was performed under Institutional Review Board oversight, with waived informed consent for retrospective review of data from a prospectively collected quality improvement registry.

## Introduction

Since the introduction of minimally invasive lateral lumbar interbody fusion (MIS LLIF) in the early new millennium [1], indications have expanded to include more complex spinal deformity surgery. Still, in the deformity community, there remained concern that sagittal alignment may be difficult to achieve with MIS surgery [2,3]. However, the reported reduced morbidity and complication profile [4-8] coupled with high fusion rates [9,10] rendered LLIF a valuable procedure.

In an attempt to avoid major posterior osteotomies, lateral surgeons have expanded the use of LLIF to include anterior column release (ACR)

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– intentional release/resection of the anterior longitudinal ligament (ALL) in conjunction with the use of hyperlordotic interbody spacers to better address sagittal alignment correction. Reports of such techniques have mostly been used in the context of long instrumented fusions, with relatively short follow-up [11-14].

While there are several small and mostly short-term follow-up series, there is no long-term data reflecting the occurrence of reoperations and adjacent segment disease. The current case series was compiled to assess the efficacy of short-segment anterior column release performed through a lateral transpsoas (LLIF-ACR) or an anterior approach (ALIF-ACR) and the use of hyperlordotic interbody fusion devices in the treatment of focal lumbar sagittal deformity, highlighting the effect of minimally invasive techniques and preservation of fusion levels on mid- to long-term alignment correction and incidence of proximal junctional complications.

## Materials and methods

### *Patient cohort*

Consecutive patients treated at one center by a single surgeon who met the following inclusion criteria were included for retrospective extraction of prospectively collected chart data: primary diagnosis of sagittal malalignment deformity with or without scoliosis who underwent MIS-LLIF and/or ALIF with anterior column release (ACR) through resection of the anterior longitudinal ligament (ALL) and insertion of either a 20 or 30 degree hyperlordotic interbody device at one or more lumbar or lumbosacral levels, existence of preoperative and postoperative long-cassette standing radiographs, and a minimum of 6 months postoperative follow-up. Sagittal malalignment was defined by one or more of the following well-established criteria: PI-LL>10°, PT>25°, SVA>50 mm, TPA>14°, and/or T1SPi>0° [15-17].

### *Operative details*

One important objective of the surgery was to reconcile spinopelvic parameters without having to cross the thoracolumbar junction. As such, the operative strategy was to reduce the number of fused levels with the possible advantage of reducing perioperative morbidity while still achieving spinal realignment objectives. All degenerative levels and those within the extent of either coronal or sagittal deformity were included in the fusion construct. Choice of UIV was with consideration for avoiding the apex of the curve and identifying the proximal stable, neutral, horizontal level. Patients with osteoporosis, significant thoracolumbar kyphosis, or rotary scoliosis in the upper lumbar or thoracolumbar segments were treated more extensively and therefore excluded from this cohort.

Direct decompression was performed when required, based on bony canal stenosis, stenosis with maintained disc height, locked facets, extruded discs and if radicular neurologic symptoms were present at rest. All decompressions were performed minimally invasively using a split-blade retractor. Except in two cases, one a revision of pre-existing spinal instrumentation, patients underwent percutaneous pedicle screw instrumentation at all fused levels and MIS facet releases, as classified by Schwab et al. [18] as needed either during the same anesthetic or as a staged procedure. The patient with pre-existing instrumentation underwent a limited exposure to remove the hardware and the remaining levels were instrumented with percutaneous pedicle screws.

All instrumented levels included interbody cage support, whether from a pre-existing fusion or from the index procedure. Eleven patients (32.4%) underwent staged procedures where the posterior component was performed 2-4 days following the anterior portion. The graft material used in all cases was autologous bone marrow aspirate concentrate and synthetic bone extender.

**Table 1**
Distribution of interbody fusion (IBF) levels and those in which anterior column release (ACR) was performed.

| | # IBF Levels | # ACR Levels | # Patients |
|---|---|---|---|
| LLIF | 70 | 48 | 29 |
| ALIF | 15 | 15 | 8 |
| P/TLIF | 4 | 0 | 4 |

LLIF = lateral lumbar interbody fusion; ALIF = anterior lumbar interbody fusion; P/TLIF = posterior / transforaminal lumbar interbody fusion; IBF = interbody fusion; ACR = anterior column release.

### *Radiographic assessment*

All patients prospectively underwent full-length radiographic imaging at the preoperative and 6-week, 3-month, 6-month, 12-month, and subsequent annual postoperative visits. The following spinopelvic parameters were measured using SurgiMap software (Nemaris; New York, NY): pelvic incidence (PI), pelvic tilt (PT), lumbar lordosis (LL), L4-S1 lordosis (L4-S1 LL), coronal Cobb (CC), T1 pelvic angle (TPA), sagittal vertical axis (SVA), T1 spinopelvic inclination (T1SPI), proximal junction angle (PJA) above the upper instrumented vertebra (UIV+1 and UIV+2). The following criteria were defined as successful alignment: PI-LL<10°, PT<25°, TPA<20°, T1SPi<0°, and/or SVA<50 mm [15-17]. Additionally, proximal junctional kyphosis (PJK) was defined as a PJA of greater than 10° *and* a pre- to postoperative change of greater than 10° [19].

### *Statistical analysis*

Statistical analysis included descriptive statistics of each measured parameter at each time point and paired comparisons (via matched pair t-test) across time points to quantify corrective effect. Measures of covariance were tested to determine the influence of preoperative patient factors and surgical variables on the measured outcomes. All analyses were performed using JMP statistical software (SAS Institute; Cary, NC) with a significance level set at 0.05.

## Results

Thirty-four (34) patients met the inclusion criteria. The majority (62%) were male and average age at the time of surgery was 63 years (range: 47-83). Comorbidities included smoking (7.1%) and diabetes mellitus (17.9%). In addition to coronal and sagittal deformity, 24 (70.6%) had stenosis. Sixteen (16, 47.1%) had had prior decompression surgery, 6 of those at levels of current ACR procedure. Eleven (11, 32.4%) had previous instrumented lumbar fusion surgery, mostly at levels adjacent to the current ACR procedures, except in one case of posterior-only fusion being revised to multi-level interbody fusion.

Interbody fusions (IBF) were performed in a total of 89 levels (Table 1): 70 LLIF levels in 29 patients, 15 ALIF levels in 8 patients, and 4 P/TLIF levels in 4 patients. All P/TLIF levels were performed at L5-S1, and none included ALL release/ACR. All ALIF levels included ALL release/ACR and included L5-S1 in all 8 patients, L4-5 in 6, and L3-4 in 1. LLIF was performed at 70 levels, of which 48 included ALL release/ACR, most commonly performed at L3-4 (22, 46%), then equally at L4-5 and L2-3 (12, 25%), and infrequently at L1-2 (2, 4%).

IBF procedures were supplemented posteriorly with percutaneous pedicle fixation, including iliac fixation in 9 (26.5%); none crossed the thoracolumbar junction. The upper instrumented vertebra (UIV) was most commonly L2 (18, 52.9%), then L3 (8, 23.5%), then L1 (6, 17.6%), then L4 (2, 5.9%). A direct decompression was included in 11 (32.4%). Facet releases were performed in 10 (29.4%) patients (6 Grade 1; 4 Grade II [18]). Posterior procedures were staged in 11 (32.4%). Average follow-up was 25.4 months (range: 5.4 – 85.2 months): 3 (9%) were

seen last at their nominal 6-month, 12 (35%) at their 12-month, and 19 (56%) at their 24-month or later postoperative follow-up visit.

In non-staged procedures, total combined (anterior and posterior procedures) operative time averaged 272 minutes and total combined blood loss averaged 376 mL. Staged surgeries averaged 198 minutes for anterior and 255 minutes for posterior procedures, and 359 mL blood loss for anterior and 507 cc for posterior procedures. Following staged or non-staged surgery, mean preoperative to postoperative hemoglobin and hematocrit drop was 14.2 g to 10.8 g and 42.3 to 32.0, respectively. Six (6, 17.6%) were transfused, 2 due to intraoperative vascular complications that led to elevated blood loss (maximum intraoperative blood loss was 1.6 L). Average hospital stay was 5.5 days including staged procedures, the majority (76.5%) discharged to home.

### *Complications*

Surgical complications occurred in 2 (5.9%) patients. Another 8 (23.5%) patients experienced medical and/or anesthesia-related complications. Surgical complications included one case where venous bleeding was encountered after the ALL retractor was removed in a right-lateral approach at the L4-5 level. Bleeding was controlled intraoperatively with hemostatic agents, and immediate postoperative venography showed a distal inferior vena cava injury but no active bleeding. The patient was managed with 3 months of anticoagulants and completion of the procedure was achieved with a second stage-surgery. The second surgical complication was in a patient who developed a transient postoperative neuropraxia ipsilateral to a right-sided 3-level LLIF ACR from L2-L5. The patient also underwent Grade 2 posterior osteotomies at the same levels and open pedicle fixation.

Medical complications included 3 cardiopulmonary events, 2 acute renal failures, cholecystitis, urinary retention, and ileus.

### *Reoperations*

Two patients required reoperation during the same admission: one patient with cholecystitis returned to the OR for cholecystectomy; another patient who underwent L2-4 LLIF-ACR with L1-5 MIS fixation returned to the OR for unresolved radiculopathy symptoms requiring L1-2 direct decompression. An additional two patients underwent additional surgery more than one year later: one patient who underwent primary L2-5 fusion required L5-S1 microdiscectomy 15 months post-primary surgery; another patient who underwent primary 4-level L2-S1 fusion later (after determination of solid fusion) required unilateral removal of painful hardware 32 months postoperative.

No patient was reoperated for symptomatic pseudarthrosis; nor was any patient identified as having asymptomatic pseudarthrosis based on hardware loosening, hardware breakage, or cage subsidence.

### *Radiographic Results*

Representative case examples are shown in Figures 1 and 2. Average changes in radiographic parameters from pre- to postoperative are shown in Table 2. Notably, all spinopelvic parameters improved, most statistically significantly, including overall lumbar lordosis (LL), L4-S1 LL, and PI-LL mismatch. A further breakdown of segmental correction is shown in Table 3, demonstrating that ACR (regardless of approach) significantly improved segmental lordosis, whereas non-ACR levels did not.

At last follow-up visit, all patients (100%) demonstrated successful achievement of one or more alignment goal. The distribution of goals achieved is shown in Table 4. Achievement of these goals was not dependent on sex, age, severity of preoperative deformity (classified as either moderate or severe based on SVA, PT, and PI-LL mismatch), number of instrumented levels, use or level of posterior release, form of fixation (open vs. percutaneous), level of UIV, or number or location of ACR levels ($p>0.05$).

Since all surgeries were intended to minimize levels of fusion and avoid crossing the thoracolumbar junction, the uppermost instrumented vertebra (UIV) was always lumbar: 17.6% at L1, 52.9% at L2, 23.5% at L3, and 5.9% at L4. At last follow-up, 3 patients (9%) had a UIV+1 angle greater than 10° and a change from baseline of greater than 10°. In this group, the UIV+1 PJA averaged 19.5° and the change from pre- to postoperative averaged 18.1°. When using the same radiographic PJK definition but with UIV+2, an additional 2 patients (total of 5 or 15%) met the definition. In this group, the UIV+2 PJA averaged 21.9° and the change from pre- to postoperative averaged 14.1°.

Helgeson et al. [20] proposed 15° change at UIV+1 as the definition of PJK, which was based on two standard deviations from the mean in their study. Coincidentally, two standard deviations from the mean angle at UIV+1 at preoperative was 15.2° degrees in the current study. Using this definition, the results of the current study would include 2 patients (6%) using UIV+1, or 1 patient (3%) using UIV+2.

The incidence of radiographic PJK was not dependent on sex, age, number of instrumented levels, use or level of posterior release, form of fixation (open vs. percutaneous), level of UIV, or number or location of ACR levels ($p>0.05$). No preoperative spinopelvic parameter was predictive of PJK by either definition. There were no instances of PJF or revision or reoperation for proximal junctional complications at any timepoint.

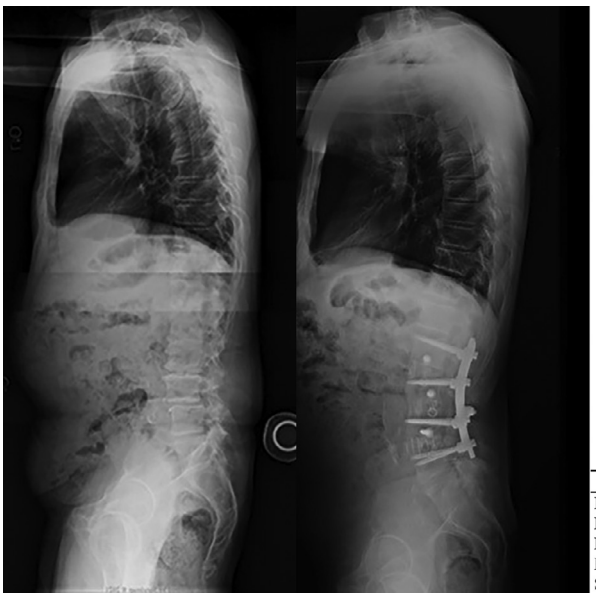
## Discussion

Several published studies have described the use of hyperlordotic cages in conjunction with anterior longitudinal ligament release (ACR) in the correction of sagittal malalignment deformity. One of the earliest experiences with the lateral ACR technique was reported by Akbarnia et al., wherein a cohort of 17 patients showed an average increase in lumbar lordosis by 22° by first-stage ACR, and total average lordosis increase of 29° following second-stage posterior procedures [11]. Berjano et al. described a similar experience with 12 patients where segmental angular correction averaged 24° and average lumbar lordosis was increased by 31° [12]. Both of these studies concluded that correction capability with ACR is similar to what can be achieved through a more invasive pedicle subtraction osteotomy [21]. However, both of these cohorts included Smith-Petersen osteotomies at the level of the ACR and used open posterior instrumentation.

Murray et al. reported on 31 patients and 47 levels with a mix of all MIS (ACR with percutaneous posterior fixation) and hybrid procedures (MIS-ACR with open posterior osteotomies and fixation) [13]. They reported an overall increase in lumbar lordosis of 17.6° and a complication rate of 61%. Turner et al. reported on 34 patients at 5 centers with a minimum 1-year follow up [14]. An average of 7 levels (range 2-16) were fused and ACR was performed at an average of 1.7 levels. Open posterior instrumentation was performed in 76.5 % of cases. They found that the average segmental correction with ACR (14.1°) was over 4 times more than what was achieved with LLIF alone (3.3°), and the addition of posterior osteotomy increased lordosis by another 72.7%.

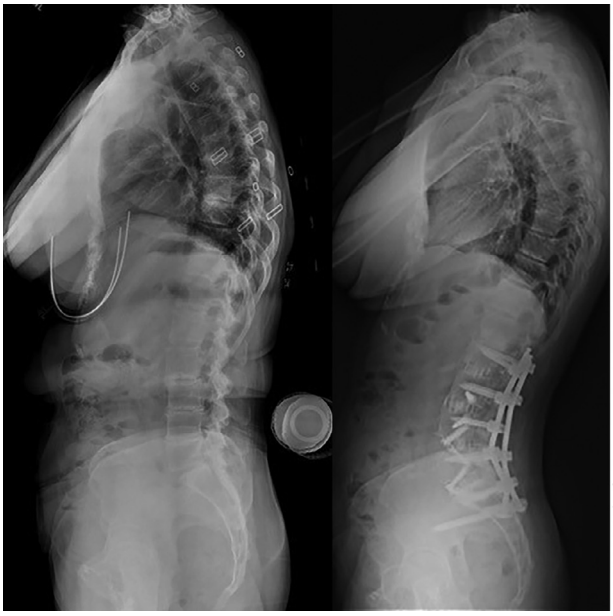
Saigal et al., based on a literature review that included the above-referenced studies [22], made the recommendation of applying ACR in patients with moderate sagittal deformity, or Grade II as classified by the Mummaneni et al. algorithm [23], i.e., when SVA>60 mm but PT<25° and PI-LL<30°, although the authors left room for modification of such MIS deformity algorithms with evolving techniques, experience, and learnings.

The current study cohort included both of what Mummaneni et al. would classify as Grade II and Grade III (SVA>60 mm, PT>25°, and PI-LL>30°) sagittal deformities, or what the current study considers as both moderate and severe sagittal deformities. Mummaneni's classification suggests that Grade II (moderate) deformities can be treated with MIS decompression and interbody fusion at the apex of the curve, while Grade III (severe) deformities should be treated with open surgery, posterior osteotomies, and extension of the fusion into the thoracic spine.



| | Pre-op | Post-op |
|---|---|---|
| LL | -16.8° | -41.8° |
| PI | 51.1° | 51.4° |
| PI-LL | 34.3° | 9.6° |
| PT | 39.3° | 24.2° |
| SVA | 73.6 mm | 56.6 mm |

**Fig. 1.** Preoperative (left) and last (7-yr) postoperative (right) standing lateral radiographs of a 55-year-old male who underwent L2-L5 LLIF ACR with staged grade II osteotomies and open pedicle fixation posteriorly. Short-segment approach in this patient resulted in improved lumbar lordosis (+25.0° overall, and +8.2° across L4-S1) and corrected overall standing alignment. *LL = lumbar lordosis; PI = pelvic incidence; PI-LL = pelvic incidence - lumbar lordosis mismatch; PT = pelvic tilt; SVA = sagittal vertical axis.*



| | Pre-op | Post-op |
|---|---|---|
| LL | -39.8° | -57.8° |
| PI | 63.9° | 63.7° |
| PI-LL | 24.1° | 5.9° |
| PT | 35.6° | 30.6° |
| T1SPI | -5.3° | -11.6° |

**Fig. 2.** Preoperative (left) and last (2-yr) postoperative (right) standing lateral radiographs of a 68-year-old female who underwent L2-S1 anterior column realignment via L2-L4 LLIF ACR and L4-S1 ALIF ACR, with percutaneous posterior fixation L2-Ileum. Short-segment approach in this patient resulted in improved and harmonious lumbar lordosis and corrected overall standing alignment. *LL = lumbar lordosis; PI = pelvic incidence; PI-LL = pelvic incidence - lumbar lordosis mismatch; PT = pelvic tilt; T1SPI = T1 spino-pelvic inclination.*

**Table 2**
Average radiographic parameters at preoperative and immediate and last postoperative visits. Last postoperative visit averages nominally 24 months (range: 6 months – 7 years).

| | Pre-op | Immediate Post-op | Last Post-op | p-value (Pre-Last) |
|---|---|---|---|---|
| CC | 11.9° | 6.6° | 6.9° | p<0.0001 |
| LL | -34.6° | -49.3° | -45.4° | p<0.0001 |
| PI | 53.2° | 52.9° | 54.1° | p=0.3249 |
| PI-LL | 18.6° | 2.4° | 10.1° | p<0.0001 |
| PT | 23.1° | 16.7° | 19.3° | p=0.0003 |
| TPA | 22.5° | 15.1° | 18.8° | p=0.0003 |
| T1SPI | -0.4° | -1.4° | -1.1° | p=0.5381 |
| SVA | 55.2 mm | 35.0 mm | 37.9 mm | p=0.1690 |
| L4-S1 LL | 25.1° | 30.6° | 29.0° | p=0.0260 |
| UIV+1 angle | -2.4° | 1.1° | 4.0° | p<0.0001 |
| UIV+2 angle | -2.2° | 3.8° | 4.1° | p<0.0001 |

CC = coronal Cobb (angle); LL = lumbar lordosis; PI = pelvic incidence; PI-LL = pelvic incidence - lumbar lordosis mismatch; PT = pelvic tilt; TPA = T1 pelvic angle; T1SPI = T1 spino-pelvic inclination; SVA = sagittal vertical axis; UIV = upper instrumented vertebra.

**Table 3**
Average segmental lordosis values at preoperative and last postoperative visits. Last postoperative visit averages nominally 24 months (range: 6 months – 7 years).

| | Pre-op | Last Post-op | Pre- to Last Post-op Difference | p-value (Pre-Last) |
|---|---|---|---|---|
| Non-ACR levels | -9.1° | -10.8° | -1.7° | p=0.2482 |
| All-ACR levels | -10.2° | -19.3° | -9.1° | p<0.0001 |
| LLIF-ACR levels | -7.7° | -17.1° | -9.4° | p<0.0001 |
| ALIF ACR levels | -18.4° | -26.5° | -8.1° | p=0.0002 |

ACR = anterior column release; LLIF = lateral lumbar interbody fusion; ALIF = anterior lumbar interbody fusion

**Table 4**
Percentage of patients meeting alignment goals at preoperative and immediate last postoperative visits. Last postoperative visit averages nominally 24 months (range: 6 months – 7 years).

| | Pre-op | Immediate Post-op | Last Post-op |
|---|---|---|---|
| PI-LL < 10° | 18% | 73% | 53% |
| PT < 25° | 65% | 88% | 79% |
| TPA < 20° | 29% | 87% | 63% |
| T1SPI < 0° | 61% | 67% | 56% |
| SVA < 50 mm | 50% | 80% | 52% |

PI-LL = pelvic incidence - lumbar lordosis mismatch; PT = pelvic tilt; TPA = T1 pelvic angle; T1SPI = T1 spino-pelvic inclination; SVA = sagittal vertical axis.

The rationale behind the current authors' application of short-segment ACR was to provide adequate sagittal correction while minimizing the number of fused levels to reduce the morbidity of the procedure and incidence of proximal junctional issues. MIS posterior techniques (percutaneous screws and facet releases) were employed in most (excepting 2 cases requiring hardware revision), and no fusions crossed the thoracolumbar junction. Like the prior ACR studies, LL, PI-LL mismatch, and PT were all significantly improved, even with increased reliance on MIS techniques and with longer follow-up than prior reports. Further, achievement of global alignment goals was independent of whether the deformity was moderate or severe according to Mummaneni's classification, suggesting that their prescription for more aggressive open constructs extending into the thoracic spine may be unnecessary to achieve and maintain successful sagittal alignment.

Moreover, these perioperative clinical results compare favorably with those of long-construct corrections, not unsurprisingly, as sparing levels and use of MIS techniques are intuitively expected to reduce morbidity. Osteotomies, in particular, result in increasingly higher complication rates with increasing grade [24], although with a trade-off for increasing correction capacity. In the current cohort, the most serious complication occurred in a patient with iatrogenic flatback where, in addition to LLIF-ACR, a more extensive (Schwab Grade II) osteotomy was performed along with hardware revision.

A literature review of short- versus long-segment fusions in the setting of adult degenerative scoliosis found no significant difference in overall correction, yet a lower complication profile when short-segment fusion was employed [25]. The authors concluded that shorter fusion constructs should be used, when indicated, in order to reduce perioperative time, costs, and complications. The determination of inclusion of levels, and in particular the UIV, is a topic of continued study and debate. It has been proposed and commonly argued that multi-level corrections that stop at the upper lumbar region should extend to T10 or higher to avoid proximal level breakdown.

However, as highlighted in a debate article by Shufflebarger et al. [26], while this T10-pelvis dogma was based on reasonable biomechanical assumptions considering the increased rigidity of the spine at levels with true rib attachments, it seems to have been based on a relatively small experience, and has perhaps overshadowed the algorithmic recommendations for indication of UIV. The concluding case example in that debate article in fact highlights Shufflebarger's successful outcome with a short-construct solution, albeit one that was achieved through three stages of open procedures and undoubtedly more morbidity than what is similarly achieved by the MIS solutions in the current study.

Consistent with Shufflebarger's teaching, Bridwell et al. suggested that decision-making about where to stop a fusion construct proximally requires identification of the "stable, neutral, and horizontal vertebra" [27]. Having accomplished this in the treatment selection for the current cohort, the long-term results have been good, with no symptomatic proximal level failures.

A systematic literature review by Cho et al. [28] reports that the prevalence of PJK following adult spinal deformity surgery varies widely from 6-62%. They also report that PJK does not appear to affect clinical outcomes and that risk factors include age, bone quality, shorter fusion constructs, UIV below L2, and inadequate restoration of global sagittal balance. The results of the current study both support and challenge these findings.

While the incidence of PJK in the current short-segment cohort ranged from 3-15% (depending on the definition used), that radiographic result did not affect clinical outcomes, as no revision or reoperation was required. However, unlike Cho et al., neither number of levels nor level of UIV was a factor in the incidence of PJK. Kim et al. similarly showed that choice of proximal level, comparing T9, T11, and L1) was not a factor in radiographic and clinical outcomes or prevalence of revision [29]. The authors concluded that the more distal proximal fusion level at a neutral and stable vertebra may be satisfactory, consistent with the recommendation Bridwell et al. It is presumed that, along with this recommendation, ultimately, it is the overall alignment achieved and maintained that is the most significant factor. Notably, all patients in the current cohort met one or more alignment goals.

Limitations of the study include the lack of inclusion of patient reported outcomes. While the focus was on radiographic outcome and clinical complications and failures requiring revision (none), patient-reported pain, function, quality of life, and satisfaction with outcome are important and will be the subject of future studies.

The cohort was not entirely homogeneous given the variations in levels treated, but we attempted to qualify the type of patient for whom this surgical strategy was applied, and limited the analysis population to those meeting a specified set of inclusion criteria. Due to what was an evolution in clinical decision-making, this stratification created a relatively isolated cohort without an effective control group for comparison, since patients with less complex deformities would have been treated less aggressively (e.g., LLIF without ACR), and those with more complex deformities and/or comorbid factors such as osteoporosis would have been treated more aggressively by applying less segmental correction across more levels. Future studies across multiple practices may enable matched-cohort comparisons and further assessment of this strategy.

## Conclusion

The current study results support the concept that it is feasible to minimize fusion levels while correcting moderate to severe sagittal deformity if adequate release of the ALL and disc annulus is performed, with MIS posterior facet releases if needed, along with hyperlordotic cages and supplemental MIS posterior instrumentation. Such

short-segment technique may also be effective in reducing morbidity and risk of proximal junctional issues.

## Declarations of Competing Interests

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

## Supplementary materials

Supplementary data associated with this article can be found, in the online version, at 10.1016/j.ejor.2015.01.016.

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