Spino-pelvic sagittal parameters in patients with degenerative thoracolumbar kyphosis combined with lumbar stenosis syndrome

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Abstract

Objective The patients diagnosed degenerative thoracolumbar kyphosis (DTLK) with lumbar spinal syndrome (LSS) were enrolled, to identify the significance of spino-pelvic parameters in this group.

Methods An overall 138 (M/F=53/85) patients were enrolled with a mean follow-up of 24.6 ± 11.1 (m). All cases were performed short-segment posterior fusion on LSS region. Radiological parameters were TLK, LL, PI, PT and SVA obtained on the X-ray. Quality of life (QOL) were evaluated by the visual analogue scale (VAS) and the Oswestry disability index (ODI). According to age-related formula by Lafage, various thresholds on PI-LL, PT and SVA were determined, ensuing three pairs of normal and abnormal groups were respectively divided into based on these parameters.

Results Both VAS and ODI statistically improved ($P < 0.001$). At the endpoint, TLK decreased by a mean of $8.2 \pm 8.8^\circ$ and cases got TLK-correction occupied 40.4%. The whole balance status (normal SVA) was improved compared to baseline ($P=0.006$), so was the ratio of matched PI-LL ($P=0.002$), but the ratio of normal PT and larger PT was of no significance ($P=0.794$). The final balance status was irrelevant to QOL whatever balance status at baseline. However, ODI in PI-LL matched group or in normal PT group were respectively less than that of abnormal groups ($P=0.022$ and $P=0.019$).

Conclusions The mean TLK decreased even a short-segment fusion purely performed on LSS. QOL was related to PI-LL and PT, but not to SVA in DTLK patients.

1 Background

Degenerative thoracolumbar kyphosis (DTLK) combined with lumbar spinal syndrome (LSS) is common in adult spinal deformity, the treatment and reconstruction for this population mainly depends on the spino-pelvic sagittal sequence, which determines sagittal balance and kinematics of the spine [1]. Kim et al. [2] suggested the importance of pelvic incidence (PI) minus lumbar lordosis (LL) on spino-pelvic sequence of volunteers. In recent years, scholars proposed doubtful point that sagittal parameters were not always in line with the quality of life (QOL). Maciejczak et al. [3] believed that in patients with LSS and low-grade spondylolisthesis, the pelvic balance and PI-LL had no correlation with QOL. Sagittal vertical axis (SVA), as the indicator for evaluating the overall sagittal balance, reflects the dynamic characteristics. Schwab et al. [4,5] recommended the threshold of SVA of 40 mm while studies found that QOL was not statistically reduced when SVA exceeded 50mm, especially for the elderly [6]. It is considered that spine-pelvic sequence may not be so important as reported or their threshold is not applicable to the elderly. Thus, the role of sagittal parameters and overall balance in DTLK with LSS has not been determined yet.

In addition to SVA, the threshold of PI-LL and pelvic tilt (PT) are also determined based on the correlation between sagittal sequence and QOL [5]. Subsequently, various adjustment on the thresholds of these parameters are proposed followed by many researches. Lafage et al. [7] reckoned that age should be considered adequately during reconstruction surgery on spinal deformity and then formulated age-related

threshold of PI-LL, PT and SVA [8]. However, the meaning of these parameters in this condition on DTLK with LSS should be further identified.

In early stage for adult spinal deformity, the surgeon tried to correct local malformation and balance within the normal range, while probably ensuing poor outcomes of QOL [9]. Then short-segment fixation was successfully proposed and favored on deformed ones after integrating cost-benefit analysis. In that case, satisfactory QOL have still been achieved after relaxing the threshold of parameters in the elderly in despite of the imperfect orthopedics [10,11]. Similarly, we hypothesized that the short-segmental decompression and instruments only on stenotic segment for DTLK with LSS could also acquire proper correction and efficient QOL, it would be significant for supplementary surgical strategies. Therefore, the middle-aged and elderly patients diagnosed DTLK with LSS performed short-segment fixation on LSS were enrolled in this study, to evaluate the short-term surgery efficacy and to identify the significance of sagittal parameters in this group through the modified formula by Lafage.

2 Materials And Methods

2.1 Participants and surgery

The single-center retrospective study was performed from June 2015 to June 2019. Patients diagnosed DTLK combined with LSS were enrolled. The severity of LSS uniformly reached to surgical-indications, mainly based on the patient's symptoms, physical and radiological examination. The protocol was approved by ethics committee in our institution and all participants have signed informed consent.

The inclusion criteria were (1) patients diagnosed LSS reached to surgical-indications, (2) cases > 55 years old, (3) with complete and clear X-rays of lumbar and the whole spine at pre- and post-operation, (4) patients underwent short-level fixation, where the upper instrumented vertebrae (UIV) was selected at no above than L2 and the lower instrumented vertebrae (LIV) was at L5. The exclusion criteria included (1) patients with coronal scoliosis or imbalance, (2) those who underwent previous spinal surgery, (3) cases with other types of spinal deformity such as neurofibromatosis, (4) patients with thoracic spinal stenosis, wedge fractures of the vertebral, (5) surgery with long-segment fixation, (6) spine with infections and malignance. The enrolled patients were performed posterior lumbar interbody fusion (PLIF) + posterior-lateral fusion (PLF) on segment with LSS, disc hernia and instability. Pedicle screws were inserted on both sides and the pinous process, lamina and inner edge of the articular process with LSS were removed. All operations were completed by the same senior surgeon.

2.2 Radiological parameters and QOL evaluation

Radiological parameters were obtained on the X-ray at preoperation (baseline) and final follow-up (endpoint). TLK, LL, 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 $TLK \geq 15^\circ$ caused by degeneration [12]. LL was between the upper endplate of L1 and the upper endplate of S1 (Fig. 1). Two surgeons independently measured the parameters.

At baseline and endpoint, QOL were both evaluated by the visual analogue scale (VAS) and the Oswestry disability index (ODI). VAS ranged from 0 to 10 score and higher scale meant a more severe pain. ODI was composed of 10 questions that reflected life functions (between 0–50 score) and a lower score meant a better QOL.

2.3 Modified threshold of PI-LL, PT and SVA

According to Schwab et al. [13], PI-LL, PT and SVA were regarded as the most valuable spino-pelvic sagittal parameters. According to age-related formula mentioned by Lafage [7], $PI-LL (^{\circ}) = (age-55) / 2 + 3$, $PT (^{\circ}) = (age-55) / 3 + 20$ and $SVA (mm) = 2 \times (age-55) + 25$, where each age (55-84y) was respectively substituted into Lafage formula. Various thresholds on PI-LL, PT and SVA could be obtained and the mean thresholds were SVA of 53 mm, PT of 24.6° and PI-LL of 10°. Then three-subgroup comparisons were further performed according to their thresholds, lumbar-pelvic matching versus mismatching by PI-LL, normal pelvis versus retroversion by PT and sagittal balance versus imbalance by SVA (Fig. 2).

2.4 Statistical analysis

The measurement data were expressed as mean $\pm$ standard deviation. The comparisons on radiological and clinical parameters between baseline and endpoint employed paired sample t-test. The comparisons on kyphosis apex distribution used Mann-Whitney U test. Chi-square test was used for comparisons on the number of cases of three subgroups. Independent sample t test was used for comparisons of radiological parameters and QOL in each subgroup. The data was analyzed by SPSS 22.0 (IBM, Armonk, New York, USA) and $P < 0.05$ indicated statistical significance.

3 Results

An overall 138 (Male: Female = 53: 85) patients were included with an average age of 68.8 ± 7.7 (y) (55-84y) and body mass index (BMI) of 26.1 ± 3.6 (kg/m²). The mean follow-up time was 24.6 ± 11.1 (m) (12-49m).

3.1 Evaluation of QOL and radiological parameters

The mean change of VAS and ODI were respectively 4.9 ± 1.9 and 29.9 ± 9.9 and both VAS and ODI statistically improved at the endpoint (both $P < 0.001$). At the endpoint, TLK decreased by a mean of $8.2 \pm 8.8^{\circ}$ compared to baseline ($26.6 \pm 9.6^{\circ}$ vs $18.3 \pm 8.6^{\circ}$, $P < 0.001$), and the proportion of cases got TLK-correction was 40.4%. The vertebral kyphotic apex concentrated on T11-L1 before surgery while it mainly focused on T10-T12 at the end and there was an increased ratio for T8-T9 as the apex ($Z = -2.193$, $P = 0.028$). There were 65 cases with larger LL and 49 cases with less LL and PI-LL along with SVA were lower contrasted to baseline ($P < 0.05$) (Table 1).

Table 1
Radiological and clinical parameters at preoperation and endpoint

	Preoperation	Endpoint	P
PI-LL, °	9.6 ± 16.3	6.7 ± 12.4	0.020
PT, °	20.1 ± 10.5	18.9 ± 9.7	0.189
SVA, mm	44.0 ± 44.4	29.4 ± 36.7	0.045
TLK, °	26.6 ± 9.6	18.3 ± 8.6	< 0.001
VAS	6.9 ± 1.4	2.0 ± 1.7	< 0.001
ODI	38.0 ± 6.5	8.8 ± 7.1	< 0.001
Footnote: PI: pelvic incidence; LL: lumbar lordosis; PT: pelvic tilt; SVA: sagittal vertical axis; TLK: thoracolumbar kyphosis; VAS: visual analogue scale; ODI: Oswestry disability index			

3.2 Outcomes of QOL in three subgroups

There were 98 patients in balance and 40 cases in imbalance at baseline while the number became 117 and 21 respectively at last ($P = 0.006$). There were 89 (90.8%) cases keeping balance and 28 (70.0%) cases acquiring balance-restoring while 9 (9.2%) cases fell into imbalance. The matched PI-LL and unmatched PI-LL were 56 and 82 cases respectively and there was an increasing ratio of matched PI-LL (58.7%, $P = 0.002$). The proportion of retention of matching, new unmatching and matching-restoring was 46 (82.1%) case, 10 (17.9%) cases and 35 (42.7%) cases respectively. The normal and retroversional pelvis were 94 and 41 cases respectively while with no significance compared to baseline ($P = 0.794$) (Table 2). At the end, there were overall 28 cases preserving whole balance, PI-LL matching and PT normal simultaneously and 2 cases acquiring all correction of PI-LL, PT and SVA.

Table 2
Outcomes of QOL in normal and abnormal groups

Baseline		Endpoint	
		Normal ^a	Abnormal ^a
Balance	98B	89BB'	9BI'
Imbalance	40I	28IB'	12II'
Sum	138	117BB'+IB'	21BI'+II'
Match	56M	46MM'	10MU'
Unmatch	82U	35UM'	47UU'
Sum	138	81MM'+UM'	57MU'+UU'
Normal pelvis	97N	80NN'	17NR'
Retroversion	41R	15RN'	26RR'
Sum	138	95NN'+RN'	43NR'+RR'
Footnote: QOL: quality of life; B: balance; I: imbalance; M: match; U: unmatched; N:normal; R: retroversion.			
a: Normal or abnormal means balance or not, match or not and normal-pelvis or not. eg: 89BB' means 89 cases keeps whole balance both at baseline and endpoint; 10MU' means 10 cases are in matched PI-LL at baseline while falls into unmatched PI-LL at the endpoint.			

PI-LL was larger in whole imbalanced subgroup than balanced subgroup ($P < 0.05$) with a mean of $12.5 \pm 12.5^\circ$. PT and SVA were respectively $14.3 \pm 6.3^\circ$ and 17.4 ± 27.6 mm in PI-LL matching group, both less than unmatched ones ($P < 0.01$). PI-LL was $19.0 \pm 14.1^\circ$ in retroversional pelvic group and larger than normal group ($P < 0.01$).

In whole balance group at preoperation, there was no significant difference in VAS and ODI and their changes in final balanced and imbalanced patients ($P > 0.05$), the same to the whole imbalance group at preoperation. Thus, the final balance status had nothing to do with the outcomes of QOL whatever the preoperative balance status. At the endpoint, it showed that ODI in PI-LL matched group was less than that of unmatched group ($P = 0.022$). Similarly, ODI in normal PT group was less than retroversional group ($P = 0.019$) (Table 3 and Fig. 3).

Table 3
The relationship between QOL and sagittal parameters at the endpoint

	SVA		PI-LL		PT	
	B'	I'	M'	U'	N'	R'
VAS'	1.7 ± 1.3	1.3 ± 1.3	2.0 ± 1.2	1.8 ± 1.7	1.9 ± 1.3	1.9 ± 1.8
ΔVAS	5.5 ± 1.4	6.3 ± 1.4	5.0 ± 1.6	5.5 ± 1.9	5.1 ± 1.6	5.6 ± 2.1
ODI'	10.7 ± 9.2	9.1 ± 13.3	8.3 ± 6.5	11.8 ± 7.6*	8.8 ± 6.0	12.1 ± 7.1*
ΔODI	29.8 ± 9.1	33.4 ± 15.4	29.7 ± 8.4	28.5 ± 11.0	29.1 ± 8.1	27.1 ± 12.6
Footnote: QOL: quality of life; PI: pelvic incidence; LL: lumbar lordosis; PT: pelvic tilt; SVA: sagittal vertical axis; B: balance; I: imbalance; M: match; U: unmatched; N: normal; R: retroversion; VAS: visual analogue scale; ODI: Oswestry disability index						
B' means whole balance at the endpoint; Δ means the change of variables; * means there is a significance (P < 0.05)						

4 Discussion

The spino-pelvic matching is reported an important predictor of QOL. A study conducted by Smith et al. [14] compared patients with improved PI-LL, PT, and SVA with uncorrected ones and found that a better spino-pelvic parameters after orthopedics lead to a significantly satisfied life. Based on the correlation between the sagittal sequence and QOL, Schwab et al. regarded SVA < 40 mm, PI-LL < ± 10° and PT < 20° as the target of sagittal sequence alignment. However, Gelb et al. [15] confirmed that the threshold for SVA of 8.0 cm is appropriate for asymptomatic people over 60s, suggesting the strictness of SVA and PI-LL matching in elderly should be relaxed [7]. With a less physiological LL in middle-aged and elderly relative to the young, the PI and LL was in a mismatched tendency and thus a constant threshold of parameters is unreasonable for various age groups. DTLK is an outcome with dual effects of compensation and decompensation [16] and there was probably significance on sagittal spino-pelvic sequence in DTLK with LSS compared to non-deformed LSS. This study explored the importance of spino-pelvic parameters on DTLK underwent short-segment fixation with more than 2-year follow-up. It was believed that the postoperative QOL was related to PI-LL and PT, but not to SVA.

Lafage et al. believed that DTLK with LSS tended to be performed surgery as the increased function demanding for the elderly [8]. They included 773 patients (mean of 53.7 years) and found the ideal spino-pelvic parameters (SVA, PT, and PI-LL) increased with the age, where the elderly had more LL loss and trunk forward tilt, which is necessary to be considered during surgical reconstruction.

Long-segment fixation can obtain satisfactory local correction and sequential reconstruction, but there are also many disadvantages such as large cost, long operation and recovery time, even probably with unsatisfied outcomes [17, 18]. In recent decades, the concept of short-segment fixation on adult spinal deformity has become more mature. Wang et al. [19] implanted short-segment fixation in degenerative

scoliosis and found though the sagittal and coronal Cobb angle adjacent to UIV increased, it made no effects on VAS and ODI. Kim et al. [20] compared short-segment fusion (UIV at T9-L1) and long-segment fusion (UIV at T1-T6) with a 2-year follow-up and believed the latter required longer operation time and hospital stay while the rate of complications and clinical outcomes was comparable. In our data, the UIV was selected lower than L2 and LIV was uniformly fixed at L5 since the fixation of S1 could affect pelvic rotation with more selection bias. Although the fusion range escaping from TLK, the postoperative TLK was still reduced and the sagittal parameters tended to be "reasonable". At first, preoperative LSS and nerve root compression forced a decrease of LL and compensate trunk anterior tilt, which was corrected by sufficient decompression after surgery [21, 22]. Then, more anterior version of pelvis, improved PI-LL matching and proximal TK compensation were acquired with the fixation and 1–2 grade of osteotomy on L4-S1. In addition, the increased strength of the paraspinal muscles in the two years by functional exercises may also improve the sagittal sequence [23].

In this study, the final PI-LL matching and whole balance got improved while with no significance on PT, indicating that the pelvic rotation was not obvious in DTLK group according to the preoperative PT ($20.1 \pm 10.5^\circ$) nearly in a normal range. There were limited cases acquired all correction of three parameters, reflecting that the sagittal parameters are not improved simultaneously. Where, the sagittal sequence rebuilt sometimes ignored the whole balance and the reconstruction of the sequence was probably not equivalent to sagittal balance [24].

Berjano et al. [25] described the sagittal compensation mechanism and observed three stages of the whole imbalance: equilibrium state, compensate balance and compensate imbalance. Jackson et al. [26] pointed out the whole imbalance was a common cause in patients with low back pain and suggested the correction of sagittal balance could improve the symptom. However, Hasegawa et al. [27] believed that the postoperative QOL had nothing to do with the balance state while close to the muscle tension, which was in accordance with the point of this study. According to the theory of Barrey et al., the majority of DTLK patients were in a state of compensate balance. Although some cases were in imbalance after the surgery, the tension of paraspinal muscle was relaxed and with no difference in QOL compared to ones with equilibrium state [8, 28].

PI is the only morphological parameter and has a strong correlation with LL. Initially, $PI-LL < 10^\circ$ was determined as the standard range, roughly estimating the reasonable LL and the degree of orthopedics [29]. However, the threshold of PI-LL was dynamically adjusted with the differences of ethnics and age, where Lafage proposed that the ideal PI-LL was more than 17.0° for people over 75 years old. Physiologically, middle-aged and elderly patients were with intervertebral disc dehydration and height collapse with a tendency of LL losing. According to Hasegawa et al. [27] with the ideal relationship $LL = 32.9 + 0.60 \times PI - 0.23 \times \text{age}$, the trend of PI-LL was close to this study and our series believed the mismatch of PI-LL would affect the clinical efficacy. Zhang et al. [30] included spinal deformed patients (mean of 65y) with fusion and showed that the $PI-LL < 10^\circ$ group had a lower ODI score and rate of complications.

PT was a sensitive parameter of lumbar spino-pelvic mismatch and more studies realized that pelvic rotation could affect surgery efficacy. Lazennec et al. [31] confirmed that patients suffering from persistent low back pain after lumbar surgery had decreased SS and increased PT ($P = 0.020$) and the PT was almost twice that of normal ones. Therefore, not removing the risks for pelvic retroversion could cause lose of LL, similar to sitting posture, which is considered in retroversion state, discomfort could derive from the long-term overstretching of the back muscles terminating on the iliac crest. There was no consensus on ideal threshold of PT and some believed $PT < 20^\circ$ was the fixed range, while Vialle et al. [32] reducing the formula of $PT = 0.37 \times PI - 7$ was widely accepted. Kim et al. [33] conducted the relationship between lumbar spine balance and clinical outcomes after PLIF and found that the improvement of VAS and ODI was correlated to the correction of PT but not to other spino-pelvic parameters. After lumbar spine fusion, the LL motion sharply reduced and the range of PI-LL was restricted, where the sequence adjustment was mainly depended on the proximal thoracic spine and the rotation of pelvis. Thus, PT was crucial in the evaluation of postoperative clinical efficacy.

There were some limitations. Firstly, it was a series study only with pre- and post-operative contruction, while the control group composed of non-deformed ones and long-segment fixation ones were not included. Then, the choice of LIV at S1 may have an impact on pelvic rotation, but this study did not include ones with S1 as LIV for stratification analysis. Finally, postoperative complications such as proximal junctional kyphosis and adjacent segment degeneration were not regarded, while the comprehensive outcomes and longer follow-up would strength the intensity of conclusion.

5 Conclusion

Overall, there was a significant improvement on VAS and ODI for DTLK patients and satisfactory QOL was achieved after 2-year follow-up. The mean TLK decreased even a short-segment fusion purely performed on LSS. The sagittal parameters were improved at the endpoint, and the number of cases with whole balance and PI-LL matching increased. The relationship between SVA and QOL was not clear, while PI-LL matching and normal PT played an important role on postoperative QOL.

Abbreviations

degenerative thoracolumbar kyphosis (DTLK)

lumbar spinal syndrome (LSS)

pelvic incidence (PI)

lumbar lordosis (LL)

quality of life (QOL)

Sagittal vertical axis (SVA)

pelvic tilt (PT)

upper instrumented vertebrae (UIV)

lower instrumented vertebrae (LIV)

posterior lumbar interbody fusion (PLIF)

posterior-lateral fusion (PLF)

visual analogue scale (VAS)

Oswestry disability index (ODI)

Declarations

Ethics approval and consent to participate: This study has obtained ethics approval and consent of the ethics committee in our hospital.

Consent for publication: Not applicable

Availability of data and material: The datasets used and/or analysed during the current study are available from the corresponding author on reasonable request.

Competing interests: The authors declare that they have no competing interests.

Authors' contributions: Conceptualization: LHY, GC; Data Curation: LHY,GC, ZZQ; Formal Analysis: LY, XS; Investigation: LY, WKF; Methodology: XS, GC,LY; Project Administration: LHY; Resources: XS; GC; Software:XS, GC, LY; Validation: LY; Visualization: LHY; Writing & Editing: LHY, GC, XS. All authors read and approved the final manuscript.

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Figures

Figure 1

(A) the definition of TLK and LL; (B) the definition of LCIV. TLK: thoracolumbar kyphosis; LL: lumbar lordosis; LCIV: lumbar crossing indentation value

Figure 2

LCIV in increased LL and decreased LL subgroup in DTLK group. *: statistical difference between variables ($P < 0.05$); **: statistical difference between variables ($P < 0.01$)

Figure 3

The cases with DTLK in less LL, normal LL and larger LL subgroups respectively. (A-B) 73-year-old male, BMI=26.4kg/m², TLK=26.3°, LL=5.9°, LCIV in L3-4 was 7.2mm, mLCIV was 5.8mm; (C-D) 68-year-old male, BMI=26.5kg/m², TLK=28.2°, LL=32.1°, LCIV in L3-4 was 11.2mm, mLCIV was 7.5mm; (E-F) 68-year-old male, BMI=25.8kg/m², TLK=29.8°, LL=61.9°, LCIV in L3-4 was 5.2mm, mLCIV was 12.0mm