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"Reasonable threshold" of spinopelvic parameters after fixation on distal stenosis in patients with degenerative thoracolumbar kyphosis

A STROBE-compliant article

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Abstract

The short-segment instrument for precision treatment of lumbar stenosis syndrome (LSS) combined with degenerative thoracolumbar kyphosis (DTLK) receives more attention and the reasonable range of sagittal parameters is debatable in these elderly patients. This study aimed to include LSS patients combined with DTLK performed short-segmental fixation on LSS, to evaluate the efficacy of this procedure, and to determine the reasonable threshold of sagittal parameters. Overall 138 patients (female, 62.3%) were eligible (mean age of 68.8 ± 7.7 years) with a follow-up time of 24.6 ± 11.1 months. Spinopelvic sagittal parameters containing TLK, lumbar lordosis (LL), pelvic incidence (PI), pelvic tilt (PT), and sagittal vertical axis were obtained at baseline and final visit, where |PI-LL|, PT, and sagittal vertical axis were seen as the main parameters. Quality of life was evaluated by the Oswestry Disability Index (ODI), which were divided into 4 quarters orderly. The reasonable threshold of parameters corresponding to ODI was determined by both linear regression and logistic regression. For all participants, TLK decreased by a mean of 8.3° and cases got TLK correction occupied 40.4%. ODI got improvement by the change of 29.9 ± 9.9. At baseline, ODI was correlated to |PI-LL|, while at final, ODI was correlated to |PI-LL| and PT. The independent factor affecting preoperative ODI was |PI-LL|, with ODI = 0.19 × |PI-LL| + 36.9 and the mean threshold of preoperative |PI-LL| was 10.7°. At final, PT was the influencing factor with ODI = 0.21 × PT + 3.16 and PT = 0.60 × |PI-LL| + 12.22. The mean threshold of postoperative |PI-LL| was 16.0° and PT was 23.1° by both linear regression and logistic regression. With short-segment fixation on LSS, >40% of patients with DTLK acquired TLK correction. |PI-LL| = 16.0° and PT = 23.1° was the "reasonable threshold" of sagittal parameters with the procedure for this population.

Abbreviations: ASD = adult spinal deformity, DTLK = degenerative thoracolumbar kyphosis, LIV = lower instrument vertebrae, LL = lumbar lordosis, LSS = lumbar stenosis syndrome, ODI = Oswestry Disability Index, PI = pelvic incidence, PLIF = posterior lumbar interbody fusion, PT = pelvic tilt, SRS = Scoliosis Research Society, SVA = sagittal vertical axis, UIV = upper instrument vertebrae.

Keywords: degenerative thoracolumbar kyphosis, lumbar stenosis syndrome, posterior lumbar interbody fusion, reasonable threshold, sagittal alignment

1. Introduction

Adult spinal deformity (ASD) exists about as high as 60% of old population with spinal degenerative disease, with a gradual increase tendency all over the world.[1,2] The classification system for ASD can not only characterize the disease, but also provide evidence-based treatment; however, there is still no consensus on the standardized ASD classification.[3,4]

In 2010, Silva and Lenke[5] proposed the Lenke-Silva classification depending on the neurologic symptoms, radiological features, and sagittal balance status, but which cannot include all types of ASD. In 2012, Scoliosis Research Society (SRS) addressed the updated SRS-Schwab classification based on Schwab classification, considered as the most authoritative ASD classification worldwide.[6] However, SRS-Schwab classification hardly offered guidance for surgical procedures. Then, Berjano

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The datasets generated during and/or analyzed during the current study are not publicly available, but are available from the corresponding author on reasonable request.

This study has obtained ethics approval and consent of the ethics committee in our hospital.

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and Lamartina[7] focused on the responding segment and supported a theory compensating the defect of SRS-Schwab classification properly. Nevertheless, SRS-Schwab classification mainly focused on patients with degenerative scoliosis rather than those with sagittal deformity or imbalance.

Lumbar stenosis syndrome (LSS) combined with degenerative thoracolumbar kyphosis (DTLK), as a most common ASD, has become a central issue since the precise levels for fixation and fusion for this disease was still under debate.[8] Although conducted by Lenke-Silva classification, some experts addressed that the procedures might be radical with this guidance, consequently with excessive range of instruments, longer surgical time, increasing hospital costs, and probable higher risk on operation. In addition to adequate decompression and consolidated fixation, the goal of surgery is to confine the sagittal parameters within a reasonable range.

Notably, the reasonable threshold of sagittal parameters varied from ages, where the normal range increased by ages. Lafage et al[9] explored the spinopelvic sequences in voluntary population, finding the increase in pelvic tilt (PT) and sagittal vertical axis (SVA) and the decrease of lumbar lordosis (LL) and TK with age. Contrasted with the normal population, most DTLK patients had the "abnormal" value of sagittal parameters, even an inadequate correction after surgery, but interestingly, most of them could lead a better quality of life. Likewise, in LSS patients combined with DTLK with extensive range of parameters, they can still acquire satisfied quality of life after the surgery with short-segmental fixation focusing on levels with LSS; the very range could also be defined as the reasonable range.[9,10]

Universally known, the quality of life in patients is the gold standard to evaluate a procedure. If the quality of life in LSS patients with DTLK gets improved and becomes stable, it proves the effectiveness of short-segmental fixation and the reasonability of redefined range of parameters. Therefore, LSS patients combined with DTLK performed short-segmental fixation were included, we aim to evaluate the efficacy of this procedure, to explore the relationship between sagittal parameters and quality of life, and to preliminarily confirm the reasonable threshold of sagittal parameters in this population.

2. Materials and Methods

2.1. Participants

It was a single-center, retrospective case series study. LSS patients with DTLK performed surgery in our institution from June 2016 to December 2019 was review. The study has acquired approval of ethnics committee of our institution and all participants have signed informed consent.

The inclusion criteria were patients without coronal deformity or imbalance, and they were with surgical indication and underwent short-segmental posterior lumbar interbody fusion (PLIF). They all acquired pre- and postoperative films on the whole spine and lumbar spine with age >50 years. Exclusion criteria were patients with coronal deformity or imbalance or underwent long-segment fusion on thoracolumbar spine. In addition, they diagnosed as other spinal deformity such as scoliosis, traumatic kyphosis, ankylosing spondylitis, and Scheuermann's disease and vertebral infection, spinal malignancy, or with severe comorbiditywere all excluded. The cases experienced surgery on thoracolumbar or lumbar spine before all lost to follow-up were also excluded. All cases were performed PLIF focused on the levels with severe LSS, with in-suit fusion or grade 1 to 2 osteotomy. Upper instrument vertebrae (UIV) was lower than L2 and lower instrument vertebrae (LIV) was L5. All operations were completed by the same senior surgeon.

According to previous studies, the effect size |ρ| of all parameters was 0.3 among patients. We defined the α error possibility to be 0.05 and the power (1 − β error possibility) to be 0.80, together with the estimation of loss rate of follow rate was 20% and 30%, so the sample size of this study was 178. Therefore, a total of 180 participants were reviewed and consequentially, 138 patients (female, 62.3%) were eligible for this study with a loss rate of 23.3%. The reason for loss included the following: lost to follow-up (19 cases), with severe comorbidity (8), unclear X-ray (7), performed secondary operation for other parts during follow-up (4), vertebral fracture (3), and infection (1). The qualified group was with a mean age of 68.8 ± 7.7 years, body mass index of 26.1 ± 3.6 kg/m^2, and the follow-up time of 24.6 ± 11.1 (12–49) months. The proportion of single-, double-, and triple level was 20.8%, 35.8%, and 43.4%.

2.2. Spinopelvic sagittal parameters

Sagittal parameters were obtained on the X-ray at preoperation (baseline) and final follow-up. TLK, LL, pelvic incidence (PI), PT, and SVA were respectively measured. TLK was the angle between the upper end plate of T10 and the lower end plate of L2, and DTLK was defined as TLK ≥15° caused by degeneration.[11] LL was between the upper endplate of L1 and the upper endplate of S1. The definition of other parameters is shown in Figure 1. Two surgeons independently measured the parameters. According to Schwab et al,[12] |PI-LL|, PT, and SVA were regarded as the most valuable spinopelvic sagittal parameters.

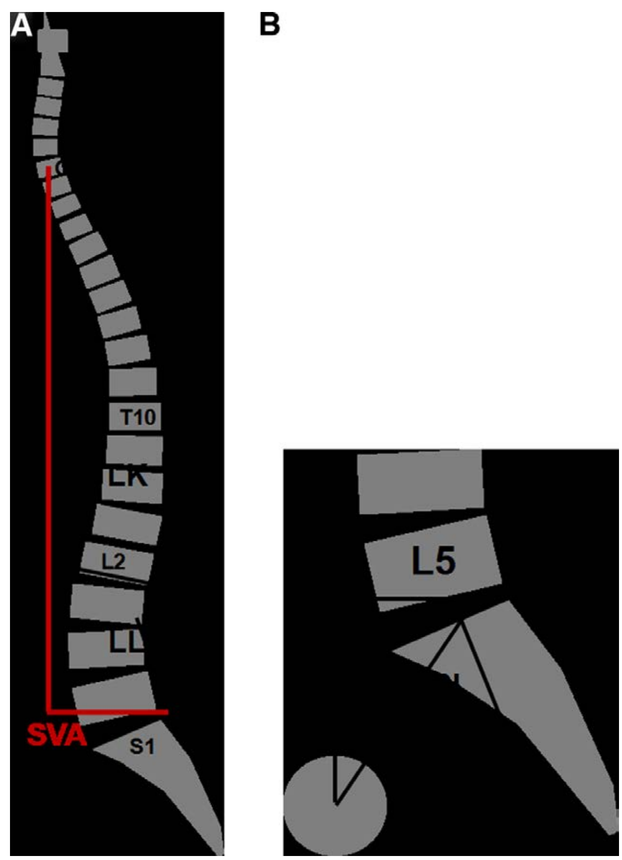

Figure 1. Diagram of spinopelvic sagittal parameters. (A) TLK was the angle between upper endplate of T10 and lower endplate of L2. LL was between upper endplate of L1 and upper endplate of S1. SVA was the interval between C7 plumb line and the posterior upper corner of S1. (B) PT was the angle between plumb line and the center of the femoral head to midpoint of upper endplate of S1. PI was the vertical line passing through the midpoint of upper endplate on S1, then second line connecting midpoint of the upper endplate on S1 and the femoral head and the angle between the second line and vertical line. LL = lumbar lordosis, PI = pelvic incidence, PT = pelvic tilt, SVA = sagittal vertical axis, TLK = thoracolumbar kyphosis.

2.3. The evaluation of quality of life

At baseline and final visit, quality of life was evaluated by the Oswestry Disability Index (ODI). ODI was composed of 10 questions that reflected life functions (between 0–50 score) and a lower score meant better quality. The change of ODI at final (ΔODI) ≥12.5, 25, and 35.7 means mild-, middle-, and obvious improvement, respectively.

According to ODI at baseline, the degree of dysfunction before surgery were divided into 4 levels: 25% population with minimum ODI among all included patients were reckoned as "mild" dysfunction of life, then the second quarter, third quarter, and the last quarter were orderly defined as "submild," "subsevere," and "severe" dysfunction, respectively.[13] Similarly, 4 levels were also divided with ODI at the final visit: the 25% group with minimal ODI was with "excellent" life quality, and other quarters were respectively "good," "fair," and "poor" life quality.

2.4. Parameter threshold determination

Identifying the influencing factors of ODI at pre- and postoperation, then the corresponding thresholds can be calculated by the algebra, which contains the 4 parameter ranges corresponding to the 4 quarters at baseline and last visit, and the latter is applied for parameter threshold determination. We assumed PI-LL could be changed by short-segment PLIF, which then can affect the rotation of pelvis. Thus, the range of PT can be calculated by postoperative ODI, and the reasonable threshold of |PI-LL| can be extrapolated.

2.5. Statistical analysis

The measurement data was expressed as mean ± standard deviation. The paired *t* test was used for parameters comparison between pre- and postoperation. Descriptive statistic was used for determination of ΔODI and 4 intervals of ODI. Pearson analysis was to evaluate relationship between sagittal parameters and ODI.

The double judgment of linear regression and logistic regression was performed for identifying the influencing factors of ODI.[14] On the one hand, the cutoff value of dependent variable is determined by linear regression. On the other hand, we transformed dependent variable into dichotomous; then the risk factor was determined by logistic regression, followed by χ^2 test and receiver operating characteristic (ROC) curve analysis. With the relation Youden index = maximum of (sensitivity + specificity) − 1, the value of independent variable corresponding to Youden index is the cutoff value by logistic regression, and the final threshold of parameters of the mean cutoff values by both linear and logistic regression.

Data analysis was performed using SPSS 22.0 software (International Business Machines Corporation, Armonk, NY), and $P < .05$ means statistical significance.

3. Results

3.1. The relationship between ODI and parameters

At baseline, the kyphotic vertex of DTLK concentrated on T11 to L1, while it ranged from T10 to T12 at final follow-up and the proportion of vertex at T8 to T9 increased ($P = .028$). Compared to baseline, the number of increased and decreased LL were 65 and 49 cases, respectively. TLK decreased ($P < .001$) by a mean of 8.3°, where the proportion of normal TLK corrected from DTLK was up to 40.4%. At final, PI-LL and SVA decreased ($P < .05$). In total, ODI got improvement at the final follow-up ($P < .001$) by a change of 29.9 ± 9.9 (Table 1). The change of ODI belonged to mild-, middle-, and obvious improvement was 96.5%, 68.2%, and 23.6%, respectively, where only 2 cases with increased ODI at last. At baseline, ODI was positively correlated to |PI-LL| ($P = .011$) but not to SVA and PT ($P > .05$). At the final visit, there was no relationship between ODI and SVA, but ODI correlated to both |PI-LL| and PT (Table 2 and Fig. 2).

3.2. The contributing parameters of ODI in DTLK

Pre- and postoperative ODI was seen as dependent variables and measurements with $P < .1$ by correlation analysis were independent variables. By regression analysis, it showed |PI-LL| was the influencing factor for preoperative ODI and PT was the influencing factor for final ODI (Table 3).

At baseline, the ODI was from 15 to 50 score, and the interval of ODI corresponding to "mild" dysfunction of the first quarter was 13 to 35. Likewise, the intervals of ODI reflecting to the other 3 quarters was 35 to 39, 39 to 43, and 43 to 50, orderly. The final ODI ranged from 0 to 40 score, so the ODI corresponding to the quarters with "excellent," "good," "fair," and "poor" life quality were 0 to 4, 4 to 8, 8 to 12, and 12 to 40, respectively (Table 4).

3.3. Reasonable threshold of sagittal parameters

The independent factor effecting preoperative ODI was |PI-LL|, with the formula of ODI = 0.19 × |PI-LL| + 36.9. Therefore, according to ODI-|PI-LL| function, |PI-LL| corresponding to the "mild" and "submild" dysfunction before surgery was 0° and 0° to 11.1°, respectively, and there was obvious limitation on capacity when |PI-LL| was beyond 32.1° (Table 4 and Fig. 3).

The preoperative ODI corresponding to |PI-LL| of 11.1° was the cutoff value between mild and severe dysfunction (ODI = 39) and then we transformed it into dichotomous. The logistic regression with "forward-step" method showed |PI-LL| was the influencing factor ($\chi^2 = 4.86$, $P = .027$, odds ratio

Table 1

The sagittal parameters and clinical outcomes of DTLK.

	Baseline	Final visit	P
PI, °	47.3 ± 12.1	46.2 ± 10.3	.292
LL, °	36.8 ± 19.8	39.1 ± 14.1	.068
PI-LL, °	9.6 ± 16.3	6.7 ± 12.4	.020
PT, °	20.1 ± 10.5	18.9 ± 9.7	.189
SS, °	26.8 ± 11.0	27.8 ± 9.9	.246
SVA, mm	44.0 ± 44.4	29.4 ± 36.7	.045
TLK, °	25.6 ± 9.6	19.3 ± 8.6	<.001
ODI	38.0 ± 6.5	8.8 ± 7.1	<.001

DTLK = degenerative thoracolumbar kyphosis, LL = lumbar lordosis, ODI = Oswestry disability index, PI = pelvic incidence, PT = pelvic tilt, SS = sacral slope, SVA = sagittal vertical axis, TLK = thoracolumbar kyphosis.

Table 2

Relationship between ODI and sagittal parameters.

	Parameters	r	P
At baseline	SVA and ODI	0.062	.479
	|PI-LL| and ODI	0.192	.011
	PT and ODI	0.110	.150
At final visit	SVA and ODI	−0.131	.350
	|PI-LL| and ODI	0.188	.029
	PT and ODI	0.208	.008
Change	ΔSVA and ΔODI	0.031	.807
	ΔSPI-LL and ΔODI	−0.012	.868
	ΔPT and ΔODI	−0.061	.378

LL = lumbar lordosis, ODI = Oswestry Disability Index, PI = pelvic incidence, PT = pelvic tilt, SVA = sagittal vertical axis.

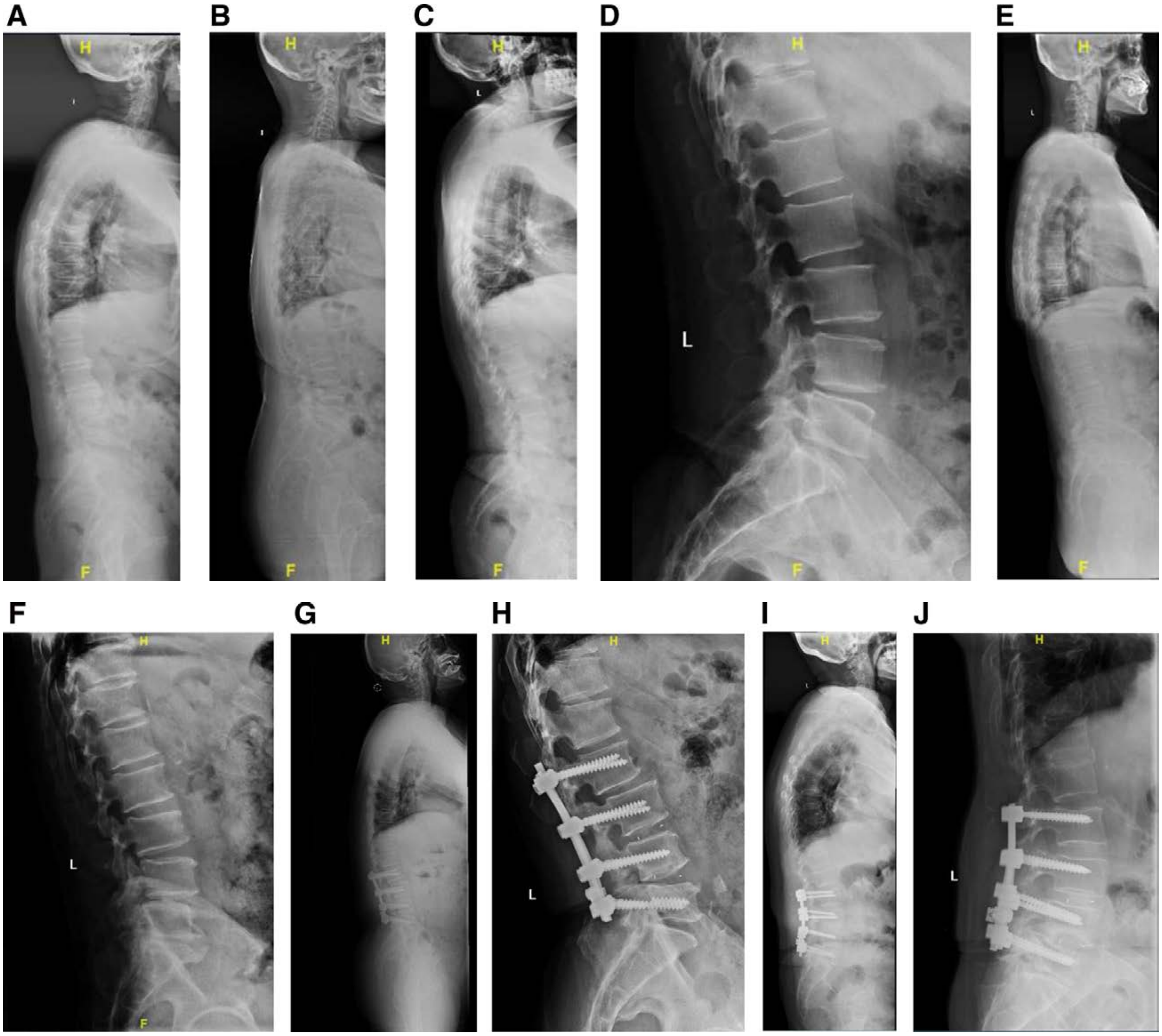

Figure 2. Cases on the relationship between sagittal parameters and clinical outcomes. (A, B) At baseline: 73-yr-old female with SVA of 68.5 mm and ODI of 38; 71-yr-old female with SVA of –6.1 mm and ODI of 41. (C–F) At baseline: 61-yr-old female with |PI-LL| of 0.2° and ODI of 29; 63-yr-old female with |PI-LL| of 20.1° and ODI of 38. (G–J) At final: 61-yr-old female performed L2–L5 PLIF, with SVA of 63.3 mm, PI-LL of 6.3°, PT of 12.8°, and ODI of 8 with a follow-up of 28 m; 68-yr-old female performed L2-L5 PLIF, with SVA of –65.0 mm, PI-LL of 42.8°, PT of 32.4°, and ODI of 19 with a follow-up of 30 m. LL = lumbar lordosis, ODI = Oswestry Disability Index, PI = pelvic incidence, PLIF = posterior lumbar interbody fusion, PT = pelvic tilt, SVA = sagittal vertical axis.

Table 3

Influencing factor of ODI at baseline and final by linear regression.

		Unstandardized		Standardized		
	Coefficient	B	SE	Beta	T	P
ODI at baseline	(constant)	36.933	0.775		47.674	<.001
	|PI-LL|	0.113	0.044	0.192	2.562	.011
ODI at final	(constant)	3.163	1.472		4.186	<.001
	PT	0.182	0.068	0.208	2.679	.008

LL = lumbar lordosis, ODI = Oswestry Disability Index, PI = pelvic incidence, PT = pelvic tilt, SE = standard error.

[OR] = 1.97). Then the area under curve (AUC) of ROC was 0.597 and Youden index was 0.188, so the corresponding cutoff value of |PI-LL| was 10.4°, and the mean threshold of preoperative |PI-LL| was 10.7°, when there was a more mild dysfunction before surgery (Tables 4 and 5; Fig. 3).

Table 4

The intervals of ODI corresponding to for quarters at baseline and final visit.

	ODI intervals	Corresponding ODI	Determining factor* (°)
At baseline	≤25%	15–35	0
	25%–50%	35–39	0–11.05
	50%–75%	39–43	11.05–32.11
	75%–100%	43–50	>32.11
At final	≤25%	0–4	0–4.00
	25%–50%	4–8	4.00–23.04
	50%–75%	8–12	23.04–42.10
	75%–100%	12–40	>42.10

ODI = Oswestry disability index, PI = pelvic incidence, PT = pelvic tilt.
*It meant |PI-LL| at baseline and meant PT at final visit.

At final follow-up, PT was the influencing factor with ODI = 0.21 × PT + 3.16, the PT corresponding to "excellent" and "good" quarters was 0° to 4° and 4° to 23.0°. Similarly, the

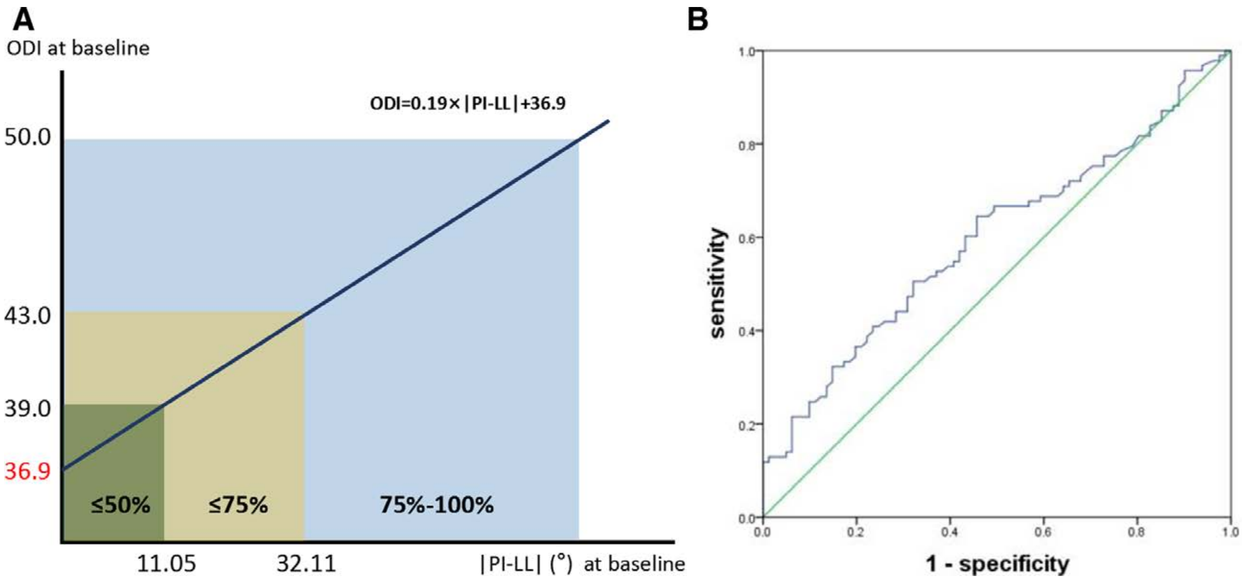

Figure 3. The determination of the threshold of |PI-LL| at baseline. (A) The intervals of |PI-LL| correspond to the quarters of ODI by linear regression analysis. (B) The logistic regression was performed with ODI of dichotomous. Then, ROC curve was figured out to determine the cutoff value of |PI-LL|. LL = lumbar lordosis, ODI = Oswestry Disability Index, PI = pelvic incidence, ROC = receiver operating characteristic.

Table 5

Influencing factor of ODI at baseline and final by logistic regression.

Dependent valuable	Independent valuable	B	SE	Wald	*P*
ODI at baseline	|PI-LL| at baseline (°)	0.044	0.016	7.245	.007
	(constant)	–0.470	0.268	3.067	.080
ODI at final	PT at final (°)	0.034	0.018	3.458	.043
	(constant)	–0.480	0.389	1.524	.217
PT at final (°)	|PI-LL| at final (°)	0.178	0.027	43.827	<.001
	(constant)	–2.761	0.378	53.425	<.001

LL = lumbar lordosis, ODI = Oswestry Disability Index, PI = pelvic incidence, PT = pelvic tilt, SE = standard error.

final ODI corresponding to |PI-LL| of 23.0° was the cutoff value (ODI = 8) and logistic regression was performed. It showed PT was the influencing factor for ODI ($\chi^2 = 7.20$, $P = .007$, OR = 2.59). The ROC-AUC was 0.602 and Youden index was 0.245, so the cutoff value of PT was 23.2° by this method and the mean threshold of postoperative PT was 23.1° (Tables 4 and 5; Fig. 4).

By linear regression, there was the fitting formula PT = 0.60 × |PI-LL| + 12.22. Thus, when PT <23.1° and |PI-LL| <18.1°, the cases could lead a better life quality while PT >42.1° and |PI-LL| >49.8° would acquire less efficacy. In that case, PT was seen as dependent variable and PT = 23.1° was the cutoff value by logistic regression. It addressed |PI-LL| was the influencing factor of PT at the final visit ($\chi^2 = 62.71$, $P < .001$, OR = 16.19), where the ROC-AUC was 0.836 and Youden index was 0.578, so the cutoff value of |PI-LL| was 13.9° and the mean threshold of postoperative |PI-LL| was 16.0° (Tables 4 and 5; Fig. 4).

4. Discussion

ASD classifications facilitate surgeons to qualify and quantify the characteristics of spinal deformity and support treatment strategies. Contrasted to SRS-Schwab classification,[6] Lenke-Silva classification may take excessive measures to patients, largely due to the missing consideration of physical degenerative factors.[5,15] Hence, more age-related formulas appeared in order to readjust the threshold of sagittal parameters, especially for the elder.[9,16] Physically, the LL of older was less than the young with a more adaptive PI-LL. For most LSS with DTLK, comprised of the elderly, once the postoperative LL was rebuilt into so-called normal range, it will be difficult to tolerate them.[17,18] Moreover, long-segment fixation is accompanied with higher cost, longer operation time, extensive incision, and sometimes with lumbosacral osteotomy, ensuing with longer recovery duration and probable higher complication rate.[15] Therefore, for LSS patient with DTLK, this study hypothesized short-segmental fixation on LSS can still bring satisfactory efficacy with a more tolerate "reasonable threshold" of parameters.

The latest studies showed a complication rate between 8.4% and 42% and a revision rate between 9.0% and 17.6% for ASD patients, while as high as 26% of these adverse events were considered as over-orthopedics.[19,20] Besides osteotomy with massive hemorrhage and drainage, Lafage et al[21] found SVA correction wasn't correlated to the osteotomy level. In addition, long-segmental procedure would increase anesthetic risk in the prone position, restrict the motion of thoracic spine, and incur fixation rupture, adjacent segment degeneration, and even proximal junction kyphosis with poor designation.[22,23] The appearance of complication correlates to the operation skill and the choice of instrument vertebrae segments, as well as the pursuit for overharsh realignment. In the follow-up for ASD patients with long-segment fusion, Zhang et al[24] found ODI and complication rate (degeneration of adjacent segments and proximal junction kyphosis) were lower with moderate grade of PI-LL (10°–20°, Grade B in SRS-Schwab classification) than Grade A and C.

Previous studies[24–26] concluded the relationship between balance status and therapeutic effectiveness based on the global sagittal balance and lumbar-pelvic matching. In this study, almost all cases acquired significant improvement after PLIF procedure, which was mainly attributed to the adequate release of nerve root and rehabilitation for paraspinal tissue. In addition, the correction of PI-LL and whole alignment after surgery played an important role. We focused on the correlation between life quality and sagittal parameters, finding ODI had positive correlation to PI-LL at baseline while PT, but not SVA, was the key factor for ODI at the final visit. Interestingly, there was a certain proportion of cases with SVA and PI-LL imbalance based on SRS-Schwab classification, even after surgery.

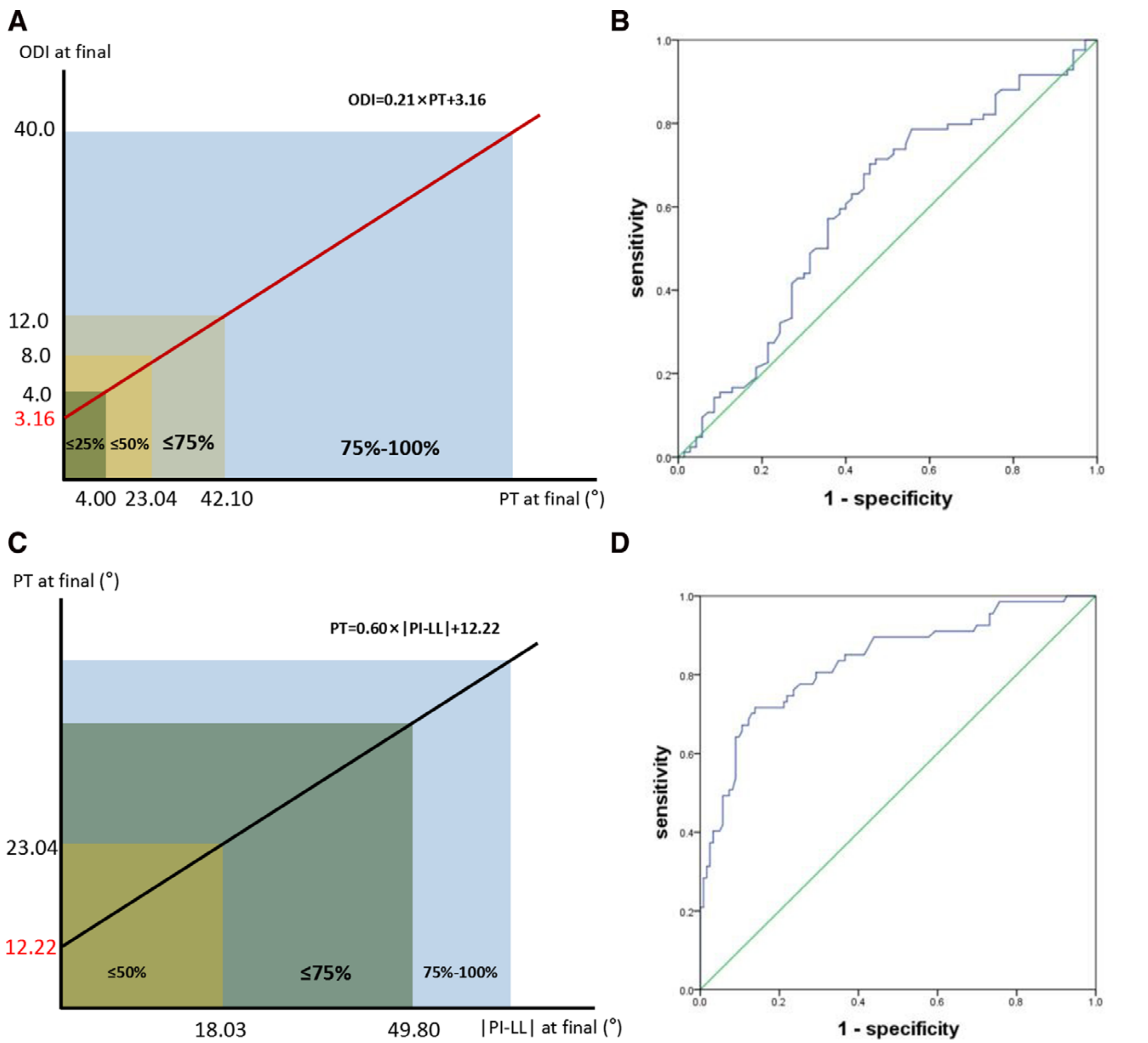

Figure 4. The reasonable threshold of sagittal parameters after short-segment fixation on DTLK. (A) The intervals of PT corresponding to the quarters of ODI by linear regression analysis. (B) The logistic regression was performed with ODI of dichotomous. Then, ROC curve was figured out to determine the cutoff value of PT. (C) The intervals of |PI-LL| corresponding to the PT by linear regression analysis. (D) The logistic regression was performed with PT of dichotomous. Then, ROC curve on PT and |PI-LL| was figured out to determine the cutoff value of |PI-LL|.[27] DTLK = degenerative thoracolumbar kyphosis, LL = lumbar lordosis, ODI = Oswestry Disability Index, PI = pelvic incidence, PLIF = posterior lumbar interbody fusion, PT = pelvic tilt, ROC = receiver operating characteristic.

In a review for 352 patients with ASD, Glassman et al[27] showed a worse quality of life with increased positive balance of SVA with a cutoff value of 50 mm. However, Maciejczak and Jablonska-Sudol[25] demonstrated global balance had no correlation to ODI in the elderly and emphasized the recovery of physical posture and horizontal visibility by surgery was the goal. Our data showed similar point that SVA was not a painstaking element for DTLK surgical designation. In the elderly, a slightly enlarged SVA maybe more adaptable, where the compensation works by extension of proximal thoracic spine, pelvic retroversion, and flexion of hip, and consequently, with less tension of the muscle and decreased energy consumption. It reported that postoperative SVA <8.0 cm was allowed in patients >75 years.[9,28] In our study, most cases with SVA <8.0 cm before and after surgery, which showed that SVA increased slightly by physical compensation and this parameter may not be paid more attention to for DTLK patients.

In these studies, preoperative PI-LL was associated with lower ODI, which demonstrated lumbar spinal-pelvic mismatch can lead to worse life quality and PI-LL should be confined in order to support conditions for patient adjustment. A retrospective study on 125 ASD cases verified that patients with PI-LL <9° had a less ODI than cases with unmatched PI-LL by a decrease of 15.4.[9,28] With matched PI-LL, it benefits patients with wider motion of lumbar spine, rational lumbar spinopelvic co-regulation, the adaption of standing, walking, and even sitting positions simultaneously.[29,30] By short-segment fixation, LL was properly corrected and lumbar motion was preserved, triggering coordinate compensation of lumbar spine and pelvis. If greater PI-LL was left, there was limited regulating capacity for unfused and pelvic retrorotation, enhancing long-term overextension on dorsal muscles.[7,31,32] Simultaneously, decompensation of proximal spine can enlarge thoracic kyphosis.[33] Thus, greater PI-LL can influence clinical efficacy in DTLK patients although with decompression for LSS.

In our data, there were no significant differences in PT and SS before and after surgery, indicating no statistical changes in lumbosacral pelvic morphology after surgery. Therefore, the change in TLK may not be significantly correlated with the local morphological parameters of the spine. First, nerve root compression in LSS patients forced a decrease of LL to compensate trunk anterior tilt for the enlarged spinal canal volume, which was relieved by adequate decompression after surgery.[34] Then, improved PI-LL matching and proximal TK compensation were achieved with the 1 to 2 grade of osteotomy, mainly on L4-S1. In addition, the increased strength of the paraspinal muscles in the 2 years by functional exercises may also improve the sagittal sequence. Furthermore, the whole spinal balance was slightly improved (44.0 ± 44.4 vs 29.4 ± 36.7 mm) after surgery, where the thoracolumbar region was considered as a main contributor.

At baseline, for LSS patients, the symptom relief was mainly depended on the increase of spinal canal volume via flexion of trunk and lumbar movement, and pelvic regulation was relatively insignificant.[25] While after surgery, since there was restriction on lumbar spine by instruments, PT, together with SS, gradually played a role in sagittal alignment. Pelvic compensation sustained horizontal visibility and stability and was proved to associated with walking endurance. By short-segment instrument, the lordosis of lumbar spine dynamically changed and ensuing the pelvic regulation occurred. Thus, with the restriction of |PI-LL| <16.0° and consequently PT <23.1°, the procedures can bring satisfactory effectiveness for LSS patients with DTLK, which is the "reasonable threshold" of sagittal parameters for this group.[27]

There were limitations that should be mentioned. Although all participants were with LSS reaching surgical indications, the heterogeneity on severity of LSS and degree of TLK was still perceptible. For many included DTLK patients, sagittal parameters were in normal range with a narrow span, while a wider range could figure out the fitting relationship of parameters and effectiveness with solid evidence. Adverse events were not included as clinical outcomes, and patients with fixation spanned over TLK were not induced as control group, which would eliminate the strength of conclusion. Finally, the result was only suitable for LSS patients with DTLK, and probably inapplicable in patients with coronal deformity.

5. Conclusion

With short-segment fixation on LSS, almost all DTLK patients experienced improvement with middle-term efficacy and >40% acquired TLK correction. At baseline, quality of life was associated with PI-LL. The modification of PI-LL and PT could influence therapeutic effectiveness after surgery, while SVA may not be paid more attention to. Specifically, preoperative PI-LL in DTLK patients exceeding 11.5° would compromise their quality of life, while restricting |PI-LL| of 16.0° and PT of 23.1° via short-segment fixation may be the "reasonable threshold" of sagittal parameters for this population.

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Author contributions

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