Impact of sagittal imbalance correction on clinical outcomes in patients undergoing MIS-TLIF for LSS

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ABSTRACT

Objective: In the present study, we aimed to evaluate the effect of sagittal imbalance correction on clinical outcomes in patients undergoing single-segment minimally invasive transforaminal lumbar interbody fusion (MIS-TLIF) for lumbar spinal stenosis (LSS).
Patients and methods: A total of 114 LSS patients with a minimum 2-year follow-up were included. Preoperative and final follow-up sagittal parameters were determined. Sagittal imbalance was defined as a sagittal vertical axis (SVA) ≥ 40 mm. Patients were divided into balanced group (group A: preoperative SVA < 40 mm) and imbalanced group (group B: preoperative SVA ≥ 40 mm), and group B was further divided into recovered group (postoperative SVA < 40 mm) and unrecovered group (postoperative SVA ≥ 40 mm). Visual analog scale (VAS) score, Japanese Orthopaedic Association (JOA) score and Oswestry Disability Index (ODI) were used to assess clinical outcomes.
Results: The incidence of preoperative sagittal imbalance in LSS patients was 36.0% (41/114). A large mismatch between pelvic incidence and lumbar lordosis (PI-LL) was a risk factor for sagittal imbalance. After 2-year follow-up, sagittal imbalance was normalized in 65.9% of patients. Single- segment MIS-TLIF led to a significant decrease in SVA, pelvic tilt (PT) and PI-LL, as well as a significant increase in LL, thoracic kyphosis (TK) and sacral slope (SS) in both group A and group B. Preoperatively, the VAS, JOA and ODI scores were significantly poorer in patients with sagittal imbalance compared with those without sagittal imbalance. After MIS-TLIF, all clinical outcomes improved significantly. However, there was no significant difference in postoperative VAS, JOA and ODI scores between the group A and group B. In addition, there was no significant difference in postoperative VAS, JOA, and ODI scores between the recovered group and unrecovered group.
Conclusions: A significant proportion of LSS patients with preoperative sagittal malalignment had a compensatory mechanism rather than a structural malalignment, while single-segment MIS-TLIF could effectively improve sagittal imbalance at 2-year follow-up. However, we found no correlation between the improvements of sagittal imbalance and 2- year clinical outcomes. Reconstruction of sagittal balance might not be the main goal of single-segment MIS-TLIF for LSS, and did not affect its clinical results at two-year follow-up.

1. Introduction

Lumbar spinal stenosis (LSS) is a common clinical degenerative disease, which can cause low-back pain (LBP), leg pain and neurogenic intermittent claudication. Most LSS patients tend to exhibit a forward-bending posture when standing or walking. Therefore, preoperative imaging examination often reveals sagittal imbalance in LSS patients.

Schwab et al. have reported that sagittal balance should meet three conditions: sagittal vertical axis (SVA) < 40 mm, mismatch between pelvic incidence and lumbar lordosis (PI-LL) < 10° and pelvic tilt (PT) < 20° [1]. Some studies have found that sagittal imbalance is

associated with functional disability and pain [2–5]. Restoration of sagittal balance should be considered when choosing the appropriate surgical approach in the treatment of lumbar degenerative diseases and deformities, such as lumbar degenerative kyphosis. For example, patients with lumbar degenerative kyphosis can benefit from improvements in LL and thoracic kyphosis (TK) [6]. However, it remains controversial whether LSS patients associated with preoperative sagittal imbalance need to reconstruct sagittal balance [7]. In the past, the effect of single-segment lumbar fusion on sagittal imbalance has been overlooked. Whether single-segment minimally invasive transforaminal lumbar interbody fusion (MIS- TLIF) for LSS can effectively restore
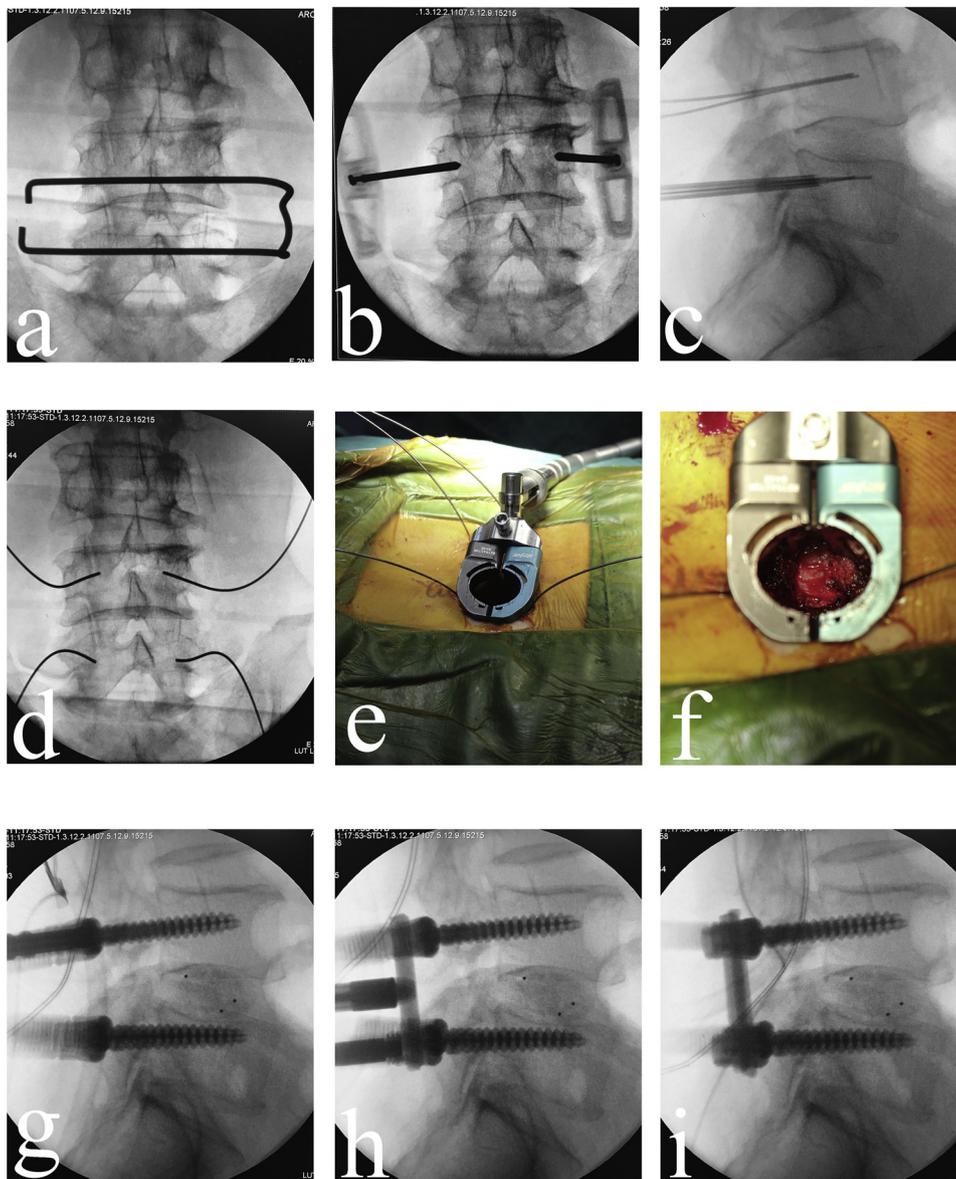
Fig. 1. Surgical procedures.
Fluoroscopic C-arm was used to mark L4-L5 pedicles (a). Under fluoroscopic C-arm machine guidance, Jamshidi needles were inserted into bilateral L4 and L5 pedicles. Then K-wires were inserted through the needles (b, c, d). Serial dilators were used to split the muscle fibers, and minimally invasive retractor was placed to expose L4-5 facet joints (e). Unilateral facetectomy, decompression, discectomy, and endplate preparation were performed under microscopy visualization (f). Pedicle screws and rods were inserted percutaneously (g, h, i).

sagittal balance remains unclear.

In the present study, we aimed to investigate the effect of single-segment MIS-TLIF on sagittal imbalance and evaluate the impact of sagittal imbalance correction on clinical outcomes. We retrospectively reviewed 114 LSS patients who were treated by the same surgical team, with a minimum follow-up of 2 years. Standing radiographs at the preoperative period and the final follow-up were assessed.

2. Materials and methods

2.1. Patients

This study was approved by our Institutional Review Board, and informed consents were obtained from all patients. As the clinical results might not be properly comparable if we included cases at different levels, only the LSS cases at L4-5 level were included in this series. Inclusion criteria were as follows: (1) patients with spinal stenosis only

at L4-L5 level who underwent MIS-TLIF; (2) patients whose pre- and post- operative imaging information was complete; (3) patients who were followed-up for more than 2 years. Exclusion criteria were as follows: (1) patients with lumbar coronal deformity according to the Scoliosis Research Society- Schwab classification [1], spine fractures, spine infections, spinal trauma, spinal tumors, rheumatic diseases, myogenic diseases, hip and lower extremity disorders; (2) patients with previous spinal and limb surgery history.

A total of 114 LSS patients were enrolled in the present study. The diagnosis of LSS was based on clinical symptom (such as LBP, leg pain and numbness, and neurogenic intermittent claudication) and radiographic data. The radiographic criteria for spinal stenosis was that the antero-posterior diameter of the spinal canal was less than 10 mm on magnetic resonance imaging (MRI) [8]. Among them, 51 cases were associated with degenerative spondylolisthesis, all of which were present with a Meyerding grade of I [9]. According to the Scoliosis Research Society-Schwab classification system [1], sagittal imbalance was
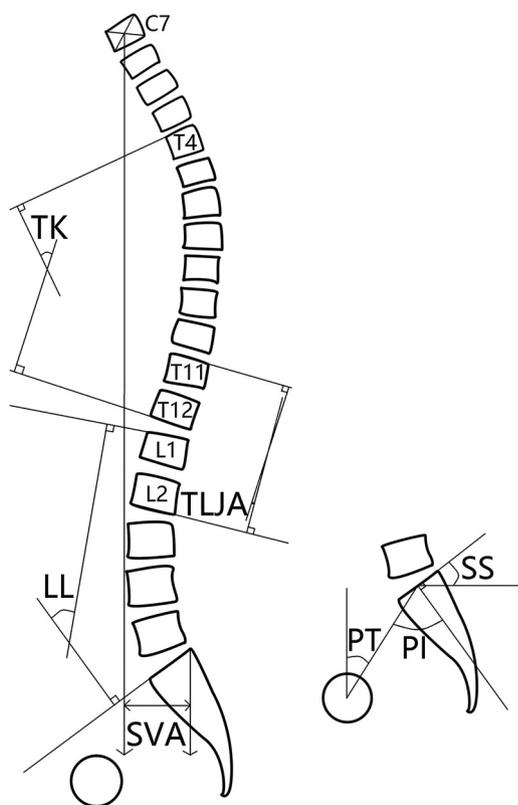
Fig. 2. Measurement of spino-pelvic parameters.
SVA: sagittal vertical axis; LL: lumbar lordosis; TK: thoracic kyphosis; TLJA: thoracolumbar junctional angle; PI: pelvic incidence; SS: sacral slope; PT: pelvic tilt.

defined as a SVA ≥ 40 mm on full spine standing radiographs. Patients were divided into balanced group (group A: preoperative SVA < 40 mm) with 73 cases and imbalanced group (group B: preoperative SVA ≥ 40 mm) with 41 cases. According to postoperative SVA, 41 cases in group B were also divided into recovered group (postoperative SVA < 40 mm) with 27 cases and unrecovered group (postoperative SVA ≥ 40 mm) with 14 cases.

2.2. Indication for MIS-TLIF

Patients who met one of the following conditions underwent MIS-TLIF: 1. LSS combined with degenerative spondylolisthesis (Grade I), 2. LSS combined with segmental instability (slip distance > 5 mm or range of motion > 10° on flexion and extension radiographs), 3. LSS combined with severe calcification of the protruded disc and huge osteophyte of the posterior vertebral body, 4. LSS combined with severe intervertebral disc degeneration (the intervertebral space was significantly narrowed and accompanied with discogenic pain).

2.3. Surgical procedures

LSS patients with or without spondylolisthesis were treated with the similar surgical techniques. Patients were kept in a prone position under general anesthesia. Fluoroscopic C-arm was used to mark L4-L5 pedicles. Under fluoroscopic C-arm machine guidance, Jamshidi needles were inserted into bilateral L4 and L5 pedicles. Then K-wires were inserted through the needles. A skin incision was made between the L4 and L5 K-wires only on the more symptomatic side. Serial dilators were used to split the muscle fibers, and minimally invasive retractor was placed to expose L4-5 facet joints. Subsequently, unilateral facetectomy, decompression, discectomy, and endplate preparation were

Table 1
Results of comparative analysis of group A and group B.

		Group A (n = 73)	Group B (n = 41)	P value
Age (y)		54.2 ± 10.6	55.0 ± 13.7	0.709
Spondylolisthesis (Grade I)		34 (46.6%)	17 (41.5%)	0.598
SVA (mm)	Preop.	−7.2 ± 24.8	90.1 ± 44.4	< 0.01**
	Postop.	−13.2 ± 21.2	34.2 ± 52.4	< 0.01**
	P value	< 0.01**	< 0.01**	
LL (°)	Preop.	44.5 ± 14.8	28.1 ± 15.4	< 0.01**
	Postop.	46.6 ± 12.7	36.9 ± 12.8	< 0.01**
	P value	< 0.01**	< 0.01**	
TK (°)	Preop.	−31.2 ± 13.6	−21.6 ± 11.2	< 0.01**
	Postop.	−33.4 ± 10.2	−30.7 ± 9.8	0.173
	P value	< 0.01**	< 0.01**	
TLJA (°)	Preop.	−6.3 ± 10.6	−2.6 ± 7.7	0.058
	Postop.	−6.0 ± 8.8	−3.1 ± 6.0	0.062
	P value	0.770	0.618	
PI (°)	Preop.	50.5 ± 11.1	54.5 ± 12.6	0.081
	Postop.	50.8 ± 10.7	55.0 ± 11.8	0.054
	P value	0.536	0.483	
SS (°)	Preop.	29.5 ± 9.7	27.1 ± 10.3	0.219
	Postop.	31.5 ± 8.4	30.2 ± 8.5	0.449
	P value	< 0.01**	< 0.01**	
PT (°)	Preop.	21.0 ± 10.7	27.4 ± 9.0	< 0.01**
	Postop.	19.3 ± 9.2	24.8 ± 9.8	< 0.01**
	P value	< 0.05*	< 0.05*	
PI-LL (°)	Preop.	6.0 ± 13.7	26.4 ± 14.8	< 0.01**
	Postop.	4.2 ± 11.6	18.1 ± 13.2	< 0.01**
	P value	< 0.05*	< 0.01**	
VAS-back (/10)	Preop.	4.0 ± 1.3	4.8 ± 2.4	< 0.01**
	Postop.	0.6 ± 0.8	1.0 ± 1.2	0.226
	P value	< 0.01**	< 0.01**	
VAS-leg (/10)	Preop.	4.9 ± 1.7	5.5 ± 2.3	< 0.05*
	Postop.	0.7 ± 1.0	1.1 ± 1.2	0.138
	P value	< 0.01**	< 0.01**	
JOA (/29)	Preop.	15.3 ± 3.2	11.7 ± 4.2	< 0.01**
	Postop.	22.5 ± 2.4	21.5 ± 4.0	0.199
	P value	< 0.01**	< 0.01**	
ODI (/45)	Preop.	20.3 ± 5.1	24.9 ± 7.5	< 0.01**
	Postop.	9.8 ± 3.7	11.4 ± 6.6	0.227
	P value	< 0.01**	< 0.01**	
JOA score improvement ratio (%)		50.8 ± 19.6	54.3 ± 25.7	0.281

SVA: sagittal vertical axis; LL: lumbar lordosis; TK: thoracic kyphosis; TLJA: thoracolumbar junctional angle; PI: pelvic incidence; SS: sacral slope; PT: pelvic tilt; VAS: visual analog scale; JOA: Japanese Orthopaedic Association; ODI: Oswestry Disability Index.
 * P < 0.05 .
 ** P < 0.0 1.

Table 2
Risk factors for sagittal imbalance.

	OR (95% CI)	P value
Age	1.002 (0.957, 1.049)	0.935
LL	1.018 (0.961, 1.078)	0.551
TK	0.950 (0.889, 1.016)	0.134
PT	0.864 (0.772, 0.967)	< 0.05*
PI-LL	1.231 (1.103, 1.375)	< 0.01**

OR: odds ratio; LL: lumbar lordosis; TK: thoracic kyphosis; PT: pelvic tilt; PI-LL: mismatch between pelvic incidence and lumbar lordosis.
 * P < 0.05 .
 ** P < 0.0 1.

performed under microscopy visualization. One cage filled with autologous bone particles and allogeneic bone particles was inserted into the intervertebral space. Then pedicle screws and rods were inserted percutaneously. Finally, set screws were used to tighten the rod. (Fig. 1)

2.4. Radiological assessment

All patients underwent a full spine X-ray examination. According to
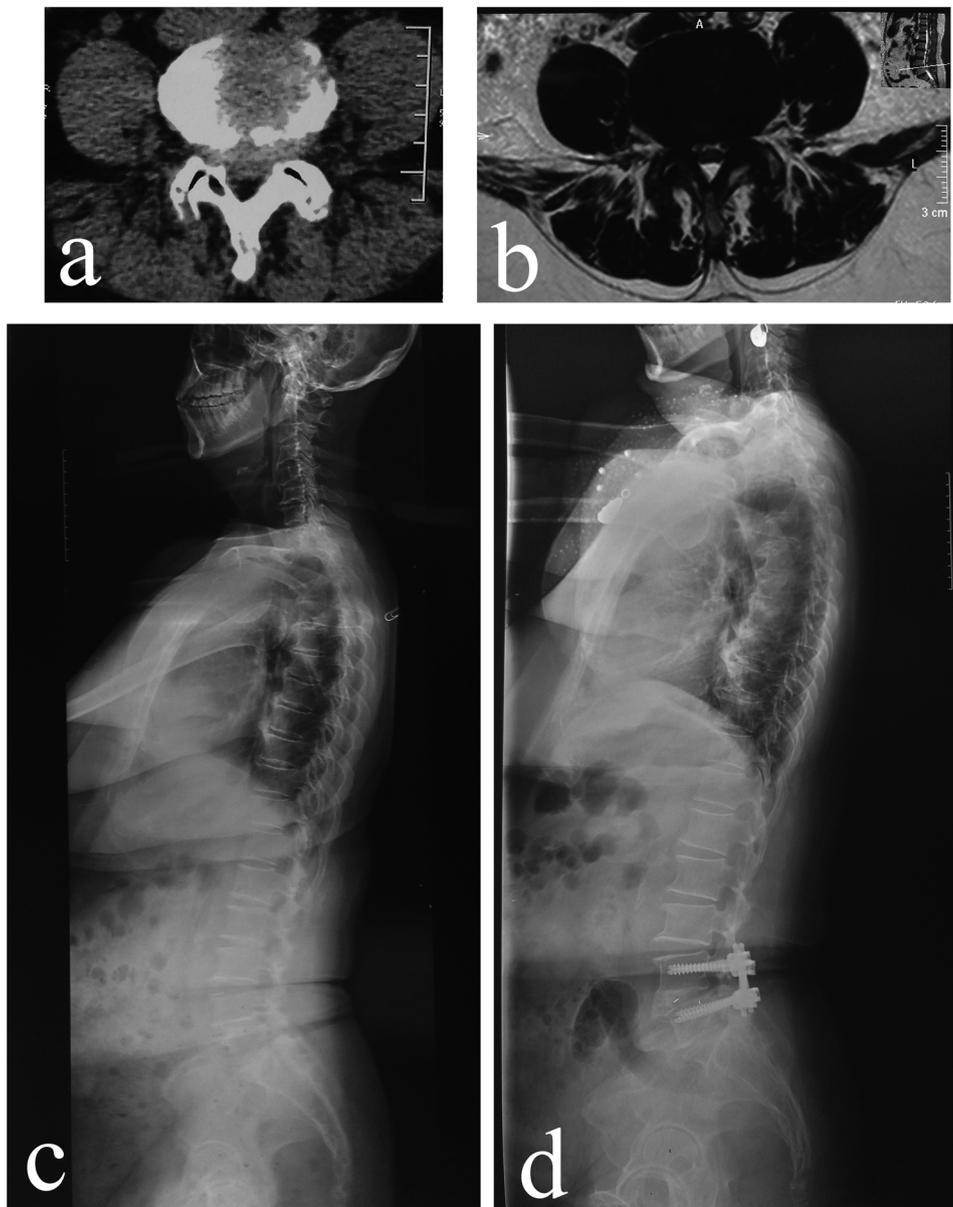
Fig. 3. Typical case 1.
CT and MRI showed LSS at L4-5 level (a, b). Preoperative radiographs showed sagittal balance (SVA = −28.1 mm) (c). Postoperative radiographs showed sagittal balance (SVA = −36.3 mm) at final follow-up (d).

Horton et al., the patients were asked to stand in a comfortable position with their hips and knees fully extended [10]. Radiological parameters included (1) SVA-the horizontal distance between the posterosuperior corner of S1 and C7 plumb line; (2) LL-Cobb's angle between the superior endplate of L1 and S1; (3) TK-Cobb's angle between the superior endplate of T4 and the inferior endplate of T12; (4) thoracolumbar junctional angle (TLJA)-Cobb's angle between the superior endplate of T11 and the inferior endplate of L2; (5) PI- the angle between the line perpendicular to the sacral plate at its midpoint and the line connecting this point to the femoral heads axis; (6) PT-the angle between the vertical line and the line connecting the midpoint of sacral plate to the femoral heads axis; and (7) sacral slope (SS)-the angle between the sacral plate and the horizontal line. Lordotic angles were noted as positive, and kyphotic ones were noted as negative. The measuring method was shown in Fig. 2.

2.5. Clinical evaluations

Clinical outcomes and lumbar function were evaluated by using visual analog scale (VAS) score, Japanese Orthopaedic Association (JOA) score and Oswestry Disability Index (ODI). A 10-cm VAS was used to assess pain or numbness. A score of 0 indicates no pain or numbness, while a score of 10 indicates the worst imaginable pain or numbness [11]. The JOA score improvement ratio (%) was calculated as follows: (postoperative JOA score - preoperative JOA score)/(29 - preoperative JOA score) $\times$ 100% [12]. The ODI was used to evaluate lumbar function [13].

2.6. Statistical analysis

The collected data were statistically analyzed using SPSS 22.0 software (SPSS, IBM Corporation, USA). Comparisons between groups were analyzed by Student's t-test, Chi-square test and non-parametric test. The risk factors of sagittal imbalance were analyzed by one-way
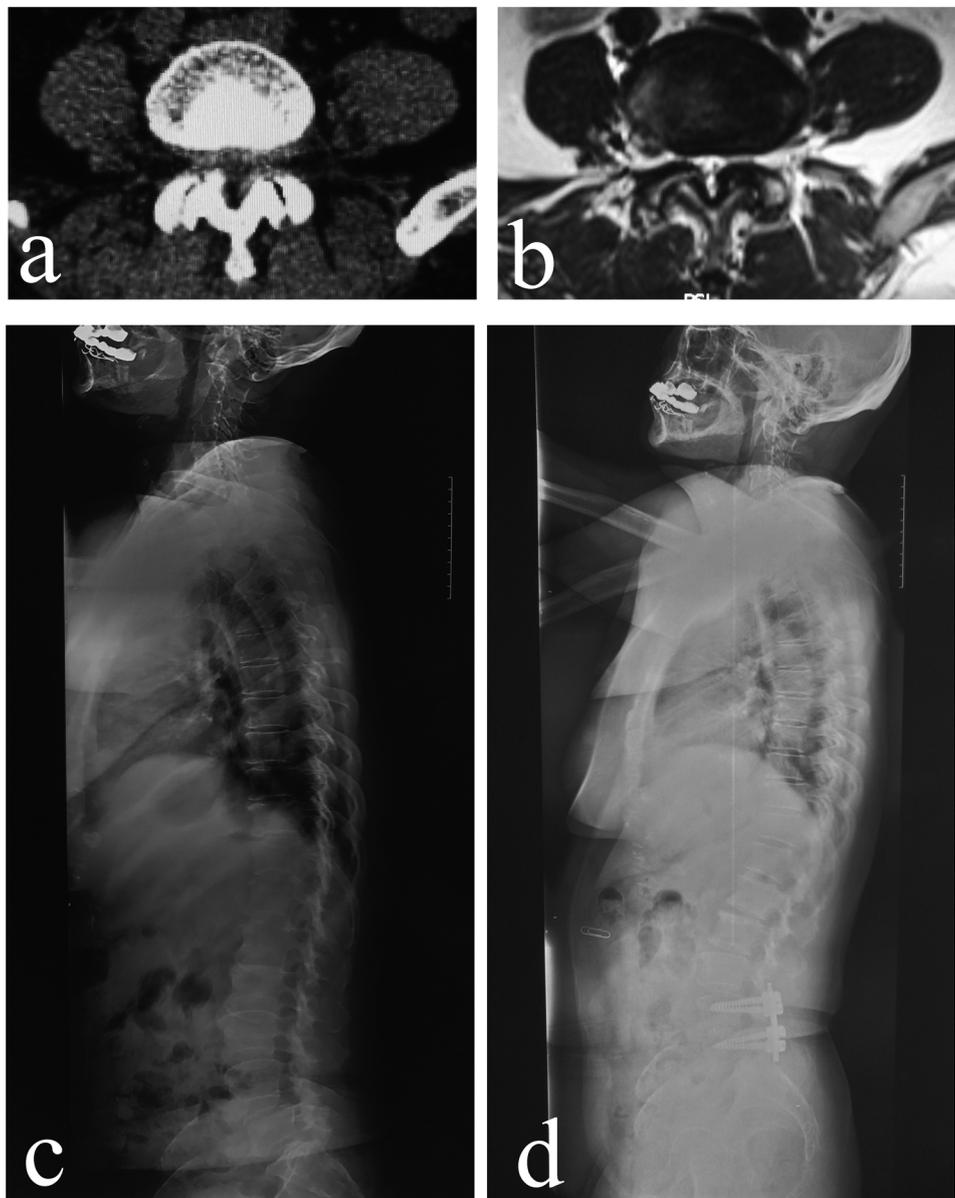
Fig. 4. Typical case 2.
CT and MRI showed LSS at L4-5 level (a, b). Preoperative radiographs showed sagittal imbalance (SVA = 71.5 mm) (c). Postoperative radiographs showed sagittal balance was restored (SVA = −12.5 mm) at final follow-up (d).

ANOVA and logistic regression analysis. A paired t-test was used to compare pre- and postoperative radiological parameters. A p < 0.05 was considered as statistically significant.

3. Results

3.1. Risk factors associated with sagittal imbalance

The incidence of preoperative sagittal imbalance in LSS patients was 36.0% (41/114). Table 1 exhibits the differences between the group A and group B, showing that preoperative LL and TK were significantly smaller, while preoperative PI-LL and PT were significantly larger in the group B compared with the group A. Chi- square analysis showed that there was no significant correlation between preoperative sagittal imbalance and spondylolisthesis (p = 0.598) (Table 1). One-way ANOVA analysis revealed that age, LL, TK, PT and PI-LL were suitable for logistic regression analysis. Moreover, logistic regression analysis showed that larger PI-LL was the risk factor associated with sagittal imbalance

(Table 2).

3.2. Effect of preoperative sagittal imbalance on clinical outcomes

Table 1 illustrates the improvement of sagittal parameters after MIS-TLIF. Single-segment MIS-TLIF led to a significant decrease in SVA, PT and PI-LL, as well as a significant increase in LL, TK and SS in both group A and group B (Table 1, Figs. 3 and 4). Preoperatively, the VAS, JOA and ODI scores were significantly poorer in patients with sagittal imbalance compared with those without sagittal imbalance (Table 1). After MIS- TLIF, all clinical outcomes improved significantly. However, there was no significant difference in postoperative VAS, JOA and ODI scores between the group A and group B (Table 1).

3.3. Impact of sagittal imbalance correction on clinical outcomes

Patients in the recovered group and unrecovered group were compared in Table 3. There were 41 patients with preoperative sagittal

Table 3
Results of comparative analysis of recovered group and unrecovered group.

	Recovered group	Unrecovered group	P value
Age (y)	54.6 ± 11.8	55.9 ± 17.4	0.766
Spondylolisthesis (Grade I)	13 (48.1%)	4 (28.6%)	0.228
Preop. SVA (mm)	64.3 ± 17.1	140.0 ± 37.6	< 0.01**
Preop. LL (°)	32.6 ± 14.7	19.5 ± 13.1	< 0.01**
Preop. TK (°)	− 24.4 ± 10.8	− 16.1 ± 10.3	< 0.05*
Preop. TLJA (°)	− 2.6 ± 7.7	− 2.7 ± 7.9	0.962
Preop. PI (°)	52.7 ± 13.1	58.1 ± 11.2	0.201
Preop. SS (°)	27.4 ± 10.9	26.5 ± 9.6	0.803
Preop. PT (°)	25.3 ± 7.7	31.5 ± 10.2	< 0.05*
Preop. PI-LL (°)	20.1 ± 12.9	38.6 ± 10.1	< 0.01**
Preop. VAS-back (/10)	4.9 ± 2.5	4.6 ± 2.2	0.471
Preop. VAS-leg (/10)	5.6 ± 2.2	5.3 ± 2.7	0.881
Preop. JOA (/29)	11.9 ± 3.7	11.4 ± 5.3	0.488
Preop. ODI (/45)	24.1 ± 7.3	26.4 ± 8.1	0.391
Postop. VAS-back (/10)	0.9 ± 1.3	1.1 ± 1.1	0.559
Postop. VAS-leg (/10)	1.1 ± 1.2	1.1 ± 1.4	0.881
Postop. JOA (/29)	21.4 ± 4.1	21.8 ± 3.8	0.903
Postop. ODI (/45)	11.1 ± 6.6	12.0 ± 6.8	0.615
JOA score improvement ratio (%)	55.5 ± 20.9	51.9 ± 33.9	0.968

SVA: sagittal vertical axis; LL: lumbar lordosis; TK: thoracic kyphosis; TLJA: thoracolumbar junctional angle; PI: pelvic incidence; SS: sacral slope; PT: pelvic tilt; PI-LL: mismatch between pelvic incidence and lumbar lordosis; VAS: visual analog scale; JOA: Japanese Orthopaedic Association; ODI: Oswestry Disability Index.

  * $P < 0.05$.
  ** $P < 0.01$.

imbalance, and the balance recovery rate was 65.9% (27/41) after 2 years. We found that the preoperative SVA, PT, and PI-LL were significantly larger, while preoperative LL and TK were significantly smaller in the unrecovered group (Table 3). Failure of sagittal balance restoration was observed in patients with a preoperative SVA ≥ 80 mm (Fig. 5). And no significant difference in postoperative VAS, JOA, ODI scores and JOA score improvement ratio was found between the two groups (Table 3). There was no correlation between the improvements of sagittal imbalance and 2-year clinical outcomes.

4. Discussion

4.1. Risk factors associated with sagittal imbalance

Sagittal balance refers to a sagittal curvature, in which an individual can maintain a stable standing posture with minimal muscular strength. Most LSS patients tend to exhibit a forward-bending posture when standing or walking. And preoperative imaging examination often reveals sagittal imbalance in LSS patients. The main features of LSS sagittal imbalance include 1. C7 plumb line forward, 2. decrease in LL, 3. increase in TK, and 4. increase in PT [14–16]. Abbas et al. have found that the LL and SS are significantly smaller in LSS patients compared with the asymptomatic subjects [17]. In this study, sagittal imbalance was observed in 36.0% of patients. And the sagittal parameters were significantly different between the balanced group and imbalanced group. LL and TK were significantly smaller, and PI-LL and PT were significantly larger in the imbalanced group compared with the balanced group. The rate of spondylolisthesis in LSS patients was 44.7% (51/114), however there was no correlation between spondylolisthesis and sagittal imbalance (Table 1). The risk factors for sagittal imbalance were large PI-LL (Table 2). Other risk factors for sagittal imbalance noted in the literature include old age, high PT and low TK [18–20]. In this study, the average age of the patients in the imbalanced group was greater than that in the balanced group, but there was no statistical significance due to the small sample size. When the sagittal imbalance occurs, the compensatory mechanisms limit the consequences of lumbar kyphosis [15]. Barrey et al. have found the main compensatory

mechanisms include reduction of TK, intervertebral hyperextension, retrolisthesis, pelvis backward, knee flexion and ankle extension, and this basic concept has been extended to adjacent segments of the kyphotic spine [16]. Logistic regression analysis of this study revealed that larger PT was a protective factor of sagittal balance (Table 2). Therefore, pelvic compensation might play an important role in maintaining sagittal balance, which was consistent with the above-mentioned findings.

4.2. Effect of preoperative sagittal imbalance on clinical outcomes

Fujii et al. have found that 54% of patients with sagittal imbalance have good ZCQ scores after decompression without fusion [7]. Dohzono et al. have demonstrated that there is no significant correlation between preoperative sagittal imbalance and postoperative JOA score after microendoscopic laminotomy in patients with LSS [20]. Cho et al. have retrospectively analyzed 88 LSS cases with spondylolisthesis and found that there is no significant difference in the improvement of VAS and ODI scores between the balanced group and imbalanced group, suggesting that preoperative sagittal imbalance has no effect on clinical outcomes in patients undergoing a short-level lumbar fusion surgery for LSS [21]. Preoperatively, the VAS, JOA and ODI scores were significantly poorer in patients with sagittal imbalance compared with those without sagittal imbalance in our study. After MIS-TLIF, all clinical outcomes improved significantly. However, there was no significant difference in postoperative VAS, JOA and ODI scores between the balanced group and imbalanced group. There was no significant correlation between preoperative sagittal imbalance and clinical outcomes, which was consistent with Hikata et al. [18].

4.3. Impact of sagittal imbalance correction on clinical outcomes

Shin et al. have demonstrated that 17 patients exhibit an SVA ≥ 80 mm, 12 (71%) patients display improved sagittal imbalance after decompression surgery, and it is difficult to restore the sagittal balance with simple decompression for patients with spondylolisthesis and smaller TK before operation [19]. Fujii et al. have demonstrated that sagittal imbalance is normalized in 43% (28 out of 65) of patients after decompression surgery, and found that sagittal recovery is not successful in patients with preoperative PI-LL > 21.5° or SVA > 69 mm, while postoperative sagittal imbalance is not correlated with clinical outcomes [7]. Hikata et al. have found that sagittal balance cannot be restored in patients with severe sagittal imbalance (SVA > 80 mm) after decompression surgery, while postoperative sagittal imbalance negatively affect clinical and HRQOL outcomes [18]. In our study, there were 41 patients with preoperative sagittal imbalance. Sagittal imbalance was normalized in 65.9% of patients after more than 2 years. Failure of sagittal balance restoration was observed in patients with a preoperative SVA ≥ 80 mm (Fig. 5). Most LSS patients with preoperative sagittal imbalance could effectively restore sagittal balance by single-segment MIS-TLIF. Therefore, the sagittal imbalance in LSS patients was mostly functional and posture-protective, not structural. To our best knowledge, there are a few studies that have directly evaluate the effect of sagittal imbalance correction on clinical outcomes in patients undergoing single-segment MIS-TLIF for LSS. Our results showed that there was no significant difference in postoperative VAS, JOA and ODI scores between the recovered group and unrecovered group, indicating that there was no correlation between the improvements of sagittal imbalance and 2-year clinical outcomes. Therefore, even if there is postoperative sagittal imbalance, it does not mean that patient really suffers from LBP and leg pain caused by sagittal imbalance. Collectively, the clinical efficacy should be determined by whether the decompression is sufficient. Moreover, the preoperative sagittal imbalance in LSS patients might not be the objective basis for deciding whether the imbalance needed to be corrected.
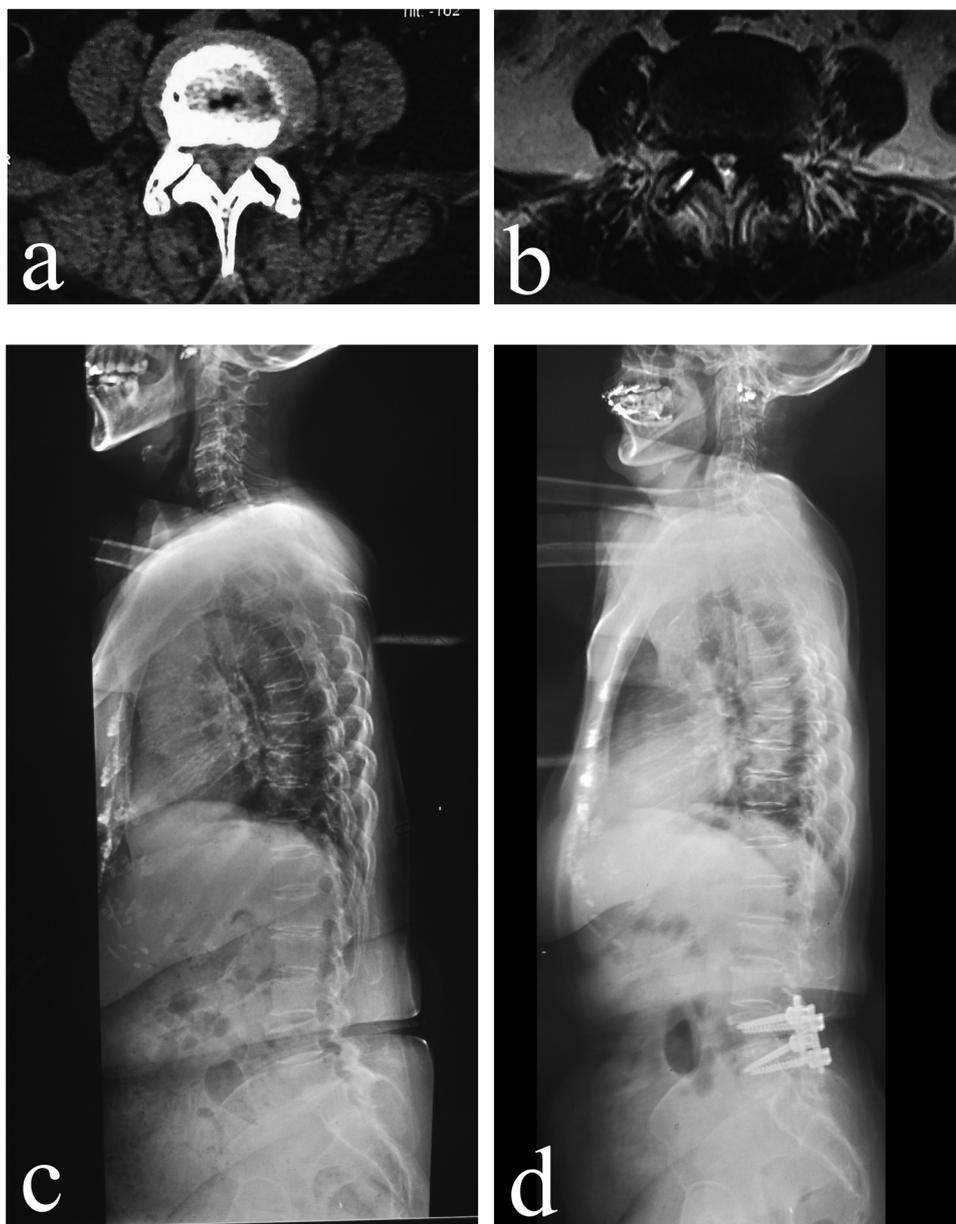
Fig. 5. Typical case 3.
CT and MRI showed LSS at L4-5 level (a, b). Preoperative radiographs showed sagittal imbalance (SVA = 98.9 mm) (c). Postoperative radiographs showed sagittal imbalance was not restored (SVA = 48.7 mm) at final follow-up (d).

4.4. Limitations

First, the retrospective nature of the study caused bias. Therefore, larger prospective studies are necessary. Second, a 2-year follow-up period might not be sufficient to show the changes in sagittal parameters after operation.

5. Conclusions

Sagittal imbalance was normalized in 65.9% of patients after 2 years. A significant proportion of LSS patients with preoperative sagittal malalignment had a compensatory mechanism rather than a structural malalignment, while single-segment MIS-TLIF could effectively improve sagittal imbalance at 2-year follow- up. In this series, we found no correlation between the improvements of sagittal imbalance and 2-year clinical outcomes. Reconstruction of sagittal balance might not be the main goal of single-segment MIS-TLIF for LSS, and did not affect its

clinical results at two-year follow- up.

Conflicts of interest

The authors declare that they have no conflicts of interest.

Acknowledgments

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