The Spine Journal 19 (2019) 1529−1539

THE SPINE JOURNAL

Clinical Study

Curve patterns deserve attention when determining the optimal distal fusion level in correction surgery for Scheuermann kyphosis

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Received 28 October 2018; revised 8 April 2019; accepted 8 April 2019

Abstract

BACKGROUND CONTEXT: The surgical strategy to decide distal fusion level for Scheuermann kyphosis (SK) is controversial. Some spinal surgeons advocate that instrumentation should end at the first lordotic vertebra (FLV), whereas others recommend extending spinal fusion to the sagittal stable vertebra (SSV). Scheuermann kyphosis has two curve patterns: Scheuermann thoracic kyphosis (STK), with the curve apex above or at T10; and Scheuermann thoracolumbar kyphosis (STLK), with the curve apex below T10. To our knowledge, curve patterns have not been taken into consideration when determining the distal fusion level.

PURPOSE: This study aims to analyze the clinical and radiographic outcomes, including the distal junctional problems, in pediatric patients with STK and STLK who underwent fusion with different distal fusion levels.

STUDY DESIGN: This is a retrospective, single-center, institutional review board-approved study.

PATIENT SAMPLE: A total of 45 consecutive pediatric patients with STK or STLK.

OUTCOME MEASURES: The following parameters were evaluated: global kyphosis (GK), deformity angular ratio (DAR), correction rate of GK and DAR, thoracolumbar kyphosis (TLK), lumbar lordosis (LL), sagittal vertical axis (SVA), T1 pelvic angle (TPA), the distance from the center of the lower instrumented vertebra (LIV) to the posterior sacral vertical line, pelvic incidence (PI), pelvic tilt (PT), sacral slope (SS), and distal junctional kyphosis (DJK).

METHODS: This work was supported by the National Natural Science Foundation of China (Grant No. 81171672), Nanjing Clinical Medical Center, and Jiangsu Provincial Key Medical Center. Patients with STK were fused to SSV at the distal level (Group STK), whereas patients with STLK were fused to FLV (Group STLK). Whole spine x-rays obtained before surgery, immediately after operation, and at the latest follow-up were evaluated. The radiographic and clinical data were compared between Groups STK and STLK. All patients had a minimum of 2 years of follow-up.

RESULTS: Before surgery, Groups STK and STLK were comparable in terms of age, gender, body mass index, fusion levels, follow-up time, some radiographic parameters and the 22-item Scoliosis Research Society questionnaire (SRS-22) evaluation. DAR and TLK were significantly smaller, whereas PI was significantly greater, in Group STK than those in Group STLK. Despite different distal fusion strategies, STK and STLK were corrected to an equivalent extent, with similar GK, correction rate, LL, SVA, TPA, PT, and SS immediately after operation and at the final follow-up. The DAR and TLK retained were smaller, whereas the PI retained was greater, in Group

FDA device/drug status: Not applicable.

Author disclosures: **WZ**: Nothing to disclose. **XS**: Nothing to disclose. **WP**: Nothing to disclose. **HY**: Nothing to disclose. **ZL**: Nothing to disclose. **YQ**: Nothing to disclose. **ZZ**: Nothing to disclose.

Funding: This work was supported by National Natural Science Foundation of China (Grant No. 81171672), Nanjing Clinical Medical Center, and Jiangsu Provincial Key Medical Center.

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https://doi.org/10.1016/j.spinee.2019.04.007

1529-9430/

STK than STLK after surgery. Distal junctional kyphosis complications were found in five patients with STK curve type. In Group STK, patients with DJK were found to have significantly larger preoperative GK (87.5±7.0 vs. 77.5±9.0, p=.024), correction rate of GK (62.9±10.2% vs. 51.3±8.5%, p=.021), and correction rate of DAR (55.9±4.5% vs. 36.6±13.7%, p=.011) than those without DJK. Pre- and postoperative SRS-22 assessments did not show any significant difference between Groups STK and STLK or between patients with and without DJK.

CONCLUSIONS: Curve patterns should be taken into attention when determining the optimal distal fusion level in correction surgery for SK. For patients with STLK, relatively shorter fusion stopping at FLV is enough to correct SK with the preservation of more lumbar motility and less development of DJK. For patients with STK, we suggest extending fusion to the SSV, which could restrict more distal junctional problems than fusion to the FLV. Large GK and correction degree might be the associated factors of developing DJK in STK patients.

Keywords: Curve pattern; Distal fusion level; Distal junctional kyphosis; First lordotic vertebra; Sagittal stable vertebra; Scheuermann kyphosis

Introduction

Scheuermann disease is mainly characterized by vertebral body wedging, vertebral end plate irregularity, and diminished anterior vertebral growth, which is the most frequent cause of structural thoracic and thoracolumbar spinal hyperkyphosis during adolescence [1,2]. Aiming to prevent further progression of the hyperkyphosis, surgical treatment is usually performed when kyphosis exceeds 70°, with unacceptable cosmetic concerns, persistent back pain, or neurologic deficit [1,3]. Clinically, determination of fusion levels is one of the most important issues in surgical treatment of Scheuermann kyphosis (SK). Most surgeons agree that the upper instrumented vertebra should be the proximal end vertebra in the measured kyphosis to prevent proximal junctional kyphosis (PJK) [4,5]. With regard to the lower instrumented vertebra (LIV), however, the exact criteria for selection have not been well established.

Optimal distal fusion level should strive to preserve lumbar motility and avoid distal junctional problems, such as distal junctional kyphosis (DJK). Early authors advocated the instrumentation should end at first lordotic vertebra (FLV), which they thought could minimize the risk of developing distal junctional problems [6,7]. In 2009, Cho et al. [8] described a concept of sagittal stable vertebra (SSV) in their study including 31 patients with thoracic hyperkyphosis and found that fusion to the SSV may be superior in terms of preventing DJK compared with fusion to FLV. Thus, they recommended that fusion should be extended to SSV. Similarly, Lundine et al. [9] also found that fusion to SSV rather than FLV was superior at preventing DJK in their study of 22 thoracic hyperkyphosis patients. In studies involving SK subjects, however, the findings were inconsistent. Some authors found that extending fusion to SSV rather than FLV resulted in fewer distal LIV complications [10,11], whereas others did not reveal more DJKs when fusion to FLV compared with SSV and thought it was unnecessary to fuse the SSV [12]. Therefore, the surgical management dealing with LIV in SK patients is still controversial.

Scheuermann Kyphosis has two curve patterns: Scheuermann thoracic kyphosis (STK) and Scheuermann thoracolumbar kyphosis (STLK) [13]. Because of the disparate sagittal spinopelvic alignments and morphologies between STK and STLK, we speculate that biomechanics of the two curve patterns are different and hypothesize that curvature type should be taken into account when choosing distal fusion level. To our best knowledge, previous studies have not taken curve patterns into consideration when determining the distal fusion level. In our center, patients with STK are fused to SSV, whereas those with STLK are fused to FLV since June 2010. Therefore, we conducted this retrospective study to analyze the clinical and radiographic outcomes, particularly DJK, in patients with STK and STLK who underwent different distal fusion strategies.

Materials and methods

Subjects

The diagnosis of SK was based on the radiographic criterion of anterior vertebral wedging greater than 5° involving three or more contiguous vertebrae [14]. All of the patients suffered from intractable pain, neurologic deficit, or had unacceptable cosmetic appearance.

After receiving institutional review board approval, a cohort of 45 patients who previously underwent correction surgery at our hospital between June 2010 and December 2015 were retrospectively included in the study. The following inclusion criteria were applied: (1) age <18 years; (2) having a curve severity over 70°; (3) undergoing one-stage all pedicle screw instrumentation and fusion; and (4) with a minimum follow-up of 2 years. Subjects with any other spinal anomaly and history of spinal trauma or surgery were excluded from this study. They were 42 boys and 3 girls, with an average age of 15.8±2.1 years (range 12−18 years).

Fusion strategy

Hyperkyphosis with an apex above T10 (include T10) was defined as STK (Fig. 1, Left) and hyperkyphosis with an apex below T10 was defined as STLK (Fig. 2, Left) [13]. Scheuermann thoracic kyphosis was found in 18 patients and STLK was found in 27 patients. In our center, patients with STK were fused to SSV at the distal level (Group STK), whereas patients with STLK were fused to FLV (Group STLK). The proximal end vertebra in the measured kyphosis was selected as upper instrumented vertebra for all the patients.

Surgical procedure

The surgeries were performed by three different spine surgeons, using all pedicle screw constructs with titanium rods. No osteotomies were performed. Posterior fusion was accomplished with autograft and allograft. All the operations were conducted under intraoperative neuroelectrophysiological monitoring.

Radiographic and clinical evaluation

Radiographic measurements were performed on long-cassette lateral radiographs of the spine in the fist-on-clavicle position before surgery, immediately after operation and at the latest follow-up. Global kyphosis (GK) was measured from the upper end to the lower end vertebra of the kyphosis according to the Cobb method. Deformity angular ratio (DAR) was calculated as the maximum kyphotic angle divided by the number of vertebral levels involved [15]. Thoracolumbar kyphosis (TLK) was measured from T10 to L2. Lumbar lordosis (LL) was measured from T12 to the sacrum. Global sagittal balance was assessed with sagittal vertical axis (SVA), the horizontal distance between the C7 plumb line and the posterior-superior corner of the sacrum. Negative values indicated that the C7 plumb line fell behind the sacrum. T1 pelvic angle (TPA) was the angle subtended by a line from the femoral heads to the center of the T1 vertebral body and a line from the femoral heads to the center of the superior sacral end plate [16]. Negative values

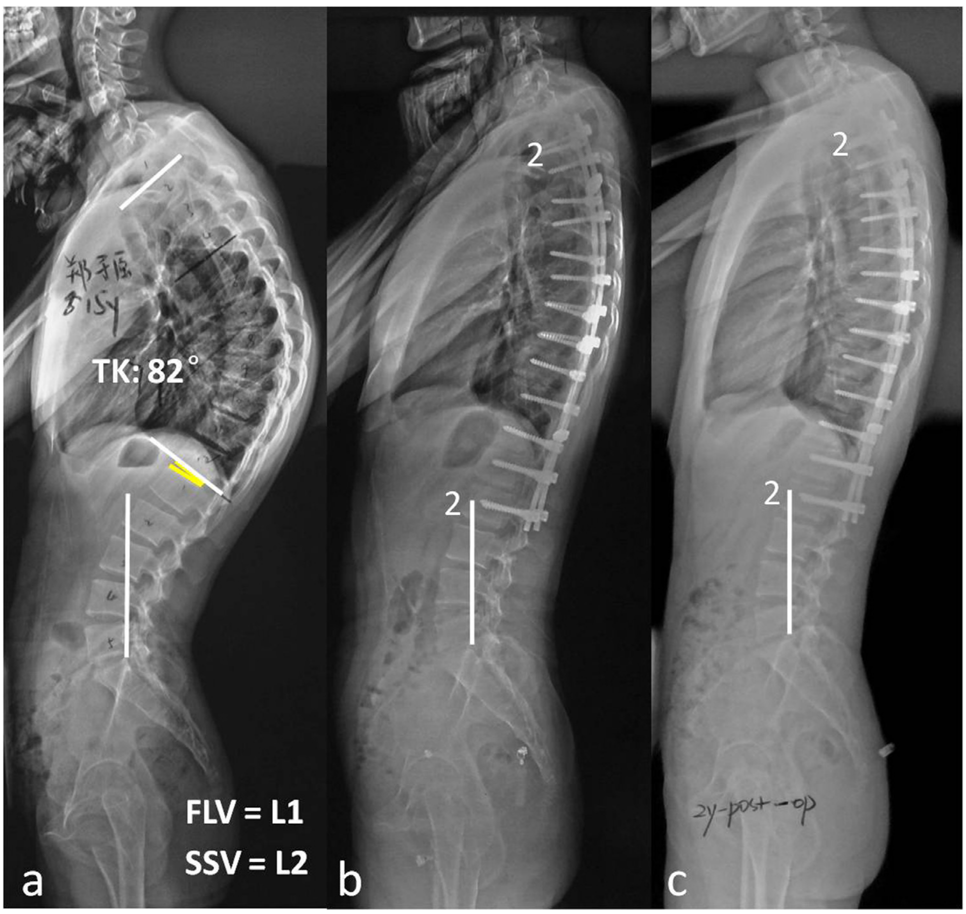

Fig. 1. (Left) A 15-year-old boy with a Scheuermann hyperkyphosis of 82°. The proximal end vertebra in the measured kyphosis is T2. FLV is located at L1 (yellow line) and SSV is located at L2 (white line). The kyphosis apex is T8 (above T10), so the curve type is STK. (Middle) According to our fusion strategies, this patient with STK was fused to SSV (L2). After surgery, the hyperkyphosis was corrected to 42°, with a correction rate of 48.8%. (Right) Two years after operation, the correction was maintained stable without any junctional problem.

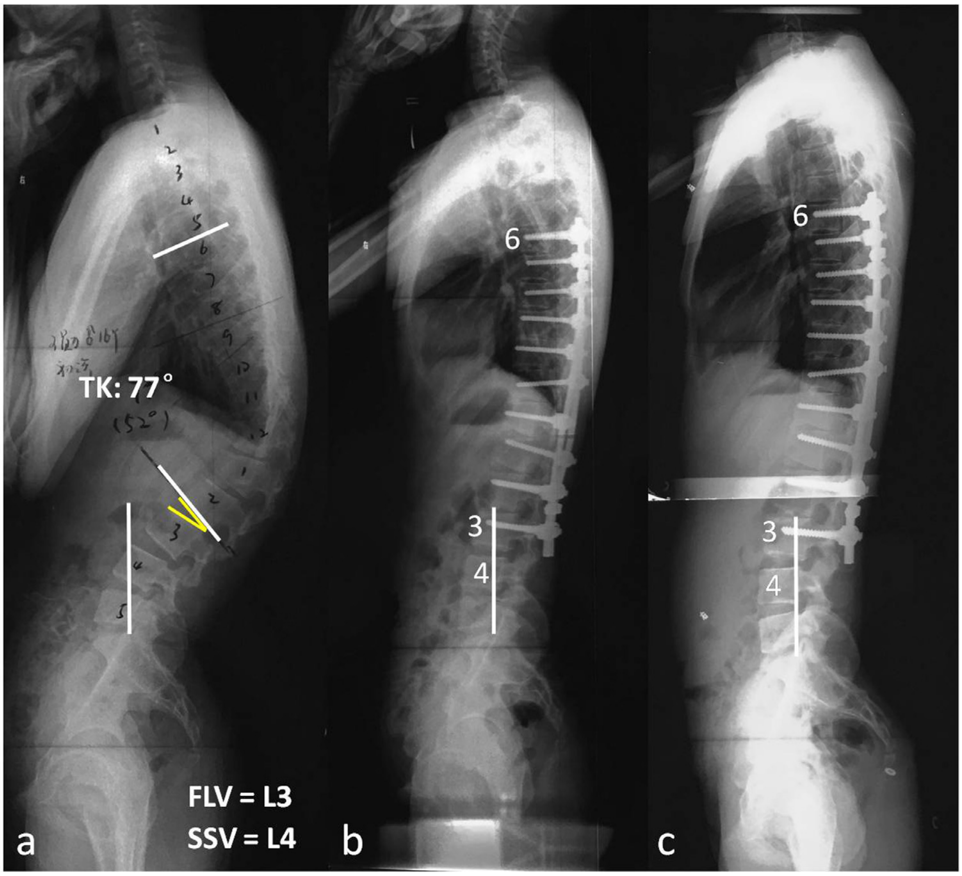

Fig. 2. (Left) A 16-year-old boy with a Scheuermann hyperkyphosis of 77°. The proximal end vertebra in the measured kyphosis is T6. FLV is located at L3 (yellow line) and SSV is located at L4 (white line). The kyphosis apex is T12 (below T10), so the curve type is STLK. (Middle) According to our suggestions, this patient with STLK was fused to FLV (L3). After surgery, the hyperkyphosis was corrected to 16°, with a correction rate of 79.2%. Despite fused to FLV, the mass of this vertebra was still placed over the sacrum and within the center of gravity (white line). (Right) Twenty-five months after operation, the correction was maintained stable. Despite the correction rate was more than 50%, no distal junctional problem was observed.

indicated that the line from the femoral heads to the center of the T1 was placed behind the line from the femoral heads to the center of the superior sacral end plate. The distance from the center of the LIV to the posterior sacral vertical line was measured to assess whether the distal fusion mass was centered over the sacrum [8]. Negative values also indicated that the center of the LIV was placed behind the sacrum. Pelvic incidence (PI) was the angle between the perpendicular to the sacral plate at its midpoint and the line connecting the point to the middle axis of the femoral heads. Pelvic tilt (PT) was the angle between the line connecting the midpoint of the sacral plate to the middle axis of the femoral heads and the gravity line. Sacral slope (SS) was the angle between the sacral plate and the horizontal plane.

Distal junctional kyphosis was defined as an abnormal distal junctional angle ≥10°, between the superior end plate of the lowest instrumented vertebra and the inferior end plate of the adjacent distal vertebra [17]. If the disc space just below LIV that was lordotic before surgery became neutral or kyphotic after correction, it was also defined as DJK [9]. Distributions of FLV, SSV, and LIV in the whole cohort and subgroup were evaluated. A spinal surgeon who was independent of the operations performed all radiographic assessments.

All the patients were required to complete the 22-item Scoliosis Research Society questionnaire (SRS-22) evaluation of quality of life before surgery and at the 2-year follow-up, respectively [18].

Statistical analysis

Values were expressed as mean ± standard deviation. Statistical analysis was performed by use of the SPSS version 19.0 (Chicago, IL, USA). Comparisons of preoperative and postoperative radiographic measurements and SRS-22 values were performed using the Mann-Whitney *U* test. Chi-square analysis was applied to assess the categorical variables. Statistical significance was defined as a p value <.05.

Results

Distributions of first lordotic vertebra, sagittal stable vertebra, and lower instrumented vertebra in the whole cohort and subgroup

The distribution of FLV and SSV is shown in Table 1. For the whole cohort, FLVs and SSVs were found to be the same vertebrae in four patients. In other patients, FLVs

Table 1
Distribution of FLV and SSV in the whole cohort

Vertebra	T12	L1	L2	L3	L4	L5
FLV	1	3	19	21	1	0
SSV	0	2	5	17	20	1
p	<.001					

FLV, first lordotic vertebra; SSV, sagittal stable vertebra.

Table 2
Comparison of distribution of FLV, SSV, and LIV between Groups STK and STLK

		T12	L1	L2	L3	L4	L5
Group STK	FLV	1	3	14	0	0	0
(n=18)	SSV	0	2	4	12	0	0
	LIV	0	2	4	12	0	0
Group STLK	FLV	0	0	5	21	1	0
(n=27)	SSV	0	0	1	5	20	1
	LIV	0	0	5	21	1	0
p (STK vs STLK)	p_{FLV}<.001, p_{ssv}<.001, p_{LIV}=.270						

STK, Scheuermann thoracic kyphosis; STLK, Scheuermann thoracolumbar kyphosis; FLV, first lordotic vertebra; SSV, sagittal stable vertebra.

were found about one vertebra higher than SSVs: most of FLVs (88.9%) were located at L2 and L3, whereas most of SSVs (82.2%) were located at L3 and L4 (p<.001).

The distributions of FLV and SSV between Groups STK and STLK were significantly different (p<.05, Table 2). Of FLVs, 94.4% were found at L1 (16.7%) and L2 (77.8%) in patients with STK, whereas 96.3% of FLVs were found at L2 (18.5%) and L3 (77.8%) in those with STLK. FLVs in STK were found about one vertebra higher than those in STLK (p<.001). Similarly, SSVs were also found about one vertebra higher in STK than STLK (p<.001). Patients with STK were fused to SSV and those with STLK were fused to FLV. As a result, distribution of LIVs did not differ significantly between the two groups (p>.05, Table 2).

Radiographic and clinical outcomes of the whole cohort

For the 45 patients, the mean preoperative GK and DAR were78.8±9.3° and 11.3±3.9, which were decreased to 37.9±8.3° and 6.7±2.2 immediately after operation, with a mean correction rate of 51.9±8.7% and 39.0±14.2%, respectively. The deformity correction was maintained during the follow-up. Thoracolumbar kyphosis and LL were decreased significantly after surgery and at final follow-up. Global sagittal balance maintained within a balanced range from preoperation to the latest follow-up. Mean TPA was 0.6±7.7° preoperatively, 2.0±6.6° immediately after surgery, and 2.1±7.3° at final follow-up. The center of LIV behind the sacrum before surgery (−15.8±16.3 mm) was placed over the sacrum after surgery (8.1±10.4 mm) and maintained over the sacrum (5.1±10.2 mm) at last follow-up (Fig. 2). Pelvic parameters retained constant after operation (Table 3). As shown in Table 4, the preoperative pain and self-image scores of SRS-22 questionnaire were significantly improved 2 years after surgery. As for other domains including function and mental health, no significant changes were observed.

At the latest follow-up, the complication of DJK was found in five patients who had the STK curve type (Fig. 3). Also, one patient developed the complication of PJK, caused by starting short of the upper end vertebra. In addition, superficial wound infections were found in two patients, which were successfully treated with antibiotic treatment and without surgical debridement. No patient was observed to have a pseudoarthrosis, implant failure, or neurologic deficits. No revision surgery was required during the follow-up time.

Comparisons of radiographic and clinical assessment between Groups Scheuermann thoracic kyphosis and Scheuermann thoracolumbar kyphosis

Before surgery, Groups STK and STLK were comparable in terms of age, gender, body mass index, fusion levels, follow-up time, some radiographic parameters (GK, correction rate, LL, SVA, TPA, PT, and SS), and SRS-22 evaluation. Deformity angular ratio and TLK were significantly smaller, whereas PI was significantly greater in Group STK (8.3±1.0, 22.7±22.0°, and 39.3±6.7°, respectively) than those in Group STLK (13.6±3.7, 59.4±17.2°, and 30.7±9.9°, respectively, p<.05).

The hyperkyphosis deformities in both groups were obviously corrected and the corrections were maintained stable during follow-up (Table 5). Despite with different distal fusion strategies, STK and STLK were corrected to the equal extent, with similar GK, correction rate, LL, SVA, TPA, PT, and SS immediately after operation and at the final follow-up as well. Postoperative DAR and TLK were smaller in Group STK than STLK (p<.05). With respect to the positions of LIV, they were located more anteriorly in Group STK than Group STLK before and after surgery (Table 5).

As for the evaluation of quality of life, the preoperative assessments were similar between Groups STK and STLK. At 2-year follow-up, there was no significant difference between the two groups in any of the five domains (Table 5).

Comparisons of radiographic and clinical assessment between patients with or without distal junctional kyphosis in Group Scheuermann thoracic kyphosis

All patients suffering from DJK complications were found to have STK curve type. In addition, all cases of DJK were defined based on the definition of the disc space just below LIV that was lordotic before surgery becoming neutral or kyphotic after surgery. Patients with DJK were found to have significantly larger preoperative GK (87.5±7.0 vs. 77.5±9.0, p=.024), correction rate of GK (62.9±10.2% vs. 51.3±8.5%, p=.021), correction rate of DAR (55.9±4.5% vs. 36.6±13.7%, p=.011), and significantly smaller postoperative DAR

Table 3
Radiographic outcomes of the whole cohort

	Preoperatively	Immediately after surgery	p value*	At final follow-up	p value†
Global kyphosis (°)	78.8±9.3	37.9±8.3	<.001	39.0±7.7	.601
Correction rate of global kyphosis (%)	–	51.9±8.7	–	50.4±8.8	.837
Deformity angular ratio	11.3±3.9	6.7±2.2	<.001	6.7±2.0	.907
Correction rate of deformity angular ratio (%)	–	39.0±14.2	–	38.3±15.4	.975
Thoracolumbar kyphosis (°)	44.2±26.4	16.0±10.7	<.001	15.1±10.7	.686
Lumbar lordosis (°)	55.1±22.9	46.2±12.8	.026	46.9±11.7	.745
Sagittal balance (mm)	−21.4±23.8	−21.9±17.4	.522	−19.6±12.3	.207
T1 pelvic angle (°)	0.6±7.7	2.0±6.6	.680	2.1±7.3	.528
LIV-PSVL (mm)	−15.8±16.3	8.1±10.4	<.001	5.1±10.2	.098
Pelvic incidence (°)	34.2±9.5	34.1±9.3	.950	35.0±9.6	.708
Pelvic tilt (°)	6.6±11.7	5.0±7.1	.597	5.0±8.3	.674
Sacral slope (°)	27.4±12.7	29.2±11.3	.744	30.0±9.0	.586

LIV-PSVL, the distance from the center of the low instrumented vertebra to the posterior sacral vertical line.
* Comparison between preoperation and immediate postoperation.
† Comparison between immediate postoperation and final follow-up.

Table 4
SRS-22 results of the whole cohort

	Preoperatively	At 2-year follow-up	p value
Function	3.7±0.54	3.7±0.72	.263
Pain	3.5±0.52	4.2±0.61	.022
Self-image	3.4±0.73	4.4±0.83	.019
Satisfaction	–	3.9±0.69	–
Mental health	3.4±0.65	3.6±0.64	.104

(3.8±0.4 vs. 7.2±2.1, p=.002) than those without DJK. Difference was not found between the two groups in terms of the demographic data, fusion levels, follow-up time, and other sagittal parameters (Table 6).

Pre- and postoperative SRS-22 assessments did not show any significant difference between patients with and without DJK (Table 5).

Discussion

King et al. [19] first introduced the concept of the stable vertebra in the surgical strategy of thoracic idiopathic scoliosis with the aim of achieving a balanced and stable spine. Considering the theory of stable vertebra could also be applied to sagittal deformity, Cho et al. [8] described fusion to the SSV in their study of 31 patients (age range 13−38 years) with thoracic hyperkyphosis including SK. Combined and posterior approach surgeries with hybrid instrumentation were performed. They found the rate of postoperative distal junctional problems when fusing to SSV (8%) was lower than that fusing to FLV (38%). Similarly, Mikhaylovskiy et al. [11] also found fusion to the SSV (4%) was superior at preventing DJK compared with proximal level (71%) in their retrospective study of 36 SK patients (age range 14−32 years) using hybrid system. Therefore, they concluded that the fusion level ending at FLV was not sufficient and recommended the SSV concept to guide selection of the distal fusion level in the setting of thoracic hyperkyphosis.

It is worth mentioning that the instrumentation in their study was a hybrid system including hook constructs, such as all hook or partial hook, which is known to be less stable and to be more prone to cause junctional problems related to more soft tissue dissection [5,20]. As a rigid and stable instrumentation system, all pedicle screw constructs are currently used as the main correction technique for SK [21,22]. However, the surgical strategy dealing with distal fusion level for SK patients is still controversial. In a study of 54 patients (age range 12−43 years) with SK undergoing all pedicle screw instrumentation, Yanik et al. [12] did not find significantly higher incidence of DJK when fusion to FLV (23.5%) compared with SSV (15%, p=.409) and thought it was not necessary to fuse the SSV. Recently, Kim et al.'s [10] study of 44 SK patients (children and adults) showed an inconsistent result that extending fusions to the SSV rather than FLV resulted in fewer distal LIV complications (5% vs. 36.3%, p=.04), despite all pedicle screw constructs.

Scheuermann kyphosis has two types of curve patterns: STK with an apex above T10 (include T10; Fig. 1, Left) and STLK with an apex below T10 (Fig. 2, Left) [13]. In the present study, STLK was more prevalent than STK (27 vs. 18 cases), with the location of FLVs and SSVs about one vertebra lower in STLK. Because most of the lumbar flexibility is contributed by the lower lumbar spine (L4 and L5) [23], mobility would be restricted if extending distal fusion level to SSV (L4) for patients with STLK, which may have an important influence on function. Therefore, patients with STLK in this study were fused to FLV. With respect to patients with STK, most of FLVs were located at L1 and L2, which were within the thoracolumbar junctional segment (T10−L2). The thoracolumbar junction is the transformation region of kyphosis and lordosis. In our opinion, segments within this region are more inclined to form a kyphotic alignment (including the junctional kyphosis) under certain conditions such as positive sagittal spinal imbalance, relatively unstable constructs, and implants

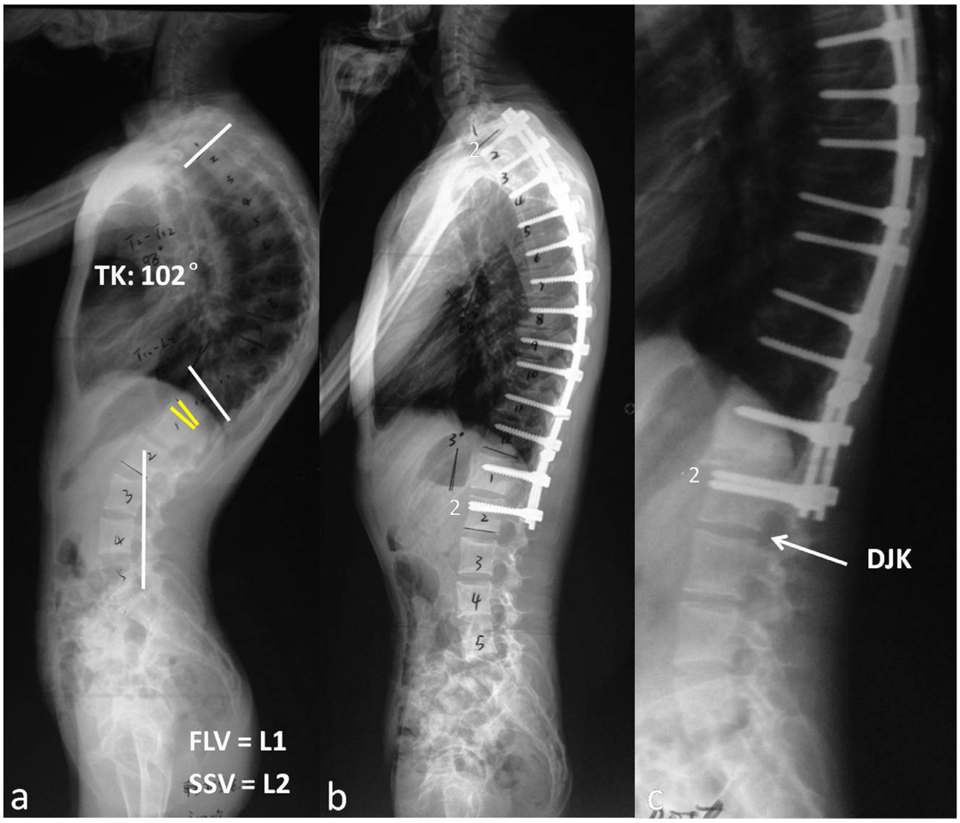

Fig. 3. (Left) A 18-year-old man with a Scheuermann hyperkyphosis of 102°. The proximal end vertebra in the measured kyphosis is T2. FLV is located at L1 (yellow line) and SSV is located at L2 (white line). The kyphosis apex is T7 (above T10), so the curve type is STK. (Middle) According to our fusion strategies, this patient with STK was fused to SSV (L2). After surgery, the hyperkyphosis was corrected to 43°, with a correction rate of 57.8%. (Right) At the latest follow-up (26 months), DJK was observed despite stopping at SSV.

problems compared with the lower lumbar spine. Therefore, we suggest extending distal fusion level to SSV for patients with STK (Fig. 1). In this manner, individualized fusion can adequately preserve lumbar flexibility for patients with STLK and also minimize the risk of developing distal junctional problems for patients with STK.

Global kyphosis was significantly decreased after surgery (p<.001) and maintained up to final evaluation in the whole cohort (correction rate: 51.9±8.7% and 50.4±8.8%, respectively, Table 3), which is similar to that in previous studies [6,11,12]. Deformity angular ratio was also significantly decreased, with correction rate of 39.0±14.2% after surgery and 38.3±15.4% at final follow-up. With regards to the subgroups, our study showed comparable results of radiographic (except DAR, TLK, and PI) and SRS-22 evaluations between the two types of hyperkyphosis (STK and STLK) after surgery, despite different distal fusion strategies (Table 5). For STK curve, the vertebrae involved in the maximum kyphotic angle were more than STLK curve; therefore, DAR was then smaller based on the similar GK. According to the definition, the apex of STK was above T10 and the apex of STLK was below T10, so it was easy to comprehend that T10−L2 angle (TLK) in STLK curve was larger than STK curve. Our previous study reported lower PI in patients with STLK than STK (29.1 ± 11.3° vs. 36.5 ± 8.4°, p<.001) [13], which was also demonstrated in the current study (30.7±9.9° vs. 39.3±6.7°, p=.030). We speculated that the relatively lower apex in STLK limited the compensatory function of lumbar spine. The subsequent compensatory changes occurred in the pelvis to maintain the sagittal balance, which contributed to the lower PI. The greater DAR and TLK and lower PI in STLK were maintained after surgery and up to final follow-up. After mean follow-up of 27 months, 5 DJK complications were observed. However, unlike the higher incidence of DJK when fusion to FLV than SSV in previous studies [8,10,11], our results showed that all the 5 DJKs were found in patients with STK who were fused to SSV. Interestingly, the distal fusion levels of the 5 patients were all within the thoracolumbar junctional segment, with 2 levels located at L1 and 3 levels located at L2 (Fig. 3). Because DJK problems were not severe at the 2-year follow up, SRS-22 assessments did not show statistically significant differences between affected and unaffected patients and the impact of the radiographic findings is unclear. Further study is needed to observe the impact of DJK over a longer follow-up.

Previously, some authors considered curve correction over 50% as a risk factor for the development of junctional kyphosis [5,6], whereas others did not find any difference in terms

Table 5
Comparison of clinical and radiographic assessment between Groups STK and STLK

	Group STK (n=18)	Group STLK (n=27)	p value
Age (year)	18.5±5.0	19.1±4.7	.627
Gender	Female: 2; Male: 19	Female: 1; Male: 23	.905*
Body mass index (kg/m^2)	29.0±4.7	28.2±3.2	.431
Fusion levels	11.8±1.6	10.6±1.6	.088
Follow-up (months)	27.4±3.4	27.1±4.3	.809
Global kyphosis (°)			
Preoperatively	77.7±9.5	79.6±9.4	.524
Immediately after surgery	39.9±7.4	36.4±8.8	.213
Final follow-up	40.3±8.3	38.1±7.3	.396
p value	p_1<.001, p_2=.930	p_1<.001, p_2=.752	
Correction rate of global kyphosis (%)			
Immediately after surgery	49.4±8.5	53.5±8.2	.075
Final follow-up	49.1±9.6	51.2±8.0	.224
p value	p_2=.844	p_2=.881	
Deformity angular ratio			
Preoperatively	8.3±1.0	13.6±3.7	<.001
Immediately after surgery	5.0±1.1	7.9±2.0	<.001
Final follow-up	5.1±1.2	7.9±1.6	<.001
p value	p_1<.001, p_2=.954	p_1<.001, p_2=.945	
Correction rate of deformity angular ratio (%)			
Immediately after surgery	38.1±15.4	39.7±13.8	.723
Final follow-up	36.9±16.1	39.3±15.4	.740
p value	p_2=.817	p_2=.823	
Thoracolumbar kyphosis (°)			
Preoperatively	22.7±22.0	59.4±17.2	<.001
Immediately after surgery	8.6±9.4	21.2±8.5	.002
Final follow-up	7.9±8.4	20.1±9.2	.001
p value	p_1=.088, p_2=.931	p_1<.0.001, p_2=.654	
Lumbar lordosis (°)			
Preoperatively	60.1±16.1	44.2±19.5	.067
Immediately after surgery	46.7±12.7	45.6±13.4	.831
Final follow-up	48.6±11.8	44.9±11.8	.404
p value	p_1=.023, p_2=.771	p_1=.817, p_2=.880	
Sagittal balance (mm)			
Preoperatively	−19.7±13.8	−21.6±14.6	.752
Immediately after surgery	−21.2±10.9	−20.7±12.7	.905
Final follow-up	−21.3±16.2	−19.1±14.6	.592
p value	p_1=.561, p_2=.645	p_1=.556, p_2=.845	
T1 pelvic angle (°)			
Preoperatively	−0.5±8.6	1.4±7.2	.706
Immediately after surgery	4.3±8.8	0.3±4.1	.091
Final follow-up	3.2±7.9	1.3±6.9	.594
p value	p_1=.235, p_2=.506	p_1=.592, p_2=.782	
LIV-PSVL (mm)			
Preoperatively	−1.8±11.4	−19.2±13.5	<.001
Immediately after surgery	14.3±11.3	1.1±12.6	.010
Final follow-up	11.0±11.4	−1.5±12.2	.013
p value	p_1<.001, p_2=.432	p_1<.001, p_2=.527	
Pelvic incidence (°)			
Preoperatively	39.3±6.7	30.7±9.9	.030
Immediately after surgery	39.1±5.4	30.5±9.9	.022
Final follow-up	40.2±6.7	31.4±9.8	.021
p value	p_1=.977, p_2=.622	p_1=.986, p_2=.769	
Pelvic tilt (°)			
Preoperatively	5.9±15.0	7.0±9.3	.400
Immediately after surgery	5.8±9.0	4.4±5.7	.492
Final follow-up	6.3±8.0	4.1±8.7	.438
p value	p_1=.707, p_2=.750	p_1=.248, p_2=.605	

Table 5 (***Continued***)

	Group STK (n=18)	Group STLK (n=27)	p value
Sacral slope (°)			
Preoperatively	32.1±14.8	24.2±10.2	.052
Immediately after surgery	32.8±13.9	26.6±8.6	.198
Final follow-up	33.3±10.9	27.6±6.8	.069
p value	p_1=.823, p_2=.910	p_1=.836, p_2=.654	
SRS-22 (Preoperatively)			
Function	3.8±0.6	3.6±0.5	.137
Pain	3.3±0.5	3.6±0.7	.146
Self-image	3.4±0.7	3.4±0.8	.802
Mental health	3.5±0.5	3.2±0.5	.201
SRS-22 (2-year follow-up)			
Function	3.7±0.7	3.7±0.8	.631
Pain	4.0±0.6	4.3±0.8	.304
Self-image	4.3±0.9	4.5±0.6	.254
Satisfaction	4.0±0.7	3.7±0.5	.283
Mental health	3.7±0.3	3.6±0.6	.662

STK, Scheuermann thoracic kyphosis; STLK, Scheuermann thoracolumbar kyphosis; LIV-PSVL, the distance from the center of the low instrumented vertebra to the posterior sacral vertical line; SRS-22, 22-item Scoliosis Research Society questionnaire; p_1, comparisons between preoperative values and immediately postoperative values; p_2, comparisons between immediately postoperative values and values at final follow-up.

* Calculated by chi-square analysis.

Table 6
Comparison of clinical and radiographic assessment between patients with or without DJK Group STK

	Patients with DJK (n=5)	Patients without DJK (n=13)	p value
Age (year)	21.0±3.6	18.0±4.6	.535
Gender	Female: 0; Male: 5	Female: 3; Male: 37	.392*
Body mass index (kg/m^2)	29.6±4.7	27.8±3.2	.488
Fusion levels	12.2±1.6	11.2±1.5	.706
Follow-up (months)	30.0±3.8	26.7±1.8	.541
Global kyphosis (°)			
Preoperatively	87.5±7.0	77.5±9.0	.024
Immediately after surgery	32.7±9.7	37.7±8.3	.863
Final follow-up	32.3±8.4	39.1±7.8	.887
p value	p_1<.001, p_2=.944	p_1<.001, p_2=.757	
Correction rate of global kyphosis (%)			
Immediately after surgery	62.9±10.2	51.3±8.5	.021
Final follow-up	56.3±9.0	49.5±8.5	.034
p value	p_2=.726	p_2=.843	
Deformity angular ratio			
Preoperatively	8.8±0.4	11.8±4.1	.229
Immediately after surgery	3.8±0.4	7.2±2.1	.002
Final follow-up	4.0±0.3	7.1±1.8	.003
p value	p_1=.021, p_2=.564	p_1<.001, p_2=.915	
Correction rate of deformity angular ratio (%)			
Immediately after surgery	55.9±4.5	36.6±13.7	.011
Final follow-up	54.3±4.1	36.1±15.5	.016
p value	p_2=.564	p_2=.954	
Thoracolumbar kyphosis (°)			
Preoperatively	24.3±14.0	47.4±26.7	.050
Immediately after surgery	12.7±9.1	16.5±11.0	.429
Final follow-up	11.3±9.0	15.7±10.9	.216
p value	p_1=.012, p_2=.832	p_1<.001, p_2=.734	
Lumbar lordosis (°)			
Preoperatively	64.8±11.4	53.5±13.26	.111
Immediately after surgery	53.0±17.8	45.2±12.0	.291
Final follow-up	53.0±14.4	46.0±11.3	.325
p value	p_1=.083, p_2=.992	p_1=.106, p_2=.847	

Table 6 (***Continued***)

	Patients with DJK (n=5)	Patients without DJK (n=13)	p value
Sagittal balance (mm)			
Preoperatively	−22.4±15.7	−19.3±13.2	.374
Immediately after surgery	−23.5±8.6	−20.6±11.8	.458
Final follow-up	−22.0±11.4	−18.5±13.4	.506
p value	p_1=.521, p_2=.434	p_1=.466, p_2=.370	
T1 pelvic angle (°)			
Preoperatively	−2.3±11.8	1.0±7.1	.569
Immediately after surgery	1.7±6.4	1.4±6.3	.357
Final follow-up	4.5±9.4	1.7±7.0	.589
p value	p_1=.386, p_2=.773	p_1=.792, p_2=.566	
LIV-PSVL (mm)			
Preoperatively	−12.5±10.0	−10.9±16.8	.310
Immediately after surgery	2.7±4.0	9.7±13.5	.158
Final follow-up	2.9±6.7	7.4±12.3	.090
p value	p_1<.001, p_2=.856	p_1<.001, p_2=.651	
Pelvic incidence (°)			
Preoperatively	37.8±5.0	34.1±10.7	.466
Immediately after surgery	38.8±3.8	33.3±9.7	.310
Final follow-up	41.0±4.7	34.0±9.9	.137
p value	p_1=.991, p_2=.304	p_1=.969, p_2=.851	
Pelvic tilt (°)			
Preoperatively	3.0±10.2	7.1±12.0	.393
Immediately after surgery	8.5±9.1	4.4±6.8	.410
Final follow-up	9.0±11.8	4.4±7.8	.506
p value	p_1=.248, p_2=.987	p_1=.303, p_2=.676	
Sacral slope (°)			
Preoperatively	33.3±11.3	27.1±13.3	.370
Immediately after surgery	28.5±6.5	29.3±12.0	.949
Final follow-up	32.8±11.1	29.6±10.4	.506
p value	p_1=.661, p_2=.663	p_1=.661, p_2=.734	
SRS-22 (preoperatively)			
Function	3.7±0.8	3.6±0.4	.231
Pain	3.4±0.6	3.6±0.8	.172
Self-image	3.4±0.7	3.4±0.8	.860
Mental health	3.6±0.5	3.3±0.6	.220
SRS-22 (2-year follow-up)			
Function	3.7±0.6	3.8±0.9	.446
Pain	4.1±0.6	4.2±0.7	.711
Self-image	4.4±0.8	4.4±0.8	.858
Satisfaction	3.8±0.7	3.9±0.5	.401
Mental health	3.7±0.5	3.6±0.7	.552

STK, Scheuermann thoracic kyphosis; DJK, distal junctional kyphosis; LIV-PSVL, the distance from the center of the low instrumented vertebra to the posterior sacral vertical line; SRS-22, the 22-item Scoliosis Research Society questionnaire; p_1, comparisons between preoperative values and immediately postoperative values; p_2, comparisons between immediately postoperative values and values at final follow-up.

* Calculated by chi-square analysis.

of DJK between patients who were corrected over 50% or not [12]. In current study, we compared the clinical and radiographic assessment between patients with and without DJK in Group STK. Results showed that the GK curve (87.5±7.0° vs. 77.5±9.0°, p=.024), correction rate of GK (62.9±10.2% vs. 51.3±8.5%, p=.021), and correction rate of DAR (55.9±4.5% vs. 36.6±13.7%, p=.011) in patients with DJK were significantly larger, compared with those without DJK (Fig. 3). However, the number of DJK patients was limited, which was not enough to perform a multivariate analysis. Despite this, the finding could also be regard as a caution of the possibility of developing DJK for patients with STK.

Cho et al. [8] described the parameter of LIV to the posterior sacral vertical line to assess whether the distal fusion mass was centered over the sacrum as viewed on the lateral radiograph. They thought the negatively balanced LIV behind the sacrum would develop DJK to a greater extent to compensate the imbalance of global sagittal spine. Therefore, they recommended surgeons to extend fusion to SSV, so that the mass of LIV could be centered over the sacrum. In Group STLK of our study, however, the mass of LIV could also be just placed over the sacrum and within the center of gravity (1.1±12.6 mm; Fig. 2), despite not fused to SSV. The anterior moving of FLV was ascribed by correction of thoracic hyperkyphosis and realignment of spinal column. Our results underline that stopping fusion at FLV for patients with STLK was enough to achieve a balanced LIV center over the sacrum, with relatively fewer fusion levels preserving more lumbar mobility (Fig. 2) [23].

DJK is a major complication related to instrumentation after the correction surgery of SK, which needs more attention than PJK because of the risk of symptomatic pain in lumbar segment [24]. Optimal distal fusion level selection is deemed to be one of the most important factors to prevent DJK in surgery planning. Our present study is the first to report a surgical strategy that selects distal fusion level in Scheuermann patients on the basis of curvature pattern. The advantages of the current study are as following: (1) all the subjects in this study are adolescents, with no variables regarding degeneration which may affect the DJK results; (2) we used uniform posterior approach and all pedicle screw construct in a homogenous patient group. There are some limitations of this study. First, the number of subjects is relatively small. Second, because of only five patients who were found with DJK, it was not powered to perform a multivariate analysis. Third, the impact of our radiographic findings is unclear. Further study is needed to observe the DJK results after longer follow-up. Fourth, there was no comparison between STK fused to SSV and STK fused to FLV, or comparison between STLK fused to FLV and STLK fused to SSV.

Conclusion

Curve patterns should be taken into attention when determining the optimal distal fusion level in correction surgery for SK. For patients with STLK, relatively shorter fusion stopping at FLV is enough for correction with the preservation of more lumbar motility and less development of DJK. For patients with STK, we suggest extending the fusion to the SSV, which could limit distal junctional problems compared with fusion to the FLV. Large GK and correction amounts might be the associated factors of developing DJK in STK patients.

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