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ORIGINAL ARTICLE

Revision surgery following long lumbopelvic constructs for adult spinal deformity: prospective experience from two dedicated databases

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Abstract

Purpose Pan Lumbar Arthodesis (PLA) are often required for Adult Spinal Deformity (ASD) correction, reducing significantly the compensatory capacity in case of postoperative sagittal malalignment. Few papers have investigated outcomes and complications in this vulnerable subset of patients. The objective of this study was to assess revision surgery rate for PLA in ASD, its risk factors and impact on clinical outcomes.

Methods Retrospective multicenter review of prospective ASD data from 7 hospitals covering Europe and Asia. ASD patients included in two prospective databases having a posterior instrumentation spanning the whole lumbar region with more than 2-years of follow-up were reviewed. Demographic, surgical, radiographic parameters and Health-Related Quality of Life (HRQoL) scores were analyzed. Univariate and multivariate regression models analyzed risk factors for revision surgery as well as surgical outcomes. Patients with Early versus Late and PJK versus Non-PJK mechanical complications were also compared.

Results Out of 1359 ASD patients included in the database 589 (43%) had a PLA and 357 reached 2-years mark. They were analyzed and compared to non-PLA patients. Average age was 67 and 82% were females. 100 Patients (28.1%) needed 114 revision surgeries (75.4% for mechanical failures). Revised patients were more likely to have a nerve system disorder, higher BMI and worst immediate postoperative alignment (as measured by GAP Parameters). These risk factors were also associated with earlier mechanical complications and PJK. Deformity and HRQoL parameters were comparable at baseline. Non-revised patients had significantly better clinical outcomes at 2-years (SRS 22 scores, ODI, Back pain). Multivariate analysis could identify nerve system disorder (OR 4.8; CI 1.8–12.6; $p=0.001$), postoperative sagittal alignment (GAP Score) and high BMI (OR 1.07; CI 1.01–1.13; $p=0.004$) as independent risk factors for revisions.

Conclusions Revision surgery due to mechanical failures is relatively common after PLA leading to worse clinical outcomes. Prevention strategies should focus on individualized restoration of sagittal alignment and better weight control to decrease stress on these rigid constructs in non-compliant spines. Nerve system disorders independently increase revision risk in PLA.

Level of evidence II Prognosis.

Keywords Adult spinal deformity · Degenerative · Scoliosis · Spine · Surgery · Lumbar · Pelvis · Complications · Mechanical · Multicenter

Introduction

Patients with adult spinal deformity (ASD) suffer from back pain and disability and their quality of life is significantly worse than age-matched peers [1]. Surgery, when properly indicated, has been shown to improve quality of life when compared to conservative treatment [2]. In the past two

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decades, the number of adults undergoing surgery for sagittal and coronal spinal deformity correction has greatly increased [3]. At the same time, and with advances in medical and surgical care, older patients needing more complex procedures are coming forth for ASD surgery [3]. In parallel, a great proportion of these older patients are having long spinal fixations ending in the pelvis and spanning the entire lumbar region as part of their primary or revision deformity treatment [4]. This increased surgical volume, changing patients' characteristics combined with more complex and invasive surgeries are increasing overall morbidity and costs [3, 5].

In a recent predictive model analysis, both long instrumentations and fixations to pelvis have been found to be strong predictors of major complications and revisions in ASD surgery [6]. Another notorious risk factor for mechanical complications is the postoperative sagittal malalignment [7]. Pan lumbar arthrodesis (PLA) (UIV ≥ T12; LIV ≤ S1) is unique as it increases construct stiffness and decreases compensatory capacity within the instrumented anatomical region. Therefore, in cases of malalignment, compensatory mechanisms are limited to pelvic retroversion and changes at cranial levels. This iatrogenically decreased compensation capacity increases greatly the stress on the junctional regions and obliges surgeons to achieve a perfectly harmonious sagittal balance in order to avoid mechanical complications. No other study has specifically investigated the complications and outcomes of this particular subset of patients associating pelvic fixation and PLA.

The primary aim of this study is therefore to assess reoperation rate after PLA for ASD by combining two compatible prospective ASD databases, identify its risk factors and analyse the impact of unplanned revision surgeries on clinical outcomes. A special emphasis is given to sagittal parameters, mechanical revisions and proximal junctional failures in this review. As secondary objectives, and by creating a big dataset of patients with PLA, we will be able to compare the practice in Europe and Japan and offer an external validation of the Global Alignment and Proportion (GAP) score. Finally, an attempt will be made to create a predictive model for unplanned revisions using the identified risk factors.

Materials and methods

Study design and patient sample

We conducted a retrospective review of two mutually compatible prospective ASD databases from 7 hospitals covering Europe and Japan for PLA patients with more than 2-years follow-up. Consecutive surgical ASD patients were included if they were older than 18 years and had a spinal deformity: coronal Cobb > 20° or SVA > 5 cm or PT > 25° or TK > 60°. PLA was defined as having a posterior instrumented fusion spanning the whole lumbar area (UIV ≥ T12; LIV ≤ S1).

Measured variables

Demographical, surgical, radiological and functional variables were prospectively recorded and available for analysis. Upper Instrumented Vertebra (UIV) was divided into three categories for analysis (Upper Thoracic: between T1 and T5, Middle Thoracic T6-T9, or Lower thoracic T10-12), and LIV into two (ilium or Sacrum). Any non-congenital neurological disorder occurring in adulthood was labeled as Nerve system disorder (NSD). It mainly included Parkinson, cervical myelopathy, epilepsy, multiple sclerosis, traumatic brain injuries amongst others.

Radiographic parameters included overall deformity measurements, as well as sagittal coronal and spinopelvic alignment parameters including GAP Score parameters [7]. GAP alignment tool was entered categorically (proportionate, moderately disproportionate, severely disproportionate) and as a compound score. They were measured at three points: preoperatively, immediately postoperatively and at a 2 year follow-up.

Patients' reported outcomes measures (PROMSs) were obtained preoperatively and at 2 year postoperatively with validated Health Related Quality of Life (HRQoL) outcome tools.

Outcome measures and statistical analysis

We identified revision surgeries and causes for reoperations in PLA. We analysed the cumulative revision rate at 2-years. Revision rate was first compared using Kaplan Meier curves to the non-PLA population in the database with more than 2 years follow-up.

We then compared re-intervened PLA patients to unrevised PLA patients in terms of baseline demographical, surgical, radiological and functional parameters to query for potential risk factors for unplanned revision surgery. Risk factors were identified using a univariate analysis with preoperative data and immediate postoperative sagittal alignment. Identified potential risk factors were then entered into a multiple logistic regression analysis to isolate independent risk factor of revision surgery.

A ROC analysis was conducted using the GAP compound score and an ANOVA analysis was run to check for inter-group differences. We then incorporated to the GAP score the other identified independent risk factors for mechanical revisions to improve the predictive capacity of the model and a new ROC analysis was performed accordingly.

A dedicated analysis of mechanical revisions was performed and compared patients having reinterventions for Proximal Junctional Kyphosis (PJK) to those having

revisions for non-PJK mechanical failures. We also compared patients with Early Mechanical Complications (Early MC; < 90 days) to those presenting with Late MC.

Finally, the impact of revision surgery on HRQoL at 2 years was evaluated in the PLA population and in patients having mechanical complications.

All statistical analyses were performed with EZR (Saitama Medical Center, Jichi Medical University, Saitama, Japan), which is a graphical user interface for R (The R Foundation for Statistical Computing, Vienna, Austria). Descriptive and bivariate comparisons of demographic variables were performed between 2 groups using independent t-test for continuous variable, and Fischer's exact test for the categorical variables. The level of statistical significance was set at $p < 0.05$.

Results

Out of the 1359 ASD patients included in the database 589 (43%) had a PLA. PLA rate rose steadily from 2010 to 2014 and remained stable thereafter. Of these, 357 reached the 2-years follow-up and were analysed (Fig. 1; Flowchart). Average age was 66.9 (± 9.69) and 82.4% were females. The primary aetiology of index surgery was degenerative (54.9%).

100 patients had an unplanned revision by the second year (28.1%) with a total of 114 reinterventions performed. These surgeries were performed for the following reasons: 86 (75.4%) for mechanical failures, 12 for infection (10.5%), 11 for wound problems and hematomas (9.6%) and 5 for other types of complications (3.6%). 82 patients (23.0%) had at least one mechanical complication needing revision surgery. A full account of causes of revisions is reproduced in Tables 1 and 2. Rod breakage or pseudarthrosis was the major group within mechanical complications and included patients having implant loosening or dislodgment in the absence of infection.

Revision rate was similar between both PLA and non-PLA patients at one year after surgery (14.6% vs. 11.5%, $p = 0.23$). This difference was statistically different at 2 years, with twice as more PLA patients needing surgical revision (28.1% vs. 13.8%, $p < 0.001$). Kaplan–Meier survival curves for PLA and non PLA patients are reproduced in Fig. 2.

Comparison of demographic and surgical data between revised and non-revised PLA patients is summarized in Table 3. The revision group had significantly higher BMI (26.0 vs. 24.2 kg/m^2 $p < 0.001$) and more likely to have nerve system disorder (NSD) (13.0% vs. 3.1% $p < 0.001$). Both groups were similar with regards to surgical details. Overall, the number of fused levels was 9.75, and 31.7% (113 patients) underwent 3-column osteotomies and 14% had a combined Anterior–Posterior approach. 89% of patients (320) had a fixation ending with Iliac Screws and 37 had other forms of fixations (S1, S2-Iliac). 4 patients had a distal Junctional Failure (DJF) in the form of sacral (1) or iliac screw failure/breakage (3). Nearly half of the sample had the UIV in the lower thoracic region (189 patients, 52.9%) and the most common UIV was T10 (140 patients, 39.2%) followed by T9 (55 patients, 15.4%) (Fig. 3). Hooks at the UIV were only used in 17 patients. Mean blood loss was 1873 (± 1129 ml) ml and surgical time was 369 min (± 150 mn).

The choice of UIV, the type of UIV (Screw vs. Hook), the type of distal fixation and the addition of an anterior approach or 3CO did not seem to alter reintervention risk. Patients operated in Europe were more likely to be re-intervened by the second year compared to the Japanese cohort (34.7% vs. 22.1% p 0.009).

Radiographic parameters preoperatively, immediately postoperatively and at 2-year follow-up are summarized in Table 4. Preoperatively, both groups were homogeneous. Immediate postoperative sagittal alignment improved significantly in the majority of studied parameters. However, on the first radiological assessment, the unrevised group achieved a more harmonious alignment as measured by the Global Tilt [8, 9] (20.4 vs. 23.5, $p = 0.02$), Relative Pelvic Version [7] (− 7.92 vs. − 9.83, $p = 0.04$), Relative Spinopelvic Alignment (RSA) (9.3 vs. 11.5 $p = 0.048$) and GAP Scores (4.9 vs. 6.5; $p = 0.005$) (Table 5). Revision rate increased linearly from proportionate (17.4%) to mildly disproportionate (26.4%) to severely disproportionate (34.7%) ($p = 0.001$) (Fig. 4). The AUC for GAP Score alone was 0.61. At 2 years, and after accounting for surgical correction performed during revision surgeries, all radiological parameters were again similar between both groups.

Preoperative and postoperative functional results are summarized in Table 6. Again, both groups were comparable at baseline. Both groups benefitted equally from surgery and their postoperative scores at 2 years were significantly better than baseline. Nevertheless, when comparing both groups at two years, all HRQOL parameters were significantly worse in re-intervened patients. Improvements in ODI from baseline were significantly less in the revised group (16.2 vs. 9.7, $p = 0.003$). As a group, non-reintervened patients experienced average improvements above MCID for ODI for example. Their ODI gains at 2 years were 16.2, higher than the MCID for ODI (10.2) [10]. Nevertheless, the benefits of the index surgery were diluted in the event of a complication as re-intervened patients did not reach MCID in ODI when compared to their baseline (ODI gains at 2 years were 9.7). Finally, the difference between revised and non revised PLA in ODI gains with surgery (6.5) did not reach MCID.

Univariate analysis found NSD, higher BMI, and worse immediate postoperative alignment (GT, RSA, RPV and GAP score) as significant risk factors for revision surgery.

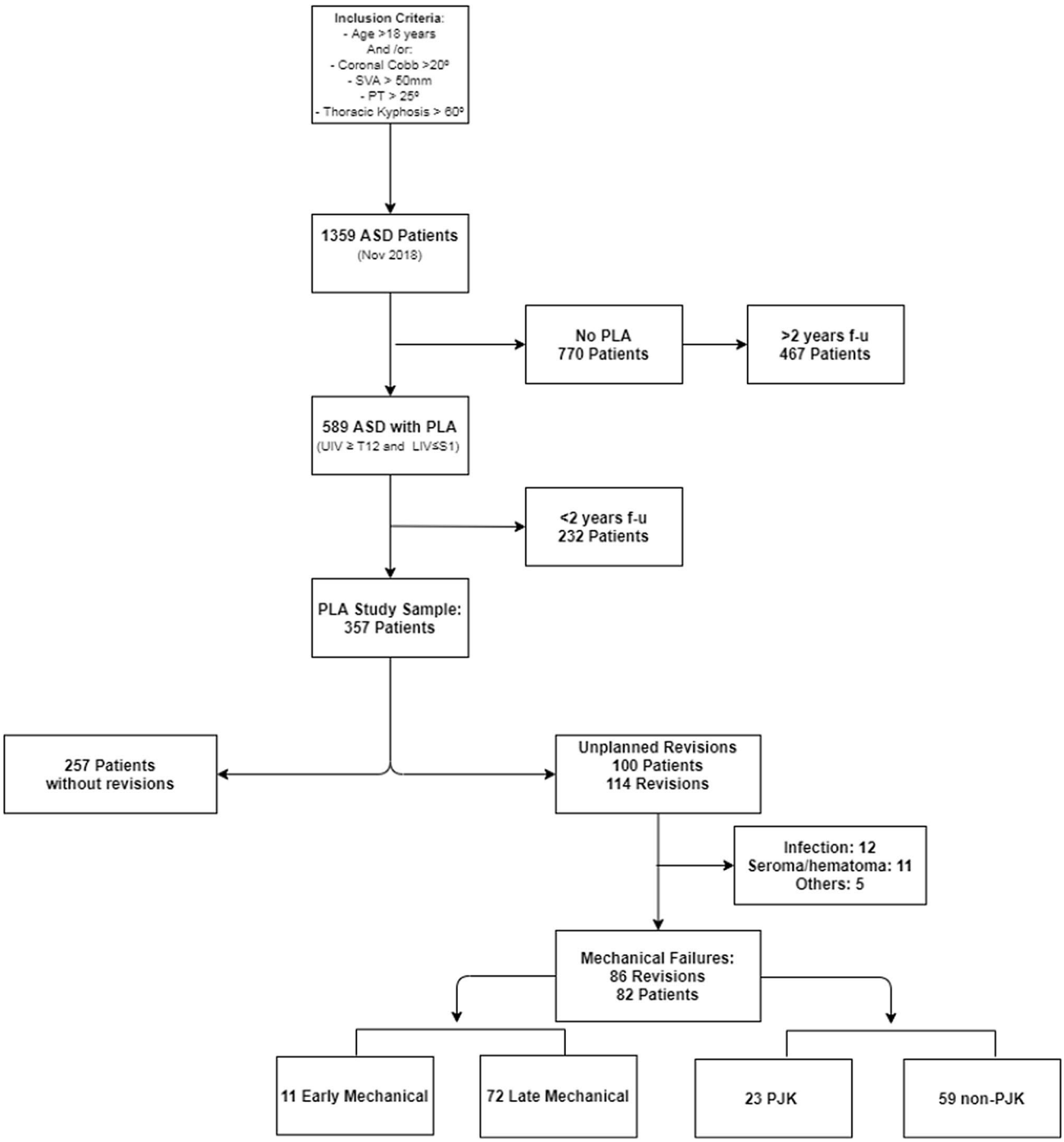

Fig. 1 Flowchart. *PJK* proximal junctional failure

Multiple logistic regression analysis could identify NSD (OR 4.76; CI 1.81–12.60; $p=0.001$) GAP Score (OR 1.08; CI; 1.01–1.16 $p=0.035$) and higher BMI (OR 1.07; CI 1.01–1.13; $p=0.015$) as independent risk factor for revision surgery after PLA (Table 7). When combining BMI and NSD to GAP score, AUC improved to 0.67. BMI and GAP being continuous variables, their ORs increase exponentially between ranks. For example, a patient with a GAP score of 12 has an OR of 2.33 of having a revision surgery when compared to a similar patient with a GAP score of 1. Similarly, a patient with BMI 35 has an OR of 2.41 when compared to someone with a BMI of 22.

82 PLA patients had at least one unplanned revision for mechanical failures and were analysed separately. There

Table 1 Mechanical or implant related complications

Mechanical or implant related complications	*n*
Pseudoarthrosis/rod breakage	54
PJK/PJF	23
DJK/Iliac screw loosening	3
Screw malposition	2
Implant/rod protrusion	2
Screw extension not removed	1
Interbody cage migration	1

Table 2 Other complications needing revisions

Other complications needing revisions	*n*
Infection	12
Seroma/hematoma	11
Coronal malalignment	2
Radicular pain	2
Cement leakage with neurological deficit	1

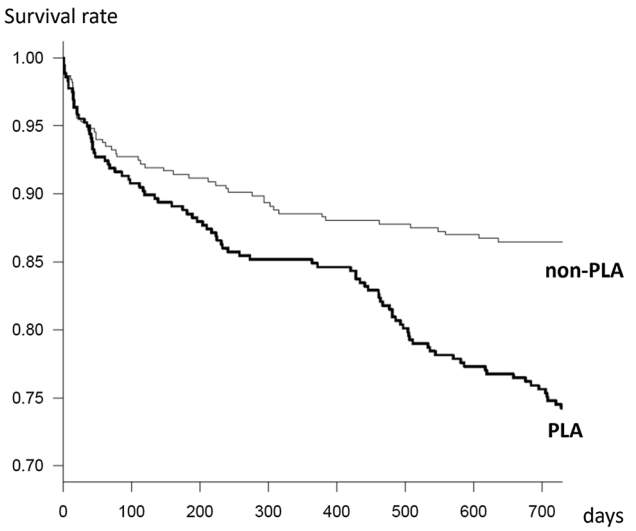

Fig. 2 Kaplan–Meier survival curves without revisions comparing patients with PLA and those without

were 86 mechanical complications needing revision. On average PJKs occurred earlier than rod breakage (mean time to revision for PJK 254.0 days vs. 637.0 days for rod breakage $p=0.001$). Patients having revisions for PJK (23/86 26.7%) were more fragile (ASA 2.26 vs. 1.95 $p=0.018$), and had a higher BMI when compared to patients having a mechanical failure other than PJK (63/86; 73.3%). Mechanical complications other than PJK were mainly pseudarthrosis and rod breakage (Table 1). Patients with PJKs were more likely to have had their index surgery for failed back (21.7% vs. 8.2% $p=0.045$). They had significantly worse immediate postoperative alignment as measured by GT and RPV, worse PI-LL mismatch (12.5° vs. 8.0° $p=0.031$), PT (26.9° vs. 21.3° $p=0.010$) and lower SS (26.8° vs. 33.8° $p=0.015$). At 2-years however, and after accounting for revision surgeries, their sagittal parameters were similar to non-PJK MC. Nevertheless they remained with significantly worse HRQoL outcomes in all measured domains with the exception of leg pain.

A similar trend was found when comparing early to late MC. Patients with early MC (11/82; 13.4%) were more fragile and had a higher BMI when compared to patients having late mechanical complications. They were also more likely to have a NSD (36.4% vs. 11.3% $p<0.001$) and with worse immediate postoperative alignment as measured by RPV, PI-LL and PT. They achieved however similar radiological alignment at 2-years but still reported worst overall HRQoL.

Below are two patients with more than 4 years of available follow-up. Patient A (Fig. 5) had a good GAP postoperative alignment and did not have any mechanical complication. Patient B (Fig. 6) had a suboptimal postoperative alignment and ultimately needed revision.

Discussion

The present work is the largest study specifically addressing revision rate, as well as radiographic and HRQOL outcomes in patients with PLA for ASD. It is also the first to try and identify potential risk factors and draft a prediction model for this population. It shows that PLA is associated with increased revision rate at 2-years. Revision is mainly for mechanical failures in PLA and picks up after the first postoperative year. Patients having unplanned revisions were more likely to have a NSD, higher BMI, and worse immediate postoperative spinopelvic alignment (GT, RPV and GAP score). In the multivariate analysis, NSD, GAP score and high BMI were found to be independent risk factors of revision. Fragile, more obese patients and those with NSD were also found to have earlier failures and were more prone to suffer a PJK.

In recently published papers, the 2-years revision rate after ASD surgery has been reported to be between 13 and 28% [6, 11, 12] similar to the results in our study. We could prove PLA was associated to higher revision rates reaching 28.1% at two years. This suggests that PLA -in accordance with results from newly established predictive model- is an important risk factor for revision surgeries [6]. Similarly, revision rate steadily increased after the first year mainly paralleling mechanical failures. The main driver for revisions in PLA was mechanical failures (75.4%) and 82% of revised patients had at least one mechanical failure. Within mechanical failures, rod breakage and pseudarthrosis were more common than PJK and more readily needed revision. They also ted to occur later on during follow-ups. This is

Table 3 Comparison of demographic and surgical data

n	All		Revision		Non-revision		*P* value
	357	(%, SD)	100	(%, SD)	257	(%, SD)	
Age in years (mean, SD)	66.9	9.69	65.7	11.09	67.3	69.06	0.146
Female gender (*n*, %)	294	82.4	80	80	214	83.3	0.536
ASA-PS (mean, SD)	1.99	0.48	2.20	0.53	1.98	0.46	0.444
BMI (mean, SD)	**24.7**	**4.52**	**26.0**	**4.82**	**24.2**	**4.31**	**0.001***
Comorbidity							
Tobacco use (*n*, %)	49	13.7	19	19.0	30	11.7	0.086
Cardiac (*n*, %)	32	9.0	11	11.0	21	8.2	0.413
Pulmonary (*n*, %)	60	16.8	19	19.0	41	16.0	0.529
Diabetes (*n*, %)	39	10.9	10	10.0	29	11.3	0.851
Hypertension (*n*, %)	147	41.2	39	39.0	108	42.0	0.633
Nerve system (*n*, %)	**21**	**5.9**	**13**	**13.0**	**8**	**3.1**	**0.001***
Osteoporosis (*n*, %)	49	13.7	32	32.0	73	28.4	0.519
Renal (*n*, %)	19	5.3	4	4.0	15	5.8	0.606
Pathology of deformity							
Degenerative (*n*, %)	196	54.9	48	48.0	148	57.6	0.124
Failed back (*n*, %)	29	8.1	12	12.0	17	6.6	0.129
Idiopathic (*n*, %)	55	15.4	16	16.0	39	15.2	0.871
Neuromuscular (*n*, %)	27	7.6	4	4.0	23	8.9	0.124
Other (*n*, %)	24	6.7	11	11.0	13	5.1	0.058
Post traumatic (*n*, %)	27	7.6	10	10.0	17	6.6	0.273
Surgical variables							
EBL (mean, SD)	1873	1229	2017	1266	1817	1212	0.167
Surgical time (mean, SD)	369	150	372	156	362	135	0.59
Fusion segment (mean, SD)	9.8	2.9	9.6	3.1	9.8	2.8	0.691
Combined approach (*n*, %)	53	14.8	11	11.0	42	16.3	0.247
LIV: Ilium (*n*, %)	320	89.6	89	89.0	231	89.9	0.847
UIV LT: T1-5 (*n*, %)	66	18.5	18	18.0	48	18.7	1
UIV MT: T6-9 (*n*, %)	102	28.6	26	26.0	76	29.6	0.602
UIV UT: T10-12 (*n*, %)	189	52.9	56	56.0	133	51.8	0.481
3-CO (*n*, %)	113	31.7	31	31.0	82	31.9	0.9

Statistically significant values ($p < 0.05$) are highlighted in bold

ASA-PS American society of anesthesiologists physical status, *BMI* body mass index, *EBL* estimation blood loses, *LIV* lower instrumented vertebra, *UIV* upper instrumented vertebra, *UT* upper thoracic, *MT* middle thoracic, *LT* lower thoracic, *SD* standard deviation

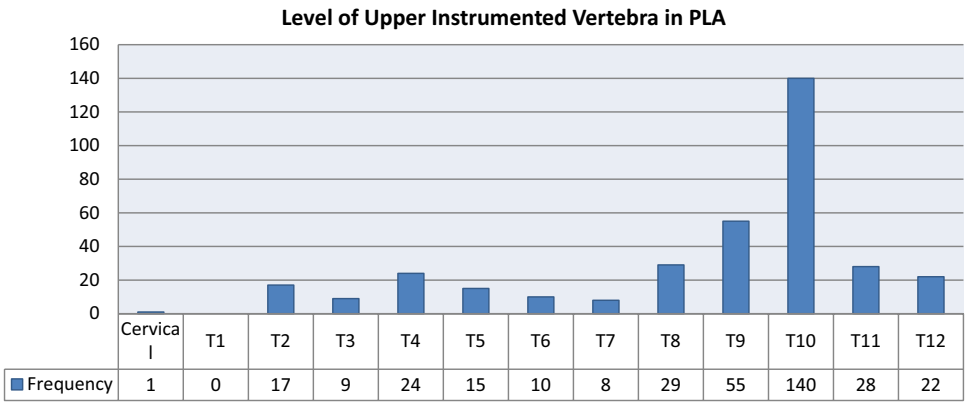

Fig. 3 Level of upper instrumened vertera in PLA

Table 4 Comparison of radiographic parameters in angles

n	All		Revised		Non-revised		*P* value
	357	(°, SD)	257	(°, SD)	100	(°, SD)	
Preoperative							
Cobb (mean, SD)	31.3°	23.0°	30.1°	23.2°	31.8 °	23.0°	0.52
GT (mean, SD)	39.2°	15.9°	41.3°	16.0°	38.4°	15.9°	0.13
SVA (mean, SD)	106.6°	78.9°	107.6°	77.9°	106.1°	79.5°	0.87
TK (mean, SD)	29.6°	19.7°	28.8°	21.3°	29.9°	19.1°	0.64
LL (mean, SD)	21.0°	23.9°	22.4°	26.9°	20.5°	22.7°	0.52
PI-LL (mean, SD)	34.1°	22.7°	33.7°	24.3°	34.3°	22.1°	0.84
PT (mean, SD)	32.2°	11.3°	32.9°	10.3°	31.9°	11.7°	0.45
SS (mean, SD)	22.9°	13.8°	23.1°	14.7°	22.8°	13.5°	0.86
PI (mean, SD)	55.2°	12.9°	56.1°	12.8°	54.8°	13.0°	0.40
Postoperative							
Cobb (mean, SD)	13.0°	12.8 °	13.4°	15.6°	12.8°	11.7°	0.69
GT (mean, SD)	21.3°	10.9°	**23.5°**	**11.6°**	**20.4°**	**10.6°**	**0.02***
SVA (mean, SD)	37.3°	45.2°	40.6°	47.4°	36.0°	44.4°	0.41
TK (mean, SD)	40.3°	13.4°	40.2°	15.0°	40.4°	12.8°	0.93
LL (mean, SD)	48.5°	13.5°	48.1°	16.1°	48.7°	12.4°	0.74
PI-LL (mean, SD)	6.2°	13.5°	8.2°	13.6°	5.5°	13.5°	0.10
PT (mean, SD)	21.1°	9.1°	21.7°	8.8°	20.9°	9.3°	0.47
SS (mean, SD)	32.9°	10.2°	32.4°	11.1°	33.0°	9.9°	0.60
PI (mean, SD)	54.7°	12.9°	56.3°	13.0°	54.2°	12.8°	0.17
2 years							
Cobb (mean, SD)	13.9°	11.9°	13.2°	11.8°	14.1°	12.0°	0.55
GT (mean, SD)	27.1°	12.2°	28.2°	12.3°	26.7°	12.2°	0.34
SVA (mean, SD)	57.6°	58.3°	54.9°	54.4°	58.5°	59.7°	0.63
TK (mean, SD)	46.1°	18.6°	46.0°	17.5°	46.1°	19.0°	0.96
LL (mean, SD)	45.0°	14.6°	44.2°	17.6°	45.3°	13.3°	0.54
PI-LL (mean, SD)	9.6°	15.5°	9.1°	15.7°	9.8°	15.5°	0.73
PT (mean, SD)	25.1°	8.8°	25.0°	8.7°	25.1°	8.9°	0.91
SS (mean, SD)	30.3°	11.5°	29.3°	13.6°	30.6°	10.7°	0.36
PI (mean, SD)	55.0°	13.5°	54.3°	14.6°	55.3°	13.1°	0.55

Statistically significant values ($p < 0.05$) are highlighted in bold

GT global tilt, *SVA* sagittal vertical axis, *TK* thoracic kyphosis, *LL* lumbar lordosis, *PT* pelvic tilt, *SS* sacral slope, *PI* pelvic incidence, *SD* standard deviation

Table 5 Postoperative GAP scores

n	All		Revised		Non-revised		*P* value
	357	(%, SD)	257	(%, SD)	100	(%, SD)	
Postoperative							
GAP score (mean, SD)	**5.3**	**3.5**	**6.1**	**3.7**	**4.9**	**3.5**	**0.005**
RPV (mean, SD)	**−8.4**	**7.7**	**−9.8**	**8.0**	**−7.9**	**7.5**	**0.04**
RLL (mean, SD)	−14.4	12.0	−15.8	13.1	−13.9	11.5	0.194
LDI (mean, SD)	69.0	24.0	71.5	30.6	68.1	21.0	0.238
RSA (mean, SD)	**9.9**	**8.9**	**11.5**	**9.8**	**9.3**	**8.4**	**0.048**

Statistically significant values ($p < 0.05$) are highlighted in bold

GAP global alignment and proportion, *P* proportioned, *MD* morerately disproportioned, *SD* severely disproportioned, *RPV* relative pelvic version, *RLL* relative lumbar lordosis, *LDI* lordosis distribution index, *RSA* relative spinopelvic alignmnet

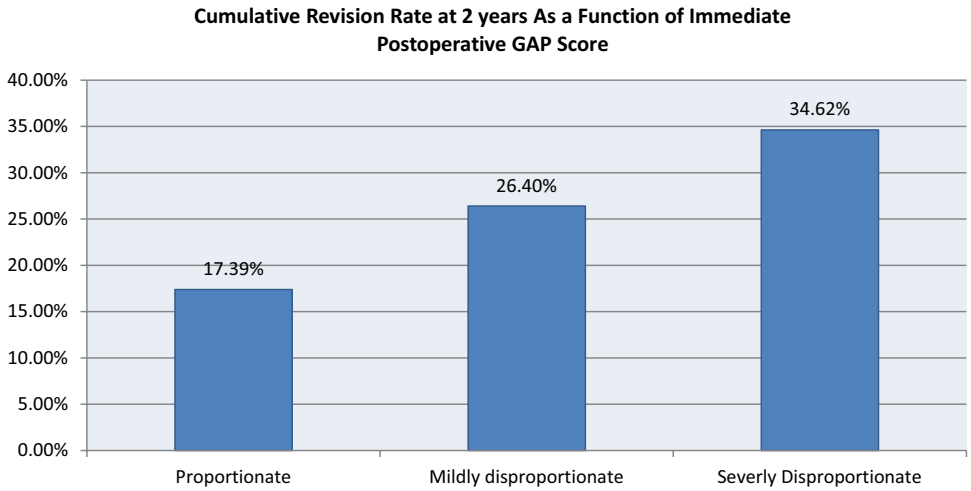

Fig. 4 Cumulative revision rate at 2 years as a function of immediate postoperative GAP score

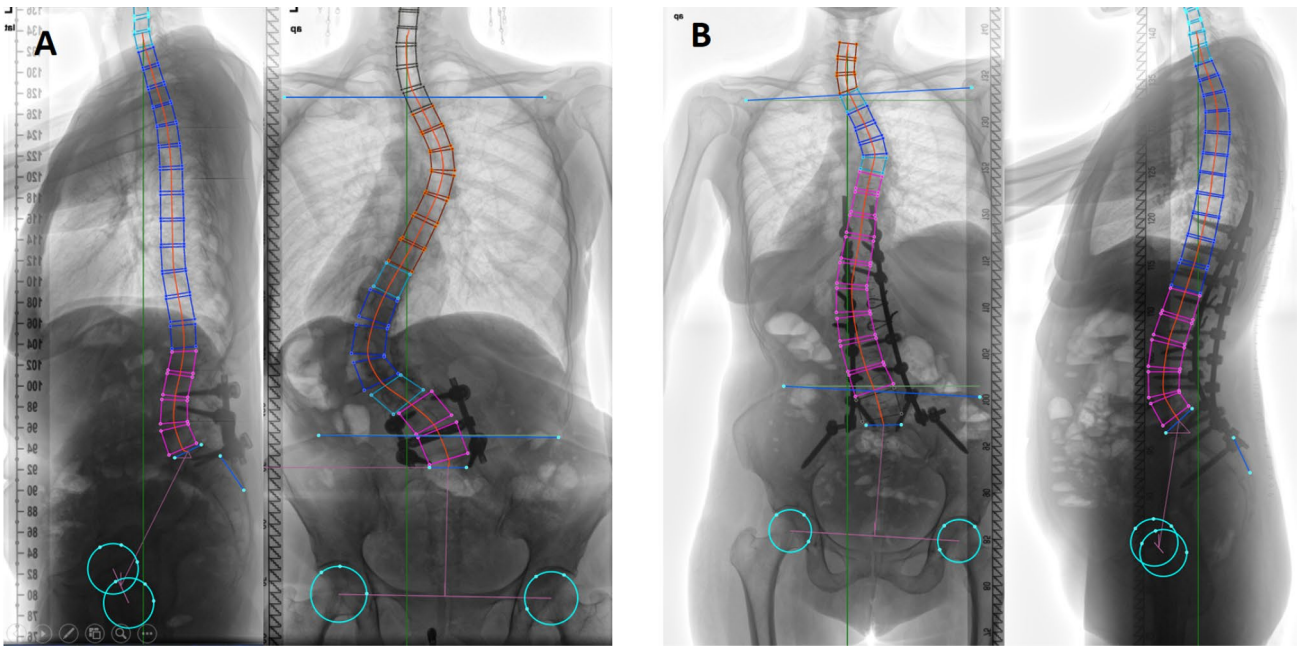

Fig. 5 54-year-old female with an idiopathic curve progressing into adulthood who has had a limited lumbar L4-S1 fusion and decompression 9 years prior to index surgery, presenting with severe back pain and claudication as well as biplanar malalignment (**A**) PI 53 LL 21° L4-S1 29° GT 33° SS 26°. GAP Score 11 preoperatively. She undergone T10 to Pelvis posterior instrumented fusion with posterior column osteotomies from T12 to L5 and L3-4 decompression. Her sagittal alignment improved postoperatively and was maintained at the 4-year mark (**B**) PI 53 LL 62° L4-S1 38° GT 10° SS 40°, GAP 0. She did not have any mechanical complication nor revision surgery

in accordance with published literature [13]. Infection was the second most common reason for unplanned revisions, with 2.8% of PLA cases having a debridement in the first 3 months after index surgeries [14]. Thus, the increase in revision rates in PLA detected after the first year was exclusively due to mechanical failures.

Patients fused to pelvis or having a PLA were reported to experience less improvements in their HRQOL [15–17]. However, stiffness does not seem to increase disability and patients still report HRQoL gains [17]. Complication in ASD surgery is known to have a long-lasting impact even if the complication is resolved [11]. The present study demonstrates that patients improved with surgery. Revised patients however had significantly worse HRQOL at 2-years after surgery, in spite of having similar final spinopelvic alignment. Interestingly enough, PLA patients needing reinterventions did not reach MCID for ODI at final follow-up. Therefore, properly selected PLA patients do benefit from surgery. The impact of

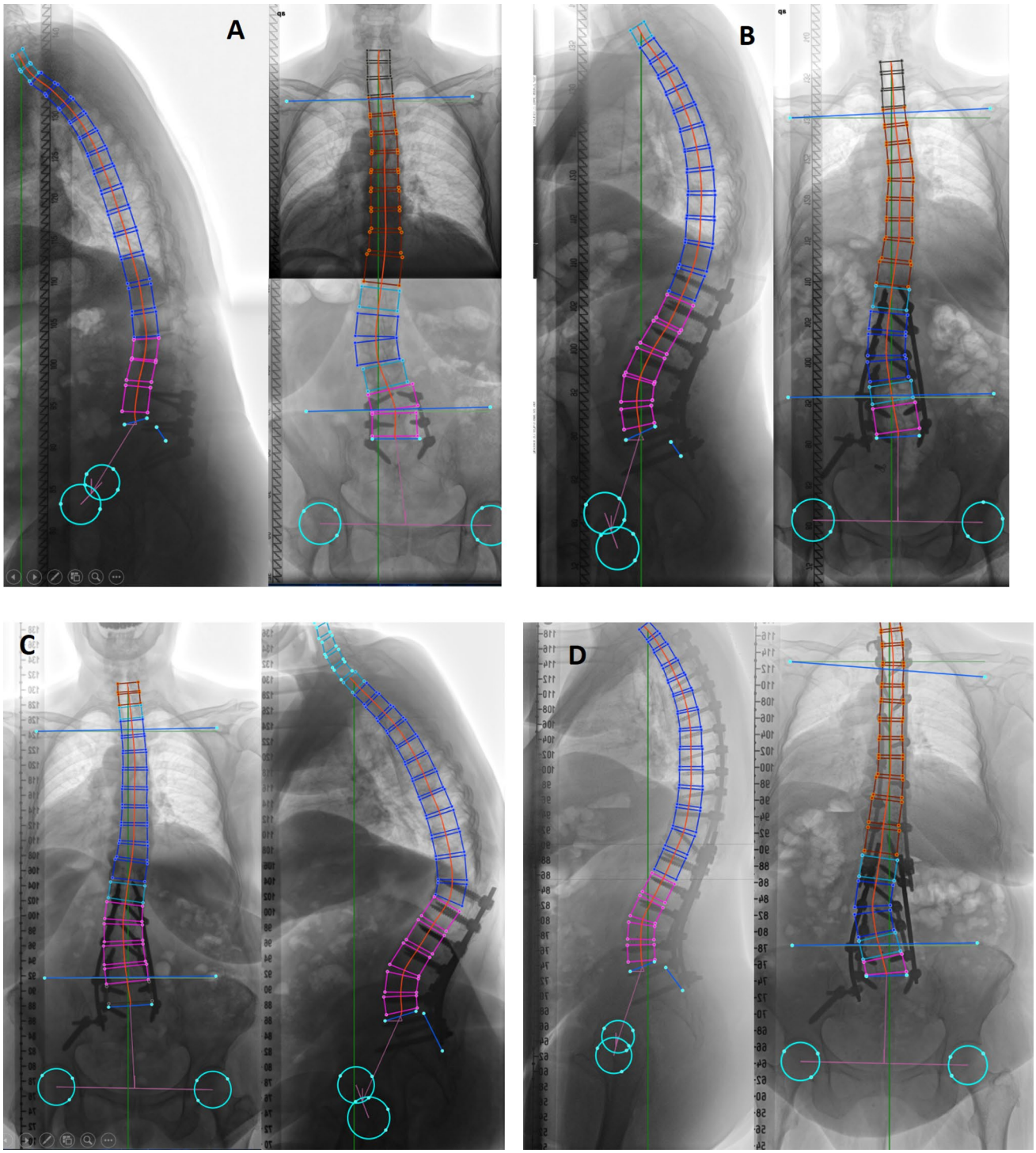

Fig. 6 60-year-old female with a degenerative sagittal and coronal malalignment who had a limited lumbar L4-S1 fusion and decompression 4 years prior to index surgery, presenting with severe back pain and claudication as well as biplanar malalignment (**A**) PI 48 LL 4° L4-S1 23° GT 48° SS 16°. GAP Score 13 preoperatively. She undergone T12 to Pelvis posterior instrumented fusion a pedicle subtraction osteotomy at L4. Her sagittal alignment improved postoperatively as can be seen at the 6 weeks mark (**B**) PI 48 LL 47° L4-S1 30° GT 16° SS 25°, GAP 7. She suffered a PJK at 3 years after surgery (**C**) for which she needed a revision surgery with extension until T2. Her radiological results 2 years revision surgery are shown in (**D**) (PI 48 LL 45° L4-S1 30° GT 16° SS 22°, GAP 4)

Table 6 Comparison of HRQoL scores

n	All		Revision		Non-revision		*P* value
	357	(Score, SD)	100	(Score, SD)	257	(Score, SD)	
Preoperative							
NRS back pain (mean, SD)	6.46	2.59	6.60	2.67	6.41	2.57	0.537
NRS leg pain (mean, SD)	4.78	3.32	4.98	3.37	4.7	3.3	0.484
ODI (mean, SD)	48.1	17.59	50.4	16.69	47.3	17.88	0.131
SRS22 activity (mean, SD)	2.6	0.71	2.57	0.72	2.61	0.71	0.642
SRS22 mental (mean, SD)	2.83	0.79	2.28	0.88	2.83	0.75	0.955
SRS22 pain (mean, SD)	2.66	0.88	2.55	0.93	2.7	0.86	0.172
SRS22 appearance (mean, SD)	2.1	0.7	2.13	0.66	2.08	0.72	0.591
SRS22 satisfuction (mean, SD)	3.03	0.88	3.05	0.94	3.02	0.85	0.827
SRS22 total (mean, SD)	2.57	0.55	2.55	0.58	2.58	0.54	0.685
2 years							
NRS back pain (mean, SD)	3.91	2.92	4.45	3.15	3.69	2.8	0.031*
NRS leg pain (mean, SD)	3.53	2.93	3.62	3.04	3.49	2.89	0.708
ODI (mean, SD)	33.8	20.07	40.7	21.16	31.1	19	< 0.001*
SRS22 activity (mean, SD)	3.12	0.82	2.91	0.85	3.2	0.79	0.003*
SRS22 mental (mean, SD)	3.26	0.81	3.07	0.85	3.34	0.78	0.005*
SRS22 pain (mean, SD)	3.55	0.99	3.26	1	3.67	0.96	< 0.001*
SRS22 appearance (mean, SD)	3.28	0.87	3.05	0.89	3.37	0.85	0.002*
SRS22 satisfuction (mean, SD)	3.74	0.99	3.59	1	3.8	0.98	0.075
SRS22 total (mean, SD)	3.34	0.72	3.12	0.74	3.43	0.7	< 0.001*
ΔODI (mean, SD)	14.4	18.69	9.7	17.86	16.2	18.72	0.003*

NRS numerical rateing scale, *ODI* Oswestry disability index, *SD* standard deviation

revision is long lasting and is independent of the final alignment achieved after revisions. Hence, in a population such as PLA with an already diminished HRQoL gains, avoiding revision surgery is essential to maximize surgical benefits.

An important strategy to diminish revisions for mechanical failure is no other than achieving a harmonious and individualized sagittal alignment. The presented data could detect significant differences in immediately postoperative alignment as measured by GAP parameters between revised and non-revised groups. Furthermore, there was a linear increase in complication rates with worsening GAP score categories. Also, patients having worse GAP alignment had earlier mechanical failures. These findings support that patients with PLA might have less mechanical tolerance to deviations from sagittal ideals when compared to patients with mobile lumbosacral segment. The more severe this deviation is from ideal alignment, the higher the overall probability to suffer from a mechanical failure—and the earlier this complication appears. This risk was not altered by changing the UIV strategies or by adding an anterior approach. These findings consolidate that adequate postoperative spinopelvic proportion could decrease revision surgery for mechanical complication in patients with PLA. It also supports the role of GAP score as to quantify postoperative sagittal misalignment and predict revision surgeries. It also provides a good cohort for external validation.

Table 7 Independent risk factor of revision by multivariate logistic analysis

	Odds ratio	95%CI	*p*-value
Postoperative RSA	1.01	0.942–0.982	0.382
Postoperative RPV	0.98	0.949–0.995	0.852
Postoperative GAP score	**1.08**	**1.01–1.160**	**0.035**
BMI	**1.07**	**1.01–1.130**	**0.015**
Nerve system disorders	**4.76**	**1.81–12.6**	**0.0017**

Statistically significant values ($p < 0.05$) are highlighted in bold

BMI body mass index

Similarly to postoperative malalignment, both BMI and NSD were associated with earlier mechanical complications and PJK. Several studies had reported that obesity is a risk factor for infection after spinal surgery [18–20]. Moreover obesity increased mechanical complication after ASD surgery [21, 22]. In recent revisions of the GAP score, weight itself was an independent risk factor for mechanical failure [23]. This can be explained by the increased mechanical stress and lever arms on stiff unbalanced constructs, decreasing tolerance to deviations from ideals. Consequently, preoperative weight control would reduce surgical risk independently and obesity itself obliges surgeons to make an extra effort to achieve

ideal alignments. The same principles apply to NSD as it alters muscular elasticity and balance. In this regards, having an inadequate supportive soft tissue might explain this inherent predisposition to mechanical complications. This is notorious and well documented in patients with Parkinson Disease having spinal deformity surgery where the surgical complications are mainly mechanical in nature and occur late due to progression of the disease itself [24].

The present work suffers from several limitations applicable to multicenter studies. These might include non-standardized labeling and management of complications in the different participating centers or partial compatibility between both databases. Non-uniformly collected variables have been excluded from analysis to improve quality of findings. We also retained revision surgeries rather than the occurrence of the complication as to reduce variability. We acknowledge however that the decision to re-intervene is surgeon-dependent and may vary between centers [6]. Our revision rates, although comparable to published literature, might underestimate the real burden of malalignment as the endpoint of the study was fixed at 2-years. Revisions in PLA increased steadily after the first year due to mechanical failures and this increase has a steady slope. Longer follow-ups might yield more significant differences between both groups. Finally we did not have a proper non-PLA control group to document the real burden of PLA. Such group is difficult to design as PLA and non-PLA patients are completely different cohorts, both in terms of demographics and deformity. The Kaplan–Meier curve portrayed in this report should be upraised in this context. However, due to the higher revision rates in PLA suggested in the present study and the possible impact of fixation to pelvis on HRQoL [25], authors advise to shy away from PLA whenever possible.

Conclusion

Revision rate after PLA for ASD is significantly higher than in ASD patients without PLA at two years after surgery. The main reason for revision was mechanical failures. Revised had worse overall outcomes. Patients with early mechanical complications or PJK do worse than other patients with mechanical complications. Prevention strategies should focus on individualized restoration of sagittal alignment and better weight control to decrease stress on these rigid constructs in non-compliant spines. Patients with nerve system disorders and higher BMI are at especially increased risk for revisions probably due to their decreased capacity to tolerate deviations from sagittal ideals.

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Declarations

Ethical approval IRB approval was obtained through each of the member sites contributing cases. Patients signed individual conscent form to be included in this database.

Conflict of interest Grants, technical support, and corporate support: The European Spine Study Group receives funding support from DePuy Synthes and Medtronic. No other conflicts of interests exist with the presented data.

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