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The Incidence of Adding-On or Distal Junctional Kyphosis in Adolescent Idiopathic Scoliosis Treated by Anterior Spinal Fusion to L3 Was Significantly Higher Than by Posterior Spinal Fusion to L3

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Objective: To compare and identify risk factors for distal adding-on (AO) or distal junctional kyphosis (DJK) in adolescent idiopathic scoliosis (AIS) treated by anterior- (ASF) and posterior spinal fusion (PSF) to L3.
Methods: AIS patients undergoing ASF versus PSF to L3 from 2000–2010 were analyzed. Distal AO and DJK were deemed poor radiographic results. New stable (SV) and neutral vertebra (NV) scores were defined for this study. The total stability (TS) score was the sum of the SV and NV scores.
Results: Twenty of 42 (ASF group: 47.6%) and 8 of 72 patients (PSF group: 11.1%) showed poor radiographic outcome. Fused vertebrae, correction rate of main curve, coronal reduction rate of L3 were significantly higher in PSF group. Multiple logistic regression results indicated that preoperative SV-3 at L3 in standing and side benders (odds ratio [OR], 2.7 and 3.7, respectively), TS score -5, -6 at L3 (OR, 4.9), rigid disc at L3–4 (OR, 3.7), lowest instrumented vertebra (LIV) rotation > 15° (OR, 3.3), LIV deviation > 2 cm from center sacral vertical line (OR, 3.1) and ASF (OR, 13.4; $p < 0.001$) were independent predictive factors. There was significant improvement of the Scoliosis Research Society (SRS)-22 average scores only in PSF group. Furthermore, the ultimate scores of PSF group were significantly superior to ASF group.
Conclusion: The prevalence of AO or DJK at ultimate follow-up for AIS with LIV at L3 was significantly higher in ASF group. Ultimate SRS-22 scores were significantly better in PSF group.

Keywords: Adolescent idiopathic scoliosis, Anterior spinal fusion, Posterior spinal fusion, Lowest instrumented vertebra, Adding-on, Distal junctional kyphosis

INTRODUCTION

Selection of fusion levels is the most important single factor that influences the surgical result following adolescent idiopathic scoliosis (AIS) surgery.[1] Inappropriately choosing the extent of fusion may result in under- or overcorrection of the major and compensatory curves. The under- or overcorrection may result in failure to stabilize the index curve and can aggravate the unfused curve and cause trunk imbalance and decompensation. Although surgical correction appears to be relatively straightforward in AIS patients, inadequate selection of fusion levels may cause adding-on (AO) phenomenon and distal junctional kyphosis (DJK).[1-4] Lowest instrumented vertebra (LIV) with rotation more than Nash-Moe grade II and significant disc angulation below LIV postoperatively and is known as the "adding-on phenomenon."[2] Furthermore, for distal fusion level selection in major lumbar and thoracolumbar curves, the selection between L3 or L4 is a debatable issue. DJK is a junctional angle > 10° measuring or at least 10° more than the preoperative value. These poor radiographic results including AO and DJK should be avoided even though we do not have a long-term follow-up study. However, few studies have focused on the distal junctional problem, when LIV stopped at L3 for AIS corrective surgery. Furthermore, there has been no comparative study focusing on the issue between anterior- (ASF) and posterior spinal fusion (PSF) stopping at L3. The purpose of this study was to compare the prevalence and identify risk factors for distal AO or DJK in AIS patients treated by ASF and PSF to L3.

MATERIALS AND METHODS

1. Patient Population

Inclusion criteria were as follows: (1) any AIS patients treated with ASF or PSF, (2) the LIV at L3, and (3) with a minimum 2-year follow-up. Patients with neuromuscular disease or congenital spinal deformity and those who underwent revision surgery were excluded. A hundred and fourteen consecutive AIS patients between 2000 and 2010 who met the inclusion criteria were identified from a single institution database. The 114 patients consisted of 104 girls and 10 boys. The mean age at surgery was 14.7 years (range, 10.0–19.6 years). The average follow-up duration was 3.2 years (range, 2.0–10.2 years). All enrolled patients were surgically treated by 2 senior attending surgeons (LGL and KHB).

2. Surgical Details for ASF or PSF

The indication of which patient should be operated from anterior or who from posterior is complex. This study includes patients having LIV at L3. ASF was chosen only for patients who have Lenke 5 or 6 curve, meanwhile PSF for all kinds of Lenke types. Determination for surgical approach was also based on surgeon's preference. ASF was chosen for patients who want to preserve their lumbar motion segment maximally for their major such as dancer, athlete, etc. Patients who had prior chest- or abdominal surgery underwent PSF. As pedicle screw system has developed, the frequency for PSF selection has increased.

For PSF, patients were flipped to a prone position on the Jackson table. Intraoperative neurophysiologic monitoring was set up. Every level facetectomy was done. Pedicle screws or sublaminar/pedicle hooks were inserted for segmental instrumentation. After screw placement, various deformity correction maneuvers including posterior column osteotomies, translation technique, rod derotation, and direct vertebral rotation were utilized. Then, balance of the shoulders and junctional discs was evaluated by intraoperative portable whole spine radiographs. Sequentially PSF was performed by abundant bone grafting using local bone with or without allograft bone chips.

For ASF, patients were flipped to lateral decubitus position on the operative table. Intraoperative neurophysiologic monitoring was set up. Every level discectomy was done. Mostly, Harm's cage with bone graft material was inserted into interbody space for bone fusion and restoring lumbar lordosis. Bicortical vertebral body screws were inserted for segmental instrumentation. After screw placement, compression or distraction maneuver was utilized. Then, coronal/sagittal alignment and junctional discs were evaluated by intraoperative portable whole spine radiographs.

3. Demographic and Surgical Data Collection

After obtaining approval from the Institutional Review Board of Washington University School of Medicine, extensive review of the patients' medical record was performed to identify demographic, surgical and complication data, including age at surgery, sex, height, weight, curve type by Lenke classification,[5] number of fused vertebrae, correction rate of the main curve, length of follow-up. For clinical outcome evaluation, Scoliosis Research Society (SRS)-22 questionnaires score was investigated.

4. Radiographic Measurements

Measurements were made on upright posterioranterior, side bending, and lateral radiographs of the entire spine. Distal AO was defined as a progressive increase in the number of vertebrae included distally within the primary curve combined with either an increase of more than 3 cm in deviation of the center of the LIV from the center sacral vertical line (CSVL) or an increase of more than 10° in the coronal angulation of the first disc below the instrumentation at ultimate follow-up. DJK was defined if sagittal disc angle below the LIV is more than 10°. In this study, poor radiographic outcomes were defined as the distance from CSVL to the center of L3 ≥ 3 cm, or a discal angle at L3–4 > 10° in the coronal or sagittal plane at ultimate follow-up.

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Investigated radiographic parameters included: Risser grade, correction rate, preoperative coronal rotation angle using Perdriolle method[6] and deviation distance of L3, coronal and sagittal disc angle at L3–4 (Fig. 1), gravity stability score in standing and side bender (new stable vertebra [SV] was defined for this study: SV-1, CSVL is passing between medial borders of pedicles of the LIV; SV-2, CSVL touching body of LIV; SV-3, CSVL does not touch LIV body), rotational stability score (neutral vertebra [NV]: vertebra without rotation; NV-1: 1 vertebra proximal to NV; NV-2: 2 vertebra proximal to NV; NV-3: 3 vertebra proximal to NV), and total stability score (summation of gravity and rotational stability score) (Table 1, Fig. 2).

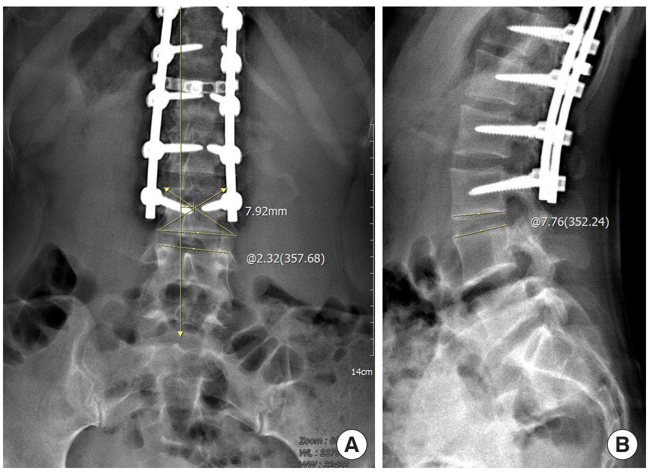


Fig. 1. An example of radiographic measurement for deviation of the center of the L3 from the center sacral vertical line, distal junctional discal angulation at L3–4 in the coronal or sagittal plane.

Table 1. Definition of gravity, rotational, and total stability score

Gravity stability score		Rotational stability score		Total stability score	
SV	LIV at SV	NV	LIV at NV	TS-0 to -6	Summation of SV and NV score
SV-1	CSVL passes between medial pedicle borders of the LIV	NV-1	LIV is 1 vertebra proximal to NV		
SV-2	CSVL touches the LIV	NV-2	LIV is 2 vertebra proximal to NV		
SV-3	CSVL does not touch the LIV	NV-3	LIV is 3 vertebra proximal to NV		

SV, stable vertebra; SV-1, CSVL is passing between medial borders of pedicles of the LIV; SV-2, CSVL touching body of LIV; SV-3, CSVL does not touch LIV body; LIV, lower instrumented vertebra; NV, neutral vertebra; CSVL, center sacral vertical line; TS, total stability.

5. Assessment of Disc Flexibility at L3–4

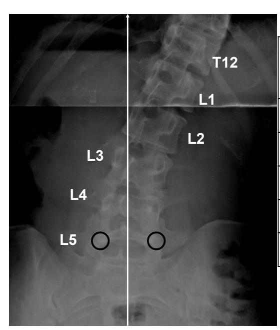
L3–4 disc angle was measured between straight lines along the inferior endplate of the upper and the superior endplate of the lower vertebra in a segment. This was done on the upright and side bending radiographs. The following equation was used for the disc flexibility at L3–4:

Disc flexibility index (%) = (upright disc angle-bending disc angle) × 100/upright disc angle

When the disc flexibility index was more than 25%, the L3–4 disc was defined as flexible. Similarly, rigid disc at L3–4 was defined if the disc flexibility index was less than 25%.

6. Statistical Analysis

Distributions of variables were given as a mean and standard deviation (±). For most variables for which data were collected preoperatively and postoperatively, paired t-tests were used to determine whether there was a significant change between timepoints. Student t-test was used to assess the difference of continuous measures between the groups. Fisher exact test was used



	Gravity Stability	Rotational Stability	Total Stability
L1	SV-3	NV-3	TS-6
L2	SV-2	NV-3	TS-5
L3	SV-1	NV-2	TS-3
L4	SV	NV-1	TS-1
L5	SV	NV	TS-0

Fig. 2. An example of radiographic evaluation for gravity, rotational and total stability scoring system. Gravity stability score (new stable vertebra [SV] was defined for this study: SV-1, CSVL is passing between medial borders of pedicles of the LIV; SV-2, CSVL touching body of LIV; SV-3, CSVL does not touch LIV body), rotational stability score (neutral vertebra [NV]: vertebra without rotation; NV-1, 1 vertebra proximal to NV; NV-2, 2 vertebra proximal to NV; NV-3, 3 vertebra proximal to NV), and total stability score (summation of gravity and rotational stability score). CSVL, center sacral vertical line; LIV, lower instrumented vertebra; TS, total stability.

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Table 2. Demographic and radiographic factors between ASF and PSF groups

Variable	ASF group (n = 42)	PSF group (n = 72)	p-value
Demographic data			
Sex, male:female	5:37	5:67	0.421
Age at surgery (yr)	15.0 ± 1.9	14.8 ± 2.0	0.540
F/U duration (yr)	4.9 ± 3.1	3.2 ± 2.0	0.003*
Risser grade	3.2 ± 2.0	3.6 ± 1.5	0.182
Preoperative radiographic factors			
Rigid disc at L3/4	5	2	0.082
Coronal disc angle at L3/4	4.9 ± 2.2	5.3 ± 2.5	0.431
Sagittal disc angle at L3/4	-8.8 ± 2.7	-8.3 ± 2.3	0.393
Postoperative radiographic factors			
No. of fused vertebrae	4.6 ± 0.8	11.4 ± 2.6	< 0.001*
Correction rate of major curve (%)	48.6 ± 18.5	67.6 ± 16.6	0.013*
Coronal reduction rate of L3 (%)	19.8 ± 3.8	33.0 ± 5.1	0.003*
Distal PX (%)	20 (47.6)	8 (11.1)	< 0.001*

Values are presented as mean ± standard deviation or number (%).
ASF, anterior spinal fusion; PSF, posterior spinal fusion; F/U, follow-up; PX, poor radiographic outcome.
*$p < 0.05$, statistically significant difference.

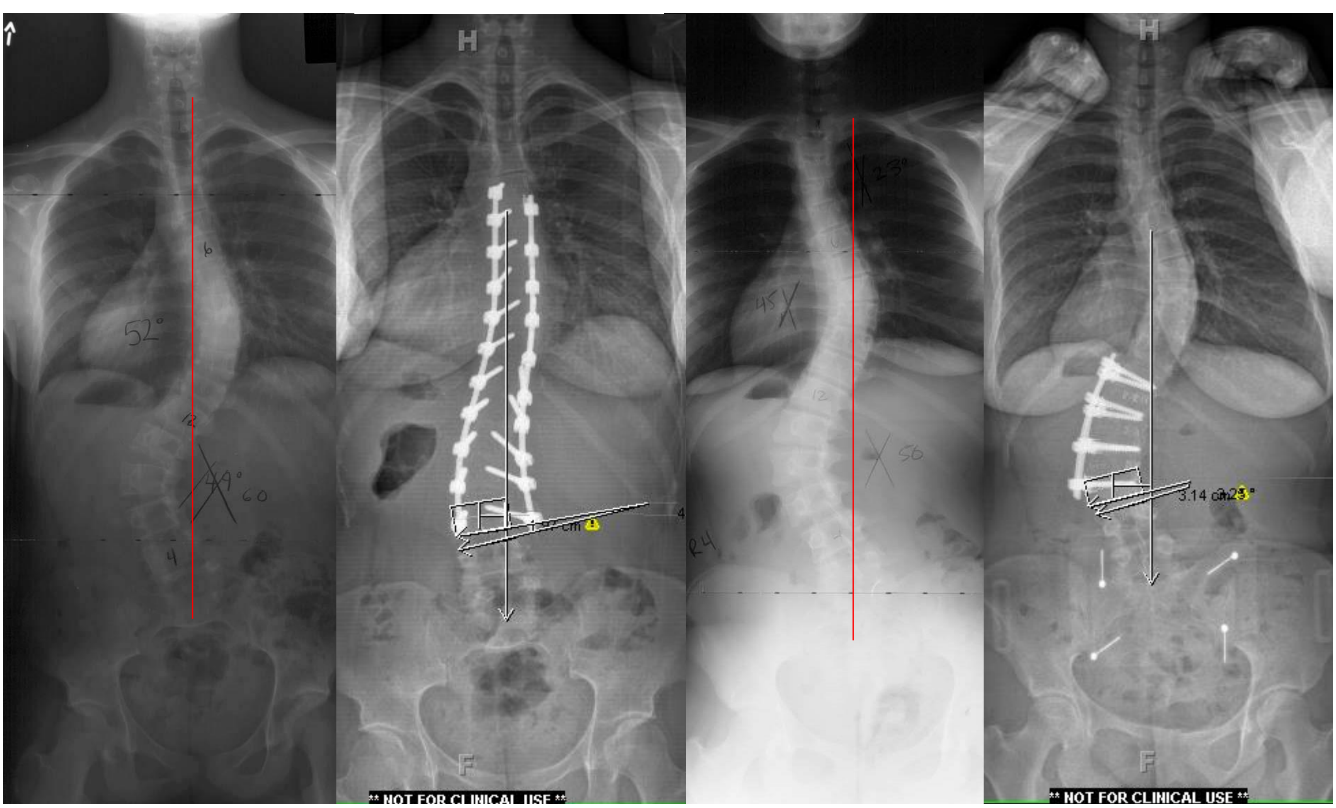

Fig. 3. An example of radiographic outcomes of patients having similar Lenke 6CN curve and same Risser grade following posterior spinal fusion and anterior spinal fusion to L3. Two-year postoperative plain films with good- (left) and poor radiographic outcome (right) showing 3.14-cm deviation of the center of the L3 from the center sacral vertical line in the coronal plane.

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Table 3. Identified risk factors associated with poor radiographic outcomes by multiple logistic regression analysis

Risk factors for PX	Odds ratio	95% Confidence interval	p-value
SV-3 at L3 in upright	2.7	1.9–3.2	0.012
SV-3 at L3 in side benders	3.7	2.9–4.4	< 0.001
Total stability score -5, -6	4.9	3.9–6.6	< 0.001
Rigid disc at L3/4	3.7	3.1–4.4	< 0.001
L3 rotation > 15°	3.3	2.5–3.9	0.001
L3 deviation > 2 cm from CSVL	3.1	2.4–3.7	0.007
Anterior spinal fusion	13.4	1.4–2.3	< 0.001

PX, poor radiographic outcome. CSVL, center sacral vertical line; SV-3, CSVL does not touch the index vertebra.

for dichotomous data analysis depending on the number of subjects involved. Multiple logistic regression test was used to identify the risk factors and odds ratio for poor radiographic outcomes including AO or DJK. A p-value of < 0.05 was considered statistically significant.

RESULTS

Twenty of 42 (ASF group: 47.6%) and 8 of 72 (PSF group: 11.1%) patients showed poor radiographic outcome. The other 22 and 64 patients of ASF and PSF group experienced good radiographic outcome. Patient demographic data and radiographic features of both groups are summarized in Table 2. Sex, age at surgery and Risser grade did not show differences between the groups. However, follow-up duration was significantly higher in ASF groups (4.9 years vs. 3.2 years) ($p < 0.001$). Fused vertebrae (4.6 vs. 11.4, $p < 0.001$), correction rate of main curve (48.6% vs. 67.6%, $p = 0.013$), coronal reduction rate of L3 (19.8% vs. 33.0%, $p = 0.003$) were significantly higher in PSF group (Fig. 3).

1. Radiographic Factors Causing Poor Outcomes

More SV-3 on standing ($p = 0.019$) and side bending films ($p < 0.001$), more proximal to NV ($p = 0.004$), lesser total stability score ($p = 0.002$), rigid L3–4 disc ($p < 0.001$), more rotation ($p < 0.001$) and deviation ($p < 0.001$) of L3 and ASF ($p < 0.001$) were identified risk factors for AO or DJK (Table 3).

Multiple logistic regression results indicated that preoperative SV-3 at L3 in standing and side benders (odds ratio [OR], 2.7 and 3.7, $p = 0.012$ and $p < 0.001$, respectively), total stability score -5, -6 at L3 (OR, 4.9; $p < 0.001$), rigid disc at L3–4 (OR, 3.7; $p < 0.001$), LIV rotation > 15° (OR, 3.3; $p = 0.001$), LIV deviation > 2 cm from CSVL (OR, 3.1; $p = 0.007$) and ASF (OR, 13.4; $p < 0.001$) were independent predictive factors associated with radiographic poor radiographic outcomes.

Table 4. Summary of clinical outcomes

Variable	ASF group (n = 42)	PSF group (n = 72)	p-value
SRS-22 average scores			
Preoperative	3.98 ± 0.58	4.09 ± 1.29	0.572
Ultimate follow-up	4.22 ± 0.60	4.49 ± 0.36	0.013*
p-value	0.084	0.019*	

Values are presented as mean ± standard deviation.
ASF, anterior spinal fusion; PSF, posterior spinal fusion; SRS-22, scoliosis research society-22 questionnaire.
*$p < 0.05$, statistically significant difference.

2. Clinical Outcomes

Any patients did not undergo revision surgery in PSF group. However, one patient having distal AO experienced fusion extension to L4 in ASF group (1 of 42, 2.3%). There was a significant improvement of the average scores of SRS-22 questionnaires only in PSF group ($p = 0.019$) versus ASF group ($p = 0.084$). Furthermore, the ultimate SRS-22 questionnaires scores of PSF group were significantly superior to ASF groups ($p = 0.013$) (Table 4).

DISCUSSION

ASF has been widely chosen because of its advantages such as releasing intervertebral discs directly, reducing fusion levels, avoiding approach-related damage to paraspinal muscle. However, as pedicle screw system has developed, frequency for PSF selection has increased. Furthermore, direct vertebral derotation maneuver during PSF can correct the rotational deformity effectively. In this study, a longer follow-up period in the ASF group than PSF group reflects the trend to select ASF or PSF.

Optimal LIV to avoid AO or DJK is extremely idiosyncratic. Various concepts and rules were introduced by previous researchers such as Harrington stable zone, SV and NV theory, disc reversal, and LTV.[3,5,7,8] However, poor interrater reliability for LIV selection was reported even among 17 SRS surgeons. In their study, 50% agreement was observed and Kappa value was 0.38 (poor reliability).[9] Moreover, there has been no comparative study focusing on the issue between ASF and PSF stopping at L3. Therefore, this study was aimed to compare the prevalence and identify risk factors for distal AO or DJK in AIS patients treated by ASF and PSF to L3.

In this series, the prevalence of AO or DJK at ultimate follow-up with LIV at L3 was 47.6% and 11.1% in ASF and PSF group, respectively. The prevalence of AO or DJK in PSF group is similar to a study focusing the prevalence (13.6%) of AO or DJK following PSSIF for AIS with LIV at L2 or above.[10] However, the prevalence (47.6%) of AO or DJK in ASF group is significantly higher compared to their result (13.6%). In their study, open tri-radiate cartilage, not touching of the LIV by the CSVL, and more rotation of the LIV was identified as risk factors for AO or DJK.[10]

In the present study, lower Risser grade, more SV-3 on standing and side bending films, lesser rotational and total stability score, rigid L3–4 disc, more rotation, and deviation of L3 were identified risk factors for AO or DJK. Furthermore, multiple logistic regression results indicated that preoperative SV-3 at L3 in standing and side benders (OR, 2.7 and 3.7, respectively), total stability score -5, -6 at L3 (OR, 4.9), rigid disc at L3-4 (OR, 3.7), LIV rotation > 15° (OR, 3.3), LIV deviation > 2 cm from CSVL (OR, 3.1) and ASF (OR, 13.4) were significant predictive factors for poor radiographic outcomes. For these analyses, we utilized a new gravity, rotational and total stability scoring system. In our new scoring system, the difference between SV-2 and SV-3 are whether CSVL does touch LIV or not. It means that SV-2 and SV-1 are LTV and substantial LTV, respectively. Total stability score is the sum of gravity and rotational stability score. By the multiple logistic regression analysis, total stability score -5 or less at L3 (OR, 4.9) is the second most significant factor associated with poor radiographic outcomes after stopping at L3. To the best of our knowledge, there are no published reports using gravity, rotational and total stability scoring system to determine optimal LIV level.

In the current study, ASF (OR, 13.4) is the most significant single factor for poor radiographic outcomes following fusion to L3. ASF can reduce fused vertebrae (4.6 vs. 11.4), however, was inferior to PSF group in terms of correction rate of main curve (48.6% vs. 67.6%), coronal reduction rate of L3 (19.8% vs. 33.0%). Furthermore, the ultimate SRS-22 questionnaires scores of ASF group were significantly inferior to ASF groups ($p = 0.013$).

In major thoracolumbar of lumbar structural curves, it had been considered that fusion should be extended down to L4 in the era of Harrington instrumentation.[1,7] However, stopping at L3 instead of L4 has been proposed in the era of segmental pedicle screw-based instrumentation. Lenke et al.[2] proposed the criteria for stopping of distal fusion at L3, as follows: (1) less than Nash-Moe grade I rotation of L3; (2) tilt of L3 < 30° and tilt of L4 < 20°; (3) L4 vertebra body was bisected by the CSVL; (4) apical disc should be located at T12–L1 or above; (5) the direction of opening at the L3–L4 level should be parallel to or opposite the L4–L5 disc level; and (6) the location of L3 should be centered by bending. Recently, selecting the last touching vertebra by CSVL as an optimal LIV can decrease the incidence of distal AO.[11-13] The previously reported factors or criteria are valuable to determine distal fusion levels in AIS.[1,2,10,13-17] However, absolute guidelines for the selection of LIV have not been defined. In the current study, we found several key risk factors for AO or DJK. Moreover, we introduce the odds ratio of each risk factor by multiple logistic regression analysis. We can share and discuss the information of predicting factors for poor radiographic outcomes with AIS kids and their guardians.

This study has several limitations. Since the study design was retrospective, criteria for ASF or PSF were not identifiable in all cases. Moreover, although PSF was chosen for all kinds of Lenke types, ASF was selected for Lenke type 5 or 6 curve in this study. Additionally, the follow-up period was significantly longer in the ASF group. The difference in follow-up period could have influenced the results. A further study between ASF and PSF for only Lenke type 5 or 6 curve might elucidate whether L3 is optimal as a LIV.

CONCLUSION

The prevalence of AO or DJK at ultimate follow-up for AIS with LIV at L3 was significantly higher in ASF group (47.6% vs. 11.1%). Ultimate SRS-22 scores were significantly better in PSF group.

CONFLICT OF INTEREST

Dr. Lenke shares numerous patents with Medtronic (unpaid). He is a consultant for DePuy Synthes Spine, K2M, Medtronic (monies donated to a charitable foundation). He receives substantial royalties from Medtronic and modest royalties from Quality Medical Publishing. Dr. Lenke also receives or has received reimbursement related to meetings/courses from AOSpine, BroadWater, DePuy Synthes Spine, K2M, Medtronic, Scoliosis Research Society, Seattle Science Foundation, Stryker Spine, The Spinal Research Foundation. Except for that, the other authors have nothing to disclose.

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