Research Article

Joint Pathologies as a Covert Risk Factor for Rod Fracture after Pedicle Subtraction Osteotomy in Adult Spinal Deformity

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Abstract

Background: The recent increase in average life expectancy has increased the prevalence of adult spinal deformity (ASD). Instrumentation failure, including rod fracture (RF), may occur even after successful procedures. RF is the most common cause of revision surgery and pedicle subtraction osteotomy (PSO) is a major risk factor of RF. However, disagreements remain regarding how results are related to hip and knee joint pathologies.

Methods: Participants comprised 89 consecutive patients (mean age, 71.2 y) who underwent deformity correction including PSO, with ≥2 years of follow-up. Patients were classified into non-RF (n = 48) and RF groups (n = 41). Radiologic factors including spinopelvic and lower-extremity parameters were measured.

Results: Both groups showed severe sagittal imbalance preoperatively. There were no significant differences between groups in patient factors, sagittal and coronal spinopelvic parameters, and osteoarthritis (OA) grade of the joints. However, preoperative structural and functional leg length discrepancy (LLD) and pelvic obliquity significantly differed between groups (P = 0.001, 0.002, and 0.002, respectively). The proportion of knee OA, structural and functional LLD, and knee angular deformity were significantly higher in the RF group than in the non-RF group (P = 0.008, 0.000, 0.020, and 0.012, respectively).

Conclusion: Elderly patients with ASD often show degenerative changes in the lower extremities, and even if spine deformity correction is successfully performed, complications, including RF, can occur if joint pathologies are not resolved. Therefore, it is important to consider perioperative treatments for the lower extremities as well as restoration of the spine and pelvis.

Keywords: Adult spinal deformity; Elderly; Hip joint; Knee joint; Knee angular deformity; Leg length discrepancy; Osteoarthritis; Pedicle subtraction osteotomy; Rod fracture; Spine

1. Introduction

The recent increase in life expectancy and active senior lifestyle has increased the demand for the treatment of age-related disabilities. Adult Spinal Deformity (ASD) is a representative age-related disability of the spine, and interest in surgical deformity correction of ASD that recovers and maintains the normal upright posture required for basic human needs has increased [1]. Of the surgical options for ASD, Pedicle Subtraction Osteotomy (PSO) is one of the most powerful methods for achieving ideal Lumbar Lordosis (LL) correction and optimal sagittal balance [2].

However, problems of PSO remain, originating not only from the complexity of the procedure itself, but also from the reported complications [3,4]. In particular, instrumentation failure, including rod fracture (RF), is the most common cause of revision surgery, and RF can be caused by PSO and other risk factors [5]. Therefore, several instruments and surgical techniques have been suggested to decrease RF [6], however, age should not be overlooked for the deformity correction in patients with ASD [7].

Most patients with ASD undergoing deformity correction are elderly, and often have comorbid degenerative joint diseases, such as hip and knee osteoarthritis (OA) [8,9]. However, it is unclear whether lower-extremity joint pathologies affect spinal disease or vice versa. In addition, there is a lack of studies on the effects of joint pathologies in patients with ASD who underwent long-segment fixation. Therefore, this study assessed the relationship between structural and biochemical changes caused by lower-extremity joint pathologies and RFs after long-segment fixation including PSO in patients with ASD aged >65 years.

2. Material and Methods

2.1 Patient selection

This study was approved by the ethics committee of our institution. We retrospectively reviewed 130 consecutive patients with ASD treated between 2009 and 2018. The inclusion criteria were as follows: age ≥65 years; ASD accompanied by sagittal malalignment (sagittal vertical axis [SVA] >50 mm, pelvic incidence [PI] minus LL >10°, and pelvic tilt [PT] >25°); ≥2 years of follow-up after deformity correction; surgically treated with long-segment fixation with sacropelvic fixation, with the uppermost and lowermost instrumented vertebrae set at the T10 and S1 levels, respectively; clear atrophy of the back musculature on cross-sectional magnetic resonance imaging and computed tomography (CT) images as a diagnostic criterion for lumbar degenerative kyphosis (LDK) and clinical signs such as walking difficulties with stooping, inability to lift heavy objects toward the front, difficulty in climbing slopes, and the need for elbow support when working in the kitchen, resulting in a hard corn on the extensor surface of the elbow [10-12]. The diagnosis of RF was based on rod breakage with recent fusion mass fracture, observed on plain radiography and CT, confirmed by uptake in either bone scan or SPECT images [5]. Patients were classified into RF and non-RF groups.

2.2 Surgical method

Every patient underwent PSO at L2 or L3, including closing-opening wedge osteotomy; the anterior vertebral cortex was fractured in patients requiring more correction [13]. The lamina at the PSO site was preserved and used for the fusion bed in cases without spinal stenosis at the PSO site by approximating the remaining upper and lower laminae of the proximal and osteotomized vertebrae, respectively. However, posterior decompression with posterolateral fusion was performed by removing the remaining laminae in cases with spinal stenosis at the PSO site. A morselized autograft was used for fusion, with a mixture of demineralized bone matrix and chipped-bone allograft [5].

2.3 Radiographic measurements

Coronal and sagittal alignments were evaluated using anteroposterior and lateral 14×36-inch whole-spine radiographs. Sagittal spine radiographs were obtained with the patient standing in a neutral unsupported fists-on-clavicle position [14]. All digital radiographs were reviewed preoperatively, and at 2 months (i.e. postoperatively) and 2 years after surgery (i.e. last follow-up), using validated software (Surgimap, Nemaris Inc.) [15]. And the last follow-up radiographic parameters of the RF group were measured at the last visit to the outpatient clinic before the onset of RF.

As sagittal spinal parameters, we measured the PI, sacral slope (SS), PT, thoracic kyphosis (TK, T5-12), thoracolumbar junction (TL, T10-L2), LL (T12-L2), lumbosacral junction (LS, T12-S1), and SVA [16,17]. As coronal spinal parameters, we measured the coronal Cobb angle (for patients with multiple coronal curvatures, the largest angle was evaluated) and coronal C7 plumb line minus the central sacral vertical line (coronal C7PL).

Orthogram was used to evaluate hip and knee joint pathologies (Figure 1). Kellgren-Lawrence grades 3 and 4 were considered to indicate pathology [18]. Definitions of clinically significant Leg Length Discrepancy (LLD) vary; we considered 10 mm to represent clinically significant LLD in the present study [19]. The functional LLD was defined as the height difference between right and left femoral horizontal reference lines (defined as the horizontal line tangent to the uppermost part of the femoral head) [20]. The structural LLD was defined as the distance between the center of the femoral head and the midpoint of the tibial plafond [21]. Pelvic Obliquity (PO) was defined as the angle between the horizontal reference line and pelvic coronal reference line (measured between the tips of the sacral ala) [20]. The angles of the line from the femoral head center to the articulating center of the distal femur at the knee and the line from the articulating center of the proximal tibia at the knee to the tibial plafond midpoint were measured to assess the angular deformity of the knee (mechanical axis) [22]. A varus or valgus angle ≥10° in the measured mechanical axis (negative for varus and positive for valgus) was defined as an angular deformity.

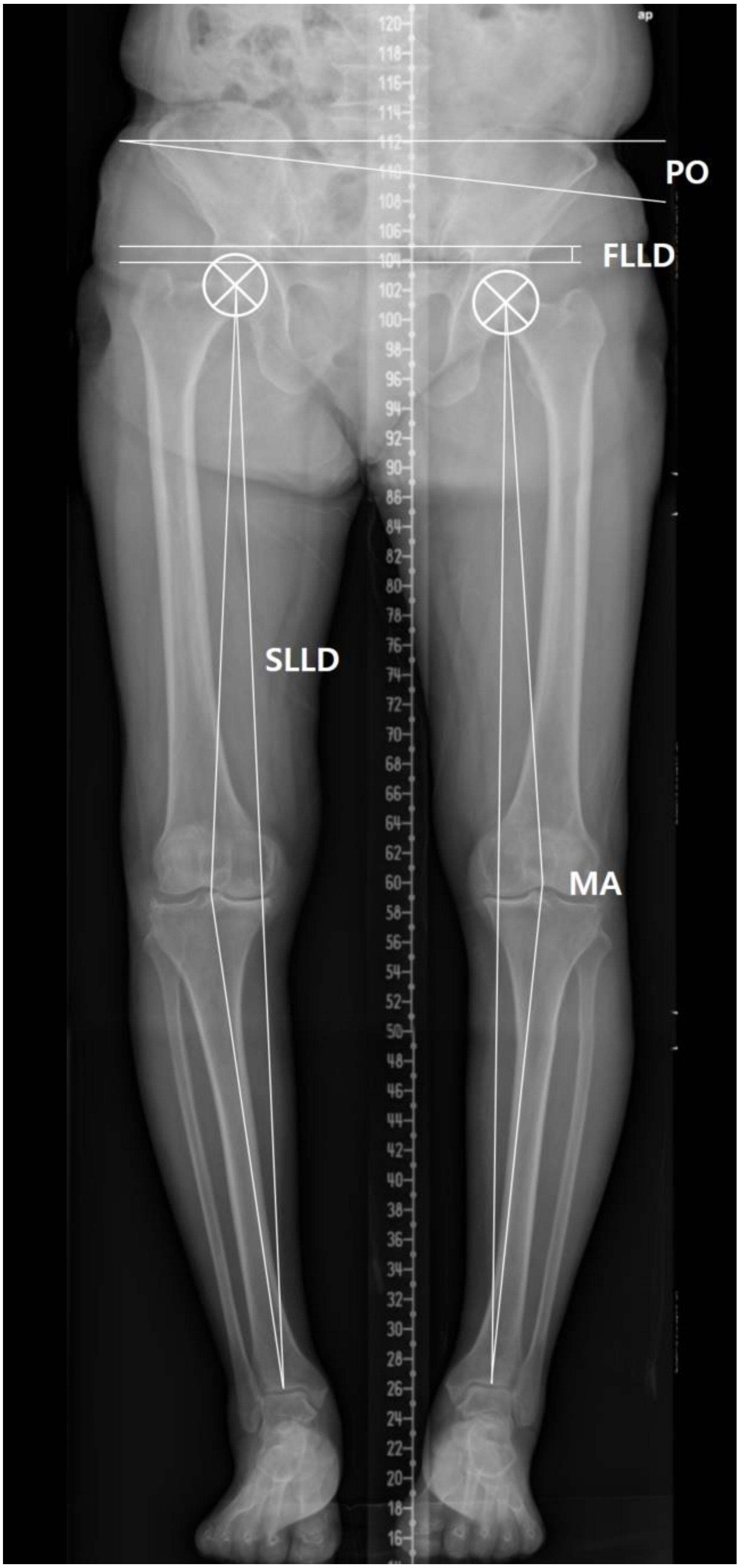

PO
FLLD
SLLD
MA

Figure 1: Orthogram was used to evaluate hip and knee joint pathologies. The functional LLD (FLLD) was defined as the height difference between right and left femoral horizontal reference lines. The structural LLD (SLLD) was defined as the distance between the center of the femoral head and the midpoint of the tibial plafond. Pelvic Obliquity (PO) was defined as the angle between the horizontal reference line and pelvic coronal reference line. The angles of the line from the femoral head center to the articulating center of the distal femur at the knee and the line from the articulating center of the proximal tibia at the knee to the tibial plafond midpoint were measured to assess the Mechanical Axis (MA).

2.4 Clinical outcome assessment

Clinical outcomes were assessed using the Oswestry Disability Index (ODI) and Visual Analog Scale (VAS) preoperatively, postoperatively, and at the last follow-up.

2.5 Statistical analysis

Statistical analysis was performed using SPSS software (version 20.0; SPSS Inc., Chicago, IL, USA). Continuous variables were evaluated by analyses of variance, unpaired t-tests, and the Wilcoxon's rank sum test, as appropriate. Categorical variables were assessed using the chi-square test and Fisher's exact test, as appropriate. The relationship between radiographic parameters was evaluated by the Pearson's correlation coefficient, and a multivariate logistic regression analysis (backward elimination method) was performed to identify the risk factors of RF. Statistical significance was set at $P < 0.05$.

3. Results

3.1 Baseline patient characteristics

Of 130 patients screened, 89 (2 men and 87 women; mean age at surgery, 71.2 years; mean follow-up period, 63.4 months) met the inclusion criteria. The mean Body Mass Index (BMI) was 25.1 kg/m2 and mean bone mineral density (BMD) was 0.96 gm/cm2.

3.2 RF characteristics

RF occurred in 41 patients at a mean of 23 months (20 and 23 months for 17 bilateral and 24 unilateral cases, respectively). RF was found at the PSO site in 37 patients and at L4-5 in 4 patients. Most patients complained of sudden back pain with a cracking noise in the back due to bending over or accidently falling, and underwent revision surgery to reduce back pain and prevent further sagittal imbalance. However, in one patient, unilateral non-symptomatic RF refused revision surgery and underwent close observation.

3.3 Sagittal spinopelvic radiographic parameters (Table 1)

Preoperatively, the patients showed severe sagittal imbalance in both groups, without significant differences. Postoperatively, the SVA, TK, LL, and TK were improved in both groups, without significant differences. At last follow-up, the SVA indicated well-maintained sagittal balance, and the TK, LL, and PT indicated spinopelvic harmony, in both groups, without significant differences.

3.4 Coronal spinal radiographic parameters (Table 1)

Preoperatively, the coronal Cobb angle and pre-coronal C7PL did not significantly differ between groups. After deformity correction, the coronal Cobb angle was normalized, and as with the C7PL, did not show a significant difference between groups (postoperatively and at the last follow-up).

3.5 Preoperative lower-extremity radiographic parameters (Table 1)

Preoperatively, the structural and functional LLD and PO were significantly greater in the RF group and in the non-RF group (P < 0.05). However, the right and left mechanical axes and lower-extremity OA grades were not significantly different between the two groups.

Variables	Non-RF group(n=48)	RF group(n=41)	P-value
	Mean ±SD	Mean ±SD	
Patient factors			
Age (year)	71 ± 5.6	71.4 ± 4.9	0.701
BMD T-score (gm/cm^2)	-1.34 ± 0.93	-1.81 ± 1.3	0.050
BMD (gm/cm^2)	0.98 ± 0.12	0.93 ± 0.16	0.065
BMI (kg/m^2)	25.4 ± 3.2	24.9 ± 3.6	0.454
Sagittal parameters			
Pre SVA (mm)	189.8 ± 70.7	201.3 ± 91	0.503
Post SVA (mm)	-9.4 ± 28.1	-19.1 ± 18.9	0.066
SVA correction (mm)	-199.2 ± 82.6	-220.3 ± 89.5	0.250
Last SVA (mm)	12.7 ± 36.5	12.9 ± 27.8	0.975
Pre TK (°)	4.2 ± 15.4	-1.3 ± 12.5	0.069
Post TK (°)	28.6 ± 12.5	24.5 ± 9.2	0.075
TK correction (°)	24.4 ± 10.1	25.8 ± 11.7	0.550
Last TK (°)	35.7 ± 15	31.6 ± 14.5	0.195
Pre TL (°)	7.6 ± 17.1	7 ± 17.3	0.860
Post TL (°)	-24.2 ± 15.7	-25.3 ± 16.3	0.730
Last TL (°)	-15.3 ± 22	-22.2 ± 17	0.100
Pre LL (°)	5.8 ± 15.6	10.1 ± 15.9	0.206
Pre PI-LL	61.6 ± 18.1	66.2 ± 19.3	0.255
Post LL (°)	-70.8 ± 8.7	-69 ± 11.5	0.395
LL correction (°)	-76.7 ± 18.4	-79.1 ± 16.9	0.521
Post PI-LL	-15.1 ± 11.2	-13 ± 12.8	0.407
Last LL (°)	-65.8 ± 25.4	-62.8 ± 23.5	0.577
Pre LS (°)	-6.3 ± 15.7	0 ± 16.1	0.065
Post LS (°)	-26.9 ± 9.4	-26 ± 8.8	0.647
LS correction (°)	-20.6 ± 17	-26.1 ± 16.7	0.134
Last LS (°)	-27.4 ± 9.5	-25.5 ± 11.6	0.412
PI (°)	55.8 ± 10.7	56.1 ± 10.4	0.902
Pre SS (°)	24.5 ± 10.5	19.8 ± 12.3	0.054
Post SS (°)	46.1 ± 7.1	44.2 ± 8.4	0.262
Last SS (°)	45.3 ± 8.6	42.4 ± 10.3	0.152
Pre PT (°)	31.3 ± 13.9	36.3 ± 11.6	0.071
Post PT (°)	11.3 ± 6.5	14.3 ± 8.5	0.073

Last PT (°)	13.2 ± 9.3	17.4 ± 12.4	0.076
Coronal parameters			
Pre coronal Cobb angle (°)	12.9 ± 10.4	13.2 ± 11.4	0.925
Post coronal Cobb angle (°)	1.5 ± 1	1.6 ± 0.7	0.373
Last coronal Cobb angle (°)	1.7 ± 1.1	2.1 ± 1.1	0.066
Pre coronal C7PL (mm)	18.4 ± 14.8	12.9 ± 12.3	0.066
Post coronal C7PL (mm)	12.6 ± 10	11.9 ± 10.4	0.756
Last coronal C7PL (mm)	11.7 ± 9.5	14.2 ± 11.3	0.257
Lower extremity OA parameters			
Pre structural LLD (cm)	0.4 ± 0.3	0.7 ± 0.5	0.001*
Pre functional LLD (cm)	0.4 ± 0.3	0.6 ± 0.4	0.002*
Pre pelvic obliquity (°)	1.2 ± 1.3	2.3 ± 1.8	0.002*
Right mechanical axis (°)	-3.3 ± 4.4	-4.3 ± 5.6	0.351
Left mechanical axis (°)	-3.3 ± 4.9	-3.6 ± 6.9	0.810
Right knee OA grade	2.6 ± 1.2	2.5 ± 1.4	0.687
Left knee OA grade	2.5 ± 1.2	2.3 ± 1.5	0.467
Right hip OA grade	2.2 ± 0.9	2.5 ± 0.8	0.095
Left hip OA grade	2.2 ± 0.9	2.5 ± 0.7	0.067
Clinical outcomes			
Pre ODI	37.8 ± 1.7	37.9 ± 2.8	0.858
Post ODI	16.4 ± 8.1	18.7 ± 5.9	0.126
Last ODI	7.5 ± 5.1	9.3 ± 3.9	0.058
Pre LBP VAS	8.2 ± 0.9	8.3 ± 1	0.325
Post LBP VAS	2.4 ± 1.5	4 ± 2	<0.05*
Last LBP VAS	1.6 ± 1.4	1.8 ± 1.3	0.357
Pre Leg VAS	8 ± 0.7	7.9 ± 1.1	0.388
Post Leg VAS	1.9 ± 0.7	1.8 ± 0.8	0.762
Last Leg VAS	0.5 ± 0.6	1.1 ± 1	<0.05*

* Statistically significant (P-value < 0.05)

RF : rod fracture; BMD: bone mineral density; BMI: body mass index; Pre: preoperative; Post: postoperative; Last: last follow-up; SVA: sagittal vertical axis; TK: thoracic kyphosis; TL: thoracolumbar junctional angle; LL: lumbar lordosis; PI: pelvic incidence; LS: lumbosacral junctional angle; SS: sacral slope; PT: pelvic tilt; C7PL: C7 plumb line; OA: osteoarthritis; LLD: leg length discrepancy; ODI: Oswestry disability index; VAS: visual analog scale

Table 1: Continuous variable comparison of risk factors between RF group and Non-RF group.

3.6 Joint pathologies as RF risk factors (Tables 2-4)

Preoperatively, the difference in degenerative lumbar scoliosis and OA between the two hip joints did not differ between the groups. However, the difference in OA between the knee joints was greater, and knee angular deformity was more frequently observed, in the RF group than in the non-RF group ($P < 0.05$). Additionally, clinically significant structural and functional LLDs were relatively more common in the RF group than in the non-RF group ($P < 0.05$). On correlation analysis, PO was not correlated with the coronal Cobb angle and coronal C7PL, but was correlated with structural and functional LLDs ($P < 0.05$). Structural and functional LLDs were also correlated with the mechanical axis difference between the knee joints. Similarly, these joint pathologies were significantly related to RF on multilinear regression analysis ($r = 0.546$). Specifically, the knee OA difference (unstandardized ß = 1.047), structural LLD (unstandardized ß = 1.771), and knee angular deformity (unstandardized ß = 1.390) were significantly associated with RF ($P < 0.05$), with larger values indicating a greater risk of RF.

Variables	**RF group (n=41)**	**Non-RF group (n=48)**	**Odds ratio (95 % Cl)**	**P-value**
Preoperative DLS (Yes/No)	18/23	24/24	0.78 (0.34:1.81)	0.671
Knee OA difference (Yes/No)	21/20	11/37	3.53 (1.42:8.77)	0.008*
Hip OA difference (Yes/No)	15/26	10/38	2.19 (0.85:5.63)	0.155
Structural LLD (Yes/No)	15/26	3/45	8.65 (2.29:32.73)	0.000*
Functional LLD (Yes/No)	9/32	2/46	6.47 (1.31:31.95)	0.020*
Knee angular deformity (Yes/No)	15/26	6/42	4.04 (1.39:11.72)	0.012*

* Statistically significant (P-value < 0.05)

RF: rod fracture; CI: confidence interval; DLS: degenerative lumbar scoliosis; OA: osteoarthritis; LLD: leg length discrepancy

Table 2: Categorical variables comparison of risk factors between RF group and Non-RF group.

	CorCobb	**CorC7PL**	**PO**	**SLLD**	**FLLD**
Post PO	-	-	0.674 **	0.411 **	0.574 **
PO	-	-	-	0.429 **	0.709 **
MD				0.306 **	0.404 **

** Significant correlations was established at the 0.01 level

CorCobb: coronal cobb angle; CorC7PL: coronal C7 plumb line; Post: postoperative; PO: pelvic obliquity; FLLD: functional leg length discrepancy; SLLD: structural leg length discrepancy; Post: postoperative; MD: mechanical axis difference

Table 3: Correlations between radiographic parameters.

	B	SE	Wald χ2	P-value	Odds ratio	95% CI
Knee OA difference	1.047	0.521	4.041	0.044*	2.848	1.027-7.9
Structural LLD	1.771	0.718	6.088	0.014*	5.874	1.439-23.975
Knee angular deformity	1.390	0.598	5.396	0.020*	4.014	1.243-12.969
Constant	-1.163	0.347	11.229	0.001	0.313	

* Statistically significant (P-value < 0.05)

RF: rod fracture; SE: standard error; CI: confidence interval; OA: osteoarthritis; LLD: leg length discrepancy

Table 4: Multivariate logistic regression analysis of the influencing factors of RF

3.7 Clinical outcomes (Table 1)

For both groups, ODI and VAS scores for back pain and radiating pain were improved postoperatively and at the last follow-up compared to preoperative values. However, the postoperative VAS score for low back pain and leg pain at the last follow-up were significantly greater in the RF group than in the non-RF group.

4. Discussion

In the current study, long-segment fixation from T10 to S1 with PSO was performed in 89 patients with ASD for deformity correction, and RF was observed in 41 patients. The target parameters of deformity correction (e.g. postoperative SVA correction, PI-LL, and PT) and other radiographic spinopelvic parameters were not significantly different between RF and non-RF groups with desirable sagittal and coronal radiological balance until the last follow-up. Additionally, patient factors, including sex, BMD, and BMI, were not significantly different between the two groups. We consider that the use of consistent surgical techniques (including PSO) and instruments in elderly patients with a single etiology of LDK led to these outcomes.

4.1 PSO and RF

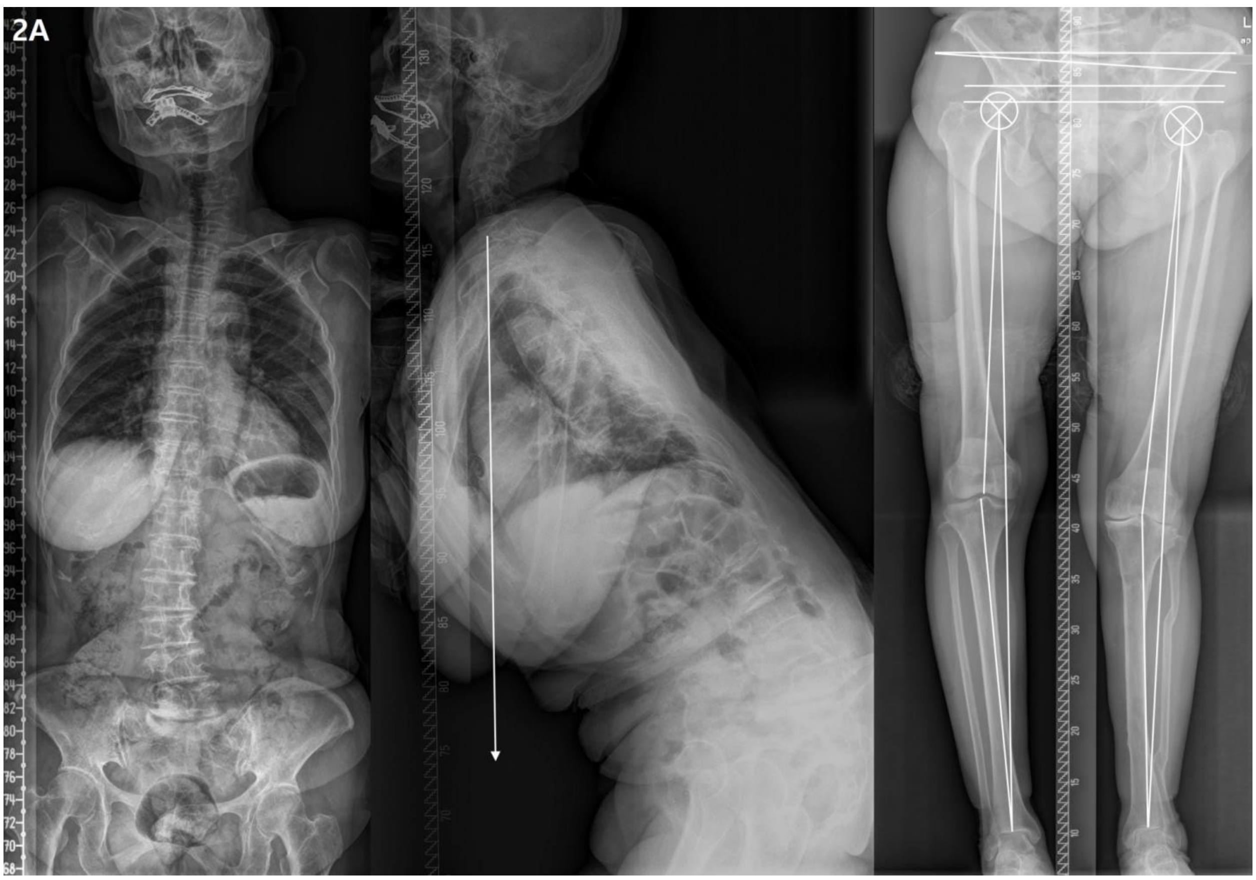
In a study of 178 patients with LDK (mean age, 70.8 years), PSO and severe preoperative sagittal spinopelvic malalignment status, including preoperative PI-LL mismatch, were revealed as important risk factors for RF after deformity correction [5]. However, PSO is a major deformity correction method for patients with LDK who have relatively large PI or a severe, rigid, and fixed deformity [23]. Therefore, various spinal instruments (e.g. thicker and stronger rods, iliac screws, and accessory rods) have been developed to reduce RF after deformity correction including PSO [5]. However, additional methods that could fundamentally reduce the incidence of RF preoperatively in patients with ASD undergoing PSO are needed. Interestingly, we found that pre-existing lower-extremity joint pathologies were revealed as potential risk factors for RF after deformity correction in ASD.

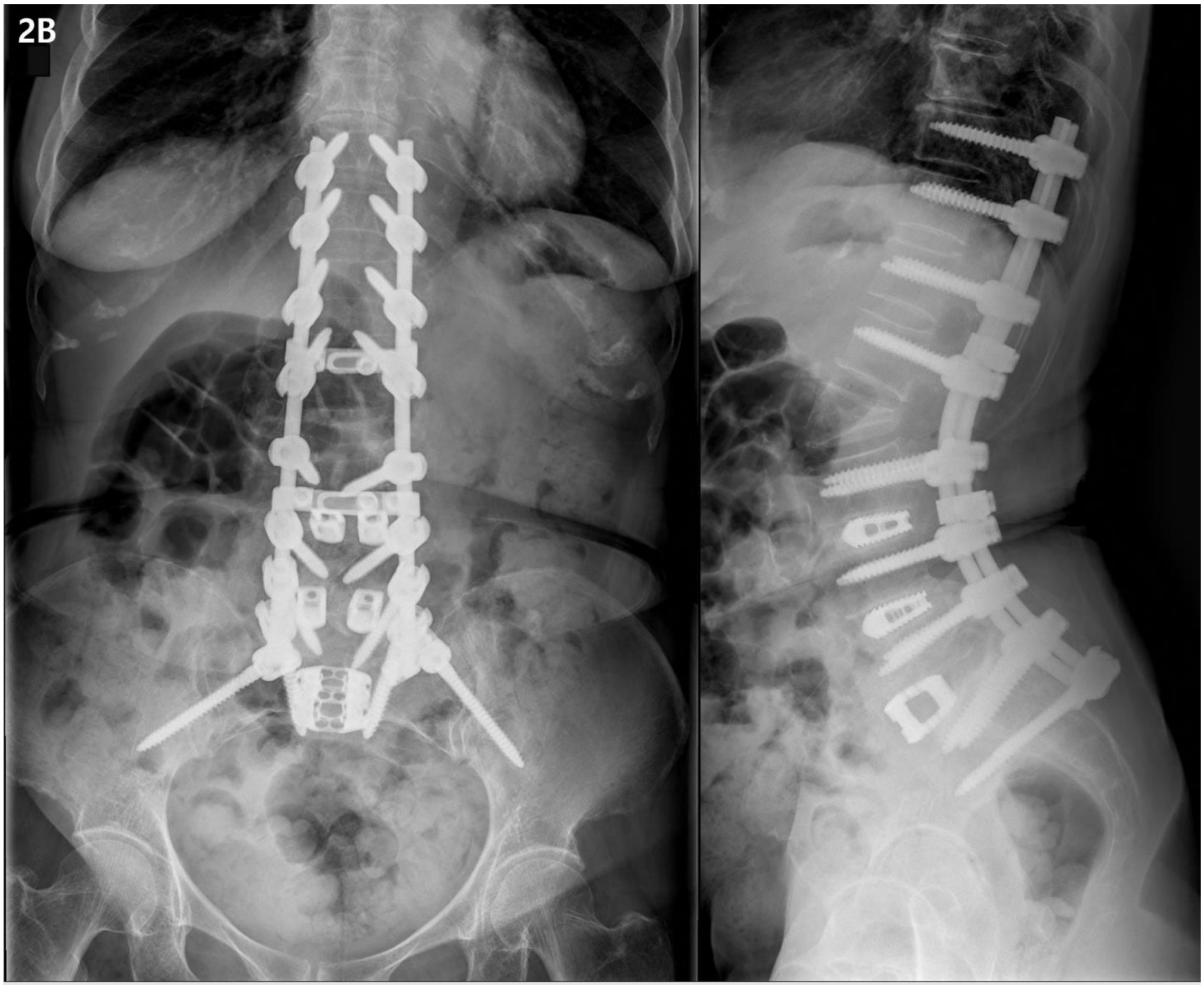
4.2 Lower-extremity OA and LLD in patients with ASD (Figure 2)

Most of our patients with ASD aged >65 years showed spinal degenerative changes and Kellgren-Lawrence OA grade 2 or higher in the knee and hip joints. Lower-extremity OA leads to articular cartilage degeneration, bone hypertrophy at the joint margins, and synovial membrane thickening [24]. In the advanced stage, articulating bone becomes severely deformed [25].

Therefore, OA of the lower-extremity joints may reduce the length of the affected leg and cause angular deformity, which may result in LLD [26-28].

LLD is associated with postural and functional changes not only in the lower extremities, but also in the pelvis and spine [29]. In most studies, LLD <20 mm has been found to be clinically insignificant [30], but although postural adjustments can compensate for the asymmetry, repetitive mechanical loading over time may lead to problems in mild LLD cases [31]. In a study of 225 chiropractic patients, patients with mild LLD (5-15 mm) had a significantly increased prevalence of degenerative joint diseases in L5-S1 spinal motion segments and L4-5 segments [26]. In particular, the prevalence of degenerative changes in elderly individuals aged ≥50 years were significantly increased in those with LLD than in those without LLD. Another study of 19 healthy subjects with artificially induced LLD (by wearing sandals with 1.45-cm height) showed that compensatory changes occur in mild LLD to equalize the functional length of the lower limbs during gait [32]. Thus, mild LLD should not be overlooked in clinical settings. In the present study, although both groups showed mild functional and structural LLD, it was more severe in the RF group than in the non-RF group. Additionally, logistic regression analysis revealed structural LLD as an important risk factor for RF. In a study of 100 patients (mean age, 40 years) with chronic low back pain, LLD (mean, 5 mm) was correlated with PO [33]. In a study of LLD using 1–5 cm foot lifts, the major compensation was in PO for low LLD, up to 2.2 cm. [34] Consistent with these previous studies, we observed a correlation between PO and structural and functional LLDs. However, PO was not correlated with the coronal Cobb angle and coronal C7PL, suggesting that the PO due to LLD could not be corrected, regardless of ideal spinal deformity correction. Therefore, LLD must be corrected first in order to correct PO, and this would reduce RF during deformity correction in ASD.

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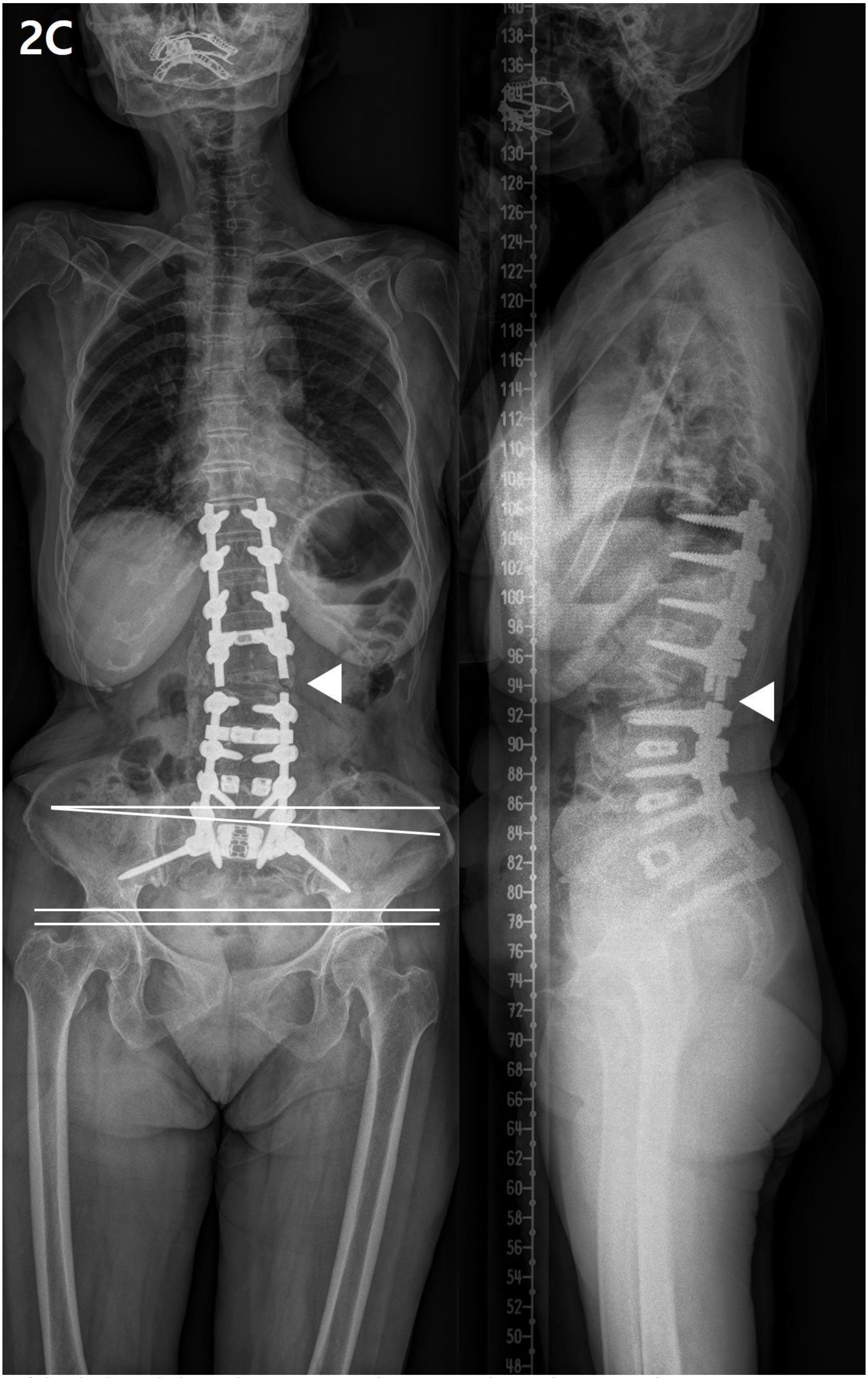
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Figure 2: Radiographs showing a 75-year-old female with degenerative lumbar kyphosis who underwent T10-S1 posterior instrumentation, PSO on L2, PLIF on L3-5, ALIF on L5S1, and sacropelvic fixation; (A) Preoperative whole spine lateral radiograph (SVA, +274 mm; PI, 63°; TK, -18°; LL, 36°; PT, 50°; SS, 13°) and orthogram (Rt. and Lt. hip OA, grade 3; Rt. knee OA, grade 2; Lt. knee OA, grade 4; SLLD, 1.6cm; FLLD, 1.4cm; PO, 3.9°; Rt. and Lt. MA difference, 14°). (B) Postoperatively, spinal deformity correction was successfully performed with ideal lumbar lordosis and optimal sagittal balance (SVA, -42 mm; TK, 18°; LL, -68°; PT, 23°; SS, 40°; PI-LL, -5). (C) RF occurred 15 months after deformity correction, with the joint pathologies persisted.

4.3 Knee joint OA and RF

In the present study, OA showed a similar pattern in both hip joints. However, the difference in OA between right and left knee joints was relatively greater, and knee angular deformity was also more common, in the RF group than in the non-RF group. Furthermore, these parameters were important risk factors for RF. In gait analysis studies of patients with hip fractures and knee joint pathologies [35-38], asymmetric gait persisted for >2 years after surgical procedures involving the gluteal muscle, manifesting as antalgic gait in patients with gonarthrosis. Therefore, continuous tensile force from lateral bending at the mid-stance phase and continuous compressive force on the contralateral side from less shock absorption in the arthritic knee joint, as well as axial rotational force from the trunk during the swing phase, seem to be coronal mechanisms for RF during asymmetric gait. Knee OA is the most common type of OA [39]. Although the mechanism is not well established, OA is usually more symptomatic and severe on one side of the knee than on the other side [39]. Therefore, in surgical treatment for patients with ASD, the evaluation of knee OA must be prioritized. In cases of severe OA, differences between knees, and PO with LLD, knee OA should be treated prior to performing spinal deformity correction.

4.4 Elderly patients and the future of treatment (Figure 3)

The prevalence of OA tends to increase with age, and 30%–50% of adults aged >65 years develop OA [24]. Elderly patients commonly develop OA in several areas, and the effects and interactions of OA in different areas have significant effects on disabilities in daily life [40]. Recent developments in medical technology have led to various osteotomy techniques, surgical methods, and instruments for spinal deformity correction. Additionally, treatment strategies for OA in other areas (e.g. arthroplasty of the hip and knee joints) are showing rapid progress. Therefore, with these developments, the treatment for elderly patients must consider the overall body, including multiple joints, and focus on improving the quality of life of patients through appropriate surgical treatment of the spine and every joint to maintain an active senior lifestyle.

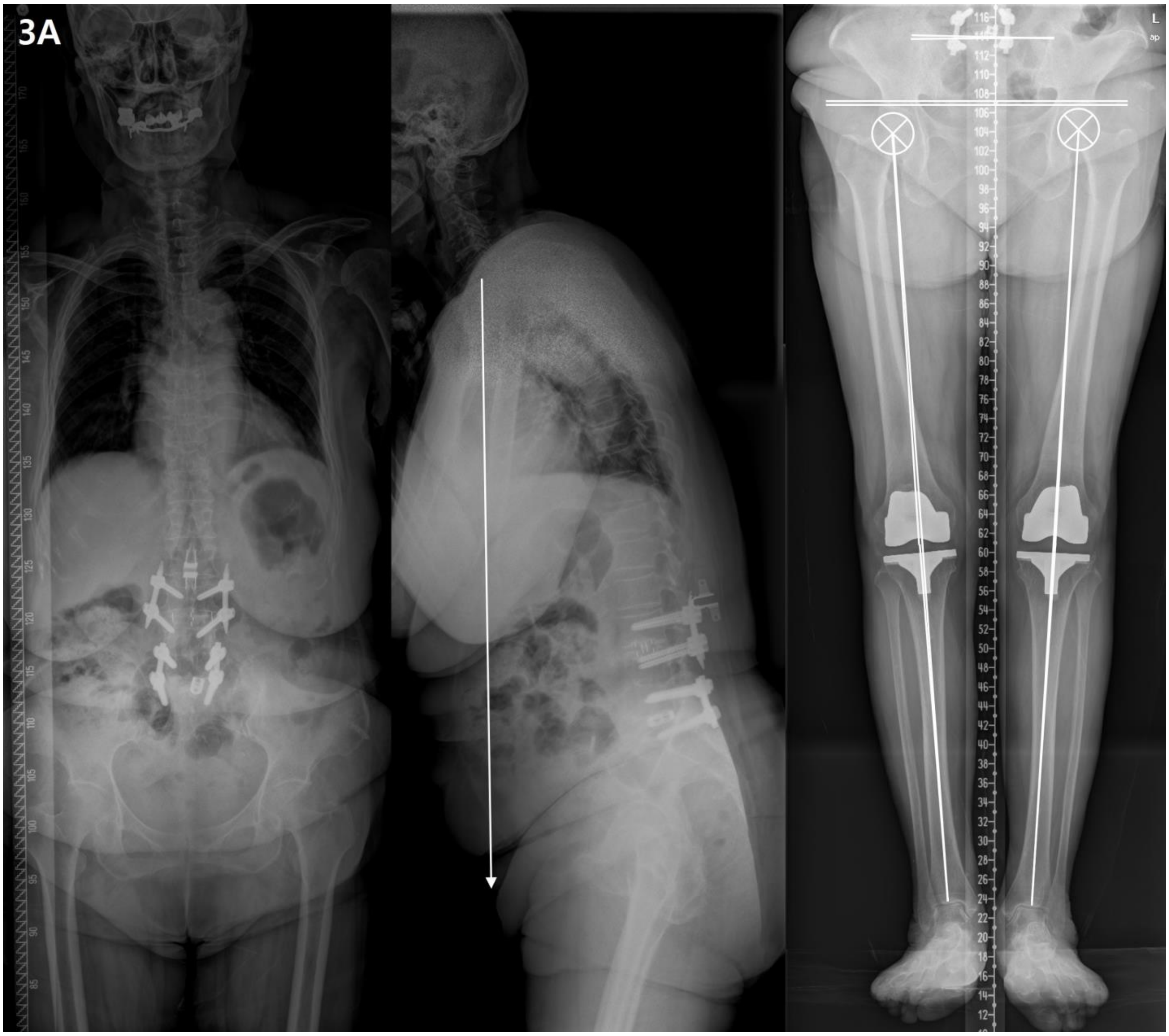
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Figure 3: Radiographs showing a 74-year-old female with degenerative lumbar kyphosis who underwent T10-S1 posterior instrumentation, PSO on L2, ALIF on L5-S1, and sacropelvic fixation. (A) Preoperative whole spine lateral radiograph (SVA,

+192 mm; PI, 41°; TK, 17°; LL, 6°; PT, 25°; SS, 16°) and orthogram (Rt. and Lt. hip OA, grade 2; Rt. and Lt. TKR state; SLLD, 0.3cm; FLLD, 0.2cm; PO, 1.1°; Rt. and Lt. MA difference, 0.7°). (B) Postoperative 2-year radiograph showing a well-maintained sagittal balance (SVA, +7 mm; TK, 50°; LL, -63°; PT, 4°; SS, 37°) without RF.

4.5 Limitations

This study has some limitations, including its retrospective design. There are several reported risk factors for pseudarthrosis including RF after PSO in ASD [41-44]. Thus, RF may be caused not only by a few factors, but also by the interaction of multiple factors. Accordingly, if RF occurs after deformity correction for ASD, a thorough causal investigation is required, and the risk factors demonstrated in the present study may not have been the cause of RF. However, as the purpose of this study was to seek strategies to fundamentally reduce RF before surgery, its findings, that preferential treatment of lower-extremity joint pathologies before surgery may reduce the incidence of RF, are meaningful.

5. Conclusion

We found that ASD in elderly patients is often accompanied by degenerative changes in the lower extremities, and concluded that even if spine deformity correction is successfully performed, complications, including RF, can occur if joint pathologies are not resolved. Therefore, when performing deformity correction in patients with ASD, it is important to consider perioperative treatments for the lower extremities, including the knee joint, as well as the restoration of the spine and pelvis.

6. Declaration

Acknowledgments

No additional person beyond the authors contributed to this study.

* We certify that no portion of this manuscript has been previously presented.

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Authors contribution

Conception and design: KYL, JHL, Data collection: KYL, SKI, Data analysis and interpretation: KYL, SKI, Manuscript drafting: KYL, Manuscript revision: JHL, Approval of the final manuscript: All the authors.

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Availability of Data and Materials

The datasets used for this study are available from the corresponding author on request.

Ethical Approval

This study was approved by the ethics committee of our institution (KMC IRB 2021-06-030).

Conflict of interest

The authors declare that there are no conflicts of interest.

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