Surgical correction of severe adult lumbar scoliosis (major curves ≥ 75°): retrospective analysis with minimum 2-year follow-up

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OBJECTIVE Prior reports have demonstrated the efficacy of surgical correction for adult lumbar scoliosis. Many of these reports focused on mild to moderate scoliosis. The authors’ objective was to report their experience and to assess outcomes and complications after deformity correction for severe adult scoliosis.

METHODS The authors retrospectively analyzed consecutive adult scoliosis patients with major thoracolumbar/lumbar (TL/L) curves ≥ 75° who underwent deformity correction at their institution. Those eligible with a minimum 2 years of follow-up were included. Demographic, surgical, coronal and sagittal plane radiographic measurements, and health-related quality of life (HRQL) scores were analyzed.

RESULTS Among 26 potentially eligible patients, 22 (85%) had a minimum 2 years of follow-up (range 24–89 months) and were included in the study (mean age 57 ± 11 years; 91% women). The cohort comprised 16 (73%), 4 (18%), and 2 (9%) patients with adult idiopathic scoliosis, de novo degenerative scoliosis, and iatrogenic scoliosis, respectively. The surgical approach was posterior-only and multistage anterior-posterior in 18 (82%) and 4 (18%) patients, respectively. Three-column osteotomy was performed in 5 (23%) patients. Transforaminal and anterior lumbar interbody fusion were performed in 14 (64%) and 4 (18%) patients, respectively. All patients had sacropelvic fixation with uppermost instrumented vertebra in the lower thoracic spine (46% [10/22] versus upper thoracic spine (55% [12/22]). The mean fusion length was 14 ± 3 levels. Preoperative major TL/L and lumbosacral fractional (L4–S1) curves were corrected from 83° ± 8° to 28° ± 13° (p < 0.001) and 34° ± 8° to 13° ± 6° (p < 0.001), respectively. Global coronal and sagittal balance significantly improved from 5 ± 4 cm to 1 ± 1 cm (p = 0.001) and 9 ± 8 cm to 2 ± 3 cm (p < 0.001), respectively. Pelvic tilt significantly improved from 33° ± 9° to 23° ± 10° (p < 0.001). Significant improvement in HRQL measures included the following: Scoliosis Research Society (SRS) pain score (p = 0.009), SRS appearance score (p = 0.004), and SF-12/SF-36 physical component summary (PCS) score (p = 0.026). Transient and persistent neurological deficits occurred in 8 (36%) and 2 (9%) patients, respectively. Rod fracture/pseudarthrosis occurred in 6 (27%) patients (supplemental rods were utilized more recently in 23%). Revisions were performed in 7 (32%) patients.

CONCLUSIONS In this single-center surgical series for severe adult scoliosis (major curves ≥ 75°), a posterior-only or multistage anterior-posterior approach provided major curve correction of 66% and significant improvements in global coronal and sagittal spinopelvic alignment. Significant improvements were also demonstrated in HRQL measures (SRS pain, SRS appearance, and SF-12/SF-36 PCS). Complications and revisions were comparable to those of other reports involving less severe scoliosis. The results of this study warrant future prospective multicenter studies to further delineate outcomes and complication risks for severe adult scoliosis correction.

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KEYWORDS spine surgery; adult spinal deformity; idiopathic scoliosis; lumbar scoliosis; degenerative scoliosis; rod fracture; pseudarthrosis
Adult spinal deformity (ASD) has a prevalence of up to 68% in the elderly and is increasingly recognized among healthcare providers as a medical condition with a significant negative impact on health-related quality of life (HRQL). As societal demographic trends continue and the elderly population expands, it is becoming increasingly more important to understand treatment options for scoliosis in the skeletally mature patient. For minimally symptomatic ASD patients with mild curves, appropriate initial management may be nonoperative and include trials of physical therapy, steroid injections, nonsteroidal antiinflammatory drugs, and narcotics. Surgery is generally reserved for patients with significant curve progression, progressive neurological symptoms, or severe pain and disability unresponsive to nonoperative treatment.

The general goals of ASD correction are to optimize global and regional alignment in both sagittal and coronal planes, reduce symptoms of axial and radicular pain or neurological deficits, and achieve spinal fusion. Prior reports have demonstrated the efficacy of surgical correction for adult thoracolumbar/lumbar (TL/L) scoliosis. However, many of these reports focused on less severe cases of scoliosis with major TL/L structural curve magnitudes ranging from approximately 20° to 70°. More severe scoliosis with structural curves of greater magnitude are often less flexible, especially in patients of more advanced age. Therefore, surgical management options for adult scoliosis may change with greater magnitude of curve severity. Currently, there are limited data in the literature to help guide ASD surgeons treating patients with more severe TL/L scoliosis. The objective of this retrospective study was to report our experience and to assess outcomes and complications after surgical correction of severe adult scoliosis (major TL/L curves ≥ 75°).

Methods

Patient Selection

We performed an IRB-approved retrospective analysis of adult scoliosis patients who underwent deformity correction at the University of Virginia Health System (Charlottesville, VA) between the years 2010 and 2016. Patients were included if all of the following criteria were satisfied: age at surgery ≥ 18 years, preoperative major TL/L coronal curve ≥ 75°, spinal deformity correction with long-segment fusion from sacropelvis to T12 or above, and complete radiographic data (preoperative, early postoperative, and final follow-up at minimum 2 years postoperatively). Patients without a minimum of 2-year follow-up data were excluded. Patients were also excluded if index scoliosis operations were performed for active spinal infection or neoplastic pathology.

Data Collection

Data on demographics, clinical characteristics, index operations, radiographic outcomes, and complications were recorded for each individual. Demographic and clinical variables included age at surgery, sex, body mass index (BMI), American Society of Anesthesiology score, history of osteopenia/osteoporosis (these patients underwent perioperative treatment to optimize bone mineral density), and etiology of adult scoliosis (i.e., adult idiopathic scoliosis, de novo degenerative scoliosis, or iatrogenic scoliosis). In some cases, adult idiopathic and de novo degenerative scoliosis can be difficult to differentiate despite meticulous medical chart review. This can be particularly challenging in cases of adult idiopathic scoliosis with superimposed degenerative changes. Also, some patients had prior operations that may partly contribute to their spinal malalignment. For these patients, the diagnosis of iatrogenic scoliosis was determined if the recent operation was thought to be the most significant contributing factor for malalignment (i.e., patients with new or severe worsening deformity soon after multilevel thoracolumbar or lumbar spine surgery). Ultimately, final diagnoses were confirmed by reviewing the operative records of the senior operating surgeon. Surgery-related variables included length of fusion, location of the uppermost instrumented vertebra, type and number of osteotomies performed, type of interbody fusions performed, posterior-only versus multi-stage anterior-posterior approach, operative duration, and estimated blood loss (EBL). Surgical strategies implemented to reduce complications were recorded and included the following: application of junctional tethers, intraoperative tranexamic acid administration, use of accessory supplemental rods, and local intrawound vancomycin powder. Complications attributed to index operations were recorded. Rod fracture and pseudarthrosis were assessed primarily using plain radiographs at follow-up unless patients developed significant back pain or neurological deficit, in which case CT imaging was performed.

Radiological Measurements

We evaluated standing posterior-anterior and lateral long-cassette radiographs (14 × 36 inches) of all patients prior to surgery, at approximately 6 weeks postoperatively, and at final follow-up. Radiographic coronal plane variables included the magnitude of the major TL/L curve (including curve apex location and superior and inferior levels for Cobb angle measurement), lumbosacral fractional curve (L4–S1), thoracic curve, and global coronal balance (C7–plumbline relative to central sacral vertical line). The flexibility of the preoperative major TL/L curve was assessed using supine imaging and calculated with the following formula: major curve flexibility (%) = [(standing coronal Cobb angle – supine coronal Cobb angle)/standing coronal Cobb angle] × 100%. Radiographic sagittal spinopelvic measurements were thoracic kyphosis from T5 to T12, lumbar lordosis (LL) from T12 to S1, pelvic incidence (PI), PI-LL mismatch, pelvic tilt, and global sagittal balance (C7 to the plumbline relative to the posterior S1 endplate).

HRQL Measurements

HRQL measurements were prospectively collected for patients concurrently enrolled in ongoing multicenter trials (clinicaltrials.gov identifiers NCT00738439 and NCT00854828). This included patients 6, 8, 9, 11, 12, 13, 14, 16, 17, 18, and 22, whose features are shown in Table 1.
HRQL data were not available for the remaining patients. HRQL measurements included the following: Oswestry Disability Index (ODI), physical component summary (PCS) and mental component summary scores from the SF-12 and SF-36 questionnaires, and Scoliosis Research Society (SRS) domains (function, pain, appearance, and mental health) from SRS-22r and SRS-30 questionnaires.

### Surgical Procedures

After a failed trial of conservative management, operative intervention can be considered for patients with significant curve progression, medically refractory pain, or progressive neurological deficits. Prior to surgery, all patients underwent CT imaging and most underwent supine full-length spine radiography to assess curve flexibility. In general, we treat patients with more flexible curves using...
Adults with Severe Lumbar Scoliosis (Major TL/L Curves ≥75°) undergoing Deformity Correction

Obtain Dynamic Imaging?*

Yes

Flexible Major Curve?

No

Major Curve Flexibility >40%

Consider Posterior-only Approach with Multilevel SPOs

Rigid Deformity

Consider Staged Anterior-Posterior Surgery or Posterior-only Approach with 3CO

Prior Multilevel TL/L Posterior Instrumented Fusion?

Yes

Posterior-only Approach with 3CO

No

Staged Anterior-Posterior Surgery**

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FIG. 1. Flowchart diagram for operative planning. This basic flowchart provides a general outline of our preoperative decision-making process and surgical planning when treating adults with severe TL/L scoliosis. Once the decision for surgical treatment is made, we suggest obtaining dynamic images to assess curve flexibility. In this study, the flexibility of the major TL/L curve was determined using supine imaging and calculated with the formula below (asterisk). Our results demonstrated that patients who underwent posterior-only approach with multilevel SPOs/TLIF had significantly greater curve flexibility than patients who underwent staged anterior-posterior operations or 3-column osteotomies (3CO) (48% vs 25%, p < 0.001). Therefore, for treating similar patients, we suggest using a minimum curve flexibility threshold of approximately 40% before considering posterior-only surgery with multilevel SPOs/TLIF. Less flexible curves (i.e., rigid deformity) may require anterior release of the scoliotic curve or 3CO to obtain adequate alignment correction. For rigid deformity patients with prior multilevel thoracolumbar or lumbar posterior instrumentation/fusion, we typically prefer posterior-only surgery with 3CO. In these patients, an anterior curve release may fail to adequately “loosen” the posteriorly instrumented and fused spine. In contrast, for rigid deformity patients without prior multilevel instrumented fusions, an anterior approach can provide direct operative access to adequately release scoliotic curves for subsequent posterior correction and instrumentation. *Curve flexibility (%) = ([standing Cobb angle – supine Cobb angle]/standing Cobb angle) × 100%. **Dense anterior or lateral bridging osteophytes and severely narrowed disc spaces (making TLIF difficult) are also factors that we consider more amenable to a staged approach with anterior curve release. Figure is available in color online only.

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a posterior-only approach and multilevel Smith-Petersen osteotomy (SPO)/transforaminal lumbar interbody fusion (TLIF). Patients with more rigid curves may require a multistage approach with anterior osteophyte release or 3-column osteotomies (pedicle subtraction osteotomy [PSO]/vertebral column resection [VCR])—the latter technique is generally reserved for patients with prior lumbar instrumentation/fusion). Figure 1 presents a basic flow diagram that summarizes our decision-making and preoperative strategy. Ultimately, ASD correction with either a posterior-only or multistage anterior-posterior approach was utilized as deemed necessary by the senior operating surgeon. The following characteristics were often present in patients treated with multistage anterior-posterior surgery: 1) dense anterior or lateral bridged traction osteophytes, 2) severe major lumbar and fractional curves of greater magnitude that tended to be more rigid,23 3) lack of prior lumbar instrumentation/fusion, and 4) severely narrowed disc spaces not readily accessible posteriorly or amenable to TLIF.

Posterior-Only Surgery

An example of a posterior-only surgery is shown in Fig. 2. With the patient prone on an open-frame Jackson table, the dorsal spine is exposed in subperiosteal fashion via standard midline incision, followed by pedicle screw instrumentation and iliac bolt fixation. Multilevel Schwab grade 1 and 2 posterior column osteotomies are performed for bony decompression and osteophyte/ligament release to mobilize the spine. Careful attention should be focused on posterior release of segments around the apex of the deformity. Further alignment correction of fixed deformities can be achieved with 3-column osteotomies (PSO/VCR; Schwab grades 3–6). If necessary, we perform asymmetrical wedge resection for increasing coronal correction. We utilize TLIFs with lordotic cages inserted at the fractional curve for indirect neural decompression and to improve LL. Lumbar scoliosis and loss of LL can be simultaneously corrected with controlled rod rotation maneuvers and cantilever force application.
lumbar alignment is achieved with the use of reduction screws, in situ rod bending, and sequential compression on the convexity of the scoliotic curvature.\textsuperscript{29,44} Prior to closure, decortication of posterolateral elements is performed for arthrodesis using off-label recombinant human bone morphogenetic protein–2 (rhBMP-2), morselized local bone, and cancellous allograft bone.

**Multistage Anterior-Posterior Surgery**

An example of a multistage anterior-posterior surgery is shown in Fig. 3. The anterior surgery consists of two separate incisions. First, the patient is placed in the lateral decubitus position (convexity side up), and the lateral flank is dissected for a retroperitoneal approach to the upper and mid-lumbar spine. Anterior release of the major curve is then performed. The annulus and anterior longitudinal ligament are transversely incised, and disc material at these levels is completely removed. Bridging osteophytes are transected and the concavity of the scoliotic curve is separated using sequential spreaders, Cobb elevators, and osteotomes. Finally, noninstrumented interbody arthrodesis of the upper and mid-lumbar spine is performed with a combination of morselized local bone (e.g., a portion of 11th rib excised during exposure), cancellous allograft bone, and rhBMP-2 packed meticulously along the concavity of the scoliotic curve. Depending on the specific application of rhBMP-2, this indication may be off label. After appropriate hemostasis and closure of the flank incision, the patient is repositioned supine for a paramedian anterior abdominal approach, retroperitoneal, and exposure of the lower lumbar spine (i.e., L4–5 and L5–S1). Anterior release is then performed at the lower lumbar levels for fractional curve correction. Again, the annulus and anterior longitudinal ligament are transversely incised, and radical discectomies are performed at each level using rongeurs, curettes, and rotating cutters. Disc material is removed in its entirety back to the posterior longitudinal ligament. If needed, an intervertebral disc spacer may be used to further open the concavity of the curvature. After satisfactory trial implantation, interbody cage spacers packed with approximately 4 mg of rhBMP-2 (off label) are implanted. We also insert midline buttress “anti-kickout” screws into L4, L5, or S1 with washers abutting our anterior lumbar interbody fusion (ALIF) grafts to maintain cage position as desired. This completes the anterior surgery. During the same hospital stay, we then perform the subsequent posterior approach procedure (similar to the steps described above) to achieve further correction and circumferential

**FIG. 2.** Patient 2. Posterior-only surgery. This 58-year-old woman (BMI 23.1 kg/m\textsuperscript{2}) with a history of de novo degenerative adult scoliosis presented with rapidly progressive thoracolumbar kyphoscoliosis, intractable axial back pain, and lower extremity radicular pain refractory to conservative management. The following preoperative measurements were made (\textbf{A and B}): 78° thoracolumbar major curve from T10 to L3 (curve apex T12–L1), 46° fractional lumbar-sacral curve, 37° thoracic curve from T3 to T9, −3.8-cm global coronal balance, 8.8-cm sagittal vertical axis (SVA), 48° pelvic tilt, 60° LL, 15° PI-LL mismatch, and 61° thoracic kyphosis. The thoracolumbar major curve appeared relatively flexible on supine imaging (inset in B), and there were lateral bridging osteophytes only at L2–3 on preoperative CT imaging (\textbf{C}); therefore, we felt the curve could be adequately mobilized from a posterior-only approach. The patient underwent posterior-only surgery with careful attention focused on posterior release of segments around the thoracolumbar junctional apex of the scoliotic deformity (SPOs from T9 to L4). We also performed bilateral transpneumatic instrumentation with iliac fixation and multilevel TLIF at L4–5 and L5–1 using 10 × 14 × 2–mm, 12° lordotic cages. Final lumbar alignment was achieved with sequential compression and in situ rod bending. The following postoperative measurements were made (\textbf{D and E}): 12° thoracolumbar major curve from T10 to L3 (curve apex T12–L1), 11° fractional lumbar-sacral curve, 2° thoracic curve from T3 to T9, 3-cm global coronal balance, −1-cm SVA, 22° pelvic tilt, 68° LL, 7° PI-LL mismatch, and 37° thoracic kyphosis. During hospitalization the patient was treated with anticoagulation for postoperative acute pulmonary embolism. After discharge she made an excellent recovery with minimal pain. AP = anterior-posterior. Figure is available in color online only.
We administer parenteral hyperalimentation during the initial convalescence since this may reduce the occurrence of postoperative nutritional depletion.

**Statistical Analysis**

Data are presented as the mean ± SD or median (range) for continuous variables and as frequency (percentage) for categorical variables. The normality of data was assessed using the Shapiro-Wilk test. Univariate radiographic measurement analyses included the paired samples t-test or Wilcoxon signed-rank test, when appropriate. For comparing curve flexibility between independent groups, the nonparametric Mann-Whitney U-test was utilized. HRQL measurements were analyzed with the nonparametric Wilcoxon signed-rank test. All tests were two-tailed, and p values < 0.05 were considered statistically significant. Statistical analyses were performed using Statistical Package for Social Science version 25.0 (released 2017; IBM Corp.).

**Results**

**Patient Population and Surgical Characteristics**

Among 26 potentially eligible patients, 22 (85%) had a minimum 2-year follow-up and were included. Reasons for exclusion included inadequate minimum follow-up duration (3 patients) and distal-most instrumentation ending fusion. We administer parenteral hyperalimentation during the initial convalescence since this may reduce the occurrence of postoperative nutritional depletion.\(^\text{13}\)
at L5 without sacropelvic fixation (1 patient). The patient without initial sacropelvic fixation had evidence of L4–5 pseudarthrosis and underwent revision for extension of instrumentation with bilateral iliac screw placement. All excluded cases were posterior-only operations, and 1 patient underwent 3-column osteotomy (T12 VCR). There was 1 revision for rod fracture and 1 early postoperative wound debridement. Preoperative major TL/L curve was corrected from a mean of 80° ± 7° to 25° ± 5° (not accounting for 1 patient without postoperative standing radiographs). The data on excluded patients were not used in the following analysis.

Demographics, preoperative radiological measurements, and surgical characteristics are listed in Table 1 for each patient who met inclusion criteria. A descriptive analysis of demographics and index operations for these included patients is summarized in Table 2. The mean age at surgery was 57 ± 11 years, 20 (91%) patients were women, and the mean BMI was 26.1 ± 5.1 kg/m². The cohort comprised 16 (73%), 4 (18%), and 2 (9%) patients with diagnoses of adult idiopathic scoliosis, de novo degenerative adult scoliosis, and iatrogenic scoliosis, respectively. The surgical approach was posterior-only and multistage anterior-posterior (with anterior osteophyte/ligament release followed by circumferential fusion) in 18 (82%) and 4 (18%) patients, respectively. Posterior column osteotomies (those not performed as part of a TLIF) and 3-column osteotomies were performed in 86% (19/22) and 23% (5/22) of patients, respectively. Of note, 3 patients had both posterior column and 3-column osteotomies. Of the 3 patients without recorded posterior column osteotomies, patient 4 underwent revision surgery with an asymmetrical L2 PSO and connection of new instrumentation to prior thoracic Harrington rods; similarly, patient 5 had prior Harrington instrumentation and then underwent an L4 extended PSO. Patient 5 did undergo posterior column osteotomies, but these were performed as part of our TLIF technique. Finally, patient 20 had undergone a previous thoracolumbar spine surgery and now presented with multilevel instrumentation failure and pseudarthrosis. After reinstrumentation, we were able to achieve adequate correction with careful in situ rod contouring, cantilever bending, and gentle compression.

TLIF and ALIF were performed in 14 (64%) and 4 (18%) patients, respectively. All patients underwent sacropelvic fixation with the uppermost instrumented vertebra in the lower thoracic spine (46% [10/22]) versus the upper thoracic spine (55% [12/22]) for a mean instrumented fusion length of 14 ± 3 levels. Surgical strategies implemented to reduce complications included application of junctional tethers (36% [8/22]), administration of intraoperative tranexamic acid (77% [17/22]), use of accessory supplemental rods (23% [5/22]), and local intrawound powdered vancomycin (59% [13/22]). The mean operative duration was 7.8 ± 1.4 hours, and the mean total EBL was 4.1 ± 3.5 L. The mean EBL for the anterior stage of anterior-posterior cases was 0.7 ± 0.2 L.

**Curve Flexibility**

Table 3 summarizes preoperative assessments of the major TL/L coronal curve flexibility using standing versus supine imaging (CT scout images were used when supine full-length spine radiographs were not available). Patients who underwent a posterior-only approach with multilevel

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**TABLE 2. Demographics and surgical data**

<table>
<thead>
<tr>
<th>Variable</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age, yrs</td>
<td>57.0 ± 11.0</td>
</tr>
<tr>
<td>Female sex</td>
<td>20 (90.9)</td>
</tr>
<tr>
<td>BMI, kg/m²</td>
<td>26.1 ± 5.1</td>
</tr>
<tr>
<td>ASA score</td>
<td>2 (2–3)</td>
</tr>
<tr>
<td>Osteopenia/osteoporosis*</td>
<td>9 (40.9)</td>
</tr>
<tr>
<td>Dx</td>
<td>Idio 16 (72.7)</td>
</tr>
<tr>
<td>De novo degen</td>
<td>4 (18.2)</td>
</tr>
<tr>
<td>Iatro</td>
<td>2 (9.1)</td>
</tr>
<tr>
<td>Pst-only approach</td>
<td>18 (81.8)</td>
</tr>
<tr>
<td>Multistage ant-pst surgery</td>
<td>4 (18.2)</td>
</tr>
<tr>
<td>Days btwn ant &amp; pst surgery</td>
<td>7.5 ± 5.3</td>
</tr>
<tr>
<td>Ant stage EBL, L</td>
<td>0.7 ± 0.2</td>
</tr>
<tr>
<td>Total EBL, L</td>
<td>4.1 ± 3.5</td>
</tr>
<tr>
<td>Ant stage EBL, L</td>
<td>0.7 ± 0.2</td>
</tr>
<tr>
<td>Length of stay, days</td>
<td>9.4 ± 4.5</td>
</tr>
<tr>
<td>Pts discharged to rehab</td>
<td>10 (45.6)</td>
</tr>
<tr>
<td>Follow-up, mos</td>
<td>52.4 ± 20.3</td>
</tr>
</tbody>
</table>

ASA = American Society of Anesthesiologists; degen = degenerative; pst = posterior.

* Values are expressed as the number (%) of patients or mean ± SD.

† Posterior column osteotomy is performed as part of our TLIF technique. For this study, we recorded SPOs performed separately from a TLIF.
SPO/TLIF had significantly greater curve flexibility than patients who underwent a multistage anterior-posterior operation or 3-column osteotomies (48% vs 25%, p < 0.001).

Radiographic Outcome Measurements

Table 4 summarizes coronal plane radiographic assessments. Preoperative major TL/L curve, lumbosacral fractional curve (L4–S1), thoracic curve, and global coronal balance were corrected from 83° ± 8° to 28 ± 13° (p < 0.001), 34° ± 8° to 13° ± 6° (p < 0.001), 35° ± 16° to 14° ± 8° (p < 0.001), and 5 ± 4 cm to 1 ± 1 cm (p = 0.002), respectively. These coronal corrections were maintained at final follow-up.

Table 4 also summarizes sagittal plane radiographic assessments. Preoperative thoracic kyphosis, LL, PI-LL mismatch, pelvic tilt, and global sagittal alignment (C7–T1) were corrected from 32° ± 9° to 22° ± 4.0° (p < 0.001), 33° ± 9° to 23° ± 10° (p < 0.001), and 9 ± 8 cm to 2 ± 3 cm (p < 0.001), respectively. All sagittal corrections were maintained at final follow-up except for thoracic kyphosis. In comparison to the early preoperative measurement, thoracic kyphosis increased to 54° ± 14° (p < 0.001) at final follow-up.

HRQL Outcome Measurements

Table 5 summarizes HRQL outcome scores. There were significant improvements between the preoperative and final follow-up scores in the SRS pain domain (2.4 vs 3.2; p = 0.009), SRS function domain (2.3 vs 3.8; p = 0.004), and SF-12/SF-36 PCS (27.0 vs 31.6; p = 0.026). No significant improvements in the SRS function domain, SRS mental health domain, MCS, or ODI were observed.

Summary of Complications

Table 6 summarizes complications related to the index operations. Transient and persistent neurological deficits occurred in 8 (36%) and 2 (9%) patients, respectively. The most common intraoperative complication was durotomy in 4 (18%) patients. All durotomies were repaired primarily, and none resulted in a postoperative CSF leak. Early postoperative complications during convalescence included arrhythmia (patient 16), delirium (patients 16 and 22), hyponatremia (patients 2, 7, and 9), ileus (patient 11),...
pulmonary embolism (patients 2 and 13), urine retention (patients 1 and 2), and volume overload causing lower extremity edema and/or pleural effusions (patients 9, 16, 17, and 22). Rod fracture/pseudarthrosis occurred in 6 (27%) patients, and 5 (23%) patients underwent rod revision surgery. Other indications for revision surgery included proximal junctional kyphosis/failure (patient 18, who also had revision for rod fracture), wound complication (patient 10), and retroperitoneal hematoma from an anterior approach (patient 21). Overall, revision operations were performed in 7 (32%) patients.

### Discussion

Aebi subdivided adult scoliosis into three groups based on pathogenesis: 1) primary degenerative (de novo) scoliosis, 2) progressive idiopathic scoliosis, and 3) secondary degenerative scoliosis.\(^1,3\) Other adult scoliosis classifications reported by Schwab et al. and the SRS provided a more clinically oriented framework intended to improve evidence-based management.\(^2,5,4,4\) In appropriately selected patients, these authors recommended corrective surgery to improve spinal alignment and to relieve pain and functional symptoms.\(^5,46\) Since then, many reports have demonstrated the efficacy of surgical correction for adult TL/L scoliosis.\(^3,2,29,33,41,44,47,59\) For example, Matsumura et al. demonstrated that posterior corrective surgery with multilevel TLIF and rod rotation techniques could achieve approximately 66% correction of the major lumbar curve (mean preoperative 59° to postoperative 20°).\(^4\) Ramieri et al. reported an approximately 54% correction rate of the lumbar Cobb angle after two-stage anterior-posterior surgery (mean preoperative 37° to postoperative 17°).\(^5\) Kim et al. performed a comparative study to assess the utility of anterior apical release and fusion to treat the lumbar scoliotic curve.\(^5\) They reported an overall correction rate of approximately 50% for the lumbar Cobb angle (mean preoperative 60° to postoperative 30°) and found no significant benefits for anterior apical release.\(^5\)

Other studies also directly compared anterior-posterior and posterior-only correction of adult lumbar scoliosis.\(^2,29,44\) Hsieh et al. demonstrated that combining ALIF with posterolateral instrumented fusion improved overall spinal alignment and corrected the lumbar Cobb angle more effectively than posterior-only surgery (77% correction [mean preoperative 41.3° to postoperative 9.3°] vs 44% correction [mean preoperative 38.5° to postoperative 21.4°], respectively).\(^2\) In contrast, studies by Pateder et al. and Crandall and Revella demonstrated no significant difference in correction of the major TL/L curve or other sagittal or coronal plane measurements when comparing anterior-posterior and posterior-only surgical cohorts.\(^2,44\)

Lateral lumbar interbody fusion (LLIF) has also been utilized as a corrective technique for adult lumbar scoliosis.\(^5,9\) Bae et al. compared three different surgical strategies in adult scoliosis patients with minimum lumbar Cobb angle > 20°: a posterior-only versus a posterior approach combined with LLIF versus a posterior approach combined with ALIF. The study demonstrated comparable radiographic outcomes and complications, with an overall lumbar Cobb angle correction rate of 48% (mean preoperative 29° to postoperative 15°); however, the posterior-LLIF group had fewer junctional failures that required revision.\(^5\) In contrast, Theologis et al. demonstrated that combining multilevel LLIF of the TL/L coronal curve apex with an open posterior instrumented fusion offered improved correction of major curves, lumbopelvic parameters, and global sagittal alignment compared to posterior-only surgery.\(^9\) Of note, the minimum lumbar Cobb angle for inclusion (≥ 40°) was higher in this study than that in the Bae et al. study, which could partially account for the differing conclusions.\(^5,9\)

These aforementioned studies focused on adult scoliosis with major TL/L structural curves ranging from approximately 20° to 70°.\(^3,2,29,33,41,44,47,59\) However, larger curves are generally less flexible and may present a greater challenge to spine surgeons when correcting coronal and sagittal plane deformities.\(^2\) Currently, there are limited data in the literature to help guide ASD surgeons treating patients with severe TL/L scoliosis. Therefore, the objective of our study was to analyze our recent surgeries and update the literature with a series of more severe cases. In this study, our patients had minimum major TL/L curves ≥ 75° since this threshold exceeds the curve magnitudes commonly reported in most contemporary adult scoliosis studies. Our results suggest that adequate, durable radiographic correction can be achieved and be associated with significant improvement in HRQL measures (SRS pain domain, SRS appearance domain, and SF-12/SF-36 PCS). In our study, the mean preoperative major TL/L, lumbosacral fractional (L4–S1), and thoracic curves were corrected from approximately 83° ± 8° to 28° ± 13°, 34° ± 8° to 13° ± 6°, and 35° ± 16° to 14° ± 8°, respectively. Our lumbar Cobb angle correction rate of approximately 66% is within the range of correction rates reported in similar studies of less severe preoperative curves.\(^3,2,29,33,41,44,47,59\)

Based on minimum clinically important difference (MCID) analyses, the statistically significant changes in SRS domains (pain and self-image/appearance) meet the threshold of improvement that is clinically relevant.\(^10,21\)
However, the clinical relevance of our demonstrated PCS score improvement (4.6 points) is less clear. Copay et al. demonstrated an MCID of 4.9 points for PCS score. How-
however, this calculation was based on a general lumbar spine surgery population encompassing a broad range of diagnostic entities. Also, different MCID calculation methods produced widely different thresholds (1.26–5.95).

Despite advancements in operative technique, instrumentation design, and perioperative management, surgical treatment of ASD is often associated with high complication rates. In our current series, the mean EBL was greater than 4 L. The high blood loss may in part be attributed to our cohort’s severe deformities (both coronal and sagittal malalignment), which required correction with longer-length instrumentation constructs (mean 14 instrumented levels), pelvic fixation, and in some cases 3-column osteotomies. Transient and persistent neurological deficits occurred in 8 (36%) and 2 (9%) patients, respectively. Rod fracture or pseudarthrosis occurred in 6 (27%) patients. Revision operations were performed for rod fracture/pseudarthrosis (5 patients), proximal junctional kyphosis (1 patient), wound complication (1 patient), and retroperitoneal hematoma (1 patient) for an overall revision rate of 32%. These complication rates are similar to

<table>
<thead>
<tr>
<th>Complication</th>
<th>No. of Pts (%)</th>
<th>Pt No. (from Table 1)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Instrumentation complications</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Rod fracture/pseudarthrosis</td>
<td>6 (27.3)</td>
<td>6, 9, 12, 18, 20, 22</td>
</tr>
<tr>
<td>Iliac screw fracture/loosening</td>
<td>2 (9.1)</td>
<td>9, 18</td>
</tr>
<tr>
<td>Transient neurological deficits</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Radicular pain</td>
<td>7 (31.8)</td>
<td>4, 5, 9, 10, 13, 19, 22</td>
</tr>
<tr>
<td>Motor deficit</td>
<td>1 (4.5)</td>
<td>19</td>
</tr>
<tr>
<td>Sensory deficit</td>
<td>2 (9.1)</td>
<td>10, 16</td>
</tr>
<tr>
<td>Persistent neurological deficits</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Radicular pain</td>
<td>0 (0)</td>
<td>NA</td>
</tr>
<tr>
<td>Motor deficit</td>
<td>0 (0)</td>
<td>NA</td>
</tr>
<tr>
<td>Sensory deficit</td>
<td>2 (9.1)</td>
<td>8, 13</td>
</tr>
<tr>
<td>Sacroiliac pain</td>
<td>6 (27.3)</td>
<td>4, 6, 7, 10, 12, 15</td>
</tr>
<tr>
<td>Intraop</td>
<td></td>
<td></td>
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<tr>
<td>Durotomy</td>
<td>4 (18.2)</td>
<td>5, 7, 13, 16</td>
</tr>
<tr>
<td>Febrile transfusion reaction</td>
<td>1 (4.5)</td>
<td>18</td>
</tr>
<tr>
<td>Profound hypotension</td>
<td>1 (4.5)</td>
<td>6</td>
</tr>
<tr>
<td>Pleural injury</td>
<td>2 (9.1)</td>
<td>13, 22</td>
</tr>
<tr>
<td>Early postop (&lt;6 wks)</td>
<td></td>
<td></td>
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<tr>
<td>Arrhythmia</td>
<td>1 (4.5)</td>
<td>16</td>
</tr>
<tr>
<td>Delirium</td>
<td>2 (9.1)</td>
<td>16, 22</td>
</tr>
<tr>
<td>Hyponatremia</td>
<td>3 (13.6)</td>
<td>2, 7, 9</td>
</tr>
<tr>
<td>Ileus</td>
<td>1 (4.5)</td>
<td>11</td>
</tr>
<tr>
<td>Pulmonary embolism</td>
<td>2 (9.1)</td>
<td>2, 13</td>
</tr>
<tr>
<td>Urine retention</td>
<td>2 (9.1)</td>
<td>1, 2</td>
</tr>
<tr>
<td>Volume overload (LE edema, pleural effusion)</td>
<td>4 (18.2)</td>
<td>9, 16, 17, 22</td>
</tr>
<tr>
<td>Wound complication</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Deep wound infection/osteomyelitis</td>
<td>2 (9.1)</td>
<td>10, 18*</td>
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<tr>
<td>Superficial/suprafascial wound infection</td>
<td>0 (0)</td>
<td>NA</td>
</tr>
<tr>
<td>Wound dehiscence or seroma (no infection)</td>
<td>1 (4.5)</td>
<td>9</td>
</tr>
<tr>
<td>Revision</td>
<td></td>
<td></td>
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<tr>
<td>Rod fracture/pseudarthrosis</td>
<td>5 (22.7)</td>
<td>6, 9, 12, 18,† 20</td>
</tr>
<tr>
<td>Proximal junctional kyphosis</td>
<td>1 (4.5)</td>
<td>18†</td>
</tr>
<tr>
<td>Wound complication</td>
<td>1 (4.5)</td>
<td>10</td>
</tr>
<tr>
<td>Retroperitoneal hematoma</td>
<td>1 (4.5)</td>
<td>21</td>
</tr>
</tbody>
</table>

LE = lower extremity; NA = not applicable.

* Intraoperative cultures from an epidural collection (no overt osteomyelitis) taken during this patient’s proximal junctional kyphosis revision operation grew peptostreptococcus. The microbial source was likely from the patient’s periodontal abscess prior to the the revision operation. The patient underwent a prolonged course of antibiotic therapy without further issue.
† Patient 18 had separate revision operations for both rod fracture and severe proximal junctional kyphosis.
those in the adult scoliosis studies discussed above. For example, the Bae et al. comparative study reported neurological complications in 8%, revision for proximal junctional kyphosis in 13%, and revision for other reasons excluding proximal junctional kyphosis in 25%.3 The Theologis et al. study reported major neurological complications in 19% of patients overall, with 31% of the posterior-LLIF patients having postoperative leg weakness.59 In the Crandall and Revella study of anterior-posterior versus posterior-only surgery, the anterior surgery cohort had pseudarthrosis in 20% of the patients and revisions in 40% of the patients.20 Of note, these other studies excluded patients who had undergone 3-column osteotomies, which may underestimate complication rates in comparison to our study (23% of our patients underwent PSO/VCR).3,10,13,20,56,59

Smith et al. recently reviewed novel complication-avoidance techniques for spinal deformity surgery.55 We utilized many of these strategies in this series, which included application of junctional tethers to reduce proximal junctional kyphosis (36% [8/22]), intraoperative systemic tranexamic acid administration to reduce blood loss (77% [17/22]), accessory supplemental rods spanning 3-column osteotomies or multilevel SPOs to reduce the occurrence of rod fracture/pseudarthrosis (23% [5/22]), and local intrawound vancomycin powder (1 g of vancomycin powder mixed with morselized bone graft prior to implantation) to reduce surgical site infections (59% [13/22]).4,8,9,11–13,16,22,28,55,62 Tethers, multirodd constructs, and intrawound vancomycin powder were more recently employed at our institution. This likely accounts for their relatively lower utilization rates compared to intraoperative systemic tranexamic acid administration, which we began consistently utilizing only shortly after starting this study (first index operation in 2011—patient 19). Given the high complication rates associated with deformity correction, we now generally utilize these techniques for all deformity cases, unless contraindicated. We use lower doses of systemic tranexamic acid (or topical administration)22 for patients with systemic tranexamic acid contraindications (e.g., deep vein thrombosis, pulmonary embolism, stroke, myocardial infarction, renal failure, seizures, or hypercoagulable disorders).61,62 Also, our junctional tethering technique has been refined since its first implementation in 2011,9 and we currently utilize the “weave” technique to anchor proximal instrumentation to the noninstrumented spine at 2 levels above.8,12

Definitive guidelines for optimal surgical management of adult lumbar scoliosis are currently unclear.29,33,44 Earlier studies advocated for multistage anterior-posterior procedures that typically consisted of preliminary anterior release followed by the placement of posterior spinal instrumentation and fusion.6,17,24,33,34 Ventrally bridged traction osteophytes tended to be difficult to transect from posteriorly and were more common in adult idiopathic rather than de novo curves.29,44 The anterior approach provided a direct operative corridor for extensive release of these ventral osteophytes.33 This was often needed to mobilize curves for subsequent fusion in proper alignment.31 Also, during the anterior approach many surgeons performed anterior column support for additional stability of the lumbosacral region.33,60 In our series, we performed multilevel ALIF using a paramedian retroperitoneal approach (patients 8, 17, 21, and 22).

More recently, the authors of some adult scoliosis studies have supported posterior-only surgery and suggested that it may achieve adequate correction and good clinical outcomes without the potential complications associated with anterior surgery (e.g., pulmonary, visceral, or vascular complications).33,38,44,58 Traditionally, posterior-only correction was generally limited to those with a more flexible spine, but increased utilization of transpedicular screw fixation has changed this.38,44 Pedicle screws allow strong fixation from the posterior elements to the anterior column and can withstand high amounts of multiplanar corrective forces.38,44 This may make spinal deformity correction feasible from the posterior aspect if extensive posterior releases are also performed.38,44 In our study, most cases were posterior-only (82% [18/22]), and considerable correction was achieved (approximately 70%) without anterior release. Only 4 cases were multistage anterior-posterior (patients 8, 17, 21, and 22), and these procedures were performed earlier during the study duration (patient 8 was the only case performed after 2011). Although our results demonstrated that considerable correction could be achieved with posterior-only surgery, the small sample size and lack of comparative design precludes definitive conclusions regarding posterior-only versus anterior-posterior approach surgery. It is important to note that some of the posterior-only patients had 3-column osteotomies, which is a challenging technique associated with high complication rates.13,56 Also, we demonstrated that patients who underwent 3-column osteotomy or multistage anterior-posterior surgery had significantly less curve flexibility than patients who underwent posterior-only operations with multilevel SPO/TLIFs. Therefore, we still recommend that surgeons consider multistage anterior-posterior operations for correcting severe scoliosis with large curve magnitudes, especially if the curves are rigid with extensive bridging osteophytes.23 Figure 1 presents a brief flow diagram of our strategy and decision-making when planning surgery.

The importance of adequate fractional curve (L4–S1) correction in adult scoliosis surgery cannot be overstated. Inadequate fractional curve correction (i.e., residual L4 coronal tilt) is a significant predictive risk factor for postoperative coronal malalignment.27 Correction of the fractional curve (which may be more rigid than the major curve) can be challenging from a posterior-only approach, especially when narrow lumbosacral disc spaces are present.23 Therefore, for some rigid deformity cases (using a curve flexibility threshold of approximately 40%), we may utilize both thoracolumbar flank and paramedian retroperitoneal approaches to anteriorly release the major and fractional curves, respectively. Subsequent lumbosacral ALIF can be performed for further correction and improved stability.

It is important to be aware of the limitations of this study. First, there are inherent biases present due to its retrospective analysis and single-center design. Patient selection, choice of surgical approach, and postoperative management were decided by the treating physicians at a single center; therefore, surgeon preference may have influenced outcomes. Also, owing to the relatively small
sample size and HRQL data set, the study was not powered to compare surgical approach/technique, identify complication risk factors, or predict outcomes. As such, this single-center retrospective study should not be interpreted as sufficient to answer these questions, which would require a larger randomized data set. Despite these limitations, the present study contributes to the contemporary adult scoliosis literature, especially due to the limited surgical data currently available in the literature for such severe cases. Until larger prospective multicenter studies are conducted, this series may provide reference for other surgeons faced with the challenge of correcting severe adult lumbar scoliosis.

Conclusions

In this single-center retrospective analysis of ASD patients with severe adult lumbar scoliosis (major TL/L curve ≥ 75°), a posterior-only or multistage anterior-posterior approach provided approximately 66% major curve correction and significant improvement in global coronal and sagittal spinopelvic alignment. Significant improvements were observed in some postoperative HRQL measures and included SRS pain domain, SRS appearance domain, and SF-12/SF-36 PCS scores. We demonstrated complication and revision rates comparable to those of other surgical reports for less severe adult lumbar scoliosis. Our results warrant future prospective multicenter studies to further delineate outcomes and complication risk factors after surgical correction for severe adult lumbar scoliosis.

References


23ory rods and cobalt chrome alloy posterior rods reduces primary rod strain and range of motion across the pedicle suction 


29. Hsieh MK, Chen LH, Niu CC, Fu TS, Lai PL, Chen WJ: Combined anterior lumbar interbody fusion and instrumented 


31. Jenkinson C, Coulter A, Wright L: Short form 36 (SF36) health survey questionnaire: normative data for adults of 


**Disclosures**

Thomas J. Buell: honorarium from Wolters Kluwer. Christopher I. Shaffrey: consultant for Medtronic, NuVasive, Zimmer Biomet, EOS, Siemens, and K2M; royalties from Medtronic, NuVasive, and Zimmer Biomet; stockholder in NuVasive; grants from NIH, DOD, and NACTN. Justin S. Smith: royalties from Zimmer Biomet; consultant for Zimmer Biomet, Cerapedics, NuVasive, K2M, and AlloSource; honorarium from Zimmer Biomet, NuVasive, and K2M; research support from DePuy Synthes and ISSGF; and fellowship support from NREF and AOSpine. Chun-Po Yen: consultant for NuVasive.

**Author Contributions**

Conception and design: Buell, CI Shaffrey, Smith. Acquisition of data: Buell, Chen, Nguyen, Christiansen. Analysis and interpretation of data: Buell, CI Shaffrey, Smith. Drafting the article: Buell. Critically revising the article: Buell, Buchholz, Yen, ME Shaffrey, CI Shaffrey, Smith. Reviewed submitted version of manuscript: all authors. Approved the final version of the manuscript on behalf of all authors: Buell. Statistical analysis: Buell. Study supervision: CI Shaffrey, Smith.

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