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ORIGINAL ARTICLE

Sagittal malalignment has a significant association with postoperative leg pain in adult spinal deformity patients

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Abstract

Purpose To evaluate the association between spinopelvic sagittal parameters and leg pain in patients with adult spinal deformity (ASD) after adjusting for demographic and surgical variables.

Methods A multicenter prospective ASD database (European Spine Study Group) was retrospectively reviewed. The characteristics (age, sex, body mass index, comorbidity, history of spine surgery, and radiographical coronal and sagittal parameters) of patients with preoperative and 6-month postoperative leg pain (PostLP; numerical rating scale score ≥5) were analyzed using univariate and multivariate analyses.

Results In this study, 204 patients (164 women and 40 men; mean age 53.1 years) were included. Fifty-three percent of the patients had preoperative leg pain (PreLP). The patients with PreLP had significantly worse sagittal parameters and less coronal Cobb angle than those with less leg pain; however, this association disappeared after adjustment for covariates. The PreLP of the ASD patients was successfully treated surgically in most cases; however, 24 % of the patients still had unexpected residual leg pain. Postoperative sagittal malalignment (sagittal vertical axis ≥40 mm, T1 sagittal tilt ≥0°, pelvic tilt ≥30°) was a significant risk factor of PostLP even after adjusting for covariates.

Conclusions Leg pain in patients with ASD was significantly associated with sagittal malalignment especially after surgical treatments. As these patients lose flexibility in the fused spinal segment, they can only depend on the remaining compensatory mechanisms below the pelvis (e.g., the hips and knees) to maintain a balanced posture. This may lead to a predisposition of these patients to postoperative leg symptoms related to spinal sagittal malalignment.

Keywords Adult spinal deformity · Leg pain · Sagittal balance · Surgical treatment · Global tilt

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Introduction

Leg pain is the most common symptom of adult spine deformity (ASD). In patients with ASD, it is considered to originate mainly from the spinal canal or foraminal stenosis (radicular pain), and is treated with either direct or indirect decompression of the affected spinal canal [1]. These surgical treatments generally provide satisfactory pain relief to patients, but some patients experience unexpected residual leg pain [1, 2]. With proper decompression and fusion, other possible origins of postoperative leg pain besides radicular pain should be considered.

Recent studies have concluded that restoration of spinopelvic alignment represented by sagittal spinal and/or pelvic radiographical parameters is essential for improved health-related quality of life (HRQL) after ASD surgery [3–8]. These studies focused on generalized patient-reported outcomes measures of HRQL, such as the Oswestry Disability Index (ODI), 36-Item Short-Form Health Survey (SF-36), and the Scoliosis Research Society-22 Questionnaire (SRS-22). As these measures do not distinguish between leg pain and back pain, the detailed analyses of the clinical presentation and etiologies of leg pain in patients with ASD are still lacking [1, 2]. Particularly, little is known about the association between leg pain and sagittal parameters.

In this study, we conducted a multiple logistic regression analysis to evaluate the possible association between sagittal parameters and leg pain in patients with ASD. We hypothesized that postoperative residual leg pain is associated with postoperative sagittal malalignment.

Materials and methods

Patient cohort and analyzed variables

This study was a part of a multicentric study comprising of six European spine centers [9–11]. Each enrolling site obtained institutional review board approval of the common protocol. We reviewed prospectively collected data of patients with ASD aged ≥18 years who met at least one of the following criteria: a spinal coronal Cobb angle ≥20°, sagittal vertical axis (SVA) >5 cm, pelvic tilt (PT) >25°, or thoracic kyphosis >60°. We excluded non-surgical candidates and patients with congenital deformity, post-traumatic deformity, neuromuscular disease, and Scheuermann disease. In addition, patients who had not yet completed 6 months of follow-up were also excluded. Although we did not conduct systematic clinical or radiographical studies for hip or knee disease, such as osteoarthritis, routine preoperative history taking and physical examination excluded symptomatic untreated hip or knee disease. All subjects had full-length standing coronal and sagittal spinal radiographs obtained in free-standing position with fists overlaying the ipsilateral clavicles [12].

The demographic independent variables analyzed were age (≤40 years, >40 years but ≤60 years, >60 years), sex, body mass index (BMI; <25, ≥25 but <30, ≥30), American Society of Anesthesiologists (ASA) grade (grades I–III), and history of spine surgery.

Radiographic parameters, including coronal curve types (SRS-Schwab ASD classification, N: no major coronal deformity, T: thoracic major curve, L: lumbar or thoracolumbar major curve, and D: double major curve) [13], SVA (<40 mm, ≥40 mm but ≤95 mm, >95 mm) [13], T1 sagittal tilt (T1ST: the angle between a line drawn from the center of the femoral head axis to the midpoint of the T1 vertebral body and the vertical line) [3, 14, 15], global tilt (GT: the supplementary angle between the line from C7 to the center of the upper end plate of S1 and the line from the center of the femoral heads to the center of the upper end plate of S1) [11, 16], PT (<20°, ≥20° but ≤30°, >30°) [13], and pelvic incidence (PI) minus lumbar lordosis (PI–LL; <10°, ≥10° but ≤20°, >20°) [13], before and after surgery were also analyzed as independent variables. The T1ST classification system was established based on previous studies [3, 14, 17] and the distribution in the database. The classifications were defined as follows: T1ST <0° (non-pathologic), T1ST ≥0° but <5° (moderate deformity), and T1ST ≥5° (marked deformity). As GT still has no validated normal value, we treated it as a continuous variable.

Variables related to surgical treatment (surgical variables) were fusion length (number of fused vertebra), lumbosacral fusion, decompression procedure, PLIF or TLIF procedure, and osteotomy procedure, including at least one Smith-Petersen osteotomy, pedicle subtraction osteotomy, or vertebral column resection. Complications related to the surgical treatment were classified as major or minor based on the literature [18]. As for the complications, major complications and reoperation have been reported to have a significant impact on worse surgical results [18, 19]. Therefore, patients were classified as having no major complication (no), a major complication requiring no reoperation (without reoperation), and a major complication requiring reoperation (reoperation). Major complications included spinal cord injury, nerve root injury, deep infection, paralysis, pulmonary embolism, sepsis, cardiac infarction, renal failure, and instrumentation or junction failure.

Dependent variables included preoperative/postoperative leg pain, evaluated using a numerical rating scale (NRS, 0–10 points) and patients with moderate to severe pain (NRS score ≥5) [2] as pain-positive. Preoperative/postoperative HRQL based on ODI scores was also examined.

Statistical analyses

Statistical analyses were performed using the JMP11 software (SAS Institute, Cary, NC, USA) and STATA14 (StataCorp, College Station, TX, USA). Statistical significance was set at a p value of <0.05. Data were reported as mean and standard deviation (SD), or median and interquartile range (IQR) if continuous and as proportions if categorical. Differences in continuous variables were

Table 1 Baseline characteristics of the preoperative leg pain and less leg pain groups

	Preop less leg pain group (NRS ≤4)		Preop leg pain group (NRS ≥5)		$P*$
(N, %total)	95	48 %	105	52 %	–
Age (mean, SD)	45.9	20.0	59.8	16.6	0.000
Female (N, %group)	74	78 %	86	82 %	0.479
BMI (mean, SD)	24.0	4.4	27.0	4.6	0.000
ASA Grade 1 (N, %group)	50	52 %	26	24 %	0.000
Past surgery (N, %group)	17	18 %	45	43 %	0.000
Preop ODI (mean, SD)	33.1	21.0	50.0	16.8	0.000
Preop leg pain NRS (median, IQR)	0	0–2	7	5–8	0.000
Preop back pain NRS (median, IQR)	6	4–8	7	6–9	0.002
Coronal Schwab Classification (N/T/L/D)[a]	31/8/25/31		58/4/30/13		0.001
(N, %group)	33 %/8 %/26 %/33 %		55 %/4 %/29 %/12 %		
Preop coronal major Cobb angle (mean, SD)	46.4	22.2	34.9	17.7	0.000
Preop SVA (mean, SD)	25.9	64.4	54.5	66.9	0.003
Preop T1ST (mean, SD)	−3.0	5.4	−1.1	6.5	0.031
Preop PT (mean, SD)	21.2	11.3	25.0	11.3	0.021
Preop PI–LL (mean, SD)	8.0	21.7	18.0	22.2	0.002
Preop GT (mean, SD)	24.0	18.5	30.5	16.6	0.011

NRS numerical rating scale, *SD* standard deviation, *BMI* body mass index, *ASA* American Society of Anesthesiologists, *IQR* interquartile range, *SVA* sagittal vertical axis, *T1ST* T1 sagittal tilt, *PT* pelvic tilt, *PI–LL* pelvic incidence minus lumbar lordosis, *GT* global tilt

* *P* value: calculated using Pearson's Chi-square test, Student's *t* test, or Mann–Whitney's *U* test

[a] *N* no major coronal deformity, *T* thoracic major curve, *L* lumbar or thoracolumbar major curve, *D* double major curve

analyzed using Student's *t* test or Mann–Whitney *U* test, and differences in categorical variables were analyzed using Pearson's Chi-square test.

Multivariate logistic regression models were fitted separately for preoperative/postoperative leg pain. Odds ratios (ORs) with 95 % confidence intervals (95 % CIs) of the risk of preoperative/postoperative leg pain for the radiographic parameters and covariates were estimated from these models with robust standard error. For postoperative multivariate models, based on the limited number of postoperative leg pain-positive cases ($n = 48$), three covariates to be entered into the final model were selected based on the clinical interest, namely, preoperative leg pain, age, and decompression procedure. Owing to the strong correlation observed between the various radiographic sagittal parameters, four separate models were tested, namely: (1) including SVA and PT (model 1), (2) T1ST and PT (model 2), (3) PI–LL (model 3), and (4) GT (model 4).

Stratification and interaction analysis for each model was used to investigate differences between the age groups and radiographic sagittal parameters. However, because of the insufficient number of subjects jointly exposed to the two variables, which lead to reduced power and unstable interaction estimates, no significant interaction was detected; thus, they are not discussed further in this study.

Results

Demographic characteristics

In this study, 204 patients (164 women and 40 men) were included. The mean age was 53.2 years (range 18–85 years), and 95 patients (47 %) were above 60 years. Sixty-two patients (30 %) had a history of spine surgery. The preoperative median NRS score was 5 (IQR 0–7) for leg pain and 7 (IQR 5–8) for back pain. The mean (SD) preoperative ODI score was 42.0 (20.5). The patients with preoperative leg pain of an NRS score of ≥5 (PreLP) were significantly older, and had higher BMI, higher rate of prior spine surgery, higher ODI, and more severe leg and back pains than the patients with preoperative leg pain of an NRS score of ≤4 (PreNLP). As for radiographic parameters, the PreLP patients had a higher rate of type N coronal Schwab classification (no coronal deformity), indicating that these patients have sagittal deformity. In addition, the

PreLP patients had a lower mean coronal Cobb angle of a major curve, higher SVA, T1ST, PT, PI–LL, and GT than the PreNLP patients (Table 1).

Multivariate logistic regression analyses of preoperative leg pain

In the multivariate logistic regression models for preoperative leg pain (NRS score ≥5) that consisted of explanatory variables, including age, sex, BMI, ASA grade, past surgery, and sagittal parameters, only age, BMI, and past surgery were significantly associated with PreLP (Table 2). Contrary to the results of the univariate analyses (Table 1), no association was found between the sagittal parameters and PreLP.

Surgical treatments

The median number of fused vertebra was 9 (IQR 7–13). Of the patients, 112 (56 %) received lumbosacral fusion; 74 (36 %), decompression procedure; and 65 (32 %), the TLIF/PLIF procedure. Of the patients, 92 (45 %) received at least one Smith-Petersen osteotomy, pedicle subtraction osteotomy, or vertebral column resection. The PreLP group received statistically significant shorter fusion, higher rate of lumbosacral fusion, decompression procedure, and TLIF/PLIF procedure (Table 3).

Surgical results and complications

After surgery, the ODI significantly decreased (improved HRQL) from 42.0 to 32.4. The postoperative median NRS score was 0 (IQR 0–4) for leg pain and 3 (IQR 1–5) for back pain. The percentage of the patients with leg pain and back pains (NRS score ≥5) decreased from 53 to 24 and from 82 to 30 %, respectively. In addition, all the radiographic parameters except PT significantly improved postoperatively (Table 4). Of the patients, 39 (19 %) experienced at least one major complication, such as deep infection and/or instrumentation failure, and 22 (11 %) received reoperation until 6 months after surgery.

Univariate and multivariate analyses of postoperative leg pain

The baseline characteristics of the patients with postoperative leg pain of NRS scores of ≥5 (PostLP) and ≤4 (PostNLP) are presented in Table 5. The PostLP patients had significantly higher BMI, lower rate of ASA grade 1, higher preoperative ODI, and more severe preoperative leg and back pains than the PostNLP patients. No significant difference in radiographic parameters was observed between the PostLP and PostNLP patients (Table 5). The PostLP

patients received a higher rate of decompression and open canal procedures. Postoperative SVA, T1ST, PI–LL, and GT were significantly larger in the PostLP patients (Table 6).

In the multivariate logistic regression models for PostLP that consisted of the covariates of age, PreLP, and decompression procedure, postop SVA, T1ST, PT, and GT were significantly associated with PostLP (Table 7). Contrast analysis with estimated models revealed that the significant risk factors of PostLP were postoperative SVA ≥40 mm (OR to SVA <40 mm, 3.48; 95 % CI 1.26–9.66; $p = 0.016$) in model 1, postoperative T1ST ≥0° (OR to T1ST <0°, 4.77; 95 % CI 1.59–14.4; $p = 0.005$), and postoperative PT ≥30° (OR to PT <30°, 3.19; 95 % CI 1.16–8.77; $p = 0.024$) in model 2. Owing to the significant association of BMI and ASA grade with PostLP in the univariate analysis, models with ASA grade and BMI in place of age as covariate were also tested. Other models with open canal procedure (at least one decompression or TLIF/PLIF) in place of decompression as covariate were tested as well. In these multivariate models, postoperative SVA (model 1), T1ST and PT (model 2), and GT (model 4) were still significant risk factors of postoperative leg pain.

Discussion

In this study, 53 % of the ASD patients had PreLP, of whom 66 % received decompression and/or TLIF/PLIF procedures. A higher rate of receiving decompression and/or TLIF/PLIF procedures indicates that surgeons diagnosed PreLP as radicular pain. The patients with PreLP had significantly worse sagittal parameters and less coronal Cobb angle than PreNLP. However, this association disappeared after adjustment for age, sex, BMI, ASA grade, and history of spine surgery. Only age, BMI, and past spine surgery were significantly associated with PreLP in the ASD patients. These results suggest that PreLP is related to degenerative or iatrogenic radiculopathy.

The PreLP of the ASD patients was successfully treated surgically and resulted in satisfactory relief in most cases. However, 24 % of the patients still had unexpected residual leg pain. At the time of surgical treatment, the patients received appropriate decompression and fusion procedures for preoperative radicular pain caused by disk degeneration or spinal canal stenosis, and their symptoms could be affected more by sagittal malalignment than by neurological symptoms. To support this hypothesis, we constructed multiple logistic regression models consisting of radiographic spinal sagittal parameters and covariates. To adjust for PreLP that is persistent or on the way of recovery, the PreLP and decompression procedure (or open canal procedure) were entered in the regression models. The models

Table 2 Multiple logistic regression analyses for preoperative leg pain

Variables	Preop leg pain (NRS $\geq$5, logistic regression)											
	Model 1 Pseudo R^2 = 0.18, N = 188			Model 2 Pseudo R^2 = 0.19, N = 189			Model 3 Pseudo R^2 = 0.17, N = 193			Model 4 Pseudo R^2 = 0.17, N = 193		
	Odds ratio	Std. err.	P	Odds ratio	Std. err.	P	Odds ratio	Std. err.	P	Odds ratio	Std. err.	P
Preop SVA			**0.617**									
SVA <40 (base)	1.00											
40 $\leq$ SVA $\leq$ 95	0.78	0.40	0.623									
SVA >95	1.35	0.76	0.597									
Preop T1ST						**0.206**						
T1ST <0 (base)				1.00								
0 $\leq$ T1ST < 5				0.74	0.33	0.506						
T1ST $\geq$5				2.86	2.06	0.143						
Preop PT			**0.310**			**0.175**						
PT <20 (base)	1.00			1.00								
20 $\leq$ PT $\leq$ 30	0.48	0.23	0.126	0.42	0.20	0.062						
PT >30	0.57	0.34	0.344	0.58	0.31	0.310						
Preop PI–LL									**0.953**			
PI–LL <10 (base)							1.00					
10 $\leq$ PI–LL $\leq$ 20							0.87	0.41	0.763			
PI–LL >20							0.97	0.41	0.934			
Preop GT												**0.186**
Per 20°										0.72	0.18	0.186
Age			**0.033**			**0.038**			**0.089**			**0.028**
Age $\leq$40 (base)	1.00			1.00			1.00			1.00		
40 < age $\leq$ 60	2.33	1.21	0.102	2.97	1.52	0.033	2.18	1.02	0.097	2.40	1.13	0.062
Age >60	4.29	2.39	0.009	4.15	2.39	0.014	2.87	1.41	0.032	4.24	2.31	0.008
Gender			**0.270**			**0.122**			**0.244**			**0.321**
Female (base)	1.00			1.00			1.00			1.00		
Male	0.60	0.28	0.270	0.46	0.23	0.122	0.62	0.25	0.244	0.67	0.27	0.321
BMI			**0.004**			**0.006**			**0.006**			**0.012**
BMI <25 (base)	1.00			1.00			1.00			1.00		
25 $\leq$ BMI < 30	3.67	1.49	0.001	3.74	1.56	0.002	3.42	1.35	0.002	3.16	1.26	0.004
BMI $\geq$30	2.21	1.01	0.083	2.21	1.03	0.089	2.15	0.96	0.088	2.05	0.92	0.111
ASA			0.768			0.817			0.758			0.711
Grade I (base)	1.00			1.00			1.00			1.00		
Grade II	1.23	0.49	0.612	1.11	0.43	0.788	1.27	0.50	0.535	1.29	0.51	0.523
Grade III	1.59	1.13	0.516	1.57	1.12	0.527	1.52	1.07	0.553	1.64	1.17	0.487
Past surgery			**0.008**			**0.004**			**0.012**			**0.006**
No (base)	1.00			1.00			1.00			1.00		
Yes	2.91	1.17	0.008	3.28	1.34	0.004	2.78	1.13	0.012	3.17	1.33	0.006

Bold values correspond to the *p*-value determined by the *F*-test for each variable

NRS numerical rating scale, *Std. err.* Robust standard error, *SVA* sagittal vertical axis, *T1ST* T1 sagittal tilt, *PT* pelvic tilt, *PI–LL* pelvic incidence minus lumbar lordosis, *GT* global tilt, *BMI* body mass index, *ASA* American Society of Anesthesiologists

demonstrated that postoperative spinal sagittal malalignment (SVA $\geq$40 mm or T1ST $\geq$0°, PT $\geq$30°, and higher GT) was a significant risk factor of PostLP. To the best of our knowledge, this is the first study to demonstrate the significant association between PostLP and spinopelvic sagittal alignment.

Table 3 Surgical treatments for preoperative leg pain

	Preop less leg pain group (NRS ≤4)		Preop leg pain group (NRS ≥5)		P*
Fusion length (median, IQR)	10.5	8–13	9	6–12	0.015
Lumbosacral fusion (N, %group)	40	42 %	72	69 %	0.000
Decompression (N, %group)	22	23 %	52	50 %	0.000
TLIF/PLIF (N, %group)	20	21 %	43	41 %	0.003
Osteotomy[a] (N, %group)	40	42 %	52	50 %	0.293
Open canal[b]	32	34 %	69	66 %	0.000

NRS numerical rating scale, *IQR* interquartile range, *TLIF* transforaminal lumbar interbody fusion, *PLIF* posterior lumbar interbody fusion

* *P* value: calculated using Pearson's Chi-square test or Mann–Whitney's *U* test

[a] Osteotomy: at least one Smith-Petersen osteotomy, pedicle subtraction osteotomy, or vertebral column resection

[b] Open canal: at least one decompression or TLIF/PLIF procedure

Table 4 Preoperative and postoperative ODI, pain scores, and radiographical parameters

	Preop		Postop		P*
ODI (mean, SD)	42.0	20.5	32.4	19.2	0.000
Leg pain NRS ≥5 (N, %total)	105	53 %	48	24 %	0.000
Back pain NRS ≥5 (N, %total)	165	82 %	61	30 %	0.000
Coronal major Cobb angle (mean, SD)	40.6	20.8	21.2	14.7	0.000
SVA (mean, SD)	40.2	66.6	19.1	50.5	0.001
T1ST (mean, SD)	−2.0	6.1	−4.1	4.9	0.001
PT (mean, SD)	23.3	11.4	21.8	11.1	0.212
PI–LL (mean, SD)	13.2	22.4	5.2	14.4	0.000
GT (mean, SD)	27.4	17.6	22.7	14.5	0.005

ODI Oswestry Disability Index, *NRS* numerical rating scale, *SD* standard deviation, *SVA* sagittal vertical axis, *T1ST* T1 sagittal tilt, *PT* pelvic tilt, *PI–LL* pelvic incidence minus lumbar lordosis, *GT* global tilt

* *P* value: calculated using Pearson's Chi-square test or Student's *t* test

Recently, it is a critical key point to analyze sagittal balance in patients undergoing treatment of ASD. ASD patients compensate their spinal malalignment by using spinal and/or lower extremity compensatory mechanisms [20, 21]. Compensatory mechanisms in the spinal area include cervical hyperlordosis, reduction of thoracic kyphosis, hyperextension of adjacent segments, and those below the pelvis include hip extension, knee flexion, and ankle plantar flexion [20, 21]. In patients with decreased lumbar lordosis, the center of gravity (COG) shifts anteriorly. Anteriorly shifted COG is corrected posteriorly by compensatory mechanisms and is kept on the feet. These compensations are suggested to occur, first, from the spine, and then from the hip followed by the knee [20]. After ASD surgery, which can be performed using a long construct with lumbosacral fusion, patients lose flexibility in the fused spinal segment and spinal compensatory mechanisms. These patients have limited surplus capacity to maintain a balanced standing posture, because they have to depend on the remaining compensatory mechanisms below the pelvis. This may lead to a predisposition of these patients to leg symptoms related to spinal sagittal malalignment. Duval-Beaupère et al. suggested that compensation for sagittal malalignment require patients to exert uneconomical efforts in terms of gravity load and muscle strength forces [22–24]. Increased gravity load and muscle strength forces on the hip and knee joints can be possible aetiologies of leg pain (muscle and/or joint pain) in patients with sagittal malalignment [22–24].

Another possible etiology of PostLP in patients with sagittal malalignment is sacroiliac joint pain. Lazennec et al. reported the significant association between high PT and residual pain unrelated to nerve root compression or nonunion in a group of patients who underwent a lumbosacral fusion [25]. The hypothesis for the origin of this residual pain was undue stress on the sacroiliac and hip joints during compensation by hip hyperextension. We suppose that these patients would express this residual pain as "leg pain," because as Lazennec et al. reported, it is located in the lumbosacral area, and is usually radiated to the groin area or buttock and to the posterolateral aspect of the thigh [25].

Table 5 Baseline characteristic of the postoperative leg pain and less leg pain groups

	Postop less leg pain group (NRS ≤4)		Postop leg pain group (NRS ≥5)		P*
(N, %total)	155	76 %	48	24 %	–
Age (mean, SD)	52.1	19.4	55.9	18.8	0.238
Female (N, %group)	125	81 %	39	81 %	0.926
BMI (mean, SD)	**25.0**	**4.7**	**26.7**	**4.5**	**0.016**
ASA Grade 1 (N, %group)	**63**	**41 %**	**16**	**33 %**	**0.037**
Past surgery (N, %group)	43	28 %	19	40 %	0.120
Preop ODI (mean, SD)	**38.9**	**20.0**	**51.6**	**19.1**	**0.000**
Preop Leg pain NRS (median, IQR)	**4**	**0–7**	**5**	**3–8**	**0.004**
Preop Back pain NRS (median, IQR)	**6**	**5–8**	**8**	**6–9**	**0.002**
Coronal Schwab Classification					
(N/T/L/D)[a] (N, %group)	62/8/47/38		27/4/10/7		0.131
Preop coronal major Cobb (mean, SD)	42.0	20.9	36.2	19.8	0.103
Preop SVA (mean, SD)	36.1	65.3	54.1	69.6	0.110
Preop T1ST (mean, SD)	−2.5	5.8	−0.6	6.9	0.071
Preop PT (mean, SD)	22.6	10.9	25.1	12.8	0.190
Preop PI–LL (mean, SD)	11.7	22.1	17.6	23.0	0.109
Preop GT (mean, SD)	26.1	17.2	31.2	18.5	0.085

Bold values correspond to significant differences between groups

NRS numerical rating scale, SD standard deviation, BMI body mass index, ASA American Society of Anesthesiologists, ODI Oswestry Disability Index, IQR interquartile range, SVA sagittal vertical axis, T1ST T1 sagittal tilt, PT pelvic tilt, PI–LL pelvic incidence minus lumbar lordosis, GT global tilt

* P value: calculated using Pearson's Chi-square test, Student's t test, or Mann–Whitney's U test

[a] N no major coronal deformity, T thoracic major curve, L lumbar or thoracolumbar major curve, D double major curve

Table 6 Type of surgical treatments, complications and postoperative radiographic parameters of the postoperative leg pain and less leg pain groups

	Postop less leg pain group (NRS ≤4)		Postop leg pain group (NRS ≥5)		P*
Fusion length (median, IQR)	9	7–13	9	7–13	0.990
Lumbosacral fusion (N, %group)	82	54 %	31	65 %	0.181
Decompression (N, %group)	**49**	**32 %**	**24**	**50 %**	**0.020**
TLIF/PLIF (N, %group)	45	29 %	19	40 %	0.178
Osteotomy[a] (N, %group)	66	43 %	26	54 %	0.159
Open canal[b]	**70**	**45 %**	**32**	**67 %**	**0.009**
Major complications					
(No/without reop/reop)[c]	130/12/13		34/5/9		0.095
(N, %group)	84 %/8 %/8 %		71 %/10 %/19 %		
Postop coronal major Cobb (mean, SD)	22.1	15.0	18.0	13.2	0.112
Postop SVA (mean, SD)	**12.1**	**45.0**	**44.7**	**61.1**	**0.000**
Postop T1ST (mean, SD)	**−4.7**	**4.1**	**−2.0**	**6.6**	**0.002**
Postop PT (mean, SD)	21.0	11.0	24.7	11.2	0.061
Postop PI–LL (mean, SD)	**3.6**	**13.9**	**10.1**	**14.5**	**0.011**
Postop GT (mean, SD)	**20.9**	**14.0**	**28.8**	**14.9**	**0.003**

Bold values correspond to significant differences between groups

NRS numerical rating scale, IQR interquartile range, TLIF transforaminal lumbar interbody fusion, PLIF posterior lumbar interbody fusion, SVA sagittal vertical axis, T1ST T1 sagittal tilt, PT pelvic tilt, PI–LL pelvic incidence minus lumbar lordosis, GT global tilt

* P value: calculated using Pearson's Chi-square test, Student's t test, or Mann–Whitney's U test

[a] Osteotomy: at least one Smith-Petersen osteotomy, pedicle subtraction osteotomy, or vertebral column resection

[b] Open canal: at least one decompression or TLIF/PLIF procedure

[c] No: no major complication, without reop: major complication requiring no reoperation; reop: major complication requiring reoperation. Major complications include spinal cord injury, nerve root injury, deep infection, paralysis, pulmonary embolism, sepsis, cardiac infarction, renal failure, and instrumentation or junction failure

Table 7 Multiple logistic regression analyses for postoperative leg pain

Variables	Postop leg pain (NRS ≥5, logistic regression)											
	Model 1 Pseudo R^2 = 0.18, N = 188			Model 2 Pseudo R^2 = 0.19, N = 189			Model 3 Pseudo R^2 = 0.17, N = 193			Model 4 Pseudo R^2 = 0.17, N = 193		
	Odds ratio	Std. err.	P	Odds ratio	Std. err.	P	Odds ratio	Std. err.	P	Odds ratio	Std. err.	P
Postop SVA			**0.048**									
SVA <40 (base)	1.00											
40 ≤ SVA ≤ 95	2.23	1.17	0.127									
SVA >95	5.46	3.86	0.016									
Postop T1ST						**0.004**						
T1ST <0 (base)				1.00								
0 ≤ T1ST < 5				1.41	0.80	0.545						
T1ST ≥5				16.2	13.6	0.001						
Postop PT			**0.313**			**0.034**						
PT <20 (base)	1.00			1.00								
20 ≤ PT ≤ 30	0.56	0.31	0.294	0.55	0.34	0.327						
PT >30	1.17	0.70	0.794	2.37	1.50	0.173						
Postop PI–LL									**0.304**			
PI–LL <10 (base)							1.00					
10 ≤ PI–LL ≤ 20							1.96	0.89	0.137			
PI–LL >20							1.56	0.82	0.395			
Postop GT												**0.029**
Per 20°										2.14	0.75	0.029
Age			**0.574**			**0.499**			**0.540**			**0.298**
Age ≤40 (base)	1.00			1.00			1.00			1.00		
40 < age ≤ 60	0.71	0.43	0.575	0.55	0.36	0.357	0.63	0.35	0.410	0.49	0.29	0.229
Age >60	0.50	0.33	0.300	0.44	0.31	0.244	0.56	0.30	0.273	0.39	0.24	0.123
Preop leg pain			**0.353**			**0.285**			**0.043**			**0.129**
NRS <5 (base)	1.00			1.00			1.00			1.00		
NRS ≥5	1.54	0.72	0.353	1.67	0.81	0.285	2.40	1.04	0.043	1.93	0.83	0.129
Decompression			**0.397**			**0.265**			**0.209**			**0.153**
No (base)	1.00			1.00			1.00			1.00		
Yes	1.48	0.69	0.397	1.70	0.81	0.265	1.70	0.72	0.209	1.86	0.80	0.153

Bold values correspond to the *p*-value determined by the *F*-test for each variable

NRS numerical rating scale, *Std. err.* Robust standard error, *SVA* sagittal vertical axis, *T1ST* T1 sagittal tilt, *PT* pelvic tilt, *PI–LL* pelvic incidence minus lumbar lordosis, *GT* global tilt

Other possible etiologies of PostLP are complications related to distal junction problems, such as pseudoarthritis or degeneration at the sacroiliac area with/without implant failure [26–29]. As these complications are reported to be associated with sagittal malalignment but will only be evident after 1 year [29], future studies with longer follow-up data are necessary to make deeper insight into this possibility.

Limitations of this study

Limitations of this study include the relatively short follow-up periods after surgery, leaving us unable to assess the long-term impact of the radiographic sagittal parameters on leg symptoms. Moreover, considering the high complication rate (around 40 %) after a 2-year follow-up [30], the period of 6 months is too short to assess clinical

results of ASD surgery. However, in this study, we aimed to investigate the effect of sagittal malalignment after corrective surgery for ASD on leg pain. After a long-term follow-up, detecting a significant association between the variables could be more difficult (i.e., more type 2 errors), as both radiographic parameters and HRQL could be affected by time and other confounders, such as adjacent segment degeneration, proximal junctional kyphosis, and implant failures [30]. To avoid these type 2 errors, a short follow-up evaluation could be justified. Another concern related to short follow-up period is influence of recovery period after surgical treatment, because the first significant improvement and fluctuation of patients' symptoms after surgical treatment of ASD patients are reported to occur between 6 weeks and 1 year [2, 11, 19]. Nevertheless, this bias might be adjusted in this study by adding preoperative leg pain as a covariate in the multivariate regression models. As we expect continuous progress in terms of sample size and longer follow-up among subjects in the current database, these limitations will be corrected in future studies.

The second limitation of this study is the lack of systematic clinical or radiographical studies that explain the aetiology of leg pain. To investigate the aetiologies of postoperative leg pain in ASD, patients by detailed qualitative clinical evaluation will be an issue to be addressed in the future.

The third limitation of this study is that only spinal and spinopelvic parameters were evaluated in this study. Parameters of the lower limb, such as knee flexion or angle of femur obliquity [31], would be interesting factors to consider in the evaluation of the compensatory mechanism below the pelvis. Future studies that investigate the association between lower limb compensation and leg pain using such parameters are expected.

Conclusions

Leg pain in patients with ASD was significantly associated with sagittal malalignment especially after surgical treatments. As these patients lose flexibility in the fused spinal segment, they can only depend on the remaining compensatory mechanisms below the pelvis (e.g., the hips and knees) to maintain a balanced posture. This may lead to a predisposition of these patients to postoperative leg symptoms related to spinal sagittal malalignment.

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