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CLINICAL ARTICLE

Use of multiple rods and proximal junctional kyphosis in adult spinal deformity surgery

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OBJECTIVE Multiple rods are utilized in adult spinal deformity (ASD) surgery to increase construct stiffness. However, the impact of multiple rods on proximal junctional kyphosis (PJK) is not well established. This study aimed to investigate the impact of multiple rods on PJK incidence in ASD patients.

METHODS ASD patients from a prospective multicenter database with a minimum follow-up of 1 year were retrospectively reviewed. Clinical and radiographic data were collected preoperatively, at 6 weeks postoperatively, at 6 months postoperatively, at 1 year postoperatively, and at every subsequent year postoperatively. PJK was defined as a kyphotic increase of > 10° in the Cobb angle from the upper instrumented vertebra (UIV) to UIV+2 as compared with preoperative values. Demographic data, radiographic parameters, and PJK incidence were compared between the multirod and dual-rod patient cohorts. PJK-free survival analysis was performed using Cox regression to control for demographic characteristics, comorbidities, level of fusion, and radiographic parameters.

RESULTS Overall, 307/1300 (23.62%) cases utilized multiple rods. Cases with multiple rods were more likely to be revisions (68.4% vs 46.5%, $p < 0.001$), to be posterior only (80.7% vs 61.5%, $p < 0.001$), involve more levels of fusion (mean 11.73 vs 10.60, $p < 0.001$), and include 3-column osteotomy (42.9% vs 17.1%, $p < 0.001$). Patients with multiple rods also had greater preoperative pelvic retroversion (mean pelvic tilt 27.95° vs 23.58°, $p < 0.001$), greater thoracolumbar junction kyphosis (−15.9° vs −11.9°, $p = 0.001$), and more severe sagittal malalignment (C7–S1 sagittal vertical axis 99.76 mm vs 62.23 mm, $p < 0.001$), all of which corrected postoperatively. Patients with multiple rods had similar incidence rates of PJK (58.6% vs 58.1%) and revision surgery (13.0% vs 17.7%). The PJK-free survival analysis demonstrated equivalent

ABBREVIATIONS ASD = adult spinal deformity; BMI = body mass index; GT = global tilt; LL = lumbar lordosis; PI = pelvic incidence; PI-LL = PI minus LL; PJK = proximal junctional kyphosis; PSO = pedicle subtraction osteotomy; PT = pelvic tilt; SS = sacral slope; SVA = sagittal vertical axis; UIV = upper instrumented vertebra; VCR = vertebral column resection.

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PJK-free survival durations among the patients with multiple rods (HR 0.889, 95% CI 0.745–1.062, p = 0.195) after controlling for demographic and radiographic parameters. Further stratification based on implant metal type demonstrated noninferior PJK incidence rates with multiple rods in the titanium (57.1% vs 54.6%, p = 0.858), cobalt chrome (60.5% vs 58.7%, p = 0.646), and stainless steel (20% vs 63.7%, p = 0.008) cohorts.

CONCLUSIONS Multirod constructs for ASD are most frequently utilized in revision, long-level reconstructions with 3-column osteotomy. The use of multiple rods in ASD surgery does not result in an increased incidence of PJK and is not affected by rod metal type.

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KEYWORDS adult spinal deformity; ASD; reconstruction; thoracolumbar; proximal junctional kyphosis; PJK; multiple rods; multicenter; osteotomy; lumbar; thoracic

Recent advancements in surgical techniques, instrumentation, and understanding of sagittal balance have led to increased surgical intervention for complex adult spinal deformity (ASD) patients.[1,2] However, surgery for ASD is associated with complication rates as high as 70% within the 2-year postoperative period.[3] Common complications leading to revision surgery include proximal junctional kyphosis (PJK), pseudarthrosis, and rod fracture.[4–6] Moreover, pseudarthrosis and rod fracture are particularly prevalent complications that occur at 3-column osteotomy sites and the lumbosacral junction.[7] Prospective studies have demonstrated that the incidence of rod fracture in ASD surgery may be as high as 9% and 22% in patients treated with pedicle subtraction osteotomy (PSO).[8] Multirod constructs have shown superior biomechanical stability compared with typical dual-rod constructs, decreasing the incidence of rod fracture in ASD surgery with long-level fusion, lumbosacral junction involvement, or 3-column osteotomy.[9–12]

Although multirod constructs in ASD surgery help maintain deformity correction, the increased construct stiffness may lead to higher rates of PJK.[13] Prior studies have demonstrated that multirod constructs with increased stiffness are associated with higher incidence rates of junctional screw loosening and earlier PJK.[14,15] However, these studies were limited to small numbers of patients and often did not evaluate rods of different metal types. Here, we present a multicenter study evaluating the impact of multiple rods on PJK incidence for ASD surgery.

Methods

Study Design and Inclusion Criteria

A prospective database of ASD patients who underwent surgical intervention from 2008 to 2018 at 24 spine sites was retrospectively reviewed. This study received IRB approval from each study site. Patient inclusion criteria included the following: 1) patient age ≥ 18 years; 2) at least 5-level instrumented spinal fusion had been performed; 3) the patient had at least one of the following criteria of spinal deformity, including coronal Cobb angle > 20°, C7–S1 sagittal vertical axis (SVA) > 5 cm, pelvic tilt (PT) > 25°, or thoracic kyphosis > 60°; and 4) minimum follow-up of 1 year with radiographic evaluation. Cases with spinal tumor, primary spinal infection, or acute spinal trauma were excluded. Of the 1571 patients enrolled in the study, 1300 patients had a minimum follow-up of 1 year with radiographic data and were included for analysis.

Data Collection

The collected demographic data included age, sex, body mass index (BMI), history of prior spine surgery, neurological status, Charlson Comorbidity Index score, and specific comorbidities such as smoking status, diabetes, depression, and osteoporosis. Surgical procedure data were also collected such as approach, number of levels fused, upper instrumented vertebra (UIV), lower instrumented vertebra, type and number of osteotomies, and instrumentation. For cases with multiple rods, the number of additional rods, laterality, metal type, diameter, UIV, and lower instrumented vertebra were also recorded.

Full-length, free-standing, lateral spine radiographs (36-inch long-cassette or EOS imaging) were collected preoperatively, 6 weeks postoperatively, 6 months postoperatively, 1 year postoperatively, and at every subsequent year in follow-up. Radiographic analysis was completed at a single center with standard techniques using SpineView (ENSAM, Laboratory of Biomechanics).[16] The recorded radiographic parameters included pelvic incidence (PI), PT, sacral slope (SS), lumbar lordosis (LL), PI minus LL (PI-LL), thoracic kyphosis (T4–12 Cobb angle), thoracolumbar junction kyphosis (T10–L2 Cobb angle), and C7–S1 SVA. Lordotic sagittal Cobb angles were recorded as positive values, whereas kyphotic Cobb angles were recorded as negative values.

Patients were categorized into the multirod cohort and dual-rod cohort. Patients were stratified on the basis of UIV level into the upper-thoracic UIV cohort (T8 and proximal vertebrae) and lower-thoracic UIV cohort (T9 and distal vertebrae). The incidence of PJK and number of revision surgical procedures during patient follow-up were recorded. PJK was defined as a kyphotic Cobb angle change from UIV to UIV+2 in the sagittal plane larger than 10° at any postoperative time point compared with baseline. The Cobb angle was measured from the superior endplate of UIV+2 to the inferior endplate of UIV.[17,18]

Statistical Analysis

Demographic information, surgical parameters, and radiographic parameters were compared between the multirod cohort and dual-rod cohort using the independent-samples t-test for quantitative variables and the chi-square test for categorical variables. PJK incidence was compared between the multirod cohort and dual-rod cohort with the chi-square test. PJK incidence was compared between the rod metal–type subcohorts and UIV-level subcohorts

using the chi-square test. PJK incidence was compared between cases with different numbers of rods using the chi-square test. Within the multirod cohort, PJK incidence was compared between cases with and without multiple rods extending to the UIV and between cases with and without 3-column osteotomy using the chi-square test. PJK-free survival curve analysis of the dual-rod and multirod cohorts was performed using Cox regression to control for demographic characteristics (e.g., sex, age, BMI, prior surgical history), comorbidities (osteoporosis, smoking status, depression), UIV level, preoperative sagittal parameters (PI-LL, T10–L2 Cobb angle), and postoperative sagittal parameters (PI-LL, T10–L2 Cobb angle). All statistical analysis was performed using IBM SPSS version 28 (IBM Corp.). Statistical significance was set at $p < 0.05$.

Results

Demographic Information and Surgical Parameters

In total, 1300 ASD patients were included in the analysis, including 993 cases (76.4%) with dual rods and 307 cases (23.6%) with multiple rods. Overall, cases most often utilized cobalt chrome rods (n = 818), titanium rods (n = 308), and stainless steel rods (n = 156). Cases with multiple rods utilized a total of 3 rods in 152 (49.5%) patients and a total of 4 rods in 155 (50.5%) patients. Additional rods in multirod constructs extended to the UIV level in 24 (7.8%) patients.

As compared with the dual-rod cohort, the multirod cohort was older (64.2 vs 59.0 years, $p < 0.001$), had greater BMI (29.1 vs 27.7 kg/m^2, $p = 0.001$), had a higher proportion of patients with osteoporosis (21.8% vs 15.3%, $p = 0.008$), had fewer smokers (2.0% vs 6.3%, $p = 0.004$), and was more likely to have undergone prior spine surgery (68.4% vs 46.5%, $p < 0.001$). Regarding surgical parameters, the multirod cohort was more likely to have undergone a posterior-only approach (80.7% vs 61.5%, $p < 0.001$), have more levels fused (11.7 vs 10.6, $p < 0.001$), and have undergone 3-column osteotomy (42.9% vs 17.1%, $p < 0.001$). Patients were most likely to have a UIV in the lower thoracic spine in both the dual-rod (59.6%) and multirod (58.3%) cohorts (Table 1).

TABLE 1. Comparison of demographic and surgical parameters between the dual-rod and multirod patient cohorts

Parameter	Dual Rod (n = 993)	Multirod (n = 307)	p Value
Age, yrs	59.04 ± 15.13	64.25 ± 10.58	**<0.001**
BMI, kg/m^2	27.70 ± 5.92	29.05 ± 6.24	**0.001**
CCI score	1.75 ± 1.70	1.94 ± 1.59	0.085
Female sex	729 (73.4)	229 (74.7)	0.671
Diabetes	82 (8.3)	23 (7.5)	0.664
Osteoporosis	152 (15.3)	67 (21.8)	**0.008**
Prior spine surgery	462 (46.5)	210 (68.4)	**<0.001**
Depression	262 (26.4)	84 (27.4)	0.742
Abnormal neurological status	39 (3.9)	13 (4.2)	0.813
Current smoker	63 (6.3)	6 (2.0)	**0.004**
Surgical approach			
Posterior only	61.5	80.7	**<0.001**
Anterior-posterior	38.5	19.3	
UIV			
Upper thoracic (≥T8)	40.4	41.7	0.683
Lower thoracic (≤T9)	59.6	58.3	
Osteotomy			
3-column osteotomy	17.1	42.9	**<0.001**
PSO	13.4	35.1	**<0.001**
VCR	2.7	6.7	**0.003**
Levels fused	10.60 ± 3.44	11.73 ± 3.35	**<0.001**

CCI = Charlson Comorbidity Index.
Values are shown as number (%), %, or mean ± SD unless indicated otherwise. Boldface type indicates statistical significance ($p < 0.05$).

Comparison of Sagittal Parameters

Preoperatively, the multirod cohort had greater pelvic retroversion (mean PT 28.0° vs 23.6°, $p < 0.001$), decreased SS (28.9° vs 31.8°, $p < 0.001$), decreased LL (32.4° vs 39.6°, $p < 0.001$), greater PI-LL mismatch (24.5° vs 15.9°, $p < 0.001$), greater thoracolumbar junction kyphosis (–15.9° vs –11.9°, $p = 0.001$), more severe sagittal malalignment (C7–S1 SVA 99.8 mm vs 62.2 mm, $p < 0.001$), and greater global tilt (GT) (37.8° vs 28.9°, $p < 0.001$) (Table 2).

In the comparison of 6-week postoperative sagittal parameters, the multirod cohort had greater LL (55.4° vs 52.4°, $p = 0.001$), decreased PI-LL mismatch (1.3° vs 3.0°, $p = 0.048$), and greater thoracic kyphosis (–45.1° vs –41.9°, $p = 0.001$) but had equivalent PT, SS, thoracolumbar junction kyphosis, sagittal malalignment, and GT (Table 2).

When postoperative changes in sagittal parameters were compared, the multirod cohort had greater correction in PT (–7.5° vs –3.5°, $p < 0.001$), PI-LL mismatch (–23.22° vs –12.9°, $p < 0.001$), thoracolumbar junction kyphosis (7.4° vs 4.7°, $p = 0.009$), sagittal malalignment (–73.8 mm vs –34.5 mm, $p < 0.001$), and GT (–16.1° vs –7.4°, $p < 0.001$) (Table 2).

Comparison of PJK Incidence

The multirod cohort experienced a similar rate of revision surgery (13.0%) as the dual-rod cohort (17.7%) during follow-up. There was no significant difference in PJK incidence between the multirod cohort (58.6%) and the dual-rod cohort (58.1%). Furthermore, there was no difference in PJK incidence between patients treated with 2 rods (58.1%), 3 rods (57.2%), or 4 rods (60.0%) (Fig. 1). When patients were stratified by rod metal type, those patients with multiple rods in the titanium rod (57.1% vs 54.6%) and cobalt chrome rod (60.5% vs 58.7%) subcohorts had similar PJK incidence rates. However, patients with multiple rods in the stainless steel rod subcohort had a decreased PJK incidence rate compared with those patients with dual rods (20% vs 63.7%, $p = 0.008$) (Fig. 2). When stratified by UIV level, patients with multiple rods in the lower-thoracic UIV subcohort (53.1% vs 54.9%) and upper-thoracic UIV subcohort (66.4% vs 62.8%) had similar PJK incidence rates (Fig. 3).

When the multirod cohort was specifically evaluated, there was no difference in PJK incidence between patients

TABLE 2. Comparison of preoperative and 6-week postoperative sagittal parameters between the dual-rod and multirod cohorts

Parameter	Dual Rod (n = 993)	Multirod (n = 307)	p Value
Preop			
PT, °	23.58 ± 10.78	27.95 ± 10.68	**<0.001**
SS, °	31.84 ± 12.20	28.93 ± 11.59	**<0.001**
PI, °	55.42 ± 12.89	56.88 ± 13.55	0.086
PI-LL, °	15.87 ± 21.25	24.51 ± 20.89	**<0.001**
LL, °	39.58 ± 21.67	32.38 ± 20.59	**<0.001**
T10–L2 Cobb angle, °	–11.90 ± 18.08	–15.94 ± 20.60	**0.001**
T4–12 Cobb angle, °	–33.25 ± 18.97	–35.13 ± 21.05	0.141
C7–S1 SVA, mm	62.23 ± 69.73	99.76 ± 73.89	**<0.001**
GT, °	28.86 ± 15.81	37.81 ± 16.17	**<0.001**
Postop			
PT, °	20.07 ± 9.63	20.43 ± 10.14	0.577
SS, °	35.39 ± 10.54	36.28 ± 10.28	0.194
PI-LL, °	3.01 ± 13.53	1.29 ± 12.80	**0.048**
LL, °	52.44 ± 13.80	55.42 ± 12.44	**0.001**
T10–L2 Cobb angle, °	–7.24 ± 12.58	–8.51 ± 13.04	0.126
T4–12 Cobb angle, °	–41.85 ± 14.90	–45.14 ± 15.30	**0.001**
C7–S1 SVA, mm	28.17 ± 46.12	26.10 ± 48.60	0.497
GT, °	21.54 ± 11.88	21.71 ± 12.25	0.834
Change			
PT, °	–3.51 ± 8.16	–7.53 ± 8.03	**<0.001**
PI-LL, °	–12.85 ± 18.74	–23.22 ± 17.17	**<0.001**
T10–L2 Cobb angle, °	4.66 ± 15.49	7.43 ± 18.52	**0.009**
T4–12 Cobb angle, °	–8.61 ± 14.72	–10.00 ± 16.64	0.163
C7–S1 SVA, mm	–34.47 ± 66.08	–73.78 ± 64.28	**<0.001**
GT, °	–7.42 ± 12.97	–16.14 ± 12.61	**<0.001**

Values are shown as mean ± SD unless indicated otherwise. Boldface type indicates statistical significance ($p < 0.05$).

with additional rods extending to the UIV level (41.7%) and those patients with additional rods not extending to the UIV level (60.1%). Furthermore, there was no difference in PJK incidence between multirod patients who did or did not undergo 3-column osteotomy (62.0% vs 56.5%).

PJK-Free Survival

The mean time to PJK of the whole cohort was 6.15 months, which was similar to those of the multirod cohort (5.77 months) and dual-rod cohort (6.32 months). PJK-free survival curve Cox regression was performed while controlling for demographic characteristics (e.g., sex, age, BMI, prior surgical history), comorbidities (osteoporosis, smoking status, depression), UIV level, preoperative sagittal parameters (PI-LL, T10–L2 Cobb angle), and postoperative sagittal parameters (PI-LL, T10–L2 Cobb angle). Patients in the multirod cohort and patients in the dual-rod cohort had equivalent PJK-free survival durations (HR 0.889, 95% CI 0.745–1.062, $p = 0.0195$) (Fig. 4).

Discussion

We found that ASD patients who underwent reconstruction with multiple rods were more likely to have osteoporosis, prior spine surgery, and longer fusion with 3-column osteotomy. Patients with multiple rods had greater preoperative pelvic retroversion, PI-LL mismatch, thoracolumbar junction kyphosis, GT, and sagittal malalignment, all of which corrected postoperatively. Patients with multiple rods had a similar rate of postoperative revision surgery as patients with dual rods, as well as a noninferior incidence of PJK across all rod metal–type subcohorts and UIV-level subcohorts. Patients with multiple rods also had a similar PJK-free survival duration when controlling for demographic characteristics, comorbidities, UIV level, and radiographic parameters.

This study represents one of the largest multicenter comparisons of PJK incidence among patients who underwent ASD reconstruction with dual rods or multiple

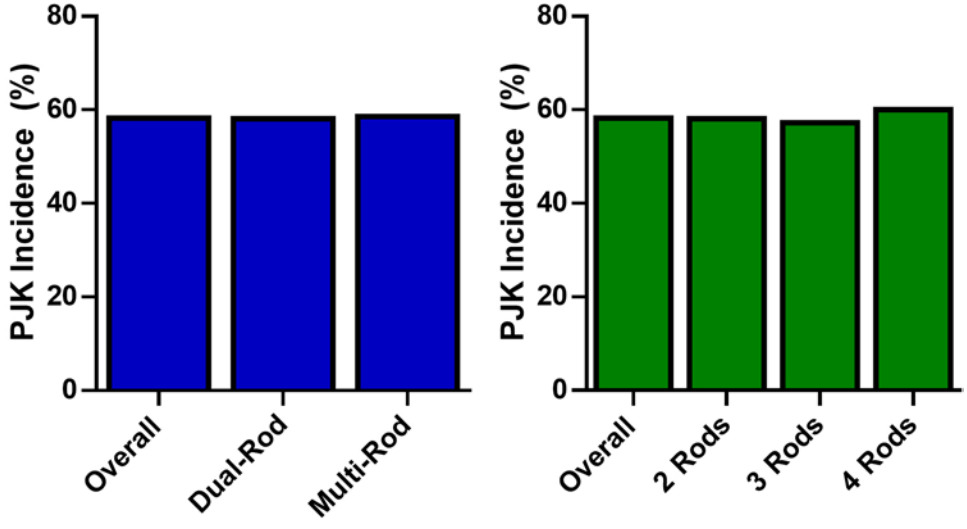

FIG. 1. Incidence rates of PJK between patients treated with dual rods or multiple rods. Figure is available in color online only.

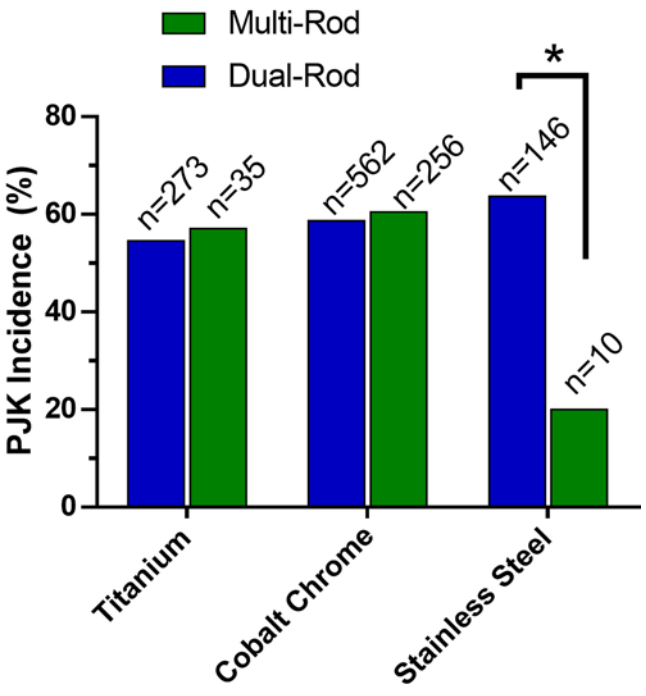

FIG. 2. Incidence rates of PJK between the multirod and dual-rod cohorts stratified by rod metal type. *p < 0.05. Figure is available in color online only.

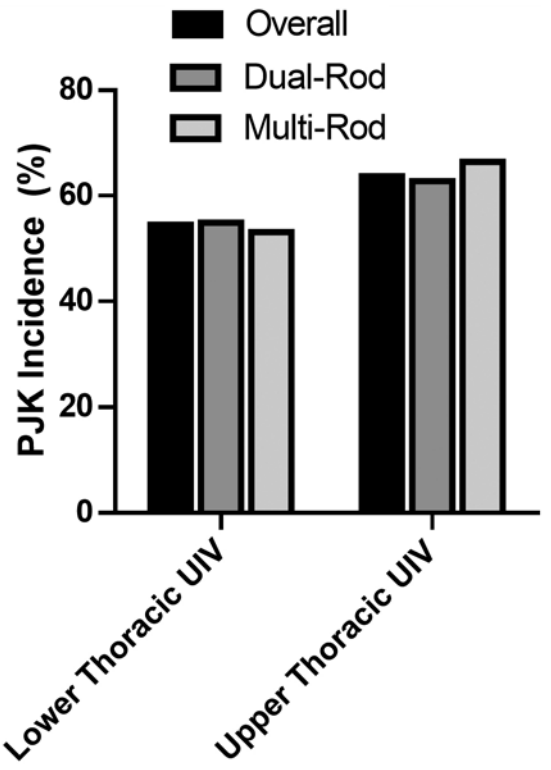

FIG. 3. Incidence rates of PJK between the multirod and dual-rod cohorts stratified by UIV level.

rods. Patients who underwent surgery with multiple rods were more likely to have undergone prior spine surgery and have greater pelvic retroversion, PI-LL mismatch, thoracolumbar junction kyphosis, and sagittal malalignment with longer fusions and more 3-column osteotomies. This suggests that the use of multirod technology was preferentially applied to cases with greater sagittal malalignment who required longer levels of fusion and 3-column osteotomy to achieve appropriate surgical correction. This is consistent with prior studies that demonstrated that multiple rods are more often used in ASD cases involving 3-column osteotomy or deformity involving the lumbopelvic junction in order to potentially decrease the risk of pseudarthrosis and rod fracture.[17–19] Interestingly, patients with multiple rods did not have a greater incidence of PJK even though prior studies have shown that severe sagittal malalignment and greater surgical correction are risk factors for PJK.[20–23]

This study found that patients who underwent surgery with multiple rods had a noninferior rate of PJK, even after patients were further stratified by rod metal type and level of UIV. Patients with multiple rods also demonstrated equivalent PJK-free survival duration after controlling for demographic, surgical, and radiographic parameters. Although patients with multiple rods had a decreased rate of PJK in the stainless steel metal–type subcohort, there were only 10 cases with multiple stainless steel rods and therefore the sample may not have been representative. Previous studies of dual rods in small numbers of patients have reported that constructs with greater stiffness, such as cobalt chrome rods, were associated with increased risk of PJK as compared to constructs with decreased stiffness, such as titanium rods.[14,24] Interestingly, this study found that the incidence of PJK was comparable when cobalt chrome constructs or titanium constructs were evaluated in the dual-rod and multirod cohorts. Although the use of additional rods may increase construct stiffness, this contribution may be negligible when considering the already significant difference in stiffness between the proximal unfused segments and distal fused segments. Another consideration is that additional rods are preferentially utilized at more distal osteotomy segments or at the lumbopelvic junction, potentially further minimizing added stress on the proximal segment adjacent to the UIV. Further biomechanical studies are needed to explore these hypotheses more definitively.

Multirod constructs can be used to augment posterior instrumentation in several different clinical scenarios (Fig. 5). For example, an accessory rod should be used when treating ASD patients undergoing long-level fusion to the pelvis in order to decrease the risk of pseudarthrosis at the lumbosacral junction.[9] In patients with concomitant coronal imbalance, an accessory rod may be placed on the side of coronal imbalance using the kickstand technique (Fig. 6).[25] In patients undergoing PSO, we prefer to use a 4-rod construct to bridge the PSO by using bilateral accessory rods or satellite rods (2-level rods across the level of the PSO) (Fig. 6).[10] In patients undergoing vertebral column resection (VCR), a 3-rod construct consisting of an accessory rod may be used across the level of the VCR.

This study was associated with several limitations. Retrospective analysis of prospectively acquired data may

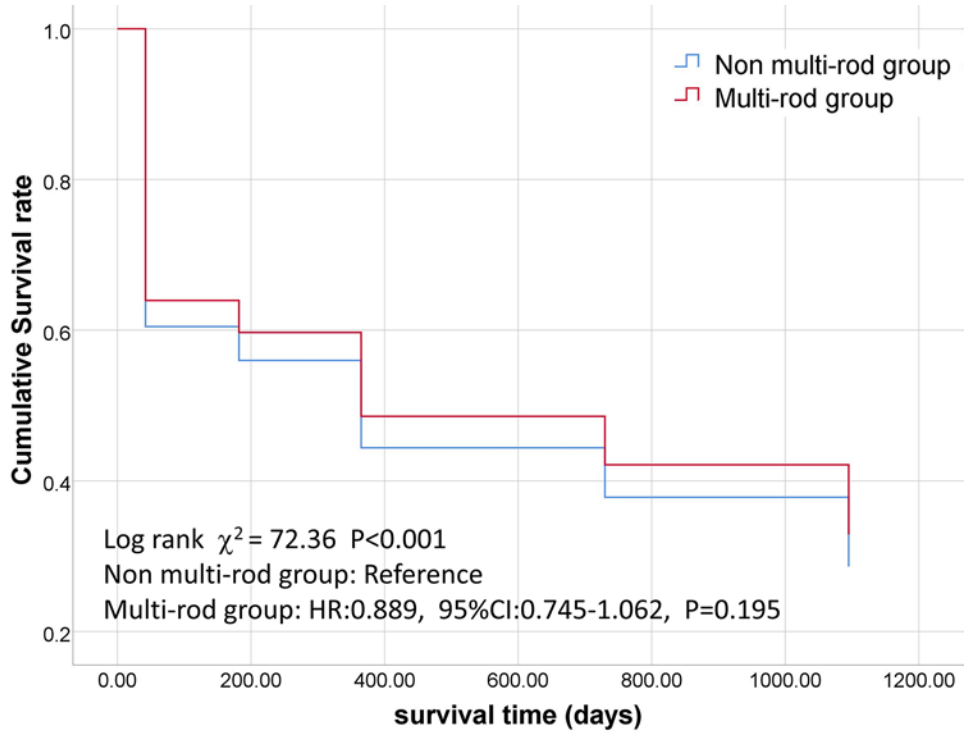

FIG. 4. PJK-free survival curves of the dual-rod and multirod cohorts after controlling for demographic characteristics, comorbidities, UIV level, preoperative radiographic parameters, and postoperative radiographic parameters. Figure is available in color online only.

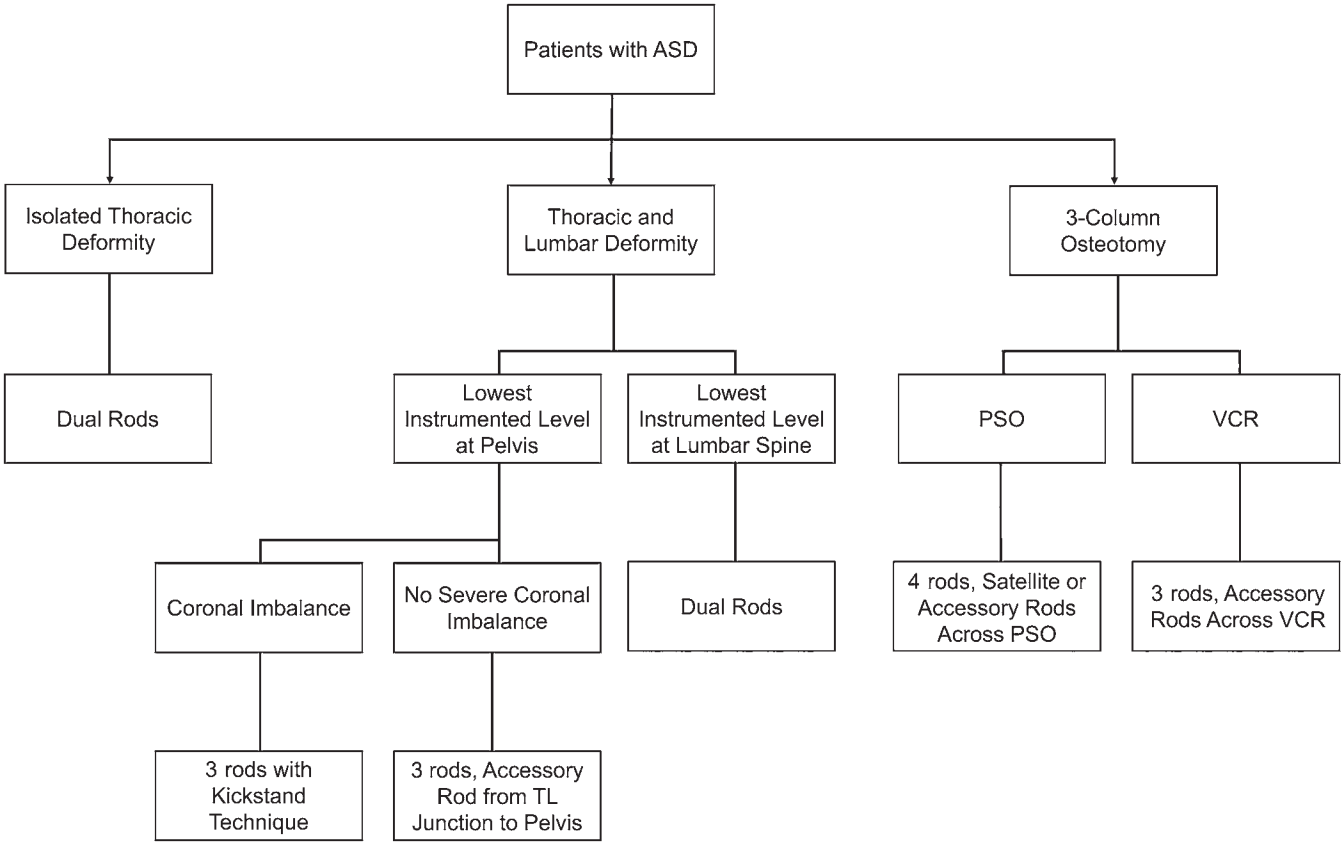

FIG. 5. Clinical decision-making algorithm for use of multirod constructs in ASD patients. TL = thoracolumbar.

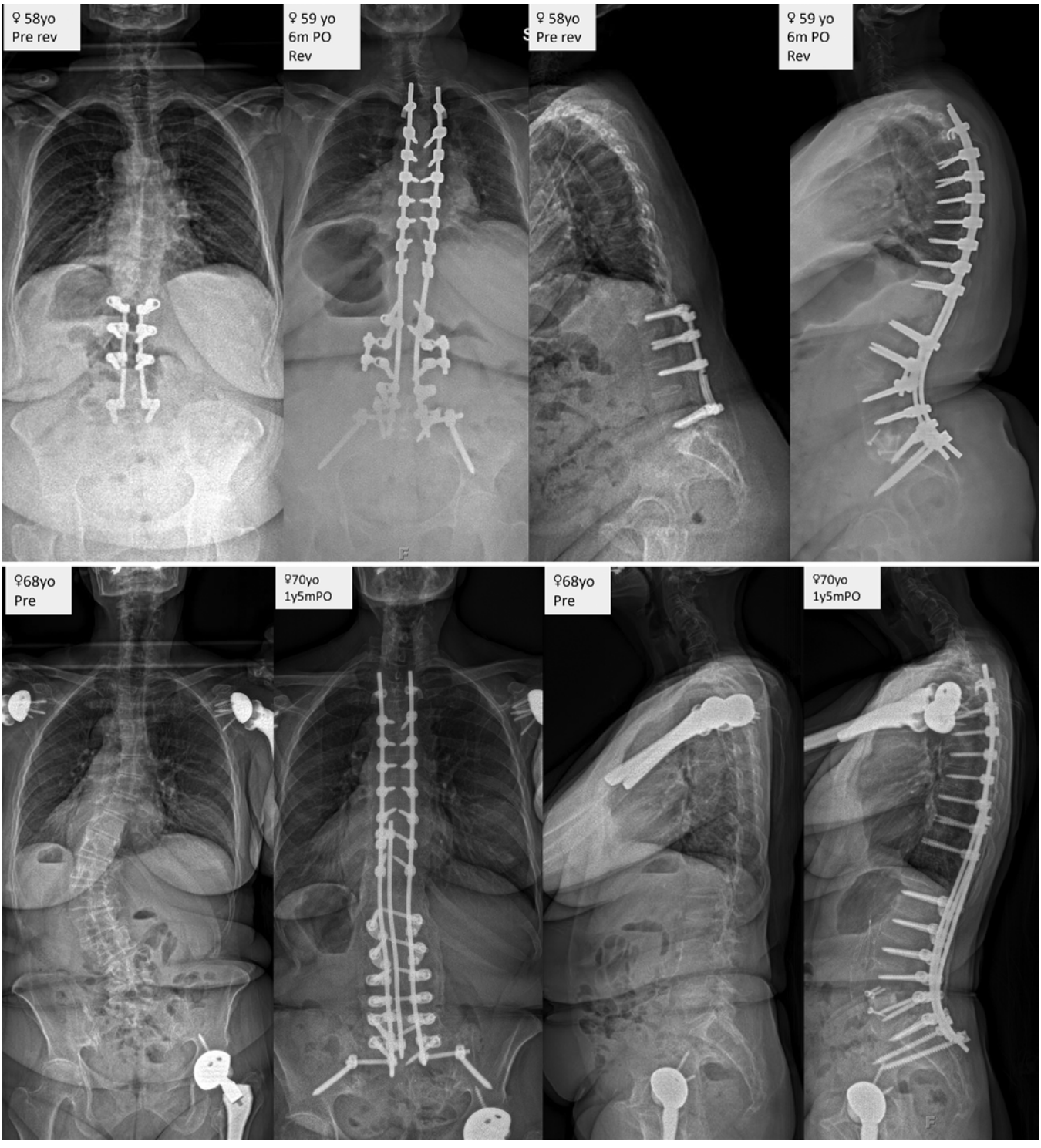

FIG. 6. Upper: A 58-year-old ASD patient with a prior history of posterior spinal instrumentation and fusion and sagittal imbalance was treated with long-segment fusion to the pelvis, PSO, and the 4-rod technique to bridge the osteotomy site. **Lower:** A 68-year-old ASD patient with coronal and sagittal imbalance was treated with long-segment fusion to the pelvis and an accessory rod. m = months; PO = postoperative; Pre = preoperative; Rev = revision; y = years; yo = years old.

have resulted in potential sampling bias. Moreover, patients in the dual-rod cohort and multirod cohort had significant differences in demographic characteristics and sagittal parameters that could have impacted the risk of PJK. Although several demographic and radiographic parameters were controlled for during PJK-free survival analysis, it is possible that not all confounding variables were accounted for and these could have affected the results of the PJK-

free survival analysis. Another limitation is that PJK was defined as a kyphotic increase of 10° or greater from UIV to UIV+2, even though several different definitions of symptomatic PJK have been used in the literature.[26]

Conclusions

Patients who underwent ASD surgery with multiple rods had more comorbidities, were more likely to have prior surgical history, and were more likely to undergo longer fusion with 3-column osteotomy. Patients with multiple rods had greater preoperative pelvic retroversion, PI-LL mismatch, thoracolumbar junction kyphosis, GT, and sagittal malalignment, all of which corrected postoperatively. Patients with multiple rods had a noninferior rate of PJK across all implant metal–type subcohorts and UIV-level subcohorts. Patients with multiple rods also had a similar PJK-free survival duration when controlling for demographic characteristics, comorbidities, UIV level, and radiographic parameters.

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