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# Does Minimally Invasive Percutaneous Posterior Instrumentation Reduce Risk of Proximal Junctional Kyphosis in Adult Spinal Deformity Surgery? A Propensity-Matched Cohort Analysis

**BACKGROUND:** Proximal junctional kyphosis (PJK) is a known complication after spinal deformity surgery. One potential cause is disruption of posterior muscular tension band during pedicle screw placement.

**OBJECTIVE:** To investigate the effect of minimally invasive surgery (MIS) on PJK.

**METHODS:** A multicenter database of patients who underwent deformity surgery was propensity matched for pelvic incidence (PI) to lumbar lordosis (LL) mismatch and change in LL. Radiographic PJK was defined as proximal junctional angle >10°. Sixty-eight patients made up the circumferential MIS (cMIS) group, and 68 were in the hybrid (HYB) surgery group (open screw placement).

**RESULTS:** Preoperatively, there was no difference in age, body mass index, PI-LL mismatch, or sagittal vertical axis. The mean number of levels treated posteriorly was 4.7 for cMIS and 8.2 for HYB ($P < .001$). Both had improved LL and PI-LL mismatch postoperatively. Sagittal vertical axis remained physiological for the cMIS and HYB groups. Oswestry Disability Index scores were significantly improved in both groups. Radiographic PJK developed in 31.3% of the cMIS and 52.9% of the HYB group ($P = .01$). Reoperation for PJK was 4.5% for the cMIS and 10.3% for the HYB group ($P = .20$). Subgroup analysis for patients undergoing similar levels of posterior instrumentation in the cMIS and HYB groups found a PJK rate of 48.1% and 53.8% ($P = .68$) and a reoperation rate of 11.1% and 19.2%, respectively ($P = .41$). Mean follow-up was 32.8 months.

**CONCLUSION:** Overall rates of radiographic PJK and reoperation for PJK were not significantly decreased with MIS pedicle screw placement. However, a larger comparative study is needed to confirm that MIS pedicle screw placement does not affect PJK.

**KEY WORDS:** Adult spinal deformity, Hybrid surgery, Kyphosis, Minimally invasive spine surgery, Spinal fusion

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Advances in the understanding of adult spinal deformity suggest that sagittal plane deformity is associated with significant morbidity.[1-3] Surgical techniques (osteotomies) can provide aggressive correction in this plane; however, these procedures have been reported to have a considerable rate of complication.[3-11] One of the most frustrating complications is proximal junctional kyphosis (PJK), which can have a significant impact on the patient, potentially requiring further treatment. Radiographically, PJK is defined as >10° kyphosis in the proximal junction as measured by Cobb angle of the caudal endplate of the uppermost instrumented vertebra (UIV) to the cephalad endplate of the vertebra 2 segments superior to it.[5,10] PJK can be caused by bone-pedicle screw interface failure at the UIV, a compression fracture of the UIV or the level above (UIV+1), diskoligamentous failure at the UIV, or facet listhesis at the UIV. The incidence of PJK in

**ABBREVIATIONS: cMIS,** circumferential minimally invasive surgery; **HYB,** hybrid; **LL,** lumbar lordosis; **MIS,** minimally invasive surgery; **PI,** pelvic incidence; **PJK,** proximal junctional kyphosis; **PPI,** percutaneous posterior instrumentation; **SVA,** sagittal vertical axis; **UIV,** uppermost instrumented vertebra; **VAS,** Visual Analog Scale patients treated for adult deformity may exceed 25%.[5,12] In most patients, PJK remains a radiographic complication without a significant impact on outcome. However, some of the patients who develop radiographic PJK may develop pain, neurological deficits, and the inability to walk upright, symptoms consistent with proximal junctional failure.[11,13,14]

Risk factors for development of PJK include severity of the preoperative deformity and the amount of lordosis correction.[15,16] One potential contributor to the development of PJK is damage to the paraspinal musculature, facet joints, and intervertebral stabilizers, which likely occurs in open surgical exposures.[15] We theorized that the use of minimally invasive posterior pedicle screw instrumentation limits dissection of the posterior muscular tension band and may decrease the incidence of PJK compared with open pedicle screw placement. In this study, we compare patients with spinal deformity who underwent either posterior percutaneous instrumentation or open pedicle screw instrumentation to assess whether patients treated with posterior percutaneous instrumentation demonstrate a lower rate of PJK compared with those treated with open instrumentation.

## METHODS

Data from a multicenter database were reviewed retrospectively. All patients had preoperative and postoperative 36-in standing anteroposterior and lateral spinal radiographs, and all had preoperative and postoperative Oswestry Disability Index scores.

Inclusion criteria for this study were a diagnosis of adult spinal deformity and age ≥18 years with at least 1 of the following radiographic parameters: Cobb angle ≥20°, pelvic tilt >25°, sagittal vertical axis (SVA) >5 cm, or thoracic kyphosis >60°, in addition to a minimum 2 years of follow-up. Preoperative and postoperative radiographic measurements, age, sex, body mass index, smoking, level of UIV, and clinical outcomes were analyzed.

One hundred ninety patients were identified and divided into the circumferential minimally invasive surgery (cMIS) patient group (n = 104), who had undergone either transforaminal lumbar interbody fusion or lateral interbody fusion with posterior percutaneous screw instrumentation, or the hybrid (HYB) patient group (n = 86), who underwent lateral interbody fusion followed by open posterior instrumentation.

In an effort to account for the severity of preoperative deformity and the amount of lordosis correction (2 risk factors for developing PJK), patients from the database were propensity matched for preoperative pelvic incidence (PI) to lumbar lordosis (LL) mismatch and change in LL. Propensity matching allowed the 2 groups to be quite similar in these parameters, which are known risk factors for the development of PJK. Only 2 covariates were chosen to maintain power in this relatively large data set because increasing covariates would decrease sample size as more restrictions were added. Propensity scores were calculated by linear regression, and 68 patients in each group were found to be similar within the 2 parameters.

Each participating institution received approval from its Institutional Review Board. In addition, all participating institutions entered into a data-sharing agreement.

### Radiographic Measurements

On lateral 36-in x-rays, SVA was measured as the offset from the C7 plumb line to the posterior-superior endplate of S1 (Figure 1). LL was measured from the upper endplate of L1 to the upper endplate of S1. PI was measured as the angle subtended by a perpendicular line from the cephalad endplate of S1 and a line connecting the center of the femoral head to the midpoint of the cephalad endplate of S1. The LL-PI mismatch can then be calculated by subtracting LL magnitude from the PI (PI-LL mismatch). Pelvic tilt was defined by the angle subtended by a line connecting the midpoint of the S1 endplate to axis center of the femoral heads and the vertical plane. The major Cobb angle was measured as the angle subtended by the intersection of lines along the vertebral body endplates of the largest coronal curve.

### Proximal Junctional Kyphosis

The proximal junctional angle was defined as the sagittal Cobb angle measurement between the inferior endplate of the UIV to the superior endplate 2 vertebrae above (UIV + 2). Abnormal radiographic PJK was defined as proximal junctional angle >10° and at least 10° greater than the corresponding preoperative measurement.

### Clinical Outcomes

Patient-reported outcomes were used to determine treatment effectiveness. The Oswestry Disability Index was used to evaluate functional outcomes, and the Visual Analog Scale (VAS) was used to assess back and leg pain.

### Statistical Analysis

Mean and standard deviation were used to describe continuous variables, and frequency analyses were used for categorical variables. Comparisons between cMIS and HYB groups were carried out with an unpaired *t*-test and a $\chi^2$ analysis. Changes between preoperative and postoperative parameters were analyzed with a paired *t* test. A value of $P < .05$ with a confidence interval of 95% was considered statistically significant. All analyses were performed with SPSS software (SPSS, Inc, Chicago, Illinois). Data were statistically

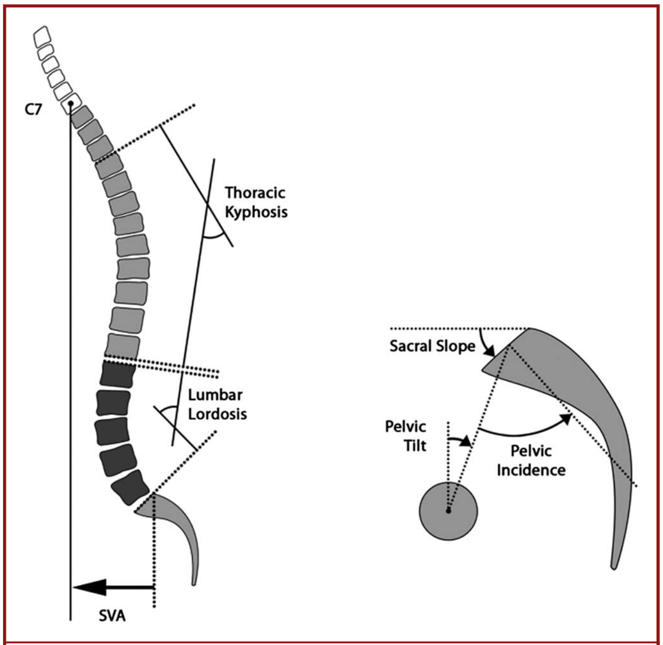


**FIGURE 1.** *Illustration of basic sagittal plane and pelvic radiographic parameters. SVA, sagittal vertical axis.*

**TABLE 1. Preoperative Radiographic Parameters[a]**

| | cMIS Group | | HYB Group | | |
|---|---|---|---|---|---|
| | Mean | SD | Mean | SD | *P* Value, Unpaired *t* test |
| Maximum coronal Cobb angle, ° | 36.6 | 15.3 | 44.4 | 17.3 | .01 |
| Thoracic kyphosis, ° | 31.5 | 15.7 | 29.5 | 13.4 | .42 |
| LL, ° | 37.8 | 16.0 | 39.2 | 18.2 | .64 |
| Pelvic tilt, ° | 24.7 | 10.7 | 23.9 | 10.5 | .66 |
| PI, ° | 53.9 | 11.5 | 56.1 | 13.5 | .32 |
| SVA, mm | 40.2 | 53.3 | 49.8 | 57.3 | .32 |
| PI-LL mismatch, ° | 16.2 | 15.1 | 16.9 | 17.7 | .78 |

[a]cMIS, circumferential minimally invasive surgery; HYB, hybrid; LL, lumbar lordosis; PI, pelvic incidence; SVA, sagittal vertical axis.

analyzed by an independent researcher who was not involved in the surgical treatment of study patients.

## RESULTS

### Patient Demographics

There were 68 adult patients with deformity (17 male and 51 female) in the cMIS group and 68 adult patients with deformity (17 male and 51 female) in the HYB group. The 2 groups were matched for preoperative LL-PI mismatch and change in LL. Mean age of the cMIS group was 59.5 years (SD = 12 years), and the mean age of the HYB group was 62.7 years (SD = 11 years) without any significant difference between groups ($P = .11$). The cMIS group had a mean body mass index (27.0 kg/m$^2$) similar to that of the HYB group (27.2 kg/m$^2$; $P = .81$).

The cMIS and HYP groups had similar numbers comorbidities (1.9 for cMIS, 2.0 for HYB; $P = .86$). There was no significant difference in preoperative American Society of Anesthesiologists Physical Status scores between groups (2.4 for cMIS, 2.2 for HYB; $P = .13$). There were 5 smokers in the cMIS group and 8 in the HYB group ($P = .28$).

The number of patients who had prior spine surgery was 16 (23.5%) in the cMIS group and 19 (27.9%) in the HYB group ($P = .35$).

### Radiographic Analysis

As expected with the propensity-matching process, preoperatively, there was no significant difference between the cMIS and HYB groups in terms of PI or PI-LL mismatch (16.2° for cMIS, 16.9° for HYB; Table 1). There were also no significant differences for any of the other sagittal spinopelvic parameters. The cMIS group had a significantly smaller coronal Cobb angle (36.6°) than the HYB group (44.4°; $P = .01$).

Comparison of preoperative and postoperative radiographic measurements revealed significant improvement in LL (cMIS, 37.8° preoperatively to 42.5° postoperatively; HYB, 39.2° preoperatively to 46.6° postoperatively; $P < .001$), PI-LL (cMIS, 16.2° preoperatively to 11.5° postoperatively; HYB, 16.9° preoperatively to 10.0° postoperatively; $P < .001$), and thoracic kyphosis (cMIS, 31.5° preoperatively to 37.0° postoperatively; HYB, 29.5° preoperatively to 38.0° postoperatively) for both groups. SVA remained physiological for both groups (cMIS, 40.2 mm preoperatively to 35.1 mm postoperatively; HYB, 49.8 mm preoperatively to 45.2 mm postoperatively; $P > .05$).

Postoperatively, there was no significant difference between the cMIS and HYB groups in any of the sagittal spinopelvic parameters (Table 2).

**TABLE 2. Postoperative Radiographic Parameters[a]**

| | cMIS Group | | HYB Group | | |
|---|---|---|---|---|---|
| | Mean | SD | Mean | SD | *P* Value, Unpaired Test |
| Maximum coronal Cobb angle, ° | 20.6 | 11.9 | 17.6 | 10.9 | .16 |
| Thoracic kyphosis, ° | 37.0 | 17.3 | 38.0 | 13.8 | .73 |
| LL, ° | 42.5 | 14.2 | 46.6 | 15.5 | .11 |
| Pelvic tilt, ° | 24.0 | 10.6 | 23.5 | 10.5 | .80 |
| PI, ° | 53.8 | 11.2 | 56.7 | 13.3 | .18 |
| SVA, mm | 35.1 | 64.4 | 45.2 | 55.3 | .33 |
| PI-LL mismatch, ° | 11.5 | 13.7 | 10.0 | 16.9 | .57 |

[a]cMIS, circumferential minimally invasive surgery; HYB, hybrid; LL, lumbar lordosis; PI, pelvic incidence; SVA, sagittal vertical axis.

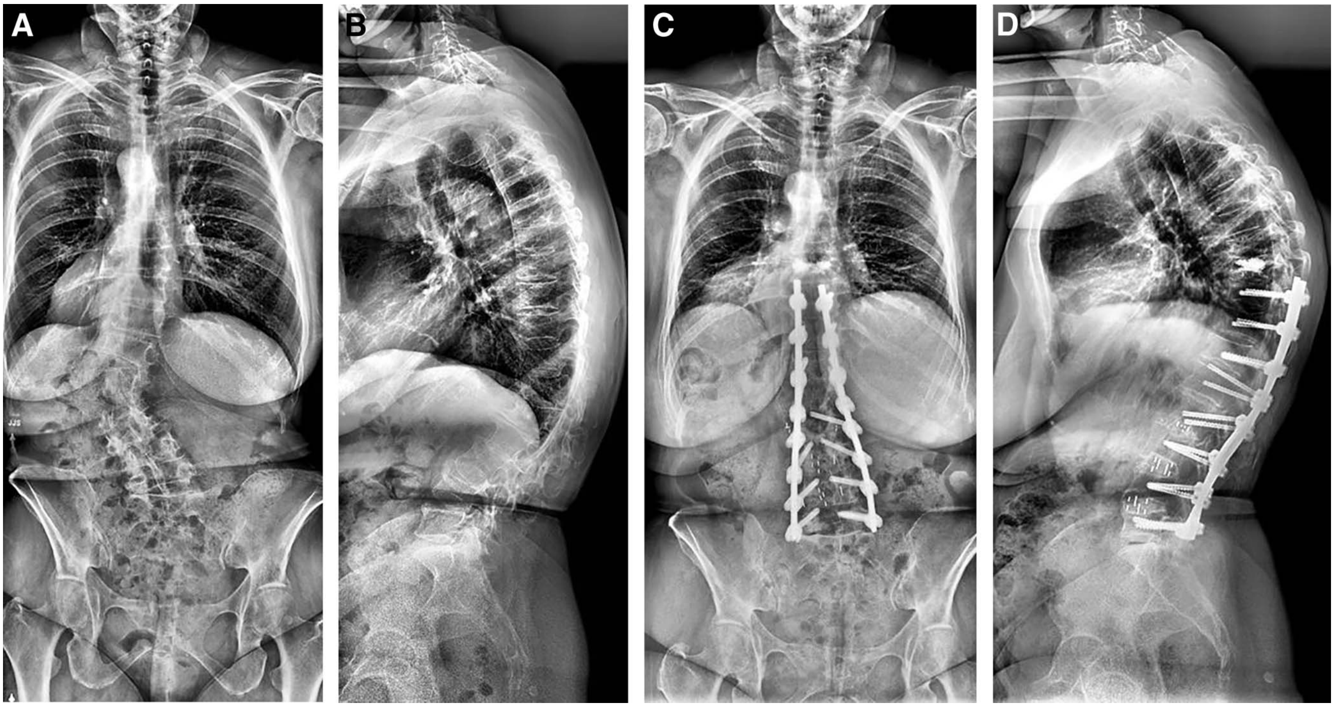


**FIGURE 2.** **A** *and* **B**, *baseline anteroposterior and lateral scoliosis x-rays.* **C** *and* **D**, *anteroposterior and lateral scoliosis x-rays at the 2-year follow-up visit showing kyphoplasty performed for proximal junctional kyphosis.*

Analysis of the junctional segment revealed that the cMIS group had a smaller change in proximal junctional angle (+7.0°) than did the HYB group (+10.8°; $P = .005$). Radiographic PJK developed in 21 patients (30.9%) in the cMIS group and in 36 (52.9%) in the HYB group ($P = .01$). Three patients (4.4%) in the cMIS group required revision surgery for PJK compared with 7 (10.3%) in the HYB group ($P = .20$; Figure 2).

**TABLE 3.** **Distribution of Uppermost Instrumented Vertebra by Group**[a]

| Uppermost Instrumented Vertebra | cMIS Group (n = 61), n (%) | HYB Group (n = 67), n (%) |
|---|---|---|
| T3 | 0 (0.0) | 7 (10.4) |
| T4 | 2 (3.3) | 7 (10.4) |
| T5 | 1 (1.6) | 2 (3.0) |
| T6 | 0 (0.0) | 0 (0.0) |
| T7 | 0 (0.0) | 1 (1.5) |
| T8 | 1 (1.6) | 1 (1.5) |
| T9 | 3 (4.9) | 8 (11.9) |
| T10 | 8 (13.1) | 12 (17.9) |
| T11 | 4 (6.6) | 10 (14.9) |
| T12 | 11 (18.0) | 4 (6.0) |
| L1 | 10 (16.4) | 4 (6.0) |
| L2 | 12 (19.7) | 2 (3.0) |
| L3 | 3 (4.9) | 1 (1.5) |
| L4 | 3 (4.9) | 3 (4.5) |
| L5 | 3 (4.9) | 5 (7.5) |

[a]cMIS, circumferential minimally invasive surgery; HYB, hybrid.

## Clinical Outcomes

Preoperatively, the cMIS group reported scores similar to those of the HYB group for both VAS back pain (6.6 for cMIS, 6.9 for HYB; $P = .40$) and Oswestry Disability Index (46.7 for cMIS, 52.5 for HYB; $P = .06$). There was no significant difference in terms of preoperative VAS leg pain scores between groups (5.8 for cMIS, 5.3 for HYB; $P = .39$).

After surgery, both groups had improved Oswestry Disability Index (−13.6 for cMIS, −15.5 for HYB; both $P < .001$), VAS back pain scores (−3.0 for cMIS, −3.1 for HYB; both $P < .001$), and VAS leg pain scores (−2.8 for cMIS, −2.2 for HYB) without any significant difference between groups.

## Surgical Procedures

The mean number of levels fixated posteriorly with pedicle screws was 4.7 for the cMIS group and 8.2 for the HYB group ($P < .001$). There was no significant difference in terms of number of intervertebral levels fused with cages between the groups (3.4 for both groups; $P = .94$). There was a wide distribution in UIV between groups, with the majority of HYB

**TABLE 4. Levels Fused, Estimated Blood Loss, and Operating Room Times by Approach[a]**

| | cMIS Group | | HYB Group | | |
|---|---|---|---|---|---|
| | Mean | SD | Mean | SD | P Value |
| Levels treated posteriorly, n | 4.7 | 3.3 | 8.2 | 4.4 | <.001 |
| Levels fused via lumbar interbody fusion, n | 3.4 | 1.7 | 3.4 | 1.5 | .94 |
| Total estimated blood loss, mL | 478.1 | 446.0 | 1471.2 | 1202.2 | <.001 |
| Total operating room time, minutes | 406.6 | 168.0 | 693.1 | 267.8 | <.001 |

[a]cMIS, circumferential minimally invasive surgery; HYB, hybrid.

patients having instrumentation end above T12 compared with the majority of cMIS patients with proximal instrumentation ending between T12 and L2 (Table 3). Fusion to the sacrum occurred in 48 HYB patients (71.6%) compared with 29 cMIS patients (46.8%; $P = .001$). Analysis of the estimated blood loss revealed that the cMIS group had significantly less intraoperative blood loss (478.1 mL) than the HYB group (1471 mL; $P < .001$). Total mean operating room time was 406 minutes for the cMIS group and 693 minutes for the HYB group ($P < .001$; Table 4).

### Subgroup Analysis

Given that the length of fusion could affect PJK occurrence, a separate subgroup analysis of patients with a similar number of instrumented levels was performed. Twenty-seven cMIS patients who had a mean of 6.4 levels instrumented posteriorly were compared with 26 HYB patients who had a mean of 7.0 levels instrumented posteriorly ($P = .08$; Table 5). Estimated blood loss and operating room time remained significantly higher for the HYB group. As shown in Tables 6 and 7, preoperative and postoperative radiographic parameters were not significantly different between groups. The UIV also was not significantly different between groups ($P = .18$; Table 8). Fifteen cMIS patients (55.6%) compared with 13 HYB patients (50.0%) had fusion to the sacrum ($P = .69$). Thirteen cMIS patients (48.1%) and 14 HYB patients (53.8%) had radiographic PJK ($P = .68$). Of these patients, 3 cMIS patients (11.1%) and 5 HYB patients (19.2%) required revision surgery for PJK ($P = .41$).

## DISCUSSION

PJK is a major potential complication of adult spinal deformity surgery.[5,13] Risk factors for postoperative development of PJK include patient age and bone quality. Another potential contributor to PJK is a substantial preoperative LL-PI mismatch requiring a large magnitude of correction to restore global alignment. Furthermore, the level of the UIV may play a role because the UIV for many deformity cases ends at the thoracolumbar junction, a transition zone between the mobile lumbar spine and the less mobile thoracic spine and rib cage. It is also possible that body mass index may contribute to the development of PJK in that the UIV may be biomechanically stressed in larger patients.

Some have suggested that preservation of the posterior soft tissue envelope (paraspinal muscles and ligamentous structures) may help prevent PJK. This theory arose after the observation that PJK is seen less frequently with anterior spinal fusion than with posterior spinal fusion.[17] Consequently, factors such as prior posterior surgery with scar tissue formation may affect the incidence of postoperative PJK. We theorized that the use of MIS with posterior pedicle screw instrumentation rather than the standard open dissection approach for pedicle screw placement may limit iatrogenic injury to the paraspinal muscles and ligaments and decrease the incidence of PJK.

We used propensity matching to analyze 2 similar groups of patients in an attempt to isolate the effect of the posterior instrumentation technique on development of PJK. The groups did not have significant differences in age, sex, tobacco use, body mass index, or number of prior surgeries. Preoperative radiographic parameters, including LL, PI, LL-PI mismatch,

**TABLE 5. Levels Fused, Estimated Blood Loss, and Operating Room Times by Approach for Subgroups[a]**

| | cMIS Subgroup (n = 27) | | HYB Subgroup (n = 26) | | |
|---|---|---|---|---|---|
| | Mean | SD | Mean | SD | P Value |
| Levels treated posteriorly, n | 6.4 | 1.2 | 7.0 | 1.0 | .08 |
| Levels fused via lumbar interbody fusion, n | 4.6 | 1.6 | 3.8 | 1.2 | .06 |
| Total estimated blood loss, mL | 600.0 | 466.8 | 1319.0 | 1184.2 | .003 |
| Total operating room time, minutes | 469.8 | 175.7 | 680.7 | 268.8 | .003 |

[a]cMIS, circumferential minimally invasive surgery; HYB, hybrid.

**TABLE 6. Preoperative Radiographic Parameters for Subgroups[a]**

| | cMIS Subgroup (n = 27) | | HYB Subgroup (n = 26) | | |
|---|---|---|---|---|---|
| | Mean | SD | Mean | SD | *P* Value, Mann-Whitney *U* Test |
| Maximum coronal Cobb angle, ° | 39.8 | 13.2 | 38.9 | 13.7 | .96 |
| Thoracic kyphosis, ° | 32.2 | 14.7 | 31.3 | 15.2 | .86 |
| LL, ° | 33.9 | 17.4 | 37.7 | 21.7 | .14 |
| Pelvic tilt, ° | 28.1 | 21.6 | 24.3 | 11.6 | .35 |
| PI, ° | 53.9 | 13.0 | 53.5 | 15.0 | .96 |
| SVA, mm | 44.7 | 51.5 | 40.9 | 51.5 | .89 |
| PI-LL mismatch, ° | 20.0 | 17.3 | 15.8 | 20.4 | .29 |

[a]cMIS, circumferential minimally invasive surgery; HYB, hybrid; LL, lumbar lordosis; PI, pelvic incidence; SVA, sagittal vertical axis.

thoracic kyphosis, pelvic tilt, and SVA, were also similar between groups.

However, perfectly matched groups are difficult to create, and there was a small difference in preoperative coronal Cobb angle. Although both groups had a mean of 4 interbody fusions, the mean number of levels fused posteriorly was 4.7 for the cMIS group and 8.2 for the HYB group. Postoperatively, both groups had significant improvements in LL and PI-LL, and there was no significant difference between the cMIS and HYB groups in any of the sagittal spinopelvic parameters. However, there were significant differences in several other radiographic parameters, including a significant increase in thoracic kyphosis in the HYB group. In addition, the magnitude of correction of the SVA was higher in the HYB group than in the cMIS group. Analysis of the junctional segment revealed that overall the cMIS group had a significantly smaller change in proximal junctional angle (+7°) than the HYB group (+10.8°). In regard to PJK, there was a significantly decreased rate of radiographic PJK in the cMIS group. However, there was no statistically significant difference in reoperation rate for PJK, although there was a higher incidence of 10.3% in the open pedicle screw group vs 4.5% in the percutaneous fixation group.

To better evaluate the impact of fusion length on PJK, a subgroup analysis was also performed in which the number of levels treated was not statistically different between the cMIS and HYB groups. Within the subgroup analysis, there was no statistical difference in baseline or postoperative radiographic parameters between groups. The subgroup analysis (in which the fusion length was similar between groups) also revealed that the rate of PJK and the rate of reoperation for PJK remained lower in the cMIS group compared with the HYB group. However, these findings did not reach statistical significance. The subgroup analysis may be underpowered to detect a difference because of the smaller sample size of the subgroups. It may be that a larger sample size is necessary to detect a true difference.

Beyond fusion length, the stopping points for fusion have been thought to affect PJK. Some have suggested that ending the UIV in the thoracolumbar region leads to a higher rate of PJK than ending the UIV in the upper thoracic region.[18] Other studies, however, have shown no statistical difference in PJK whether the UIV was in the upper thoracic or lower thoracic spine.[19,20] Although the UIV varied between the HYB and cMIS groups in the initial analysis, there was no significant difference in UIV between subgroups. Consequently, the UIV likely did not affect the results of the subgroup analysis on rate of PJK. In addition, fusion to the sacrum has been implicated as a risk factor for PJK.[21] Because fusion rates to the sacrum were similar between subgroups, fusion to the sacrum also was not a confounding factor for the subgroup analysis.

**TABLE 7. Postoperative Radiographic Parameters for Subgroups[a]**

| | cMIS Subgroup (n = 27) | | HYB Subgroup (n = 26) | | |
|---|---|---|---|---|---|
| | Mean | SD | Mean | SD | *P* Value, Mann-Whitney *U* Test |
| Maximum coronal Cobb angle, ° | 18.9 | 9.6 | 14.3 | 9.4 | .07 |
| Thoracic kyphosis, ° | 41.3 | 15.4 | 43.2 | 14.0 | .91 |
| LL, ° | 41.3 | 14.6 | 46.2 | 15.5 | .15 |
| Pelvic tilt, ° | 26.5 | 11.6 | 24.5 | 12.1 | .83 |
| PI, ° | 54.0 | 12.5 | 54.7 | 15.4 | .83 |
| SVA, mm | 43.8 | 66.2 | 47.9 | 56.1 | .72 |
| PI-LL mismatch, ° | 12.7 | 15.8 | 8.5 | 19.7 | .33 |

[a]cMIS, circumferential minimally invasive surgery; HYB, hybrid; LL, lumbar lordosis; PI, pelvic incidence; SVA, sagittal vertical axis.

**TABLE 8.** Distribution of Uppermost Instrumented Vertebra by Subgroup[a]

| Uppermost Instrumented Vertebra | cMIS Subgroup (n = 27), n (%) | HYB Subgroup (n = 26), n (%) |
|---|---|---|
| T7 | 0 (0.0) | 1 (3.8) |
| T8 | 0 (0.0) | 1 (3.8) |
| T9 | 2 (7.4) | 2 (7.7) |
| T10 | 8 (29.6) | 7 (26.9) |
| T11 | 3 (11.1) | 9 (34.6) |
| T12 | 10 (37.0) | 3 (11.5) |
| L1 | 4 (14.8) | 3 (11.5) |

[a]cMIS, circumferential minimally invasive surgery; HYB, hybrid.

### Limitations

This study suffers from several limitations, the most significant of which are confounding and selection bias. Although propensity matching and subgroup analysis were used to compensate for these limitations, confounding and selection bias are inherent to retrospective studies and mitigate the strength of evidence presented. As noted previously, the sample size was also relatively small, so this study may not have been able to detect a true difference between groups.

## CONCLUSION

PJK is particularly problematic in adult spinal deformity surgery. This study evaluated whether decreased injury to the paraspinal soft tissues and ligaments by minimally invasive pedicle screw placement could decrease PJK. Although the rate of radiographic PJK was significantly lower in a radiographically propensity-matched comparison of cases undergoing percutaneous posterior screw-rod fixation (cMIS group) compared with those undergoing open posterior screw-rod fixation (HYB), this difference was lost when for similar levels of instrumentation were taken into account. These results suggest that MIS pedicle screw-rod placement does not significantly affect PJK. A larger comparative study is needed, however, to confirm this lack of benefit in PJK incidence with MIS posterior instrumentation.

### Disclosures

Dr Mummaneni reports having direct stock ownership in Spinicity; receiving royalties from DePuy Spine, Quality Medical Publisher, and Thieme Publishers; and receiving honoraria from Globus Medical. Dr Park reports being a consultant for Medtronic, Globus Medical, and Biomet; receiving royalties from Globus Medical; and receiving non–study-related clinical/research support from Orthofix and Blue Care Blue Cross Foundation. Dr Wang has been a consultant for Aesculap Spine and DePuy Spine and a patent holder with DePuy Spine. Dr Uribe has been a consultant for NuVasive. Dr Okonkwo reports receiving royalties from Lanx. Dr Anand reports being a consultant for Medtronic, Globus Medical, and Baxano Surgical; having direct stock ownership in Globus Medical and Medtronic; and receiving royalties from Medtronic, Globus Medical, NuVasive, and Baxano Surgical. Dr Kanter reports being a consultant for NuVasive and receiving royalties from Lanx. Dr LaMarca reports being a consultant for Globus Medical and Biomet; being a patent holder with Globus Medical; and receiving non–study-related clinical/research support from Globus Medical. Dr Deviren has been a consultant for NuVasive, Guidepoint, and Stryker. Dr Smith reports being a consultant for Biomet, Globus Medical, Medtronic, and DePuy and receiving clinical/research support (equipment/material) and non–study-related clinical/research support from DePuy. Dr Mundis reports being a consultant for and receiving royalties from NuVasive and K2M. Dr Shaffrey reports serving as a consultant for Biomet, Globus Medical, Medtronic, NuVasive, and Stryker; being patent holder with Biomet and Medtronic; and receiving royalties from Biomet and Medtronic. Dr Lafage reports speaking/teaching arrangements with DePuy, Medicrea, MSD, Nemaris INC; being on the board of directors or a shareholder in Nemaris INC; and receiving grants from SRS, NIH, and DePuy. Dr Bess reports receiving research support and consultant fees from K2 and Nuvasive, as well as research support from DePuy Synthes Spine, Medtronic, Stryker Spine, and Innovasis. Dr Schwab has been a consultant for K2M, Biomet, NuVasive, and Medicrea; has MSD speaker/teacher arrangements with K2M, Biomet, NuVasive, and Medicrea; receives MSD royalties from K2M; is on the MSD Board of Directors or is a shareholder in Nemaris INC; and has received grants from AO, SRS, and DePuy Synthesis Spine. Dr Akbarnia reports being a board member for San Diego Spine Foundation; being a consultant for Nuvasive and K2M; holding stock in Ellipse and Nuvasive; and receiving royalties from DePuy Spine, K2M, and Nuvasive. Nuvasive and ISSG Foundation gave research grants to his institution. The other authors have no personal, financial, or institutional interest in any of the drugs, materials, or devices described in this article.

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## COMMENTS

This is a fairly large multicenter, nonrandomized, retrospective, comparative cohort study of adult patients with spinal deformity who underwent surgery with either circumferential minimally invasive techniques or what the authors call a hybrid technique including lateral interbody fusion with open posterior instrumentation. Patients were matched on the basis of 2 factors: the preoperative difference between pelvic incidence and lumbar lordosis and the postoperative change in lordosis. The primary outcome was the difference in rate of proximal junctional kyphosis between the 2 cohorts defined as a proximal junctional angle of $>10°$ with an increase of at least $10°$ compared with preoperatively.

With the growing practicality and popularity of multicenter clinical databases in spine surgery, studies of this sort have been and will continue to be increasingly prevalent in the literature. Because of the great potential for confounding in such studies and the limited usefulness of prevailing statistical methods in determining whether or not the results represent an underlying relationship between independent and dependent variables, authors and readers must be extremely cautious in their interpretations. "Highly significant" $P$ values of $<.01$ may be due to uncontrolled differences in nonrandomly selected patient cohorts, not to an important causal relationship between the experimental variable and outcome, and "nonsignificant" $P$ values $>.05$ may be found even in the presence of a meaningful relationship because of a lack of statistical power or random variation, among other factors.

In this study, the difference in proximal junctional kyphosis seen in the overall cohorts appears likely to be due to uncontrolled confounding. Although the methods of selecting the subgroups for analyses are not entirely clear, controlling for the number of instrumented vertebral levels largely removed the difference in incidence of proximal junctional kyphosis. Whether the confounding factor was actually construct length or whether that variable is a proxy for another, perhaps unmeasured, factor is not answerable by this study. As the authors indicate in their conclusions, larger, more sophisticated studies are necessary to try to refine our understanding of the relationship between surgical technique and proximal junctional kyphosis.

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The authors have performed a study evaluating the rate of proximal junctional kyphosis (PJK) in patients undergoing adult deformity correction via an open approach (hybrid with posterior open surgery) and via a minimally invasive (MIS) approach. The authors evaluated 190 patients and had a mean follow-up of 32.8 months. PJK rates were approximately 50% in both groups and not statistically different. Given the numbers of patients and the multi-institutional nature of this study, it merits attention as it tries to address the very vexing problem of PJK. Because there may not be a single specific cause of PJK and its pathogenesis is thought to be multifactorial, this study addresses one of the potential factors associated of PJK: posterior soft tissue and ligaments. It is common thought that during dissection the soft tissue of the posterior elements of the upper instrumented vertebra should be meticulously preserved—soft tissue, interspinous ligament, and musculature—to abate PJK. In an open procedure, such tissue preservation can be done but only to a certain extent; one must still expose enough to visualize screw entry point and to decorticate for arthrodesis. However, in an MIS procedure, the soft tissue is inherently preserved because of the very nature of MIS spine surgery. Little to no posterior tissue is dissected. Thus, the lack of difference in PJK rates between MIS and open surgery is eye-opening. It appears that even with no dissection of the soft tissues during deformity surgery, PJK cannot be fully prevented. Thus, the multifactorial origin of PJK once again comes to the forefront, and finding ways to decrease PJK remains a challenge. Despite the results of this study, careful and meticulous tissue dissection should still take place near the upper instrumented vertebra in open cases because it still may be a contributing factor to PJK. The authors should be commended on their efforts at tackling a very difficult problem.

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