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ORIGINAL ARTICLE

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Multiple-rod constructs in adult spinal deformity surgery for pelvic-fixated long instrumentations: an integral matched cohort analysis

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Abstract

Purpose Multiple-rod constructs (Multi-Rod: extra rods for additional pillar support) are occasionally used in adult spinal deformity (ASD) surgery. We aimed to compare and analyze the general outcome of multi-rod constructs with a matched two-rod cohort, to better understand the differences and the similitudes.

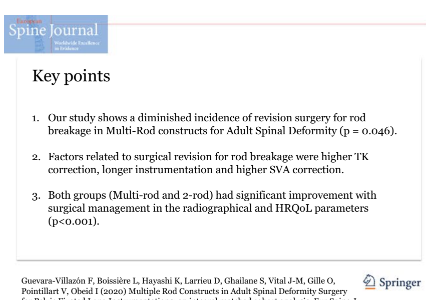
Methods This is a retrospective matched cohort study including patients with ASD that underwent surgical correction with long posterior instrumentation (more than five levels), pelvic fixation and a minimum 1-year follow-up. Matching was considered with demographical data, preoperative radiographical parameters, preoperative clinical status [health-related quality-of-life (HRQoL) scores] and surgical characteristics (anterior fusion, decompression, rod material, osteotomies). Postoperative radiographical and clinical parameters, as well as complications, were obtained. Univariate and multivariate analysis was performed regarding postoperative improvement, group variables comparison and parameters correlation.

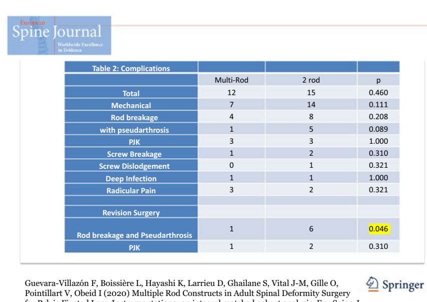
Results Thirty-three patients with multi-rod construct and 33 matched with a two-rod construct were selected from a database with 346 ASD-operated patients. Both groups had a significant improvement with surgical management in the radiographical and HRQoL parameters ($p<0.001$). Differences between groups for the postoperative radiographical, clinical and perioperative parameters were not significant. Rod breakage was more frequent in the two-rod group (8 vs 4, $p=0.089$), as well as the respective revision surgery for those cases (6 vs 1 $p=0.046$). Risk factors related to revision surgery were greater kyphosis correction ($p=0.001$), longer instrumentation ($p=0.037$) and greater sagittal vertical axis correction ($p=0.049$).

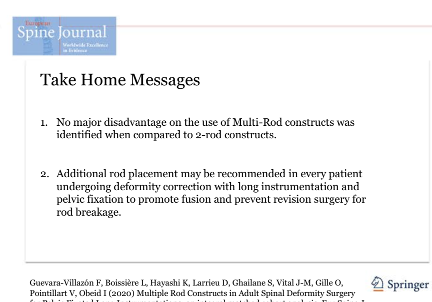
Conclusion No major disadvantage on the use of multi-rod construct was identified. This supports the benefit of using multi-rod constructs to avoid implant failure.

Graphical abstract

These slides can be retrieved under Electronic Supplementary Material.







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Extended author information available on the last page of the article

Keywords Multiple-rod construct · Adult spinal deformity · Adult scoliosis · Rod breakage · Pseudarthrosis · Pelvic fixation

Introduction

Adult spinal deformity (ASD) accounts for a great variety of entities, but the most common requiring surgical correction is those with clinical repercussion, sagittal malalignment and degenerative disease [1–4]. Many initial treatments may be directed toward focused improvement, but ultimately, many patients end up requiring long instrumentations for correction [5, 6]. However, this kind of treatment has a significant incidence of complications, especially rod breakage and pseudarthrosis, which are the most frequent reasons of late revision surgery [7]. For this reason, several ways to increase stiffness are being used, such as the use of different materials (chrome–cobalt and titanium alloy) and thicker rods (5.5–6.35 mm). But lately, multiple-rod constructs (multi-rod) are being used increasingly often [8–15].

We define a multi-rod construct when an extra rod or rods are added for additional pillar support (Fig. 1). The selected multi-rod segment is defined by the surgeon and consistently involves the areas of major stress, such as the lumbar area and/or osteotomy site. The goal is to increase immediate stiffness, so the correction can be kept longer, and bone fusion is promoted. Multi-Rod constructs vary, having complex structures like the "dual construct" described by Shen [8] where screws in different pedicle directions function as different conjunctional constructs and much simpler constructs, like the addition of a peripheral rod annexed to one or both rod columns by simple connectors [9–12]. In the general practice, probably the most frequent employment of multi-rods is in a heterogeneous way, where the position of the extra rods depends on the screw positioning, the deformity morphology and intraoperative surgeons' technical considerations. Nevertheless, no real consensus has yet been established.

Objective

The objective of this study was to determine and analyze the general outcome of patients with ASD, operated with long posterior instrumentations (more than five levels), pelvic fixation and a minimum of 1-year follow-up. We aim to compare the quality-of-life outcomes, sagittal malalignment radiographical measurements and complications between the

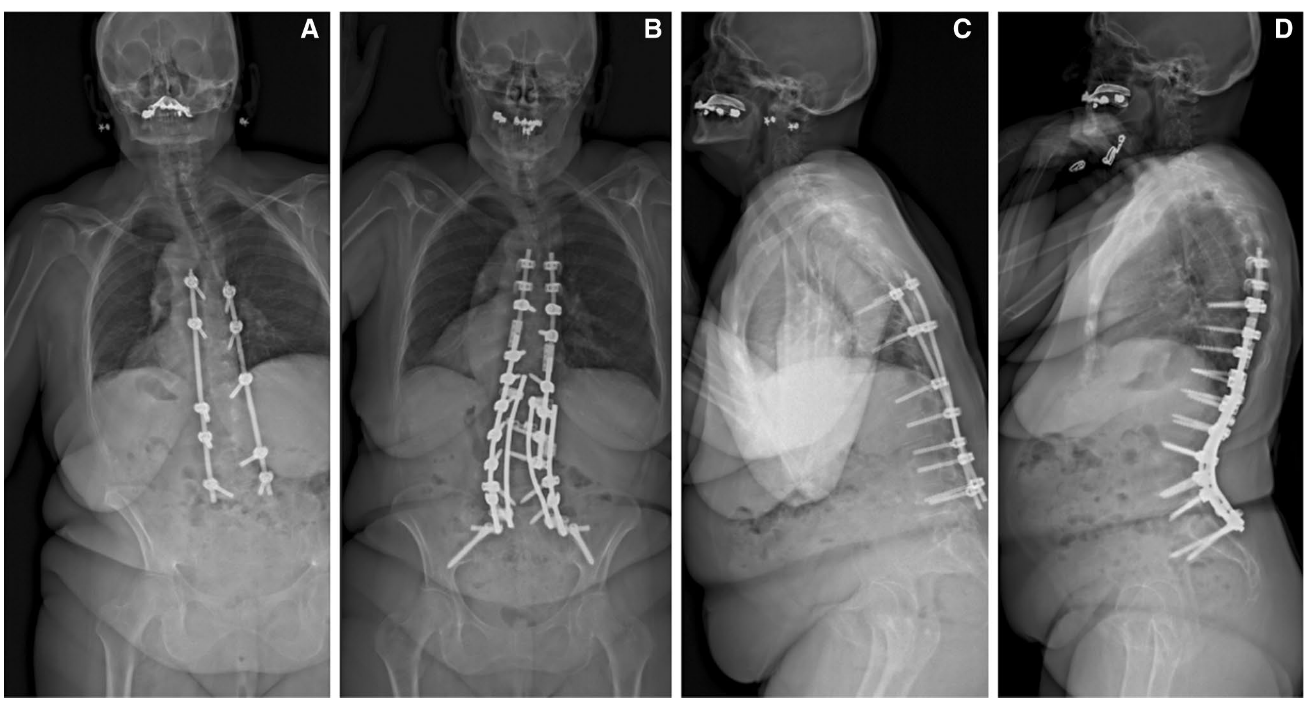

Fig. 1 Preoperative (**a**, **c**) and postoperative (**b, d**) radiographical films of the anteroposterior and lateral views showing a patient who underwent revision surgery for a coronal and sagittal deformity with loss of sagittal alignment. Pedicle subtraction osteotomy in L4 and extension of the instrumentation from T8 to iliac bone were performed using a multi-rod construct with four main rod columns (total five rods) in the lumbosacral segment

cohort of multi-rod constructs and a homogenized control group of "two-rod" patients.

Materials and methods

Patient population

We performed a retrospective case–control study on prospective enrolled data. Patients with ASD were defined by having any frontal plane deformity over 20°, thoracic kyphosis (TK) over 60°, sagittal vertical axis (SVA) over 5 cm or pelvic tilt (PT) over 25°.

We analyzed medical records of 346 patients who were operated by two spinal deformity surgeons from two spine centers, between 2013 and 2017. Inclusion criteria included: patients with lumbar degenerative deformity and symptomatic adult idiopathic scoliosis, who underwent surgical correction (primary or revision surgery) with long instrumentation with transpedicular screws (with or without additional laminar hooks), pelvic fixation, more than two main rods in any or both sides of the instrumentation construct *(two or more rods connected by an edge forming a unilateral* one-*rod column, were considered as only* one *rod*) and complete clinical and radiographical 1-year follow-up. A "two-rod-only" sample of patients with the same diagnosis, preoperative parameters (demographical, radiographical and clinical) and surgical treatment characteristics (> 5 instrumented levels, pelvic fixation, follow-up period) was selected to match the cohort ($p > 0.05$). For exclusion matters, of the patients from the multi-rod group who had had prior surgery, we verified that neither were to be of possible inclusion in the two-rod (pelvic-fixated) group. Also, two-rod patients who were revised for complications with a multi-rod construct were not analyzed afterward as multi-rod patients.

Clinical, surgical and radiographical data collection

A detailed review of patients' medical records was conducted. Demographical data were collected, including age, gender, weight, height and body mass index (BMI).

Radiographical measurements were acquired by EOS® system (Paris, France) [16] including sagittal vertical axis (SVA) of C7, thoracic kyphosis (TK), lumbar lordosis (LL), coronal deformity in Cobb angle (CD), pelvic incidence (PI), pelvic tilt (PT), sacral slope (SS), global tilt (GT), PI–LL and lumbar lordosis index (LLI) [3, 17–19]. The EOS® system is low radiation dose and it standardizes spinal measurements, with complete anteroposterior and lateral radiographs of the whole body in upright position, with arms flexed close to the thorax and eyes watching a fixed point up front.

Clinical and surgical data collected consisted of hospitalization time, surgical time and surgical blood loss, osteotomies, interbody fusion, rod diameter (5.5 mm, 6.0 mm and 6.35 mm), rod materials used (titanium alloy, cobalt–chromium or mixed), complications, type of complication (rod breakage, screw failure, adjacent segment failure, infection, etc.), time of detection and number of revision surgeries for mechanical complications. Pseudarthrosis was determined with simple x-ray and clinical data, and patients that underwent revision surgery for this also were studied with a CT scan.

Health-related quality-of-life (HRQOL) results were obtained before and after a minimum 1-year follow-up. These included: Pain Numeric Rating Scale (NRS), Core Outcome Measures Index (COMI), Oswestry Disability Index (ODI), Scoliosis Research Society Questionnaire (SRS-22) and Short-Form Survey 36 Questions (SF-36), for all patients. Using values previously described for deformity spinal surgery, minimum clinically important difference (MCID) was defined for each patient [20].

Statistical analysis

Statistical analysis was performed with IBM SPSS Statistics 23.0 (SPSS Inc., Chicago, IL, USA). Methods used were: Fisher's exact test for binominal value comparison, Mann–Whitney U for rank and score comparison, unpaired T test for univariate measurement comparison, paired T test for time-lapsed scores and measurements and multivariate general linear model for multiple variable comparison, risk factors and for assessing general outcome. Pearson's test was used to attest correlating factors with complications. A "*p*" value under 0.05 was considered statistically significant.

Results

Demographics

Thirty-three multi-rod patients and a matched control group of 33 two-rod patients were analyzed and compared. As a matched cohort study, no statistical difference was favored for demographical and preoperative characteristics. Patients' age, gender, weight, height and BMI were not different between groups (Table 1).

Surgical considerations

Surgical treatment was individualized regarding each patient, but all of them shared standardized considerations. Instrumented levels were from 5 to 18 levels. All the patients underwent pelvic fixation through standard iliac screws. Osteotomies performed were 27 pedicle subtraction osteotomies (PSO) and 20 patients with simple or multilevel posterior column osteotomies (PO). Rod

Table 1 Data comparison of multi-rod group versus two-rod group

	Multi-rod group	Two-rod control group	*p*
Demographics			
Age	68.76	71.94	0.114
Gender			0.569
Female	24.00	26.00	
Male	8.00	6.00	
Body mass index	26.72	27.15	0.697
Weight (kg)	70.64	71.39	0.789
Height (cm)	162.70	162.30	0.853
Surgical considerations			
Instrumented levels	10.15	9.82	0.664
Three-column osteotomy	17.00	10.00	0.085
Posterior column osteotomy	9.00	11.00	0.595
Number of rod columns	3.70	2.00	*0.000*
Rod material (no. of patients)			
Titanium	13.00	21.00	0.051
Cobalt–chromium	13.00	12.00	0.801
Mixed	7.00	0.00	*0.005*
Rod diameter (mm)	5.98	*6.02*	0.541
Decompression (no. of patients)	10.00	9.00	0.790
Anterior fusion with cage (no. of patients)	26.00	21.00	0.118
Total blood loss (mm)	1376.18	1344.97	0.901
Total surgical time (min)	192.88	199.70	0.660
Hospitalization days	13.85	11.09	0.246
Previous surgeries	0.42	0.24	0.121
Preoperative HRQoL			
NRS back pain	6.52	6.76	0.601
COMI back score	6.89	6.82	0.876
ODI score	46.42	44.82	0.663
SRS22 total score	2.55	2.57	0.890
SF36 physical complete score	35.37	33.87	0.376
SF36 mental complete score	38.37	40.40	0.536
Preoperative radiographical measurements			
Coronal Cobb angle (°)	29.26	21.77	*0.024*
Sagittal vertical axis (mm)	106.40	81.88	0.092
Thoracic kyphosis (°)	34.33	33.99	0.937
Lumbar lordosis (°)	−26.68	−27.64	0.795
Pelvic tilt (°)	27.13	30.10	0.163
Sacral slope (°)	28.24	25.87	0.327
Global tilt	40.37	40.39	0.995
Lumbar lordosis index	2.85	3.93	0.356
PI-LL	28.69	28.37	0.929
TK + LL + PI	63.01	62.30	0.875
Postoperative HRQoL			
NRS back pain	3.18	3.53	0.323
COMI back score	3.41	4.11	0.314
ODI score	30.21	34.12	0.676
SRS22 total score	3.55	3.37	0.496
SF36 physical complete score	41.64	39.41	0.441
SF36 mental complete score	44.77	45.24	0.717

Table 1 (continued)

	Multi-rod group	Two-rod control group	*p*
Postoperative radiographical measurements			
Coronal Cobb angle (°)	19.82	12.06	*0.001*
Sagittal vertical axis (mm)	39.90	45.78	0.840
Thoracic kyphosis (°)	49.78	52.14	0.678
Lumbar lordosis (°)	−50.91	−48.43	0.375
Pelvic tilt (°)	21.27	25.08	0.062
Sacral slope (°)	34.10	30.85	0.142
Global tilt	24.85	28.57	0.207
Lumbar lordosis index	1.12	1.20	0.193
PI-LL	4.46	7.53	0.300
TK + LL + PI	53.62	58.48	0.232
Improvement			
NRS back pain	3.33	3.22	0.854
COMI back score	3.47	2.70	0.192
ODI score	16.21	10.70	0.146
SRS22 total score	4.66	10.71	0.200
SF36 physical complete score	4.21	6.35	0.461
SF36 mental complete score	2.41	1.10	0.429
MCID NRS back pain	72%	80%	0.573
MCID COMI back score	69%	64%	0.436
MCID ODI score	59%	52%	0.330
MCID SRS22 total score	79%	64%	0.066
MCID SF36 physical complete score	66%	60%	0.454
Coronal Cobb angle (°)	10.46	9.82	0.812
Sagittal vertical axis (mm)	74.95	51.13	0.123
Lumbar lordosis (°)	25.73	24.58	0.716
Thoracic kyphosis (°)	14.65	17.58	0.305
Pelvic tilt (°)	6.44	8.38	0.172
Sacral slope (°)	7.09	8.10	0.489
Lumbar lordosis index	1.92	2.65	0.535
Pelvic incidence–lumbar lordosis	24.20	20.82	0.380
TK + LL + PI difference	8.77	2.67	0.059
Global tilt	24.80	28.50	0.207

Italicized values: statistical significance

MM millimeters; ° degrees, *HRQOL* health-related quality-of-life parameters, *PI* pelvic incidence, *LL* lumbar lordosis, *TK* thoracic kyphosis, *NRS* Pain Numeric Rating Scale, *COMI* Core Outcome Measures Index, *ODI* Oswestry Disability Index, *SRS-22* Scoliosis Research Society Questionnaire, *SF-36* Short-Form Survey 36 Questions, MCID Minimum Clinically Important Difference

material varied between chrome–cobalt, titanium alloy or both types of rods in one patient (considered as titanium alloy, for comparative analysis). Anterior interbody fusion was performed in 44 patients from different approaches (posterolateral or anterior/oblique) in one to three levels. Decompression was performed in one or more levels in 19 patients with fenestration technique. Instrumented levels, osteotomies, rod material, anterior fusion, decompression and number of previous surgeries were matched and therefore not statistically different between groups (Table 1).

Total blood loss (mean 1360 milliliters), surgical time (mean 196 min) and hospitalization days (mean 12.4 days) were not statistically different between groups.

Radiographical outcomes

Preoperative radiographical measurements regarding deformity and sagittal malalignment (SVA, TK, LL, PI, PT, SS, CD, GT, LLI, PI-LL, TK + LL + PI) were not statistically different, with exception of CD, which was higher in the multi-rod group ($p = 0.024$). Both groups had significant postoperative improvement in all the measurements with the surgical treatment ($p < 0.001$). The average improvement was: SVA = 63.03°, TK = 16.1°, LL = 25.1°, PT = 5.5°, SS = 5.4°, CD = 10.1°, GT = 26.6°, LLI = 2.2, PI-LL = 22.5, TK + LL + PI = 5.7.

Analysis detected little difference between groups in the radiographical postoperative outcomes ($p = 0.652$).

Clinical outcomes

Both groups have significant improvement in the HRQoL scores ($p < 0.0001$) (Table 1).

MCID was obtained in more than half of the patients for all the scores (76% for NRS Back Pain, 67% for COMI score, 56% for ODI score, 72% for SRS22 score, 63% for SF-36 PCS). Univariate and multivariate analysis also detected no difference between the HRQoL postoperative outcomes ($p = 0.873$) between the two-rod and the multi-rod groups.

Complications

40.9% of the patients had a surgical complication (Table 2). 77% of these complications were mechanical failure and are described below. Of the non-mechanical complications, we had five patients with postoperative radicular pain (Multi-Rod: 3 vs two-rod: 2) treated conservatively and two deep wound infections (one each) who required surgical wound debridement.

Table 2 Comparison of the complications between the groups

	Multi-rod group	Two-rod group	p
Total	12	15	0.460
Mechanical	7	14	0.111
Rod breakage	4	8	0.208
With pseudarthrosis	1	5	0.089
PJK	3	3	1.000
Screw breakage	1	2	0.310
Screw dislodgement	0	1	0.321
Deep infection	1	1	1.000
Radicular pain	3	2	0.321
Revision surgery			
Rod breakage and pseudarthrosis	1	6	*0.046*
PJK	1	2	0.310

Italicized values: statistical significance

PJK proximal junctional kyphosis

Proximal joint kyphosis (PJK)

PJK occurred in six cases (9%), three of each group. Of these, three required revision surgery, two of them from the two-rod group. Related factors were higher postoperative coronal deformity Cobb angle ($p = 0.025$) and preoperative T1 tilt ($p = 0.013$). Revision surgery consisted of instrumentation extension.

Rod breakage and pseudarthrosis

Rod breakage was the most frequent complication (12 cases, 18%), and it required revision surgery when associated with pseudarthrosis and/or clinical deficit (7 cases). The time of appearance of rod breakage was in average 912 days after surgery (234–645 days), but there was no difference between groups ($p = 0.692$). Rod breakage was more frequent in the two-rod group (8 vs 4, $p = 0.089$, considering rod breakage in the multi-rod group when it occurred in the reinforced segment), as well as the respective revision surgery for those cases (6 vs 1 $p = 0.046$). Patients undergoing revision surgery concerning rod breakage had significantly low HRQoL scores just before the revision surgery, particularly in the pain scores (NRS back pain $p = 0.008$, ODI $p = 0.035$, COMI $p = 0.097$). Factors related to surgical revision were higher TK correction ($p = 0.001$), longer instrumentation ($p = 0.037$) and higher SVA correction ($p = 0.049$) (Table 3). The area of failure always happened in the lumbar area in both the multi-rod and two-rod patients, but it was not always related to the osteotomy site; in some patients, it happened in the lumbosacral segment. A special consideration is one patient of the multi-rod group that required revision surgery for rod breakage and pseudarthrosis. This patient got the breakage and pseudarthrosis in the L5–S1 segment, which was distal to the reinforced segment of instrumentation (two rods only in L5–S1 level with pelvic fixation) (Fig. 2).

Table 3 Factors related to rod breakage revision surgery

	Revision (7)	No revision (59)	p
Length of instrumentation	12.2	9.7	*0.001*
SVA correction (mm)	106.86	57.85	*0.037*
TK correction (°)	30.02	14.47	*0.049*

Italicized values: Statistical significance

SVA sagittal vertical axis, *TK* thoracic kyphosis, *mm* millimeters, ° degrees

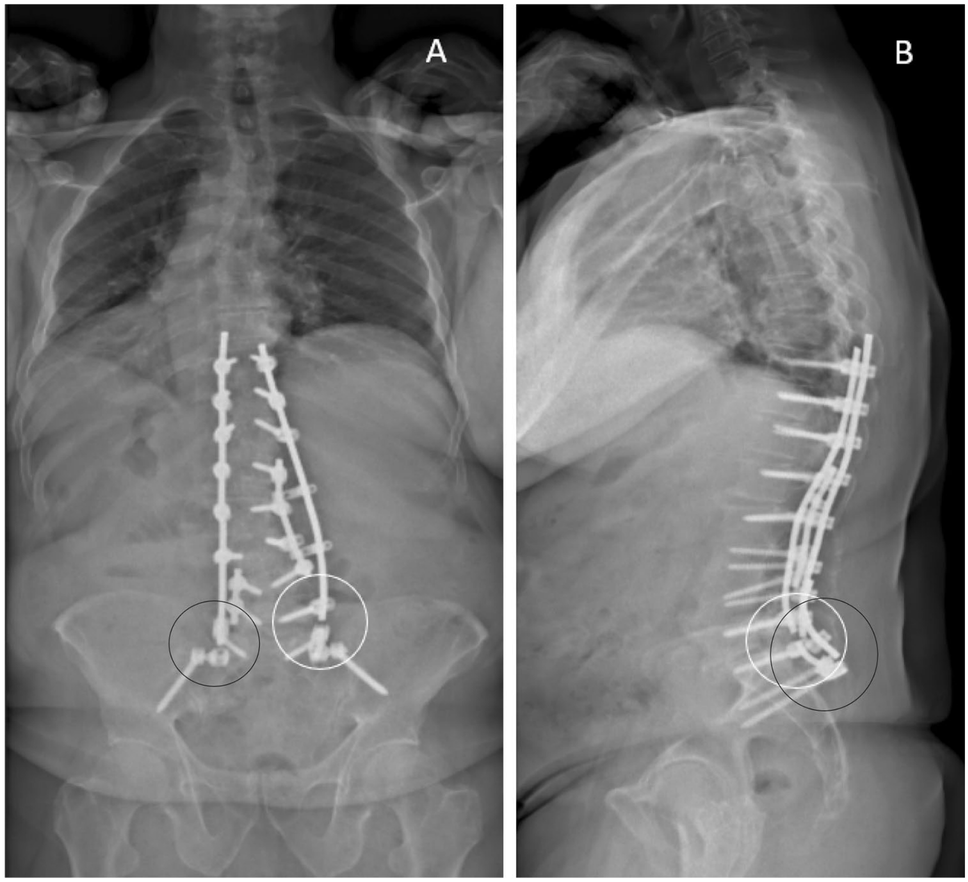

Fig. 2 Special consideration patient of the multi-rod group suffered implant failure that required revision surgery; rod breakage (white circle), rod dislodgement (black circle) and pseudarthrosis (L5–S1) occurred distally adjacent to the multi-rod segment

Discussion

The primary objective of surgery on our ASD patients was to improve HRQoL through sagittal balance restoration, degenerative disease improvement (decompression of stenosis, immobilize arthritic facets, etc.) and/or deformity correction. Long spinal fusions with pelvic fixation have demonstrated superiority to short not pelvic-fixated fusions in a long term [5, 6, 21]. In this study, the general outcome of surgical treatment led toward patient's improvement. HRQoL scores and radiographical outcomes had a significant improvement, and these were similar between groups. Though we did not expect to find a substantial benefit in these areas with the multi-rod construct, we are more concerned with pointing out that no disadvantage was found.

Complications in ASD surgery have a mean reported incidence of 42% overall [1, 7]. The most common major complications described are PJK and rod breakage [21]. We found a similar prevalence of such complications.

Inconsistently to the results of Han et al. [11], we did not find any more prevalence of PJK in multi-rod patients, but our time of follow-up is probably not long enough. In this study, he reports that the increased stiffness in multi-rod constructs of chrome–cobalt might predispose to PJK. The author also stated that the appearance time was less in such stiffer constructs. Our multi-rod constructs always leave a proximal two-rod segment. We believe that this might diminish the stress energy of the adjacent rigid construct as it is transitioned through the spine. This is comparable to the load-sharing principles used in semirigid instrumentations [22]. Therefore, the mechanical factors affecting PJK in multi-rod constructs might behave similarly to those of two-rod constructs.

Soroceanu et al. [21] and Daniel et al. [23] reported rod breakage in ASD surgery with an incidence between 9.5 and 15%. Reported related factors were: worse preoperative and postoperative sagittal malalignment, more SVA and TK surgical correction, older age, worse ASA score, heavier patients, longer fusions, three-column osteotomies, rod material and diameter. Our results agree with the longer fusions and higher SVA and TK correction. These translate in higher "lever arm" energy creating greater mechanical stress to the rods. Therefore, increasing the stiffness and the load sharing with additional rods may resist better these forces and prevent the implant failure. Taking in consideration material and diameters of the rods, there was not statistical difference between broken and not broken rods. Decision making in the selection of material and diameters is in many cases surgeon dependent, but vast knowledge of the properties of each kind of rod (stiffness, Young's modulus, etc.) is essential.

Revision surgery for rod breakage with pseudarthrosis was significantly lower with the multi-rod construct ($p = 0.046$). Similar studies comparing techniques that also consist of some types of multi-rod construct agree that rod breakage and pseudarthrosis can be diminished when improving the stability of the construct [8–12]. Several biomechanical anatomical model studies have demonstrated the increased stability that can be achieved with the addition of peripheral rods in the posterior instrumentation construct [13–15]. Hence, reduction can be kept longer and if there is failure of one or two rods, the remaining unbroken rod can still supply enough stability to promote fusion. This is inferred from the not-revised broken rod patients of the multi-rod group. The use of posterior graft in a well-prepared interspinous and laminar bone bed remains mandatory. This does not disregard the use of interbody fusion cages; they are still recommended when correctly indicated.

Revision surgery was importantly related to lower HRQoL scores, especially the pain scores. Bourghli et al. [24] stated that lack of improvement after 6 months of surgery predicts high revision rate in ASD patients. Even if the results of our multi-rod patients did not have significantly better HRQoL parameters than the two-rod patients, the interpolation to probable less revision surgery in the future might affect further HRQoL positively.

The importance of pelvic fixation and its reinforcement with multi-rod construct is denoted by the case of adjacent segment implant failure and pseudarthrosis in L5-S1 (Fig. 2). The segment L5-S1 is considered the one with most flexion/extension mobility in the lumbar spine. Therefore, it is in high risk of pseudarthrosis and implant failure when fusion is performed. Shen et al. prompt the use of pelvic fixation to diminish this problem [25]. He also addresses the issue of different segmental stiffness in outrigger and satellite rods as the forces are transmitted to the adjacent two-rod segment [8]. For this, he implements the previously mentioned 'dual construct' technique, which not only reinforces the lumbosacral junction, but also transmits the forces in pedicle independent manner. The disadvantage of this procedure is its technically demanding complexity, as stated by the author.

We acknowledge that this study has several limitations which are important to consider. Like any retrospective study, selection bias may affect the results of the study. To minimize this, we selected patients which complied with strict characteristics to homogenize the main group and the comparative cohort. Another weakness of this study is the little time of follow-up. The mean postoperative time of rob breakage is longer than the minimum follow-up period. Favorably, even if follow-up was longer in the two-rod group, this was not statistically different between groups. Multi-rods are being used more frequently in recent years in response to the growing learning curve of the surgeons. So, a minimum follow-up of 1 year was used to maintain power of analysis. Regarding the variable of a prior surgery, if the multiple-rod construct is developed for an initial case, it has different loads and requirements, than if it is for a revision case. *For example, if there was a previous fusion, rigidity of the spine deformity will require stronger constructs or more destabilizing procedures, like PSO*. Finally, considering the drawback of a low population study, we propose bigger multicenter studies to support further guidelines on the use of multi-rods.

Conclusion

In ASD surgery, the addition of extra rods to the construct may not necessarily present a demanding technical challenge for the spine surgeon; even sometimes, they facilitate the reduction and fixation. Disregarding the notorious incidence of complication in complex deformity surgery, no major disadvantage on the use of multi-rod construct was identified. No more bleeding, surgical time, hospitalization time, infection or neurological complications were statistically different. This suggests, in this and several other studies, that the benefits might outweigh any possible disadvantage. The author suggests the use of multi-rod constructs and its extension to the lumbosacral junction in long instrumentations of patients with ASD, when high level of sagittal malalignment and deformity is to be corrected.

Compliance with Ethical Statement

Conflict of interest There are no conflicts of interest for this article.

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