Comparison of two minimally invasive surgery strategies to treat adult spinal deformity

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on behalf of the International Spine Study Group

OBJECT Minimally invasive surgery (MIS) techniques are becoming a more common means of treating adult spinal deformity (ASD). The aim of this study was to compare the hybrid (HYB) surgical approach, involving minimally invasive lateral interbody fusion with open posterior instrumented fusion, to the circumferential MIS (cMIS) approach to treat ASD.

METHODS The authors performed a retrospective, multicenter study utilizing data collected in 105 patients with ASD who were treated via MIS techniques. Criteria for inclusion were age older than 45 years, coronal Cobb angle greater than 20°, and a minimum of 1 year of follow-up. Patients were stratified into 2 groups: HYB (n = 62) and cMIS (n = 43).

RESULTS The mean age was 60.7 years in the HYB group and 61.0 years in the cMIS group (p = 0.910). A mean of 3.6 interbody fusions were performed in the HYB group compared with a mean of 4.0 interbody fusions in the cMIS group (p = 0.086). Posterior fusion involved a mean of 6.9 levels in the HYB group and a mean of 5.1 levels in the cMIS group (p = 0.003). The mean follow-up was 31.3 months for the HYB group and 38.3 months for the cMIS group. The mean Oswestry Disability Index (ODI) score improved by 30.6 and 25.7, and the mean visual analog scale (VAS) scores for back/leg pain improved by 2.4/2.5 and 3.8/4.2 for the HYB and cMIS groups, respectively. There was no significant difference between groups with regard to ODI or VAS scores. For the HYB group, the lumbar coronal Cobb angle decreased by 13.5°, lumbar lordosis (LL) increased by 8.2°, sagittal vertical axis (SVA) decreased by 2.2 mm, and LL–pelvic incidence (LL-PI) mismatch decreased by 8.6°. For the cMIS group, the lumbar coronal Cobb angle decreased by 10.3°, LL improved by 3.0°, SVA in-
MINIMALLY invasive surgery (MIS) approaches for spinal fusion have become increasingly popular. Numerous studies have shown equivalent clinical outcomes for MIS transforminal lumbar interbody fusion (TLIF) compared with traditional open TLIF, with the added benefits of decreased adjacent tissue injury resulting in less blood loss, decreased postoperative pain, decreased hospital stay, and faster recovery.6,10,13,16,20,22,23 Subsequent reports have all confirmed success of MIS treatment of ASD.5,17,21,24 These studies, however, have been limited by the relatively small numbers of patients evaluated, as well as the lack of focus on sagittal alignment and spinopelvic parameters, which are factors known to significantly impact long-term disability.12,18

In addition, there has been no uniform MIS technique or combination of techniques reported for the treatment of ASD. In some studies, a combination of MIS approaches has been used. Alternatively, a hybrid (HYB) surgical approach involving a combination of open and MIS approaches has also been used. It is unclear which method is best, or whether the ideal surgical approach should be individualized to the patient. In this multicenter study, 2 different MIS approaches to ASD are compared, with evaluation of both radiographic and clinical outcomes. The primary aim of this cohort study was to determine the degree of radiographic improvement for each type of MIS approach and compare this improvement between groups. Secondarily, perioperative characteristics, complications, and the degree of pain and disability improvement were assessed for each MIS approach and compared between both approaches.

Methods
Study Design
Institutional review board approval for this study was obtained at each participating site. Eight institutions (Cedars-Sinai; Northwestern University; University of California, San Diego; University of California, San Francisco; University of Michigan; University of Pittsburgh; and University of South Florida) were involved. Eleven surgeons participated in the study, each with experience in minimally invasive spinal surgery. At each site, a database of patients who underwent MIS was retrospectively reviewed. Criteria for inclusion were age older than 45 years, coronal Cobb angle greater than 20°, 3 or more disc levels treated, and minimum of 1 year of follow-up. Included patients were stratified into 2 groups: HYB and circumferential MIS (cMIS). Patients who underwent MIS procedures, such as lateral transposas lumbar interbody fusion (LLIF) alone without a posterior component, were excluded. During the past 7 years, 317 ASD patients underwent MIS performed by the surgeons involved in this study group. After excluding patients with incomplete data and those who did not undergo cMIS or HYB approaches, 105 patients were included in our analysis. Early in the MIS experience, many surgeons did not keep track of standardized outcomes or consistently obtain 36-inch pre- and postoperative radiographs, so the majority of the 105 included patients underwent MIS within the last 3 years. Indications for surgery included symptomatic back and/or leg pain attributed to ASD that was unresponsive to conservative measures.

Group Definitions
HYB Group
Patients in the HYB group underwent initial multilevel LLIF at the targeted disc levels. The surgical technique for LLIF has been previously described.15,17 Following LLIF, patients were repositioned for a posterior approach that included open segmental instrumentation and fusion with facet resections and osteotomies as needed (Fig. 1). There were 62 patients in the HYB group.

cMIS Group
Patients in the cMIS group underwent a combination of MIS approaches. LLIF was used in each patient except in 2 patients in whom only TLIF was performed. In addition, certain patients also underwent an axial lumbar interbody fusion at L5–S1. All patients had percutaneous segmental pedicle screw instrumentation (Fig. 2). No patient had an osteotomy or facet resection. There were 43 patients in the cMIS group.

Clinical Outcome Assessment
Outcomes were assessed preoperatively and at 1 year or more following surgery using the visual analog scale (VAS) for back and leg pain and the Oswestry Disability Index (ODI), a measure of functional disability. ODI scores were based on a scale of 0–100. A score of 0–20 equated to minimal disability, 20–40 moderate disability, 40–60 severe disability, 60–80 crippled, and 80–100 bed-bound or exaggerating.7
Radiographic Outcome Assessment

Preoperative and postoperative 36-inch standing radiographs were reviewed for all patients. The degree of scoliosis was measured by the coronal Cobb angle. Lumbar lordosis (LL) was measured from the angle formed by 2 lines, one parallel to the superior endplate of L-1 and the other parallel to the superior endplate of S-1. Pelvic incidence (PI) was measured as the angle subtended by a line drawn perpendicular to the superior S-1 endplate and a line drawn from the center of the femoral head to the midpoint of the superior S-1 endplate. The proportion of LL versus PI was quantified by calculating the difference between LL and PI (LL-PI mismatch). Pelvic retroversion was quantified by the degree of pelvic tilt (PT), defined as the angle subtended by a vertical line and a line drawn from the center of the femoral head to the midpoint of the superior S-1 endplate. Finally, the sagittal vertical axis (SVA) was measured as the distance from the posterosuperior aspect of S-1 to the C-7 plumb line. All radiographs were sent to a central site where measurements were made by independent assessors to maintain consistency between sites.

Complications

Complications were recorded at each site. The definition of a major or minor complication was based on the categorization reported in the study by Glassman et al., which investigated perioperative complications after ASD surgery. As an example, perioperative complications, such as cauda equina injury or vascular injury, were considered major complications, and cerebrospinal fluid leak or excessive bleeding were considered minor complications. Postoperatively, events such as motor deficit and pulmonary embolism were defined as major complications, while superficial infection and thrombophlebitis were categorized as minor complications.

Statistical Analysis

The mean and standard deviation were used to describe
continuous variables, and frequency analyses were used for categorical variables. Comparisons between groups were carried out using ANOVA and chi-square tests. Changes between preoperative and postoperative parameters were analyzed using a paired t-test. A p value < 0.05 with a confidence interval of 95% was considered statistically significant. All analyses were performed using SPSS software (SPSS, Inc.).

**Results**

**Demographics**

Overall the groups were similar demographically at baseline. There was no significant difference in age, with a mean 60.7 years (SD, 12.1 years) for the HYB treatment group and 61.0 years (SD, 14.7 years) for the cMIS group. Similarly, there was no statistical difference in sex, body mass index (BMI), or American Society of Anesthesiologists status classification (Table 1). At baseline, however, the cMIS group had fewer comorbidities, with a mean of 1.1 (SD, 1.2), compared with 2.7 (SD, 2.4) for the HYB treatment group (p < 0.001). The mean follow-up was 31.3 months (SD, 8.9 months) for the HYB group and 38.3 (SD, 12.7 months) for the cMIS group.

**HYB Group**

On average, the HYB group had 6.9 levels (SD, 3.3 levels) treated posteriorly and 3.6 (1.2) levels of interbody fusion. The mean estimated blood loss (EBL) was 1651.1 ml (SD, 1287.8 ml), with an operating room time of 708.5 minutes (SD, 271.9 minutes) and a length of stay of 8.6 days (SD, 3.7 days). Thirty-four patients (55%) had at least 1 complication. There were 27 major and 14 minor adverse events recorded. With the exception of PT and SVA, there was a significant improvement in all radiographic parameters (p < 0.05). The coronal Cobb angle improved from 22.1° to 8.6°, LL increased from 34.1° to 42.3°, and LL-PI mismatch improved from 16.8° to 8.2° (p < 0.001 for all; Table 2). Mean ODI scores improved from 63.4 to 32.9, which approached significance (p = 0.069). Back and leg pain VAS scores improved from 7.0 to 4.6 (p = 0.013) and 5.4 to 2.9 (p < 0.001), respectively.

**cMIS Group**

On average, the cMIS group had 5.1 (SD, 2.7) levels treated posteriorly and 4.0 (SD, 1.1) levels of interbody fusion. The mean EBL was 552.4 ml (SD, 460.1 ml), with an operating room time of 452.4 minutes (SD, 212.2 minutes), and a length of stay of 8.7 days (SD, 5.7 days). Fourteen patients (33%) had a complication, consisting of 10 major and 4 minor adverse events. The coronal Cobb angle improved from 19.7° to 9.4° (p < 0.001; Table 3). LL improved from 41.2° to 44.1°, which approached significance (p = 0.076). There was no significant change in PT, LL-PI mismatch, or SVA, although on average the SVA increased by 2.1 mm. Mean ODI scores improved from 48.0 to 23.2 (p < 0.001). Mean back and leg pain VAS scores improved from 6.7 to 2.9 (p < 0.001) and 6.0 to 1.8 (p < 0.001), respectively.

**Group Comparison**

Comparison of improvement in clinical outcomes revealed no significant differences between the 2 groups in

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**TABLE 1. Patient baseline characteristics dichotomized by treatment grouping (n = 105)*

<table>
<thead>
<tr>
<th>Variable</th>
<th>HYB</th>
<th>cMIS</th>
<th>p Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>No. of patients</td>
<td>62</td>
<td>43</td>
<td></td>
</tr>
<tr>
<td>Mean age in yrs</td>
<td>60.7 ± 12.1</td>
<td>61.0 ± 14.7</td>
<td>0.910</td>
</tr>
<tr>
<td>Mean BMI</td>
<td>27.5 ± 4.8</td>
<td>26.3 ± 4.5</td>
<td>0.210</td>
</tr>
<tr>
<td>Mean no. of comorbidities</td>
<td>2.7 ± 2.4</td>
<td>1.1 ± 1.2</td>
<td>&lt;0.001†</td>
</tr>
<tr>
<td>Mean ASA grade</td>
<td>2.4 ± 0.6</td>
<td>2.1 ± 0.7</td>
<td>0.100</td>
</tr>
<tr>
<td>% female</td>
<td>83.10%</td>
<td>79.10%</td>
<td>0.609</td>
</tr>
<tr>
<td>Mean no. of levels treated posteriorly</td>
<td>6.9 ± 3.3</td>
<td>5.1 ± 2.7</td>
<td>0.003†</td>
</tr>
<tr>
<td>Mean no. of interbody fusion levels</td>
<td>3.6 ± 1.2</td>
<td>4.0 ± 1.1</td>
<td>0.086</td>
</tr>
</tbody>
</table>

ASA = American Society of Anesthesiologists.
* Mean values are presented as the mean ± SD.
† Statistically significant.

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**TABLE 2. Clinical and radiographic parameters for patients in the hybrid surgery group (n = 62)**

<table>
<thead>
<tr>
<th>Variable</th>
<th>Preop Mean</th>
<th>Preop SD</th>
<th>Postop Mean</th>
<th>Postop SD</th>
<th>Change Mean</th>
<th>Change SD</th>
<th>p Value (paired t-test)</th>
</tr>
</thead>
<tbody>
<tr>
<td>ODI score (n = 51)</td>
<td>63.4</td>
<td>115.2</td>
<td>32.9</td>
<td>18.2</td>
<td>30.6</td>
<td>116.1</td>
<td>0.069</td>
</tr>
<tr>
<td>VAS score for back pain (n = 46)</td>
<td>7.0</td>
<td>2.3</td>
<td>4.6</td>
<td>6.4</td>
<td>2.4</td>
<td>6.2</td>
<td>0.013†</td>
</tr>
<tr>
<td>VAS score for leg pain (n = 46)</td>
<td>5.4</td>
<td>3.3</td>
<td>2.9</td>
<td>2.7</td>
<td>2.5</td>
<td>4.0</td>
<td>&lt;0.001†</td>
</tr>
<tr>
<td>Lumbar CCA, degrees (n = 40)</td>
<td>22.1</td>
<td>10.6</td>
<td>8.6</td>
<td>7.3</td>
<td>13.5</td>
<td>7.4</td>
<td>&lt;0.001†</td>
</tr>
<tr>
<td>TK, degrees (n = 59)</td>
<td>25.7</td>
<td>21.0</td>
<td>35.0</td>
<td>23.2</td>
<td>9.3</td>
<td>13.1</td>
<td>&lt;0.001†</td>
</tr>
<tr>
<td>LL, degrees (n = 59)</td>
<td>34.1</td>
<td>19.0</td>
<td>42.3</td>
<td>19.9</td>
<td>8.2</td>
<td>13.9</td>
<td>&lt;0.001†</td>
</tr>
<tr>
<td>PT, degrees (n = 59)</td>
<td>24.0</td>
<td>12.9</td>
<td>25.7</td>
<td>11.9</td>
<td>1.7</td>
<td>10.2</td>
<td>0.220</td>
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<tr>
<td>SVA, mm (n = 58)</td>
<td>43.0</td>
<td>55.9</td>
<td>40.8</td>
<td>51.9</td>
<td>2.2</td>
<td>54.1</td>
<td>0.767</td>
</tr>
<tr>
<td>LL-PI, degrees (n = 51)</td>
<td>16.8</td>
<td>15.8</td>
<td>8.2</td>
<td>15.9</td>
<td>8.6</td>
<td>14.6</td>
<td>&lt;0.001†</td>
</tr>
</tbody>
</table>

CCA = coronal Cobb angle; TK = thoracic kyphosis.
* For each variable, only patients with complete preoperative and postoperative data were analyzed.
† Statistically significant.
magnitudes of improvement in ODI, VAS back pain, and VAS leg pain scores (p = 0.117, p = 0.332, p = 0.136, respectively). Preoperatively, the HYB group had a larger SVA (mean 43.0 mm) than the cMIS group (mean 30.0 mm). Similarly, there was a greater LL-PI mismatch (mean 16.8° vs 10.2°) and lumbar coronal Cobb angle (mean 22.1° vs 19.7°) in the HYB group compared with the cMIS group. However, none of these baseline radiographic parameters were significantly different between groups (p > 0.05). Postoperatively, there was no statistical difference between groups with regard to change in lumbar coronal Cobb angle, LL, SVA, or LL-PI mismatch (p = 0.750, p = 0.488, p = 0.529, p = 0.592, respectively). Of note, while not statistically significant, there was a trend toward greater overall positive improvement in radiographic parameters achieved using the HYB surgical approach.

Comparison of perioperative characteristics showed a statistically significant difference between groups. Both operative time (mean 708.5 vs 452.4 minutes) and EBL (mean 1651.1 vs 552.4 ml) were higher for the HYB treatment group (p < 0.001). However, the mean length of stay in the HYB (mean 8.6 days) and cMIS (mean 8.7 days) groups was not significantly different (p = 1.00).

There was a higher percentage of complications in the HYB group (55%) than in the cMIS group (33%), and this was significant (p = 0.024). This difference remained significant when comparing major complications, with 7 events in the HYB group and 10 in the cMIS group (p = 0.032). Although there were more minor complications, with 14 in the HYB group compared with 4 in the cMIS group, the difference was not statistically significant (p = 0.205).

Discussion

Anand et al. first described the use of several different MIS techniques to treat lumbar scoliosis in 2008. In that initial report, a combination of LLIF, axial lumbar interbody fusion, and percutaneous segmental instrumentation was used in 12 patients with a mean scoliosis of 18.9°. Although the magnitude of the scoliosis treated was mild, that study demonstrated the feasibility of an MIS approach to treat ASD. In a subsequent study, Anand et al. evaluated 71 patients with scoliosis who underwent a similar MIS approach. A mean scoliosis of 24.7° was corrected to a mean of 9.5° and a mean SVA of 31.7 mm was corrected to 10.7 mm, with significant improvement in clinical outcomes as measured by the VAS pain score, ODI score, treatment intensity score, and 36-Item Short Form Health Survey. The mean follow-up was 39 months. In a small retrospective study, Benglis et al. reported on 4 patients with degenerative scoliosis who underwent LLIF. One of these patients also underwent supplemental open posterior instrumentation. The mean follow-up was 10 months, and an average presenting scoliosis of 28.5° improved to 18.3°. Dakwar et al. retrospectively reviewed 25 patients with degenerative scoliosis treated with LLIF. Twenty-three of these patients had additional instrumentation involving lateral plates in 15, pedicle screws in 7, and both lateral plate and pedicle screws in 1. The mean scoliosis treated was 21.1°, and at a mean follow-up of 11 months, significant improvements in VAS and ODI scores were noted. In another study, Wang and Mummaneni analyzed 23 patients who underwent MIS treatment for thoracolumbar scoliosis. An average scoliosis of 31.4° improved to 11.5° and, in contrast to previous studies, the change in LL averaged an increase of 8°. Significant improvements in VAS scores were noted at an average follow-up of 13.4 months. Park and La Marca evaluated 9 patients who underwent HYB treatment that included both minimally invasive and open surgical approaches to treat thoracolumbar scoliosis. A mean scoliosis of 47.8° was corrected to 15.2°, and LL improved from a mean of 41.8° to 46.9°. Preoperative SVA averaged 13 mm and changed minimally to an average of 11 mm postoperatively. Of note, in that series, patients presenting with increased SVA greater than 50 mm were not treated by the HYB approach.

The majority of studies involving MIS treatment of ASD has been limited by a focus on the coronal curvature rather than the sagittal spinopelvic alignment. More so than the coronal alignment, proper sagittal spinopelvic alignment has been shown as a key parameter in obtaining improved outcomes. Glassman et al. retrospectively reviewed prospectively acquired data in 298 patients with ASD. One hundred twenty-six of the 298 patients had un-

<table>
<thead>
<tr>
<th>Variable*</th>
<th>Preop Mean</th>
<th>SD</th>
<th>Postop Mean</th>
<th>SD</th>
<th>Change Mean</th>
<th>SD</th>
<th>p Value (paired t-test)</th>
</tr>
</thead>
<tbody>
<tr>
<td>ODI score (n = 30)</td>
<td>48.0</td>
<td>19.3</td>
<td>23.2</td>
<td>19.5</td>
<td>25.7</td>
<td>18.4</td>
<td>&lt;0.001†</td>
</tr>
<tr>
<td>VAS score for back pain (n = 36)</td>
<td>6.7</td>
<td>1.9</td>
<td>2.9</td>
<td>2.3</td>
<td>3.8</td>
<td>2.4</td>
<td>&lt;0.001†</td>
</tr>
<tr>
<td>VAS score for leg pain (n = 36)</td>
<td>6.0</td>
<td>2.5</td>
<td>1.8</td>
<td>2.2</td>
<td>4.2</td>
<td>2.6</td>
<td>&lt;0.001†</td>
</tr>
<tr>
<td>Lumbar CCA, degrees (n = 32)</td>
<td>19.7</td>
<td>11.9</td>
<td>9.4</td>
<td>7.5</td>
<td>10.3</td>
<td>9.6</td>
<td>&lt;0.001†</td>
</tr>
<tr>
<td>TK, degrees (n = 38)</td>
<td>30.1</td>
<td>14.5</td>
<td>36.6</td>
<td>15.6</td>
<td>6.6</td>
<td>9.8</td>
<td>&lt;0.001†</td>
</tr>
<tr>
<td>LL, degrees (n = 38)</td>
<td>41.2</td>
<td>13.6</td>
<td>44.1</td>
<td>13.1</td>
<td>6.6</td>
<td>10.0</td>
<td>0.076</td>
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<tr>
<td>PT, degrees (n = 35)</td>
<td>22.2</td>
<td>8.4</td>
<td>22.6</td>
<td>9.1</td>
<td>4.0</td>
<td>5.3</td>
<td>0.657</td>
</tr>
<tr>
<td>SVA, mm (n = 35)</td>
<td>30.0</td>
<td>54.1</td>
<td>32.1</td>
<td>70.1</td>
<td>2.1</td>
<td>50.1</td>
<td>0.805</td>
</tr>
<tr>
<td>LL-PI, degrees (n = 36)</td>
<td>10.2</td>
<td>15.6</td>
<td>8.0</td>
<td>14.4</td>
<td>2.2</td>
<td>10.4</td>
<td>0.217</td>
</tr>
</tbody>
</table>

* For each variable, only patients with complete preoperative and postoperative data were analyzed.
† Statistically significant.
deregone prior fusion surgery. Of the radiographic parameters studied, global sagittal alignment was the most critical factor, with statistically significant worse pain, function, and self-image reported by those patients with positive sagittal balance. Given the impact of the pelvis on sagittal alignment, pelvic parameters have also been found to influence outcomes. Lafage et al.\(^1\) prospectively evaluated 125 patients with ASD and showed that SVA and truncal inclination as well as PT correlated with health-related quality-of-life outcomes. Increased PT was associated with worse pain and function. In addition to PT, the LL-PI relationship has been analyzed, and an LL-PI mismatch of less than 11° has been proposed to positively influence outcomes.\(^1\) Based on these and other studies, it has been suggested that the ideal radiographic parameters consist of an SVA less than 50 mm, PT less than 20°, and an LL-PI mismatch of less than 10°.

In contrast to previous reports involving MIS treatment of ASD, our investigation evaluates the impact of 2 different MIS approaches on sagittal alignment, PT, and LL-PI mismatch in addition to coronal alignment. Both approaches resulted in a significant improvement in lumbar coronal Cobb angle, with a mean 13.5° correction in the HYB group and 10.3° correction in the cMIS group. In comparison, an average 26.6° (range 9.1°–53.1°) of curve correction was reported in a systematic review of open scoliosis surgery.\(^2\) Although the HYB and cMIS groups did not achieve the reported average in the systematic review, the degree of improvement was within the range of reported curve corrections for open surgery. Regarding spinopelvic parameters, the HYB approach resulted in a significant improvement in the LL-PI mismatch; however, there was not a significant change with the cMIS approach. Given that the mean LL-PI mismatch preoperatively in the cMIS group was near normal at a mean of 10.2, a significant change was not needed. Similarly, preoperative SVA and PT were a mean of 43.0 mm and 24.0° for the HYB group compared with 30.0 mm and 22.2° for the cMIS group, so large changes were not required in either group, which is likely reflected in the postoperative results. In an analysis of patients who underwent cMIS approaches, Anand et al.\(^1\) reported that the maximum SVA correction that could be achieved was 89 mm. In addition, the ability to correct the LL-PI mismatch to 10° was limited to cases in which the preoperative LL-PI mismatch was 38° or less. Hence, current MIS approaches have limited ability to correct SVA and LL-PI mismatches. The selected use of MIS approaches for ASD cases that do not require major corrections in SVA is in keeping with the MISDEF (minimally invasive spinal deformity surgery) algorithm that was recently published by Mummaneni et al.,\(^2\) therefore, the patients in this series were appropriately selected when viewed through the lens of the MISDEF algorithm.

Surgery for ASD is associated with significant risk for complications.\(^2\) In our study, the cMIS group suffered fewer major and minor complications, which may reflect the less invasive nature of the techniques used. However, it should be noted that preoperatively the HYB group had a mean of 1.6 more comorbidities than the cMIS group, which certainly could impact the complication rate. In addition, the HYB group had a mean of 1.8 more levels treated posteriorly. The increased number of fusion levels could have contributed to the significantly increased operative time and EBL noted with the HYB approach; however, it is likely that the less invasive nature of the cMIS approach was a factor as well.

Overall, both approaches resulted in significant clinical improvement. Although the HYB group had the biggest decrease in ODI scores, with a mean change of 30.6, the results only approached statistical significance. Conversely, the mean ODI score improvement of 25.7 for the cMIS group was highly significant. Both approaches resulted in highly significant decreases in VAS back and leg pain scores. Analysis between groups for ODI or VAS score did not statistically differ, suggesting similar degrees of improvement, which were similar in magnitude to outcomes reported for traditional open ASD surgery.\(^2\)

**Study Limitations**

As with any retrospective study, the limitations in this study are selection bias and incomplete data. Although the groups were similar with regard to demographics, radiographic parameters, baseline ODI and VAS scores, and number of interbody fusion levels, there was some selection bias, as reflected in the statistically significant difference between the groups with regard to the number of levels treated posteriorly (difference of 1.8 levels between groups) and number of comorbidities (difference of 1.6 between groups). In addition, complete pre- and postoperative information for all variables analyzed was not available for each patient. However, given the lack of any other previously reported comparative investigation, this study provides a worthwhile comparative analysis of the radiographic and clinical outcomes between 2 MIS treatment approaches for ASD. Ultimately, a prospective comparative investigation will be needed to provide definitive evidence as to the efficacy of MIS approaches.

**Conclusions**

Both the HYB and cMIS treatment approaches resulted in similar and significant clinical improvement, as evidenced by decreased ODI and VAS pain scores. Although, there was no significant difference in pre- and postoperative radiographic parameters between the groups, the HYB group had greater absolute improvement in degree of lumbar coronal Cobb angle correction, increased LL, decreased SVA, and decreased LL-PP. The rate of complications, however, was higher with the HYB approach than with the cMIS approach.

**References**


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**Author Contributions**

Conception and design: Park, Wang, Lafage, Okonkwo, Uribe, Eastlack, Anand, La Marca. Acquisition of data: all authors. Analysis and interpretation of data: Park, Wang, Lafage, Nguyen, Ziewacz, Eastlack, Deviren. Drafting the article: Lafage, Ziewacz. Critically revising the article: Park, Lafage. Reviewed submitted version of manuscript: all authors. Approved the final version of the manuscript on behalf of all authors: Park. Statistical analysis: Study supervision: Park, Wang, Lafage, Okonkwo, Uribe, Anand, Fessler, Kanter, La Marca, Mummaneni.

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