CLINICAL ARTICLE

Correlation of Acetabular Anteversion and Thoracic Kyphosis Postoperatively with Proximal Junctional Failure in Adult Spinal Deformity Fused to Pelvis

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Objectives: To investigate whether the immediate thoracic kyphosis (TK) and acetabular anteversion (AA) postoperatively are correlated with proximal junctional failure (PJF) in adult spinal deformity (ASD) patients underwent surgical treatment.

Methods: This is a retrospective study. Following institutional ethics approval, a total of 57 patients (49 Female, eight Male) with ASD underwent surgery fused to sacroiliac bone (S1, S2, or ilium) from March 2014 to January 2019 were included. All of those patients were followed up for at least 2 years. Demographic, radiographic and surgical data were recorded. The maximum range of flexion motion (F-ROM) and extension motion (E-ROM) actively of hip joints was measured and recorded at pre- and postoperation. The sum of F-ROM and E-ROM was defined as the range of hip motion (H-ROM). Receiver operating characteristic (ROC) curve analysis was used to obtain the cut off value of parameters for PJF. A Kaplan–Meier curve and log-rank test were used to analyze the differences in PJF-free survival.

Results: In all, 14 patients developed PJF during follow-up. Comparisons between patients with and without PJF showed significant differences in immediate TK ($P < 0.001$) and AA ($P = 0.027$) postoperatively. ROC curve analysis determined an optimal threshold of 13° for immediate AA postoperatively (sensitivity = 74.3%, specificity = 85.7%, area under the ROC curve [AUC] = 0.806, 95% *CI* [0.686–0.926]). Nineteen patients with post-AA ≤13° were assigned into the observational group, and 38 patients with post-AA >13° were being as the control group. Patients in the observational group had smaller H-ROM ($P = 0.016$) and F-ROM ($P < 0.001$), but much larger E-ROM ($P < 0.001$). There were 10 patients showing PJF in the observational group and four in the control group (10/9 *vs* 4/34, $P < 0.001$). PJF-free survival time significantly decreased in the observational group ($P = 0.001$, log-rank test). Furthermore, patients in the observational group had much larger TK (post-TK, $P = 0.015$). The optimal threshold for post-TK (sensitivity = 85.7%, specificity = 76.7%; AUC = 0.823, 95% *CI* [0.672–0.974]) was 28.1° after the ROC curve was analyzed. In the observational group, those patients with post-TK ≥28.1° had significantly higher incidence of PJF (9/2 *vs* 1/7, $P < 0.001$) than those with post-TK < 28.1°. Moreover, PJF-free survival time in those patients significantly decreased ($P = 0.001$, log-rank test).

Conclusions: ASD patients with acetabular anteversion of ≤13° at early postoperation may suffer significantly restricted hip motion and much higher incidence of PJF during follow-up, moreover, in those patients, postoperative TK ≥28.1° would be a significant risk factor for PJF developing.

Key words: Acetabular anteversion; Adult spinal deformity; Proximal junction failure; ROC analysis; Thoracic kyphosis

Introduction

With the expected lifespan increasing, the incidence of adult spinal deformity (ASD) in general rises as well. ASD is highly prevalent in individuals over 65 years, affecting almost 68% of that population[1]. Previous studies demonstrated that ASD patients underwent scoliosis surgery

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reported statistically significant improvements in all health related quality of life (HRQOL) compared with those received non-operative treatment[2–4]. Generally, scoliosis surgery relies strongly on pedicle screw internal instrumentations, which can provide remarkable correction force and achieve a significant fusion rate. However, excessive rigid internal fixation increases the stress at the junctional region of fusion segments. Accordingly, those mechanical complications of proximal junctional kyphosis (PJK) and proximal junctional failure (PJF) were increasingly recognized complications after surgical treatment in ASD patients[5–7].

PJK was defined as a kyphotic increase at the proximal junctional region: proximal junction sagittal Cobb angle ≥10° and the angle at least 10° greater than the preoperative measurement[8]. Previous studies demonstrated that PJK was just an imaging phenomenon without affecting the daily life[8], or just decreased HRQOL scores moderately in those patients[9]. PJF is a progressive process in the spectrum of PJK with structural failures, such as vertebral body fracture and/or posterior ligament complex, screws dislodgement, and vertebral subluxation, which would bring more serious morbidities involving neurologic deficit and revision surgery[5,9].

According to previous studies[6,10,11], the risk factors for those mechanical complications of PJK and PJF were subdivided into patient-specific, surgical, and radiographic factors. Radiographic factors may be of particular importance in predicting the development of PJF according to recent study[10]. Among those radiographic parameters, larger thoracic kyphosis (TK)[12,13], larger pelvic tilt (PT) but smaller sacral slope (SS) and decreased lumbar lordosis (LL)[13,14] had significant relationships with PJK and PJF. However, those results were all just regional spine parameters. Up to now, there have been a few of studies that investigated the association of full-spine radiographic parameters with PJK and PJF[15,16]. Yagi *et al.*[16] reported a significantly increased rate ($P < 0.01$) of PJK, with 84% of patients with PJK, demonstrating a non-ideal global sagittal alignment (thoracic kyphosis + lumbar lordosis + pelvic incidence >45°) at the immediate postoperation. Additionally, the study revealed that overcorrection of the sagittal vertical axis (SVA) was associated with PJK-developing. Recently, Yilgor *et al.* proposed the global alignment and proportion (GAP) score[15], which is introduced as a "pelvic-incidence-based proportional" tool to help predict mechanical complications of PJK and PJF in ASD patients received surgical treatment. However, all of those studies did not pay attention on the effect that hip joints have on PJK/PJF in those ASD patients underwent scoliosis surgery.

There were remarkable associations among spine, pelvis, and hip joints, namely compensatory mechanism in previous studies[17–19]. Moreover, those associated effects were notable during position changing[20,21]. In a retrospective study, Buckland *et al.*[18] proposed that spinopelvic compensatory mechanisms were adapted for reduced joint mobility associated with hip osteoarthritis in standing and sitting positions. In a seated position, patients with severe hip osteoarthritis compensate for reduced hip range of motion (ROM) by preferentially increasing pelvic tilt and reducing lumbar lordosis. Additionally, Arima *et al.* performed a longitudinal cohort study suggesting that there were significant associations of postoperative posture, maximum knee extension angle, and step length during gait with the correction of the sagittal spinal deformity in patients with ASD[22]. When changing position from standing to sitting, the spine-pelvis-hip ROM includes lumbosacral and hip joints movement. However, the real mean impingement-free ROM of hip joints was only about 95° in asymptomatic people[23], then the pathological acetabular anteversion (AA) postoperatively may decrease the hip ROM significantly. Additionally, the procedure of scoliosis surgery with pelvic fixation in ASD patients restricted the compensation of the spinopelvic system, which may increase the stress in proximal junctional segments subsequently.

But there is a paucity of literature that has explored the effect of acetabular anteversion postoperatively on hip joint motion and on the mechanical complications of PJF in ASD patients after surgical treatment. The spine has a natural tendency to incline forward with increasing age. Wang *et al.*[24] reported a preoperative thoracic sagittal Cobb angle of >40° as a risk factor for PJK compared with an angle of <20°. Therefore, we performed this current study aiming to explore: (i) whether immediately postoperative AA is correlated with the mechanical complications of PJF after surgical treatment? and (ii) are there associations of AA and thoracic sagittal Cobb angle with PJF in those ASD patients after scoliosis surgery?

Materials and Methods

Inclusion and Exclusion

The inclusion criteria were as follows: (i) patients (age ≥ 45 years) with diagnosis of adult spinal deformity (ASD) based on imaging results with at least one of the following: (a) coronal major Cobb ≥20°; (b) sagittal vertical axis (SVA) ≥ 5 cm; (c) pelvic tilt (PT) ≥ 25°; and (d) thoracic kyphosis (TK) ≥ 60°[25,26]; (ii) all patients were operated on by the procedure that multi-level (≥ 4 vertebras) fusion with instrumentation and pelvic fixation by posterior-only approach; (iii) the related data of patients were integrated; and (iv) follow-up ≥2 years.

The exclusion criteria were: (i) previous spinal surgery; (ii) history of spinal tumor; (iii) history of spinal infection such as tuberculosis, or (iv) ankylosing spondylitis: (v) suffered any hip disorders; or (vi) having differences ≥2 cm between two lower extremities.

This is a retrospective study. We documented data of ASD patients in our single institution from March 2014 to January 2019, aiming to have a minimum follow-up of 24 months. Fifty-seven ASD patients were included after

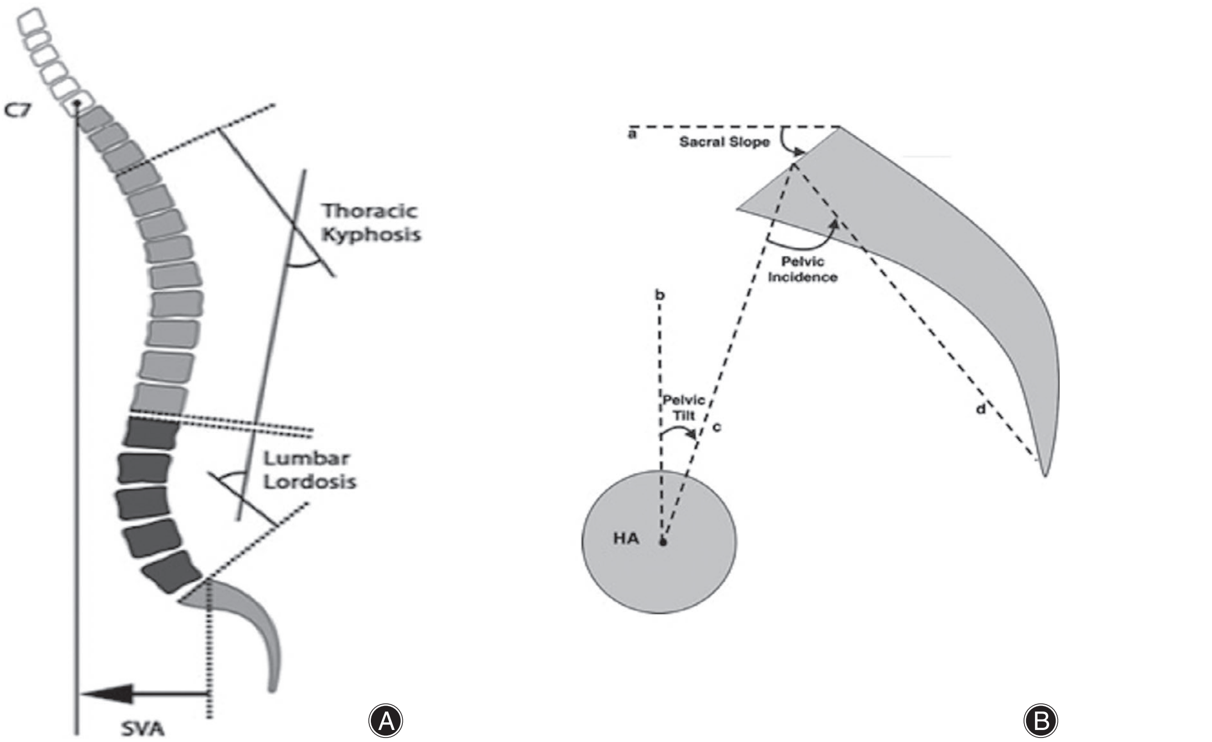

Fig. 1 Schematic drawing of each parameter. (**A**) Thoracic Kyphosis (TK), the Cobb angle between the upper endplate of T_4 and the lower endplate of T_{12}; Lumbar lordosis (LL), the Cobb angle between the upper endplate of L_1 and the upper endplate of S_1; Sagittal vertical axis (SVA), the offset between the center of C_7 and the plumb line drawn from posterosuperior corner of S_1; (**B**) Sacral slope (SS), the angle between the sacral endplate and the horizontal line; Pelvic tilt (PT), the angle between the line from the middle of the sacral plate to the middle of the hip axis and the vertical line; Pelvic incidence (PI), the angle between the line perpendicular to the midpoint of the sacral plate and the line connecting this to the midpoint of the hip axis.

appropriate Institutional Review Board approval from the Clinical Research Ethics Committee of our hospital.

Surgical Technique

All surgical procedures were performed by two senior surgeons. After inducing general anesthesia, all of those patients are positioned prone. Then, somatosensory evoked potential (SEP) and transcranial motor evoked potential (MEP) monitoring of the spinal cord were initiated. The procedure that long-fusion extending to pelvis with instrumentations was performed using the posterior approach. Partial facetectomy and laminectomy were performed in those patients who underwent posterior lumbar inter-body fusion (PLIF), and pedicle subtraction osteotomy (PSO)[27] or vertebral column decancellation (VCD)[28] at apical vertebra was performed in the patients suffered from hyper-kyphosis (Cobb≥60°).

Data Collection

Demographics (age, gender, and BMI) and surgical data involving upper instrumented vertebra (UIV), lower instrumented vertebra (LIV), and number of fixed segments (FS) were recorded. Postoperatively, mechanical complications of proximal junctional failure (PJF) development, follow-up time and PJF-free survival time after surgery were documented. Radiographs at preoperation and immediate postoperation were collected, as well as that at the final follow-up. In this current study, PJF was defined as fracture of the UIV or UIV + 1, pedicle screw loosening, dislodgment, or pullout at the UIV[8].

Outcome Measurements

Patients received standard standing full-length spine radiographic examinations at pre-, postoperation, and the final follow-up. All X-rays were scanned (View-Tec, France) and saved in JPG format (75 dpi). Spinopelvic variables were measured with valid Surgimap software (version 2.14.3, New York, NY, USA)[29]. The accuracy of Surgimap was evaluated previously and is briefly summarized here: an interobserver and intra-observer reliability analysis revealed high agreement (intraclass correlation coefficient, >0.93) for all spinopelvic parameters, and the mean difference was <0.4° for PT, PI, and LL, and <0.3 mm for SVA.

Radiographic data collection consisted of full-length standing coronal and sagittal radiographs obtained in free-standing posture with the upper limbs resting on a support, the shoulders at 30° forward flexion, and the elbows slightly flexed[30]. The radiographic parameters of interest were as follows.

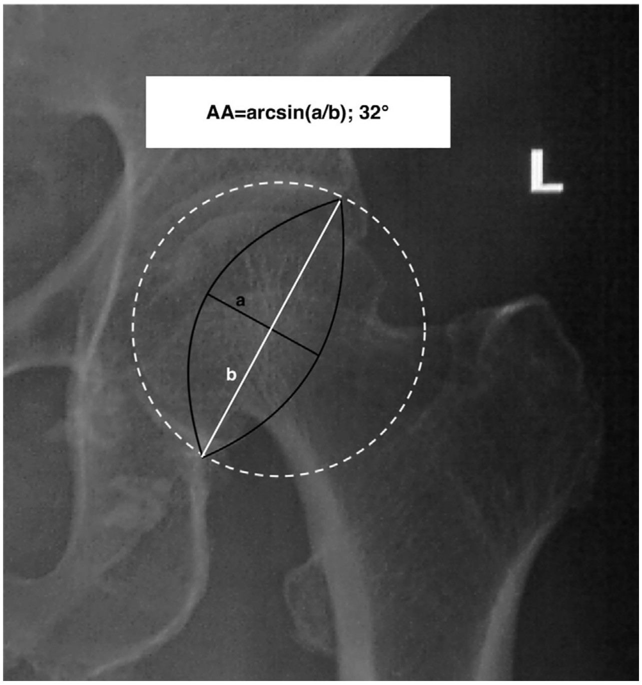

Fig. 2 An anteroposterior radiograph showing the calculation of acetabular anteversion by the Lewinnek method. Acetabular anteversion (AA) = arcsin(b/a).

Sagittal Plane

Thoracic kyphosis(TK), the Cobb angle between the upper endplate of T_4 and the lower endplate of T_{12}, represents the thoracic feature. Lumbar lordosis (LL), the Cobb angle between the upper endplate of L_1 and the upper endplate of S_1, represents the lumbar feature. Sagittal vertical axis (SVA), the offset between the center of C_7 and the plumb line drawn from posterosuperior corner of S_1, represents the global spine alignment. The details were shown in Fig. 1A. Additionally, kyphosis was presented as the positive angle and lordosis as the negative angle. Global sagittal alignment (GSA)[31] were subsequently calculated as follows: TK + LL + PI.

Pelvic Variables

Sacral slope (SS), the angle between the sacral endplate and the horizontal line. Pelvic tilt (PT), the angle between the line from the middle of the sacral plate to the middle of the hip axis and the vertical line. Pelvic incidence (PI), the angle between the line perpendicular to the midpoint of the sacral plate and the line connecting this to the midpoint of the hip axis[32]. The details were shown in Fig. 1B.

Hip Variables

Acetabular parameters: acetabular anteversion(AA) was recorded (Fig. 2). AA was a mean value of left and right AA degree, measured by the valid method proposed by Lewinnek[33,34].

Range of hip joints motion (H-ROM): In physical examination at pre- and postoperation, those patients were instructed to actively flex and extend the hip joints, and the maximum range of flexion motion (F-ROM) and the maximum range of extension motion (E-ROM) actively was recorded. H-ROM = F-ROM + E-ROM. The details were shown in Fig. 3A,B.

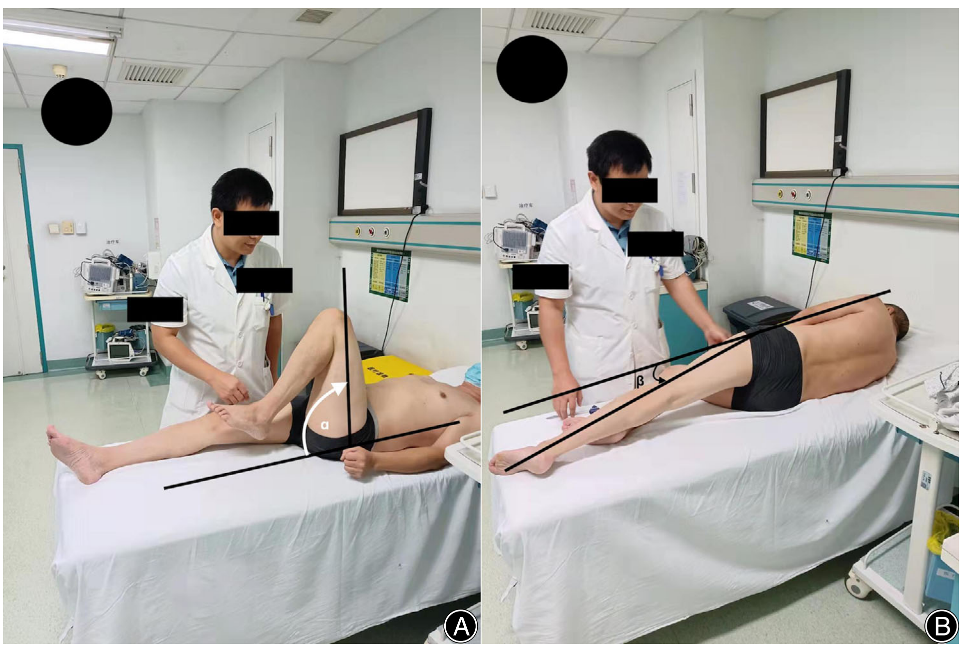

Fig. 3 Schematic drawing of extension motion range(α) in 3A, and flexion motion range(β) in 3B.

TABLE 1 the specific data of 14 patients with PJF

No.	Age, yrs	Sex	UIV	TK,°	AA,°	H-ROM,°	F-ROM,°	E-ROM,°	PJF, month
1	69	F	T9	38.7	10	100	75	25	6
2	60	F	T10	30.4	10	105	75	30	24
3	58	F	L2	19.3	11	100	70	30	36
4	53	F	T10	42.3	7	100	75	25	12
5	59	F	T10	32.8	9	105	75	30	4
6	65	F	T8	28.5	13	105	80	25	20
7	75	F	T9	42.7	12	110	80	30	10
8	58	F	T10	37.6	13	105	80	25	21
9	64	F	T10	29.3	12	105	80	25	9
10	63	F	T10	33.2	12	105	80	25	6
11	70	F	T10	1.9	20	100	90	10	43
12	62	F	T7	35.9	20	105	90	15	3
13	77	F	T10	44.5	19	115	85	30	6
14	66	M	L1	35.6	24	110	90	20	6

F, female; AA, acetabular anteversion; E-ROM, range of extension motion; F-ROM, range of flexion motion; H-ROM, range of hip motion; PJF, proximal junctional failure; TK, thoracic kyphosis; UIV, upper instrumented vertebra; yrs, indicates years.

Statistical Analysis

Continuous variables with normal distribution were expressed as the Mean ± SD, and abnormal data as the median. Categorical variables were expressed as counts and percentages. First, comparisons between patients with and without PJF were performed. The AA postoperatively value was used for receiver operating characteristic (ROC) curve analysis, with the area under the curve (AUC) calculated for post-AA thresholds according to PJF prevalence. Then, all of those patients in this current study were subdivided into yjr observational and control groups by the AA threshold value. A Kaplan–Meier curve and log-rank test were used to analyze the differences in PJF-free survival between the two groups. Comparisons of categorical variables were analyzed

TABLE 2 Comparisons of data between patients with and without PJF (Mean ± SD)

	Preoperation					Postoperation				
Variables	PJF group (n = 14)		PJF-free group (n = 43)		P value	PJF group (n = 14)		PJF-free group (n = 43)		P value
Female, n %	13 (92.9)		35 (81.4)		0.427					
Age, years	64.21 ± 6.76		65.2 ± 7.92		0.394					
BMI, kg/m^2	25.58 ± 10.3		24.17 ± 10.59		0.431					
Follow-up, month						51.2 ± 17.58		49.6 ± 19.38		0.72
UIV										0.214
T_{10} /above						11		25		
L_2-T_{11}						3		18		
FS						8.86 ± 2.07		8.72 ± 2.43		0.654
TK	23.5	12.47	13.66	8.71	**0.01**	32.26	11.02	20.55	9.05	**0.00***
LL	−19.62	25.14	−15.98	17.76	0.56	−34.3	9.63	−35.37	9.58	0.71
SS	12.53	11.78	19.91	11.98	0.051	20.8	8	28.53	8.63	**0.005**
PT	27.05	13.99	26.77	10.69	0.94	19.42	12.43	18.41	7.58	0.78
PI	39.62	11.68	46.94	11.39	**0.004**	-	-	-	-	-
SVA	56.5	78.6	63.77	51.72	0.751	18.47	49.62	17.59	29.62	0.936
AA	23.73	9	22.14	10.31	0.64	13.76	5	17.72	7	**0.027**
H-ROM	130	4.38	131	5.11	0.1	105	4.39	106	6.22	0.56
F-ROM	116.4	6.91	117.01	7.04	0.22	80.35	6.34	89.53	5.96	**0.00**
E-ROM	12.5	4.97	11.96	5.21	0.45	24.64	6.03	15.51	6.22	**0.00**
GSA	43.5	22.46	44.62	17.97	0.24	38.19	18.66	32.13	10.27	0.686
≤45°	8		24		0.93	9		39		**0.019**
>45°	6		19			5		4		

The bold numbers indicate that the differences are significant (P < 0.05).; AA, acetabular anteversion; BMI, body mass index; E-ROM, extension range of motion; F-ROM, flexion range of motion; FS, fusion segments; GSA, global spinal alignment; H-ROM, hip range of motion; LL, lumbar lordosis; PI, pelvic incidence; PT, pelvic tilt; SS, sacral slope; SVA, sagittal vertical axis; UIV, upper instrumented vertebra; TK, thoracic kyphosis.; * P < 0.001.

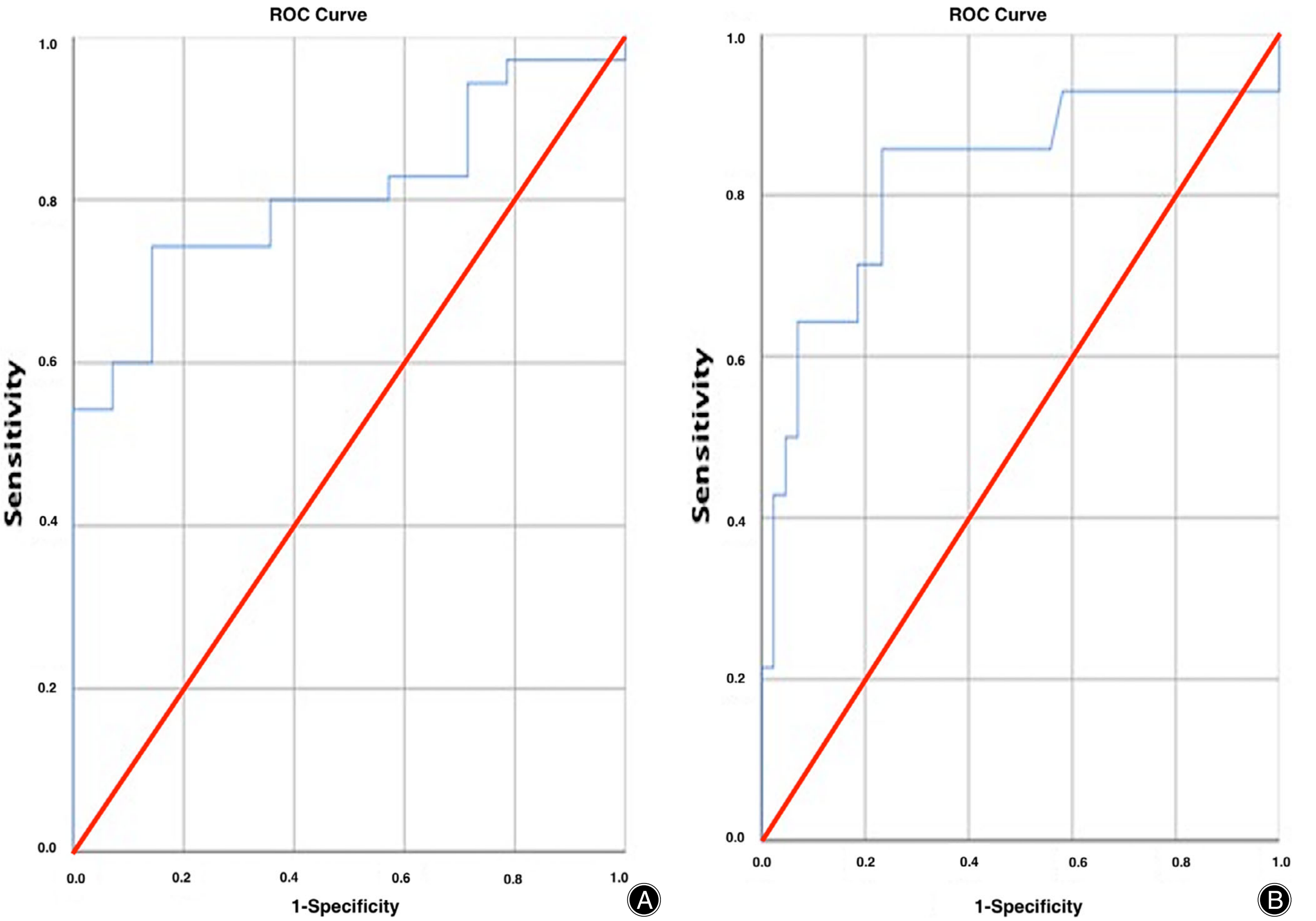

Fig. 4 The ROC curve for predicting PJF by the acetabular anteversion (AA) at early postoperation (**A**); and the ROC curve for predicting PJF by the immediate TK postoperatively (**B**).

with Chi-square analysis or Fisher's exact test. Comparisons of continuous data between the observational and control groups were performed with Independent sample *t* test. All statistical analysis was performed using IBM SPSS statistics software (Mac version 26.0, IBM, Armonk, NY, USA and 95% confidence intervals were obtained; $P < 0.05$ (two-sided) was the criterion for statistical significance.

Results

Demographic Data

A total of 57 consecutive patients (49 females and eight males) met inclusion criteria with an average follow-up of 41 months (rang, 24–72 months). The average age at the time of surgery was 64.96 years (SD 7.5; range, 45–79 years). The average body mass index (BMI) was 26 kg/m^2 (range, 16.1–39.7 kg/m^2). Fifty-seven ASD patients included 12 adult idiopathic scoliosis (21.1%), 32 degenerative scoliosis (56.1%), 13 hyper-kyphosis deformity (22.8%). The mean fixed segments was 10 (range, 4–14). There were 36 patients with upper instrumented vertebra (UIV) at T_{10} or above, and 21 patients with UIV at thoracolumbar segments covering L_2-T_{11}. The lower instrumented vertebra (LIV) located at S_1 in 28 patients, S_2 in 20 patients, and nine patients in ilium.

Comparisons between Patients with and without PJF

In all, 14 patients (24.7%; 10 patients with fracture at the UIV or UIV + 1, and four patients with pedicle screw loosening and/or dislodgment at the UIV) developed PJF during follow-up, and were assigned into the PJF group. Of the 14 patients, 12 cases suffered PJF within 24 months, and the other two patients developed PJF at 36th and 43rd months during follow-up respectively. The details of those 14 patients with PJF are listed in Table 1. The other 43 patients without PJF were being as the PJF-free group. As for preoperative data, there were no differences between the two groups in age ($P = 0.394$), gender ($P = 0.427$), and BMI ($P = 0.431$). Comparing the pre- and postoperative radiographic parameters, the mean value of LL, PT, SVA, and GSA had no

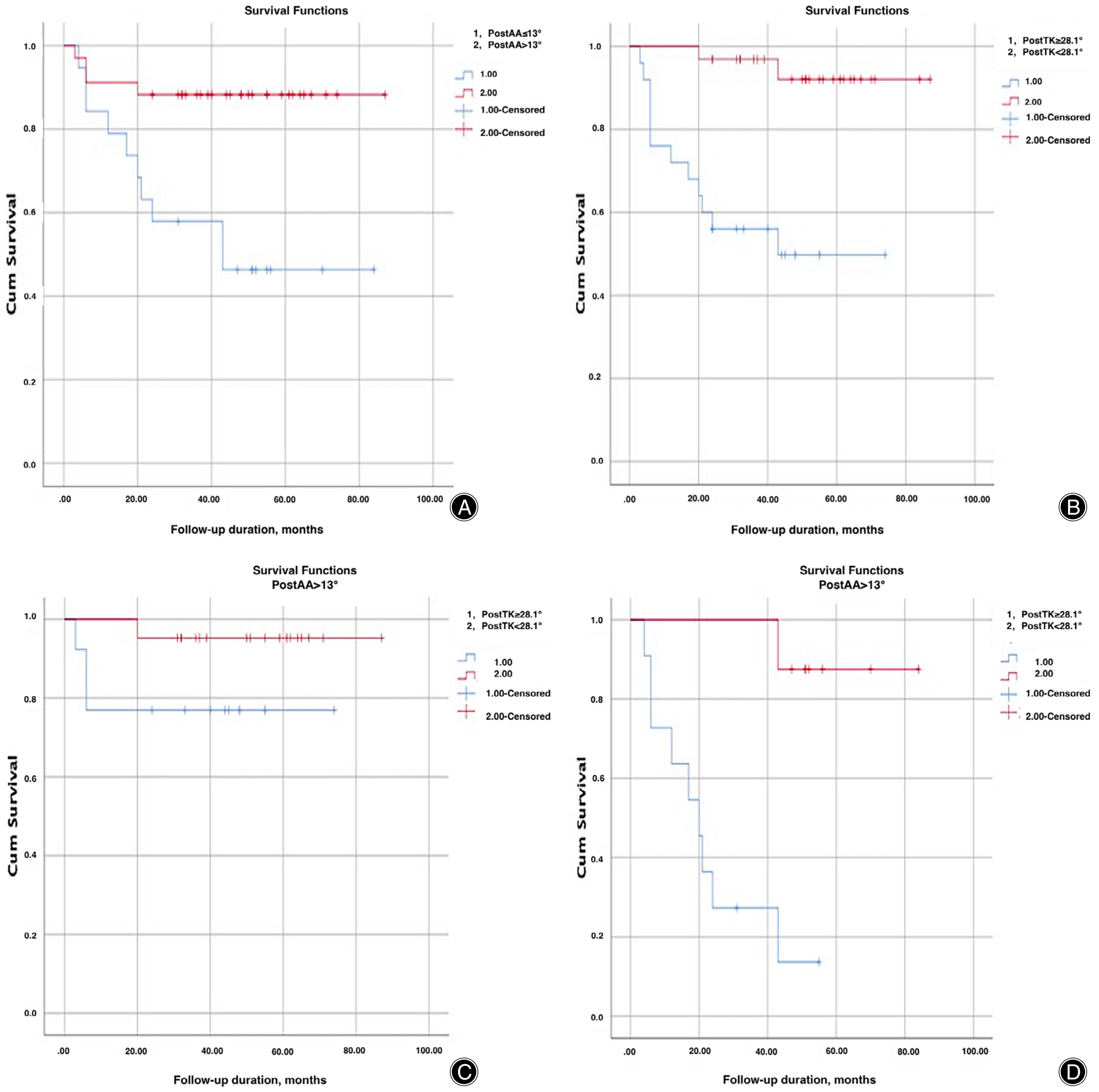

Fig. 5 Kaplan–Meier curves of time periods PJF-free stratified all patients by a threshold AA value (> 13° or ≤ 13°) (**A**), and stratified all patients by a threshold post-TK value (≥ 28.1° or < 28.1°) (**B**); Under the condition of AA >13°, Kaplan–Meier curves of time periods without PJF stratified patients into TK ≥28.1° and TK < 28.1° (**C**); Under the condition of AA ≤13°, Kaplan–Meier curves of time periods without PJF stratified patients into TK ≥28.1° and TK < 28.1° (**D**).

differences, as well as the AA preoperatively, however, immediate TK ($P < 0.001$), SS ($P = 0.005$), and AA ($P = 0.027$) postoperatively were statistically different, as well as preoperative TK ($P = 0.01$) and PI ($P = 0.004$). Postoperatively, although there was no difference in H-ROM, the F-ROM and E-ROM was $80.35° \pm 6.34°$ and $24.64° \pm 6.03°$ in the PJF group, compared with that of $89.53° \pm 5.95°$ ($P < 0.001$) and $16.51° \pm 6.22°$ ($P < 0.001$) in the PJF-free group respectively. Additionally, five patients with GSA > 45° in the PJF group, compared with four patients in the

TABLE 3 Comparisons of data between patients with post-AA≤13° and those with post-AA>13° (Mean ± SD)

	Preoperation					Postoperation				
Variables	Observational (n = 19)		Control (n = 38)		P value	Observational (n = 19)		Control (n = 38)		P value
Female, n %	17 (89.5)		32 (81.6)		0.59					
Age, years	63.94 ± 6.24		65.47 ± 8.23		0.394					
BMI, kg/m^2	24.61 ± 9.37		24.88 ± 10.1		0.789					
Follow-up, months						48.67 ± 18.92		50.12 ± 17.88		0.36
UIV										**0.02**
T_{10} /above						16		20		
L_2-T_{11}						3		18		
FS						8.95 ± 2.72		8.66 ± 2.38		0.654
PJF, n %						10 (52.6)		4 (10.5)		**0.00***
TK	20.95	11.35	13.64	9.39	**0.014**	28.26	9.55	21.01	10.6	**0.015**
LL	−15.41	24.12	−17.7	17.26	**0.014**	−33.4	8.44	−35.98	10.01	0.33
SS	13.53	12.63	20.41	11.53	**0.047**	23.0	7.13	28.45	9.45	**0.031**
PT	27.05	13.99	26.77	10.69	0.96	17.6	9.38	19.19	8.72	0.53
PI	40.61	6.42	47.64	12.85	**0.008**	-	-	-	-	-
SVA	54.77	73.48	65.69	50.48	0.567	20.68	42.92	16.37	30.95	0.666
AA	19.27	11.54	22.14	10.31	0.082	10	2.59	20.48	5.22	**0.00***
H-ROM	130.42	5.91	131.97	6.1	0.72	103.4	4.42	106.9	6.1	**0.016**
F-ROM	113.42	8.34	115.97	8.15	0.29	80.52	7.24	90.65	4.21	**0.00***
E-ROM	15.0	5.77	13.96	5.94	0.45	22.89	7.87	16.31	5.53	**0.00***
GSA	46.57	22.05	43.15	17.4	0.24	35.5	11.93	32.68	13.44	0.686
≤45°	7		24		0.09	15		33		0.44
>45°	12		14			4		5		

The bold numbers indicate that the differences are significant (P < 0.05).; BMI, body mass index; UIV, upper instrumented vertebra; FS, fusion segments; PJF, proximal junctional failure; TK, thoracic kyphosis; LL, lumbar lordosis; SS, sacral slope; PT, pelvic tilt; PI, pelvic incidence; SVA, sagittal vertical axis; AA, acetabular anteversion. H-ROM, hip range of motion; F-ROM, flexion range of motion; E-ROM, extension range of motion; GSA, global spinal alignment.

PJF-free group (5/9 *vs* 4/39, P = 0.019). Surgical data had no significant difference regarding to UIV and fixed segments (FS) (P > 0.05). The details are listed in Table 2.

Analysis based on Acetabular Anteversion Postoperatively

The postoperative AA value was used for ROC curve analysis, which determined an optimal threshold of 13° (sensitivity = 74.3%, specificity = 85.7%; AUC = 0.806 [95% *CI* 0.686–0.926]). (Fig. 4A) All patients were subdivided into the observational (AA ≤13°) and control groups (AA >13°). There were 19 and 38 patients in the observational and control group respectively. Patients showing PJF equated to 10 in the observational group, and four in the control group (10/9 *vs* 4/34, P < 0.001). Furthermore, there was significant difference in the PJF-free survival time between the two groups (P = 0.001, log-rank test). (Fig. 5A) Comparing radiographical data between the observational and control groups, those parameters of TK, SS had significant differences at pre-, and postoperation (P < 0.05), as well as the pre-LL (P = 0.014), post-AA (P < 0.001), and PI (P = 0.008). Physical examination of hip joints showed there were significant differences in H-ROM (P = 0.016), F-ROM (P < 0.001) and E-ROM (P < 0.001) at postoperation. The details are listed in Table 3.

Comprehensive Analysis of Acetabular Anteversion and Thoracic Kyphosis Postoperatively

The immediate TK postoperatively (post-TK) was used for ROC curve analysis, which determined an optimal threshold of 28.1° (sensitivity = 85.7%, specificity = 76.7%; AUC = 0.823, 95% *CI* [0.672–0.974]) (Fig. 4B). When stratifying all patients by the 28.1° (post-TK ≥28.1° or <28.1°), the PJF-free survival time decreased significantly in patients with post-TK ≥28.1° (P < 0.001, log-rank test) (Fig. 5B). Under the condition of post-AA >13°, although there was no difference of the PJF-free survival time in patients with different post-TK (≥ 28.1° and <28.1°) (P = 0.087, log-rank test) (Fig. 5C), of four patients with PJF, three patients with post-TK ≥28.1° developed PJF within 6 months (the 3rd, 6th, and 6th months respectively), one patient with post-TK of 1.9° suffered PJF at the 21st month. In the observational group, the PJF-free survival time of patients with post-TK ≥28.1° decreased significantly compared with that of patients with post-TK < 28.1° (P = 0.001, log-rank test) (Fig. 5D).

Two representative patients were shown in Figs 6 and 7.

Discussion

Associations among Spine, Pelvis and Hip Joints with Proximal Junctional Failure

There have been studies illustrating the compensatory mechanism among spine, pelvis and hip joints. Buckland *et al.*[18]

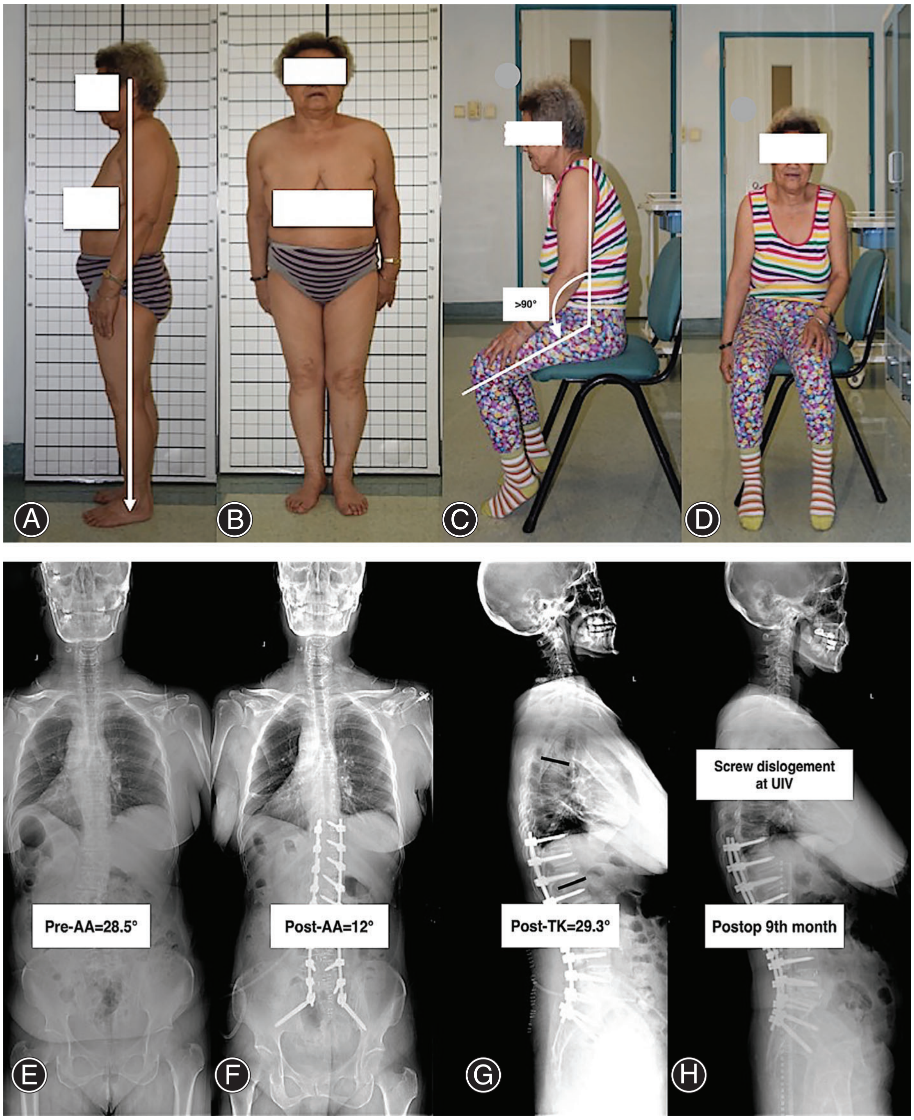

Fig. 6 The female patient with ASD, 64 years old belonging to the observational group, can keep upright posture (A and B) after surgical treatment, however, are being with restricted flexion of hip joints at sitting position (C and D). Full-spine radiographs at preoperation and immediate postoperation were shown in graph E and F, the AA was 28.5° and 12° respectively; The sagittal radiograph at immediate postoperation (G) showed TK was 29.3°. This patient developed screw dislodgment at upper instrumented vertebra at the 9th month during follow-up (H).

demonstrated that patients with severe hip osteoarthritis (OA) had much higher sagittal vertical axis (SVA), T1 pelvic angle (TPA), and pelvic tilt (PT) during position changing from standing to sitting. Then patients with restricted hip motion would increase the range of spinal motion significantly from standing to sitting due to the compensation among spine, pelvis, and lower joints. Buckland *et al.*[35] demonstrated that acetabular anteversion (AA) would decrease with spinopelvic realignment after surgical treatment in patients with spinal deformity. In this current study, all patients were operated on with the procedure of long-fusion with instrumentations extending to the pelvis. Comparisons of spinopelvic variables between patients with and without proximal junctional failure (PJF) showed that AA, range of hip motion (H-ROM), range of flexion motion (F-ROM) and range of extension motion (E-ROM) were comparable at preoperation, however, the AA and F-ROM were much smaller after surgery in patients showing PJF. Those results suggest that ASD patients with pelvic fixation and less F-ROM probably increase full-spinal inclination significantly after scoliosis surgery during position changing in daily life. The stress at the proximal junctional segments would increase accordingly, and mechanical complications of proximal junctional kyphosis (PJK) and even PJF happened subsequently at follow-up.

The Threshold of Acetabular Anteversion for PJF-Developing

In this study, ROC curve analysis revealed the best cut off value of post-AA was 13° for PJF developing. Additionally, we found patients with post-AA ≤13° had much more restricted hip joints. Consequently, PJF developed due to the

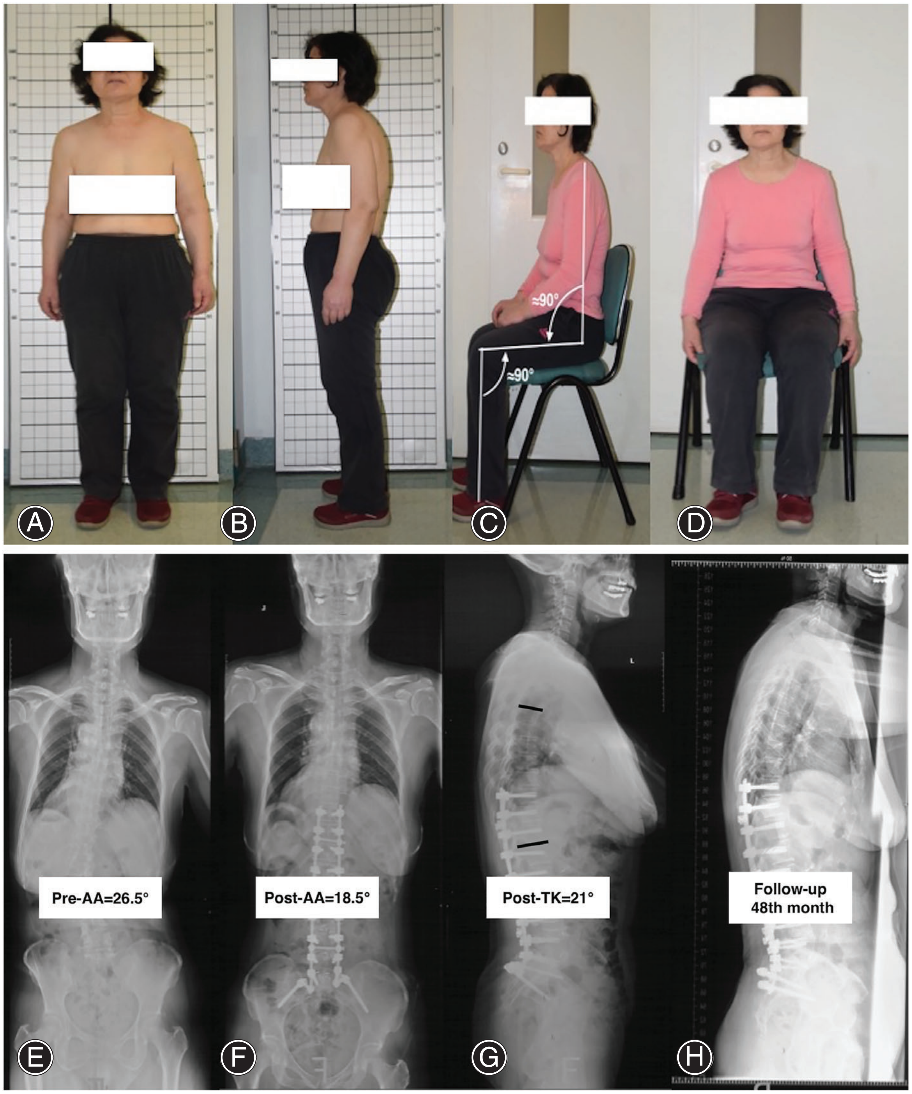

Fig. 7 A female patient with ASD, 63 years old, was belonging to the control group. The patient can keep erect standing posture (A and B) and comfortable sitting position (C and D) after surgical treatment. Anteroposterior full-spine radiographs preoperatively and immediate postoperatively were shown in graph E and F, the AA was 26.5° and 18.5° respectively; The sagittal radiograph at immediate postoperation (G) showed TK postoperatively was 21°. This patient had benign spinopelvic alignment at the 48th month during follow-up (H).

stress increasing at proximal junctional segments in those patients. The progressive thoracic kyphosis had been demonstrated as a risk factor for PJK[36]. As the representative patient showing, with AA of 12°, she can keep an erect standing position (Fig. 6A,B), however, in order to accomplish a sitting position, she has to incline her trunk forward due to the restricted hip flexion (Fig. 6C). During follow-up, the patient developed PJF at 9th month (Fig. 6E–H). But the patient in the control group underwent similar long-fusion surgery (T_{10}-S_2) had ideal AA (18.5°) and TK (21°) could keep erect standing position and good sitting position, which are shown in Fig. 7A–H.

Therefore, in ASD patients who underwent long-fusion with instrumentation extending to the pelvis, the smaller AA postoperatively would induce the restricted hip joints, which may have significant relationships with PJF developing.

The Threshold of Thoracic Kyphosis for PJF-Developing

The relative stiffness of thoracic spine, however, limits the correction that can be obtained. In this study, the mean value of TK in patients with PJF at pre- and postoperation were much larger than that in patients without PJF. Furthermore, ROC curve analysis showed the best cut off value of post-TK was 28.1° for PJF showing, and PJF-free survival time in those patients with post-TK ≥28.1° decreased significantly, which was similar with the results reported in previous studies[37,38]. In those ASD patients with much larger TK after surgery, much more stress would develop at the proximal junctional segments, and PJF developed subsequently, which was consistent with results proposed by Yagi *et al.*[36] Additionally, there were four patients who suffered PJF in the control group (post-AA >13°). Of those, three with post-TK ≥28.1° developed PJF within 6 month, PJF showing in the last patient with post-TK of 1.9° at the 21st month during follow-up. Then the larger TK (≥ 28.1°) postoperatively would be a risk factor for PJF, moreover, larger TK (≥28.1°) postoperatively probably accelerate the PJF developing in ASD patients with smaller AA (≤13°).

Other Risk Factors for PJF

Yagi *et al.*[16] suggested postoperative global spinal alignment (GSA, PI+LL + TK) over 45° may be a risk factor for PJF in patients underwent scoliosis surgery. In our current study, there were more patients with postoperative GSA over 45° in the PJF group, however, comparisons of GSA between patients with post-AA ≤13° and those with post-AA >13° showed no difference.

Lastly, previous studies revealed that demographics such as age, gender, BMI and surgical factors including the location of upper instrumented vertebra (UIV), lower instrumented vertebra (LIV), and the type of instrumentation had significant relationships with PJF[11,14,39,40]. In our study, all patients operated on had long-fusion (≥4) using posterior pedicle screw and 2-rod constructs (titanium alloy) with pelvic fixation. Comparisons of UIV between patients with and without PJF showed no difference. There were more patients with UIV fused to upper thoracic spine (T10 or above) in those with post-AA ≤13°. Then post-AA may have association with the location of UIV, further studies should be performed although. There was no difference in age, gender, and BMI.

Limitations of this study include its sample size and retrospective design. These results were based on the techniques of surgeons from a single institute and may not be extrapolated to other centers. While the impact of the AA on PJF was so significant even in this small series. Furthermore, functional scores such as SRS-22 or Oswestry disability index (ODI) were not analyzed in this study. Future research is needed to establish the relationships between hip joints, clinical symptoms, and functional scores in ASD patients. We suggest the results of this study can be used as a foundation for that purpose. Despite these limitations, we demonstrated the impact of AA and TK on PJF after surgery in ASD patients.

Conclusions

In ASD patients after scoliosis surgery, the smaller acetabular anteversion postoperatively would induce restricted hip joints, which are probably risk factors for PJF. Additionally, in those patients who suffered less hip motion, progressive thoracic kyphosis postoperatively would accelerate the PJF developing significantly. Global spinal alignment over 45° may be a predictive factor for PJF as well.

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