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# A Critical Analysis of Sagittal Plane Deformity Correction With Minimally Invasive Adult Spinal Deformity Surgery: A 2-Year Follow-Up Study

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## Abstract

**Introduction:** Sagittal plane realignment is important to achieve desirable clinical outcomes after adult spinal deformity (ASD) surgery. This study evaluates the impact of minimally invasive (MIS) techniques on sagittal plane alignment and clinical outcomes in ASD patients.
**Methods:** A retrospective, multi-center review of ASD patients (age ≥18 years, and with one of the following: coronal Cobb ≥20°, sagittal vertical axis [SVA] >5 cm, and/or pelvic tilt >25°), MIS surgery, and four or more levels instrumented. Patients were stratified by baseline SRS-Schwab global alignment modifier (GAM) into three groups: 0 (SVA <4 cm), + (SVA 4−9.5 cm), or ++ (SVA >9.5 cm). Radiographic and clinical outcomes measures were analyzed with a minimum of 2-year follow-up.

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**Results:** A total of 96 ASD patients were identified, and 63 met the study's inclusion criteria of circumferential MIS or posterior MIS only, with four or more levels instrumented (n: Group 0 = 37, Group + = 15, and Group ++ = 11). Group 0 was younger than ++ (56.8 vs. 69.6 years), with a higher proportion of females than Group + or ++ (83.8% vs. 66.7% and 54.5%, respectively).

Baseline HRQoL was similar. Postoperatively, Groups 0 and + had improved Oswestry Disability Index (ODI) and numeric rating scale (NRS) back and leg scores. Group ++ only had improvement in NRS scores. At the latest follow-up, Groups 0 and ++ had similar sagittal measurements except for PT (21.6 vs. 23.6, p = .009). The + group had improvement in PI−LL (24.2 to 17; p = .015) and LL (30.9 to 38.3; p = .013). Eight of 27 (21.6%) Group 0 patients deteriorated (4 to Group +, 4 to Group ++). Three of 15 (20.0%) Group + patients deteriorated to Group ++, and 3 improved to Group 0. Six of 11 (54.5%) Group ++ patients improved (3 to Group + and 3 to Group 0).

**Conclusions:** MIS techniques successfully stabilized ASD patients with Group 0 and + deformities and improved HRQoL. This study suggests that severe sagittal imbalance is not adequately treated with MIS approaches.


*Keywords:* Sagittal imbalance; Adult spinal deformity; Minimally invasive; Spine surgery

## Introduction

Over the past decade, there has been an expansion in the application of minimally invasive spine (MIS) surgery. The techniques have gained popularity because of their potential to minimize blood loss, decrease morbidity, expedite recovery, and reduce cost [1-6]. MIS surgery is attractive for the treatment of adult spinal deformity (ASD), in particular, given the high complication rates associated with traditional open approaches [7-9]. Although the field of MIS deformity correction is young, several studies have demonstrated favorable outcomes with reduction in morbidity and complication rates [10-14].

A variety of MIS techniques for the treatment of ASD have been described, and this variability remains a concern when discussing less-invasive approaches. We have defined the circumferential MIS (cMIS) technique as a minimally invasive means to achieve interbody fusion and posterior stabilization. Most commonly, interbody access is obtained either through a posterior paramedian, muscle-splitting transforaminal (MIS TLIF) approach, minimally invasive lateral transpsoas approach, or presacral approach for L5−S1 fusion (AxiaLIF). Posterior fixation is achieved with minimally invasive pedicle screw placement.

Sagittal malalignment is the principal cause of disability in ASD patients [15-17], and the restoration of sagittal balance is critical for durable clinical success [16,18,19]. Although the tissue-sparing approach of MIS surgery is believed to have benefit in ASD surgery, the ability to achieve alignment goals is less clear. Here we present a multicenter retrospective analysis of sagittal plane deformity correction using cMIS techniques.

## Methods

This study is a retrospective multicenter review of ASD patients undergoing MIS surgery from 2009 to 2012. Institutional review board approval was obtained at all participating sites. Patients were drawn from a multicenter retrospective database. Institutional review board approval was obtained at all participating sites. Inclusion criteria are age ⩾18 years, major coronal Cobb angle ⩾20°, sagittal vertical axis (SVA) ⩾5 cm, pelvic tilt ⩾25°, and/or thoracic kyphosis ⩾60°. Patients with spinal deformity resulting from neuromuscular conditions, tumor, or infection were excluded. Circumferential MIS (cMIS) and posterior-only MIS (pMIS) cases, with four or more levels instrumented, and a minimum of 2-year follow-up were included in the analysis. Patients were stratified using baseline SRS-Schwab global alignment modifier (GAM) into the following groups: 0 (SVA <4.0 cm), + (SVA 4.0−9.5 cm), or ++ (SVA >9.5 cm) (Fig. 1). Case examples of each group are shown in Figure 2.

Radiographic and health-related quality of life (HRQoL) measures were analyzed for all patients at baseline and 2-year follow-up. HRQoL measures included Oswestry Disability Index (ODI), and a numeric rating scale (NRS) of back and leg pain. Radiographic fusion was evaluated at each treated level with plain radiographs using the four-point Bridwell-Lenke grading system [20,21]. Patients with grades 1 and 2 for all treated levels were categorized as "confirmed fusion." Patients with grades 3 or 4 at one or more treated levels were categorized as "pseudoarthrosis." Statistical analysis was performed using SPSS software. Threshold for significance was set at p value less than .05. The Shapiro-Wilks test was used to assess normality of the data. Categorical variables were analyzed with chi-squared and continuous variables with analysis of variance (ANOVA) with the Bonferroni correction for multiple comparisons, and paired *t* test for pre to post assessment.

| Global Alignment Modifier | SVA (cm) |
|---|---|
| 0 | < 4.0 |
| + | 4.0 – 9.5 |
| ++ | > 9.5 |

Fig. 1. Patient stratification based on SRS-Schwab global alignment modifier.

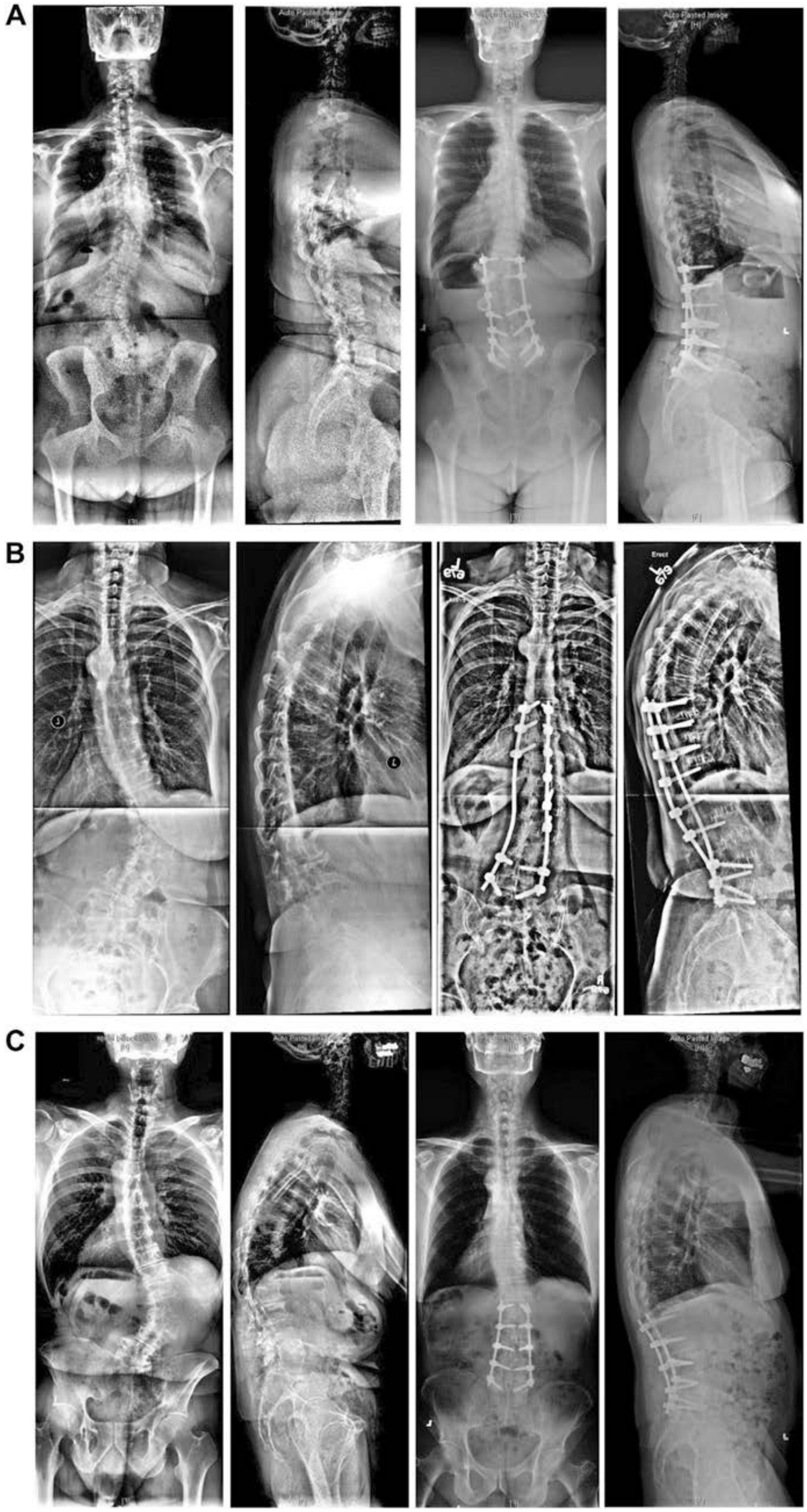

Fig. 2. Case examples of each global alignment modifier classification group with pre- and postoperative imaging.

## Results

### *Patient selection and baseline characteristics*

A total of 96 patients were queried for analysis, and 63 met all inclusion criteria (n: Group 0 = 37, Group + = 15, and Group ++ = 11). Patients had a mean follow-up of 35.3 months (22−64.5 months). The overall mean age was 60.7 years (19−84 years), and 74.6% of patients were female. Patients in Group 0 were significantly younger than those in Group ++ (56.8 vs. 69.6 years, $p < .05$, respectively; Table 1) and had a higher percentage of females than those in Groups + and ++ (83.9% vs. 66.7% and 54.5%, $p < .05$, respectively). The mean SVA was consistent with GAM stratification (Fig. 1). Patients in Groups + and ++ had lower mean lumbar lordosis (LL) and greater pelvic incidence−lumbar lordosis (PI−LL) mismatch than patients in Group 0 (LL: 30.9° and 34.3° vs. 45.7°, respectively; PI−LL: 24.2° and 24.9° vs. 6.3°, respectively, all $p < .05$). Patients in Group ++ had a higher pelvic tilt than patients in Group 0 (29.6° vs. 21.6°, $p < .05$). Maximum coronal Cobb angle (Max Cobb) was similar in all three groups, as were all baseline HRQoL outcome measures (ODI, NRS back, NRS Leg) (Table 1).

### *Treatment data*

The overall mean estimated blood loss (EBL) was 640.8 mL (50−2,950 mL). Mean total operative time was 460 minutes (180−931 minutes). The distribution of interbody approaches utilized in each group is listed in Table 2. Mean number of levels instrumented posteriorly was 6.4 (4−14 levels). Patients in the 0 and + groups were more likely to have instrumentation terminate distally at L5 or above, compared to patients in the ++ group. Overall, 38.1% of patients had their spines fused to the pelvis, with a significantly greater proportion of patients in Group ++ compared to Groups 0 and + (54.5% vs. 40.5% and 20%, respectively). The mean length of stay (LOS) was 8.4 days (range: 2−26 days; no difference between groups) (Table 2).

Table 1
Baseline radiographic and clinical parameters.

| | Group | | |
|---|---|---|---|
| SVA Schwab Modifier | 0 | + | ++ |
| n | 37 | 15 | 11 |
| Age, years | 56.8[a] | 63.7 | 69.6 |
| Gender, n females (% F) | 31 (83.8) | 10 (66.7) | 6 (54.5) |
| Pelvic tilt | 21.6[b] | 28.1 | 29.6 |
| PI−LL | 6.3[b] | 24.2 | 24.9 |
| SVA, mm | −1.7[b] | 67.1[a] | 116.2 |
| Lumbar lordosis | 45.7[c] | 30.9 | 34.3 |
| Max Cobb | 39.8 | 35.8 | 37.1 |
| ODI | 45.5 | 50.9 | 45.7 |
| NRS back | 6.5 | 6.8 | 6.8 |
| NRS leg | 6.2 | 5.0 | 5.4 |

LL, lumbar lordosis; NRS, numeric rating scale; ODI, Oswestry Disability Index; PI, pelvic incidence; PT, pelvic tilt; SVA, sagittal vertical axis.
[a] $p < .05$ compared to Group ++.
[b] $p < .05$ compared to Groups + and ++.
[c] $p < .05$ compared to Group +.

Table 2
Treatment data for each Schwab global alignment modifier group.

| | Group | | |
|---|---|---|---|
| SVA Schwab Modifier | 0 | + | ++ |
| Total EBL, mL | 614.7 | 471.7[a] | 959.1 |
| Total operation time, min | 465.6 | 380.3[a] | 549.8 |
| %Patients with LLIF | 78.4 | 86.7 | 81.8 |
| %Patients with TLIF | 24.3 | 33.3 | 27.3 |
| %Patients with ALIF | 2.7 | 0 | 9.1 |
| %Patients with AxiaLIF | 18.9 | 0 | 18.2 |
| No. of posterior levels instrumented | 6.7 | 5.6 | 6.4 |
| %Patients instrumented to L5 or above | 51.4[a] | 53.3[a] | 18.2 |
| %Patients instrumented to S1 or below | 48.6[a] | 46.7[a] | 81.8 |
| %Patients with iliac fixation | 8.1 | 6.7 | 9.1 |
| Total LOS, days | 8.2 | 8.4 | 9.0 |

AxiaLIF, axial lumbar interbody fusion; EBL, estimated blood loss; LLIF, lateral lumbar interbody fusion; LOS, length of stay; SVA, sagittal vertebral axis; TLIF, transforaminal lumbar interbody fusion.
[a] $p < .05$ compared to Group ++.

### *Radiographic and clinical outcomes*

At 2-year follow-up, Group 0 had no significant changes in sagittal alignment parameters (PI−LL, SVA, LL), except for pelvic tilt (21.6−23.6; $p = .009$) while Group + saw

Table 3
Mean clinical and radiographic outcomes at 2 years and changes from preoperative to 2-year follow-up.

| | Group | | |
|---|---|---|---|
| SVA Schwab Modifier | 0 | + | ++ |
| PT | 23.6 | 26.1 | 30.1 |
| Δ PT | −2[a] | −2 | 0.5 |
| PI-LL | 7.4[b] | 17 | 20.7 |
| Δ PI−LL | −0.6 | −7.1[a] | −4.2 |
| SVA | 5.9[c] | 63.5[b] | 111.1 |
| Δ SVA | 7.6 | −3.7 | −5.1 |
| LL | 45.1 | 38.3 | 39.3 |
| Δ LL | 0.5 | 7.4[a] | 5 |
| Max Cobb | 20 | 15.9 | 16.4 |
| Δ Cobb | −19.8[a] | −18.1[a] | −20.7[a] |
| Confirmed fusion (%) | 89.2 | 73.3 | 81.8 |
| ODI | 29.7 | 29.1 | 36 |
| Δ ODI | −15.3[a] | −21.8[a] | −9.7 |
| NRS back | 3.2 | 3.3 | 4.1 |
| Δ NRS back | −3.3[a] | −3.5[a] | −2.6[a] |
| NRS leg | 4.4 | 2.4 | 3.9 |
| Δ NRS leg | −2[a] | −2.6[a] | −1.6 |

LL, lumbar lordosis; NRS, numeric rating scale; ODI, Oswestry Disability Index; PI, pelvic incidence; PT, pelvic tilt; SVA, sagittal vertical axis.
[a] $p < .05$ change pre-to postoperative.
[b] $p < .05$ compared to Group ++.
[c] $p < .05$ compared to Groups + and ++.

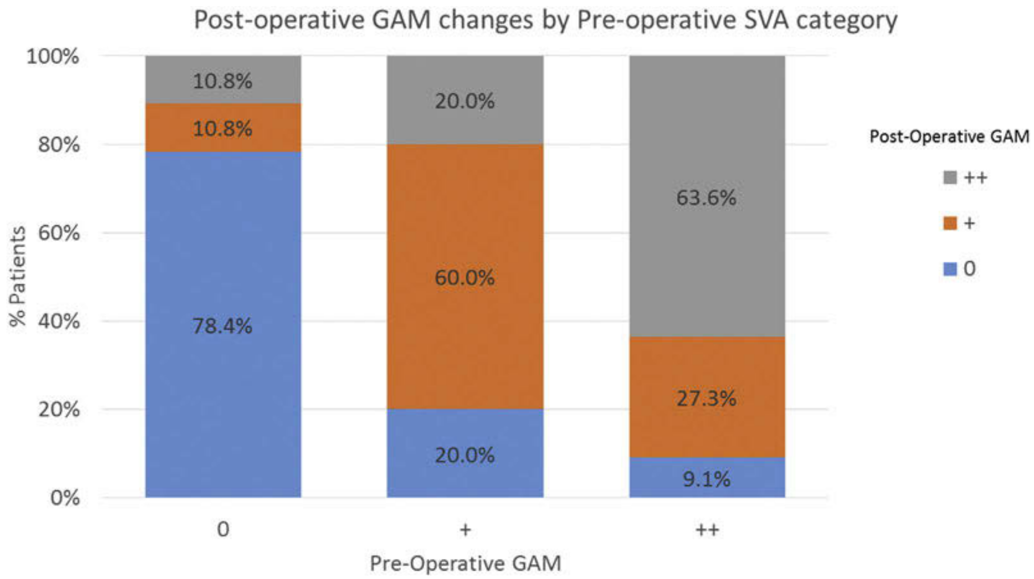


Fig. 3. Postoperative change in global alignment modifier classification.

improvements in PI−LL (24.2 to 17; p = .015) and LL (30.9−38.3; p = .0133). All three groups, 0, +, and ++, had significant improvement in max Cobb (−19.8°, −18.1°, and −20.7°, respectively). The overall fusion rate was 84.1%; there was no statistically significant difference in fusion between groups (p = .357). Clinically, Groups 0 and + improved in all HRQoL measures (ODI, NRS back, and NRS leg) at the 2-year follow-up. Group ++ had improvement in NRS back but not in ODI or NRS leg (Table 3).

The postoperative change in GAM is illustrated in Figure 3. In Group 0, 78.4% of patients remained in 0, and 10.6% of patients deteriorated to +, as well as 10.6% to ++. In Group +, 60% of patients remained +, whereas 20% deteriorated to ++, and 20% improved to 0. Finally, in Group ++, 63.6% of patients remained ++, whereas 27.3% improved to +, and 9.1% improved to 0.

## Discussion

With the promise of safer surgery and faster recovery, minimally invasive approaches to the spine have generated significant enthusiasm by clinicians and patients alike. A growing body of literature demonstrating favorable results, particularly with short-segment instrumentation, has helped the field of MIS surgery gain more acceptance in the spine community [2,4-6]. The application of these techniques to ASD is a newer venture and continues to rapidly evolve as the various technical challenges are addressed.

The benefits of MIS surgery are attributed to tissue-sparing corridors, and this fundamental principle is also the primary obstacle to effective deformity correction. Adult spinal deformity patients often have rigid, deformed spines, which require significant tissue disruption to adequately release the spine for realignment purposes; this can be difficult to accomplish with limited MIS exposures. Although the muscle-stripping techniques of open posterior surgery are considered more invasive, the exposure facilitates extensive bony, ligamentous, and interbody release. Furthermore, with the open approach, powerful corrective maneuvers can be more easily executed while minimizing the stress and strain on the spinal fixation. These factors contribute to the more extensive corrections that can be accomplished with traditional deformity surgery, and the limitations that may be encountered with MIS surgery.

This study sought to evaluate the impact of cMIS surgery on the global sagittal profile of ASD patients. SRS-Schwab global alignment modifier was used as the primary end point. Although the majority of patients with normal preoperative SVA maintained normal alignment postoperatively (82.4% of patients remained in Group 0), the majority of patients with preoperative sagittal imbalance did not improve their GAM after surgery (76.2% and 64.3% in Groups + and ++, respectively). Interestingly, however, patients with intermediate SVA values (4.5−9 cm) had significant improvement in HRQOL at the 2-year follow-up when their deformities were stabilized. Conversely, those with severe sagittal imbalance (Group ++) failed to improve clinically, in addition to significantly higher blood loss and longer operating time. An equivalent study evaluating change in GAM using standard open techniques, particularly for patients with severe sagittal imbalance, would be a useful standard for comparison, but has not yet been conducted. Nonetheless, there are multiple studies that have demonstrated a greater ability to restore the sagittal profile with severe sagittal imbalance than was achieved in this study, particularly when three-column osteotomies are employed [22-25]. Of note, patients in Group ++ were found to be significantly older than patients in Group 0 (69.6 vs. 56.8 years, respectively), which implies that these groups may represent different patient populations. Older patients often have more rigid deformities with poor bone quality and this could have influenced the results. Age matching may have been helpful to better understand the influence of age, but this was not possible in this study because of the relatively small sample size.

Maximum coronal Cobb angle improved in all three groups, though less than 50% correction of the baseline Cobb was achieved. The magnitude of correction in this study is consistent with previous reports utilizing minimally invasive techniques for ASD [26]. Nonetheless, correction of Cobb angle appears to be less impactful on quality of life than establishing normal sagittal alignment [15,17], and likely did not a have a substantial impact on the clinical outcomes.

The results of this study suggest that severe sagittal imbalance is inadequately treated with MIS surgery. This may relate to an underestimation of the severity of the deformity and/or an overestimation of the realignment power of the selected techniques. Furthermore, the database represents the experience of the surgeons earlier in the learning curve of MIS techniques (2009−2012). Other MIS techniques, which have been under development over recent years, may be more effective in achieving sagittal realignment than those used in this study. In 2014, Wang and Madhavan [27] described a mini-open approach for pedicle subtraction osteotomy, as a means of achieving greater sagittal correction without requiring a midline, open approach. Another example is anterior column realignment (ACR) surgery, which has generated promising results. ACR surgery involves release of the anterior longitudinal ligament and placement of a hyperlordotic cage through a minimally invasive lateral transpsoas approach, and is able to provide focal sagittal plane correction of approximately 15°−30°, and has the ability to correct severe global sagittal imbalance [28-30]. It is possible that greater radiographic outcomes and clinical success would have been achieved if these techniques had been employed in the more severely imbalanced patients. Alternatively, patients with more severe sagittal plane deformities may be better served with hybrid surgeries involving both MIS lateral and open approaches, or more traditional open surgical techniques to optimize radiographic realignment, and ultimately improve our patients' function and quality of life. The radiographic goals need to be evaluated in lieu of operative and perioperative risk associated with open posterior approaches [11,14,26].

This study has several limitations, most prominently the design-related issues that are common to retrospective studies, including various confounders, selection bias, and reporting bias. Additionally, this study represents a heterogeneous patient population treated with non-standardized MIS techniques.

The field of MIS deformity surgery remains in its infancy. As with all new surgical techniques, improved outcomes are expected as the technology evolves, surgeon experience expands, and clinical research provides new insight. As the field continues to grow, it is imperative that the MIS deformity surgeon be well trained in both MIS and open approaches so that the proper surgery can be tailored to the individual patient and clinical outcomes optimized.

## Conclusions

In the current study, MIS surgery for adult spinal deformity was more effective in patients with no or minimal sagittal plane deformity. In patients with significant sagittal plane deformity (SVA >9.5 cm), only 9.1% of patients had restoration of sagittal plane spinal alignment. ASD patients with severe sagittal plane deformities failed to achieve radiographic or clinical success, leaving them with a fixed sagittal plane deformity. While tissue-sparing benefits of MIS deformity surgery are attractive, techniques must be selected in the context of alignment goals to ensure that patient outcomes are not compromised, particularly for patients with severe sagittal imbalance.

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