


CLINICAL ARTICLE

Mid- and Long-Term Comparison Analysis of Two Approaches for the Treatment of Level III or Higher Lenke–Silva Adult Degenerative Scoliosis: Radical or Limited Surgery?

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Objective: As the population in general is living longer, less invasive adult degenerative scoliosis (ADS) surgery that balances risks and benefits requires long-term clinical outcomes to determine its strengths and weaknesses. We design a retrospective study to compare the postoperative mid- and long-term outcomes in terms of efficacy, surgical complications, and reoperation rate of patients with ADS treated with two different surgical approaches (long-segment complete reconstruction or short-segment limited intervention).

Methods: In this retrospective study, 78 patients with ADS (Lenke–Silva levels III or higher), who accepted surgical treatment at our hospital between June 2012 and June 2019 were included. These patients were assigned to the long-segment radical group (complete decompression with deformity correction involves ≥ 3 segments) and the short-segment limited group (symptomatic segment decompression involves < 3 segments). In addition, general information such as age, gender, fixed segment number, efficacy, radiographic parameters, and reoperation rate of patients in the two groups were compared and analyzed.

Results: There were no significant differences between the two groups with regard to gender, follow-up time, long-term surgical complications and reoperation rate ($P > 0.05$). The mean age of patients in the long-segment strategy group was 57.1 ± 7.9 years, with a mean number of fixed segments of 7.9 ± 2.4 . The mean age of patients in the short-segment strategy group was 60.8 ± 8.4 years, with a mean number of fixed segments of 1.4 ± 0.5 . At the final follow-up visit, the long-segment radical group showed better results than the short-segment limited group with regard to coronal Cobb angle, lumbar lordosis angle and sagittal balance ($P < 0.05$). The long-segment strategy group had a higher implant-related complication rate ($P = 0.010$); the adjacent segment-related complication in the two groups showed no significant difference ($P = 0.068$).

Conclusion: Considering the risk, rehabilitation pathway and costs of long-segment radical surgery, short-segment limited intervention is a better strategy for patients who cannot tolerate the long-segment surgery, improving symptoms and maintaining efficacy in the mid- and long-term, and not increasing the reoperation rate.

Key words: Adult degenerative scoliosis; Long-segment fixation; Postoperative complication; Reoperation; Short-segment fixation

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Introduction

Adult degenerative scoliosis (ADS) refers to the coronal spine deformity (Cobb's angle $> 10^\circ$) caused by the asymmetric degeneration of the vertebra, intervertebral disc, or facet joint after skeletal maturity. The occurrence and development of most ADS cases are related to spinal degeneration factors.¹ The incidence of ADS was increasing with age^{1,2} and was reported to be 32%–68% among patients over 65 years old.

The number of ADS patients is expected to increase significantly over the coming decades with the accelerated trend of people living longer. In addition, it is of concern that spinal deformity surgeries in older patients are complex, involving surgical complications and long operative times. A comparative study including 1,245,282 surgical ASD patients showed that if surgery involves ≥ 7 segments, its Surgical Invasiveness and Morbidity Score (SIMS) ranked fourth *versus* other major operations, after coronary artery bypass grafting, abdominal aortic aneurysm repair and cystectomy.³ As a result, increasing efforts are devoted to reducing complications and improving the quality of life for ADS patients instead of implementing radical spinal correction surgery. According to the analysis of the largest multicenter prospective datasets on quality metrics in adult spinal deformity surgery over the last decade, this change has been beneficial for patients. The results show that the baseline clinical characteristics have not changed since 2010, while a consistent reduction in major and minor postoperative complications and a greater gain in quality of life were observed. These are associated with a progressive reduction of surgical aggressivity (number of fused spine segments, percent pelvic fixation and percent 3-column osteotomies).⁴ However, it still requires long-term follow-up to improve reliability. Besides the factors of patient management and surgical techniques, the choice of surgical strategy plays a more important role in ADS surgery. Silva and Lenke recommended a surgical plan with increasing invasiveness based on the progression of the spinal deformity,⁵ while Berjano *et al.* tend to focus on symptomatic segments rather than deformity correction.⁶ Due to the large individualized differences in clinical manifestations of patients with ADS, the patients' general condition and expectations for treatment should be fully considered in the surgery planning.⁷ It has been shown that long-segment reconstruction surgery has a good effect in correcting the spinal deformity and that the global balance of the spine can be better maintained after surgery. Moreover, the palliative short-segment intervention can improve patients' main symptoms with lower costs and risks.⁸ However, the reality is that the high perioperative complication incidence of the long-segment strategy and the high incidence of postoperative adjacent segment degeneration of the short-segment strategy make the two strategies controversial,^{9–12} especially in elderly patients. There are always factors related to spinal degeneration during the preoperative and postoperative course of patients with ADS, so a considerable part of these controversies relates to the lack of long-term follow-up studies to confirm efficacy and long-term complications for surgical decision-making.¹³

All in all, a less invasive ADS surgery strategy requires long-term clinical outcomes to determine its strengths and weaknesses. This study focuses on the outcomes of patients with Lenke Silva level III or higher (long segment fixation and fusion recommended) who received two different surgical strategies with an average follow-up of 4.4 years (2–9 years). The purposes were: (i) to determine the efficacy, implant-related complications, adjacent segment problems and reoperation rate of the two surgical strategies in mid- and long-term follow-up; and (ii) based upon the reoperation, to identify whether the limited intervention has worse outcomes compare to the radical surgery. We hypothesized that the long-segment radical strategy had a better efficacy, fewer implant-related complications and adjacent segment problems.

Materials and Methods

Inclusion and Exclusion Criteria

Inclusion criteria included: (i) age 45 years or older; (ii) all patients were diagnosed as ADS due to lumbar degeneration, presented with low back pain and lower limb symptoms; (iii) imaging parameters met the criteria of Lenke–Silva level III or higher (in detail, Cobb's angle $> 30^\circ$,olisthesis $> 2\text{mm}$, with or without lumbar kyphosis, with or without global imbalance); (iv) duration of follow-up > 2 years; and (v) long-segment refers to the fixed and fused segments ≥ 3 ; short-segment refers to the fixed and fused segments < 3 .

Exclusion criteria included: (i) patients with ADS secondary to lumbar fracture, tumor, ankylosing spondylitis or leg length discrepancy; (ii) patients who had received any surgical treatment at symptomatic segments (drug injection, minimally invasive decompression or laminectomy); and (iii) ADS patients with compensatory posture because of radicular pain or acute back pain (this would lead to spurious imaging parameters).

General Information

Seventy-eight patients with ADS between June 2012 and June 2019 met the criteria and were admitted to this study. There were 36 cases in the long-segment group (17 males and 19 females, mean age of 57.1 ± 7.9 years) and 42 cases in the short-segment group (16 males and 26 females, mean age of 60.8 ± 8.4 years). The specific clinicopathological data are shown in Table 1.

Operation Plan

Two spinal surgeons performed the physical examination to determine the patients' sensitivity, motor function, reflexes, and bladder/rectal function. Symptomatic segments and their range of motion were confirmed by combining the patients' X-ray and/or electromyogram data. The principle of treatment was to improve symptoms and control the progression of the deformity, not to correct the deformity. Decompression and fusion of long segments ($n \geq 3$) were performed if the patient had extensive symptomatic segments and/or

TABLE 1 Clinical data of patients accepted two strategies

Items	Long-segment (n = 36)	Short-segment (n = 42)	t/ χ^2	P
Gender (male/female)	17/19	16/26	0.804	0.416
Age (year)	57.1 ± 7.9	60.8 ± 8.4	-2.047	0.044*
Number of fixed segments	7.9 ± 2.4	1.4 ± 0.5	17.239	0.000*
Follow-up duration (year)	4.3 ± 1.8	4.5 ± 1.6	-0.591	0.556
Cobb's angle (°)				
Preoperative	36.6 ± 9.4	30.5 ± 7.9	2.505	0.015*
Postoperative	7.6 ± 5.1	10.1 ± 6.3	-1.936	0.053
Final follow-up	11.1 ± 5.4	16.4 ± 5.7	-4.221	0.000*
Lumbar lordosis angle (°)				
Preoperative	6.5 ± 10.5	11.9 ± 16.1	-2.138	0.056
Postoperative	24.4 ± 8.2	23.8 ± 11.5	0.292	0.771
Final follow-up	25.4 ± 8.1	17.1 ± 7.2	4.778	0.025*
Coronal balance (mm)				
Preoperative	27.6 ± 11.5	23.7 ± 13.9	1.354	0.180
Postoperative	16.8 ± 7.9	13.6 ± 9.9	1.580	0.112
Final follow-up	16.7 ± 8.4	20.8 ± 12.3	-1.720	0.090
Sagittal balance (mm)				
Preoperative	47.8 ± 20.8	32.5 ± 12.3	4.019	0.000*
Postoperative	13.6 ± 9.9	17.9 ± 10.4	-1.887	0.063
Final follow-up	20.9 ± 12.8	35.5 ± 22.9	-3.380	0.001*
VAS scores of Low back pain				
Preoperative	6.0 ± 1.4	5.3 ± 1.7	1.744	0.082
Postoperative	2.6 ± 1.3	2.5 ± 1.0	0.597	0.552
Final follow-up	2.7 ± 1.0	3.0 ± 2.1	-0.932	0.355
VAS scores of leg pain (numbness)				
Preoperative	4.4 ± 2.0	5.3 ± 2.0	-1.947	0.055
Postoperative	2.4 ± 1.4	2.6 ± 1.9	-0.308	0.759
Final follow-up	1.8 ± 1.1	2.2 ± 1.8	-1.386	0.184

Note: VAS indicates visual analogue scale; * indicates $P < 0.05$

multiple segment instability and/or major symptoms caused by poor coronal and sagittal alignment. If it was determined that the symptoms originated from one or two segments, short segment surgery ($n < 3$) was performed only for symptomatic segments, regardless of the deformity. Moreover, after a comprehensive assessment by the multidisciplinary team, a limited intervention should be discussed for those who cannot tolerate major surgery. For patients with severe comorbidities, foregoing surgery is the only option.

Evaluation Indices

The general information and perioperative and postoperative follow-up clinical data were included. In particular, as described in Lenke-Silva classification, Cobb's angle $< 45^\circ$ without severe sagittal imbalance is considered to have little relationship with low back pain, while Sagittal vertical axis (SVA) < 5 mm does not meet the diagnostic criteria of sagittal imbalance. We did not think that the statistical differences in Cobb's angle and SVA between the two groups reach the distinguishing criteria.⁵

Efficacy Evaluation

The preoperative, postoperative, and final follow-up visual analogue scale (VAS) scores of patients for low back pain and leg pain (numbness).

Radiographic Evaluation

Coronal Cobb's Angle

Cobb's angle is defined as the greatest angle at a curve of the spine, measured from the upper endplate of a upper vertebra to the lower endplate of a lower vertebra, using a standing, full-spine X-ray image in the anteroposterior view. It is used to assess the severity of scoliosis.

Lumbar Lordosis (LL) angle

It is defined as the angle measured between the upper endplate of L1 and the upper endplate of S1 using plain X-ray images of the lateral lumbar spine in the standing position. In general, the LL angle should greater than 10° and is used to assess the local sagittal malalignment of the spine.

Coronal Balance (C7PL-CSVL)

In evaluating imaging parameters of coronal imbalance, the horizontal distance between the C7 plumb line (C7PL) and the center sacral vertical line (CSVL) is often used to assess the global balance of the spine. A value > 3 cm is defined as coronal imbalance.

Sagittal Balance (SVA)

The Sagittal vertical axis (SVA) is usually determined using the C7 plumb line method; that is, by measuring the vertical distance between C7PL and the upper back corner of the S1 endplate. A value > 5 cm is defined as sagittal imbalance.

Complication Evaluation

Implant-related complications, adjacent segment-related complications, and global imbalance were evaluated. Implant-related complications include screw/rod broken, pseudarthrosis and screw loosening. The adjacent segmental complications of the long segment included proximal junctional kyphosis (PJK) and proximal junctional failure (PJF); those of the short segment included radiographic adjacent segmental degeneration (RASD) and clinical adjacent segmental degeneration (CASD).

Proximal Junctional Kyphosis (PJK)

The proximal junction was defined as the lower endplate of the upper instrumented vertebra (UIV) to the upper endplate two vertebrae proximal. PJK was defined by two criteria: (i) proximal junction sagittal Cobb angle $\geq 10^\circ$; and (ii) proximal junction sagittal Cobb angle at least 10° greater than the preoperative measurement.¹⁴

Proximal Junctional Failure (PJF)

Based on PJK, PJF has one or more of the following features: fracture of the vertebral body of the UIV or UIV + 1, posterior osseoligamentous disruption, or pullout of instrumentation at the UIV.¹⁵

Radiographic Adjacent Segmental Degeneration (RASD)

The diagnostic criteria of RASD: (i) height loss of anterior, middle and posterior intervertebral disc ≥ 1 mm; (ii) anterior, posterior or lateral spondylolisthesis ≥ 3 mm; (iii) vertebral rotation $> 1^\circ$; (iv) grade two or three (Weiner's classification) of intervertebral disc degeneration; and (v) grade four or five (Pfirrmann's classification) of intervertebral disc degeneration evaluated by MRI (magnetic resonance imaging).¹⁶

Clinical Adjacent Segmental Degeneration (CASD)

The diagnostic criteria of CASD were: VAS score of recurrent low back pain > 3 points or recurrent radiating pain in lower limbs.¹⁶

Statistical Methods

The SPSS version 25 (IBM, Armonk, NY, USA) was used for data entry and statistical analysis. The measurement data were expressed as mean and standard deviation, the independent samples I-test was performed for comparisons between two groups and the paired samples I-test was used for within-groups comparisons. Count variables were expressed by frequency and percentage (%) and Fisher's exact probability method was used for comparison between groups. Log-Rank test was performed for the analysis of survival differences. A P -value < 0.05 indicated a statistically significant difference in all analyses.

Results**General Information**

The general information and clinical data of patients in the two groups are shown in Table 1. Due to the greater surgical trauma and high risk of the long-segment strategy, the patients who accepted it were mainly younger with fewer comorbidities than those who accepted the short-segment strategy. Compared to the short-segment strategy, coronal Cobb angle, LL angle and sagittal balance can be better maintained in the long-term with the long-segment approach ($P < 0.05$). However, there were no significant differences in the improvement and maintenance of symptoms between the two groups. And coronal balance also shows no difference between groups.

Long-Term Complications

The mean follow-up duration was 4.7 ± 1.67 years (2–9 years) and the comparison of long-term complications between the two treatment strategies is shown in Table 2. The total complication rate of the long-segment strategy was 38.9% and that of the short-segment strategy was 40.5%, showing no significant

TABLE 2 Long-term complications of patients accepted two strategies

Items	Long-segment (n = 36)		Short-segment (n = 42)		χ^2	P
	Case (n)	Percentage (%)	Case (n)	Percentage (%)		
Long-term complication	14	38.9	17	40.5	0.020	0.886
Implant-related complication	8	22.2	1	2.4	7.476	0.010*
Broken screw/rod	6	16.7	0	0	7.583	0.008*
Pseudarthrosis	1	3.8	0	0	6.625	0.012*
Screw loosening	2	5.6	1	2.4	1.074	0.553
Adjacent segment-related complication	3	8.3	10	23.8	3.343	0.068
Proximal junctional kyphosis	2	5.6	-	-		
Proximal junctional failure	1	3.8	-	-		
RASD	-	-	10	23.8		
CASD	-	-	4	9.5		
Coronal imbalance	1	3.8	6	14.3	3.143	0.116
Sagittal imbalance	3	8.3	8	19.0	1.837	0.175
Global imbalance	0	-	3	7.1	7.159	0.009*

Notice: * indicates $p < 0.05$. RASD, radiographic adjacent segmental degeneration; CASD, clinical adjacent segmental degeneration.

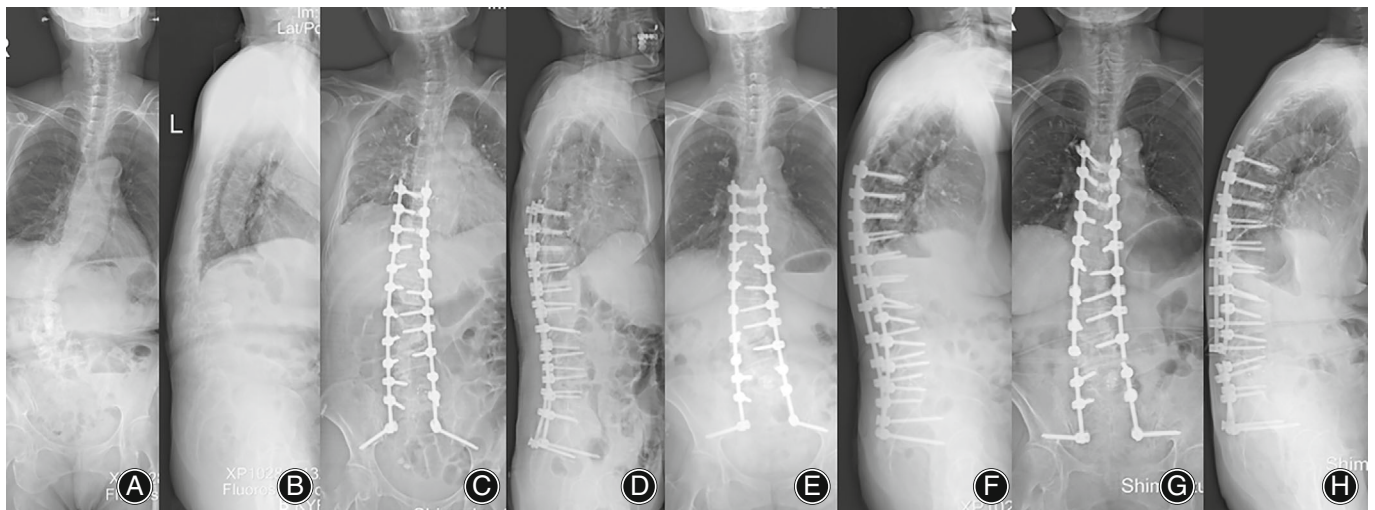


Fig. 1 A 72-year-old female patient was diagnosed with ADS. The main symptoms were continuous and severe low back pain (VAS score: 8 points) and radiating pain in the right lower limb (VAS score: 5 points). A&B, preoperative; C&D, postoperative, long-segment strategy, L5-S1PLIF, the upper instrumented vertebra: T8, the lower instrumented vertebra: S2; E&F, 2 years after the surgery, the coronal balance was well, but the sagittal alignment was worse. Proximal junctional kyphosis: 24° , reduction of lumbar lordosis and posterior pelvic tilt; G&H, 3 years after the surgery, the implant was broken, the developed coronal imbalance and no complaint of obvious low back pain. The patient was demand at follow-up every 6 months

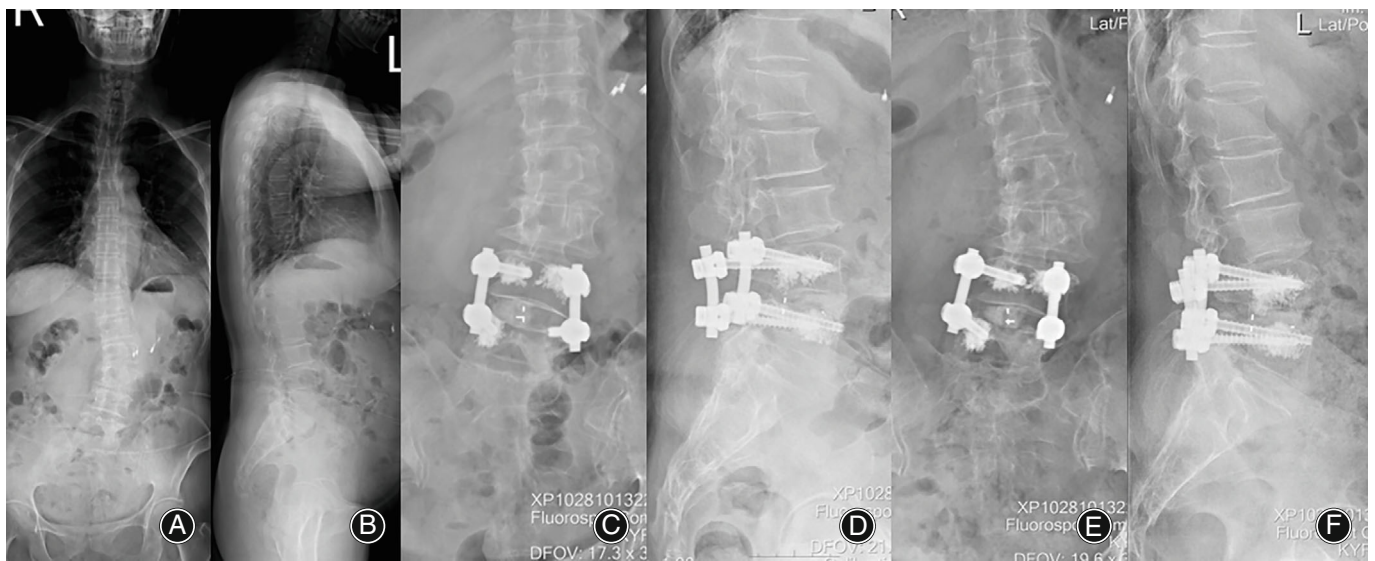


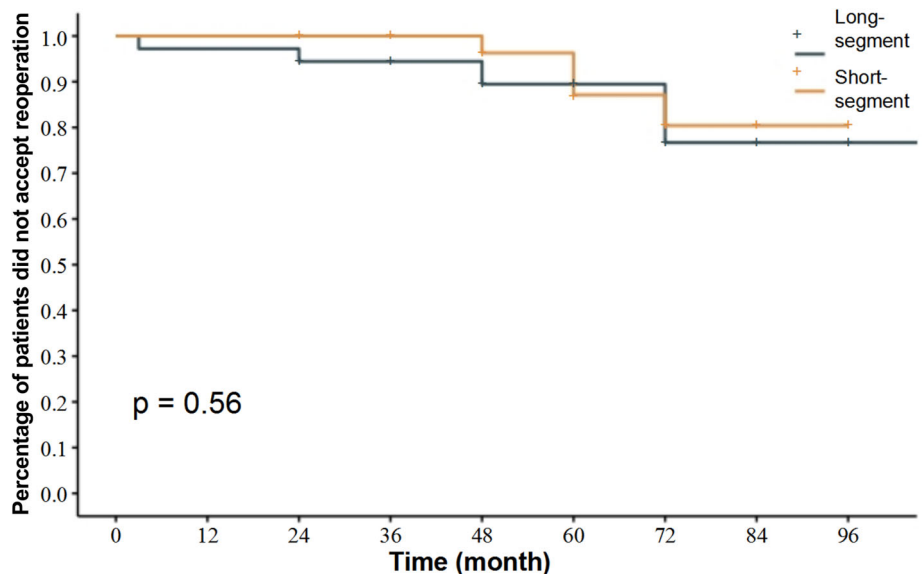
Fig. 2 A 64-year-old female patient was diagnosed with ADS. The main symptoms were low back pain (VAS score: 6 points) and radiating pain in the lower limbs (VAS score: 8 points). The symptomatic segment was localized on L4-5. The patient combined server osteoporosis, hypertension, and diabetes. A&B, preoperative; C&D, short-segment strategy, 2 years after the surgery, the patient had slight low back pain (VAS score: 2 points); E&F, 5 years after the surgery, the coronal Cobb's angle increased, L3 rotated (degree of II) and the patient was diagnosed with radiographic adjacent segmental degeneration. There were no clinical symptoms, and the patient was required to receive regular follow-up

difference ($P = 0.886$). The incidence of implant-related complications in long-segment strategy was significantly higher than that in short-segment strategy, whereas there was no significant

difference in adjacent-segment-related problems between the two strategies ($P = 0.068$). One of the patients who received the long-segment strategy developed a sagittal imbalance with

TABLE 3 Reoperation rate of patients accepted two strategies

Follow-up duration	Long-segment (n = 36)		Short-segment (n = 42)		χ^2	P
	Case (n)	Percentage (%)	Case (n)	Percentage (%)		
0–2 years	2	5.6	0	0	2.395	0.210
2–5 years	1	2.8	3	7.1	0.759	0.620
5–8 years	1	2.8	1	2.4	0.012	1.000
Total	4	11.1	4	9.5	0.053	1.000

**Fig. 3** The survival curves of the reoperation of the two strategies

implant failure and proximal junctional kyphosis. Typical cases are illustrated in Figs 1 and 2.

Reoperation

The comparative analysis for the reoperation rate of the two surgical strategies started from the immediate post-operative period until the end of follow-up. In the long-segment group, 44% of the patients were followed up for more than 5 years (16/36) while the percentage in the short-segment was 48% (20/42) ($P > 0.05$). Table 3 shows the reoperation rate in the different periods. Among the patients who received the long-segment strategy, two patients were reoperated within 2 years after surgery due to screw breakage and proximal junctional fracture, one patient was reoperated due to loosening of the S1 screw (fixation at the pelvis), and one patient was reoperated due to sagittal imbalance induced by severe lumbar pain (extended fixation at the upper thoracic vertebra). Three patients in the short-segment strategy group accepted reoperation for CASD. One patient underwent reoperation for L3-L4 and L5-S1 due to the upper segment instability and radiation pain in the lower limb after posterior lumbar interbody fusion (PLIF) of L4-5, one patient underwent oblique lumbar interbody fusion (OLIF) revision surgery for

upper segment spinal stenosis and one patient accepted endoscopic discectomy for upper segment disc herniation. Another patient who received the short-segment strategy underwent L1-S1 long-segment revision surgery due to poor fusion, implant loosening, and sagittal malalignment. There was no significant difference in the reoperation survival curves between the two groups (Fig. 3).

Discussion

The present study indicates that not all the long-segment spinal reconstruction surgeries can achieve ideal efficacy in long-term follow-up. On the contrary, although short segment surgery is more likely to cause coronal sagittal imbalance and adjacent segment degeneration, the long-term effectiveness for patients is not poor and the reoperation rate is not high. This result prompted us to further analysis and reflection.

Long-segment Surgical Strategy: Once and for All?

Two aspects must be carefully considered when planning long-segment surgery.⁶ The first is to define the symptomatic segment and its range, that is, the segment that must be treated to alleviate symptoms and prevent rapid progression

of the deformity. Second, to clarify the relationship between the symptomatic segment, the apical vertebra and the global balance of the spine, to determine the upper instrumented vertebra (UIV), the degrees of osteotomy and spinopelvic fixation to restore normal alignment of the spine, improve the rate of bone fusion and prevent postoperative internal fixation failure and adjacent segment-related problems. Therefore, radical reconstruction surgery places the whole spine in a new state of stress and must be fully evaluated before surgery. It is best to realign the spine to reduce the incidence of long-term complications.

One study provided a suggestion whether to choose L5, S1, or pelvis for the lower instrumented vertebra (LIV).¹⁷ The American Academy of Orthopedic Surgeons (AAOS) described spinopelvic fixation as a technique to reduce the

stress of the lumbosacral spine, to increase the rate of bone fusion, avoid the formation of pseudarthrosis and reduce the risk of implant failure. Its purpose is to counteract the significantly increased shear force due to dynamic flexion-extension motion and static cantilever structure in lumbosacral junction after long-segment fixation. The indications include: (i) long-segment spinal fixation (from sacrum to L2 or above, or fixed segments >5); (ii) severe lumbar spondylolisthesis (Meyerding classification > III); (iii) three-column osteotomy on the lumbar spine (Schwab grade III or above); (iv) correction of lumbar deformity and pelvic tilt (such as neuromuscular spinal deformity); and (v) unstable fracture of sacrum.^{18,19} Although the standards on the subject are scientific and reasonable, we will take into account the real needs of patients, the increased bleeding and longer operation time caused by spinopelvic

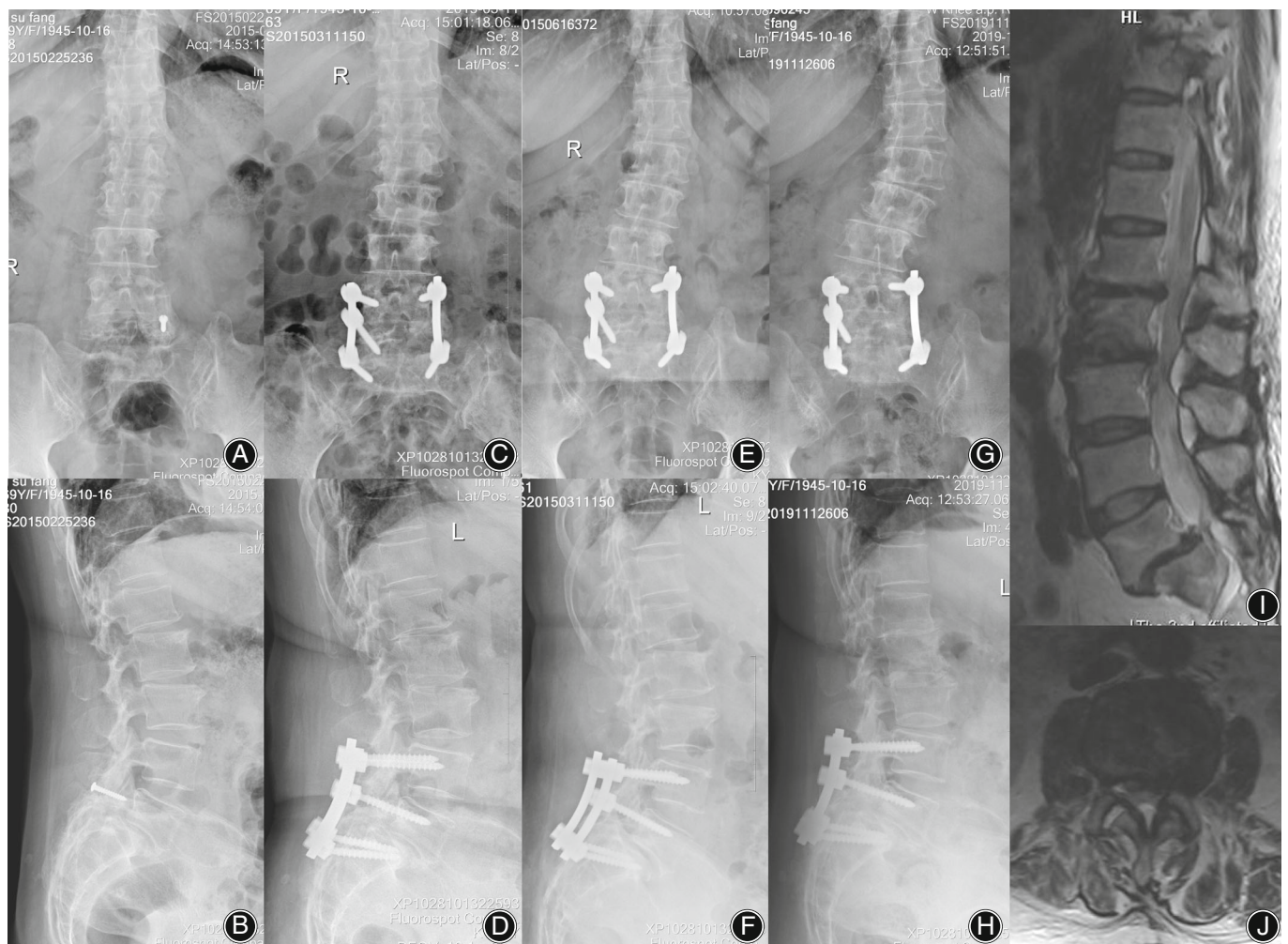


Fig. 4 A 45-year-old female patient was diagnosed with lumbar spondylolisthesis and underwent internal fixation in 1990. A&B, 25 years later, the patient came to our hospital because of progressive low back pain. C&D, postoperative, the patient underwent fixation and fusion for L5-S1 spondylolisthesis. E&F, 6 months later, the low back pain improved significantly but the compensatory curve showed a rapid progression. G&H, 4 years later, the compensatory curve became a structural curve. I&J, MRI showed significant degeneration from L1-3. The low back pain did not affect the daily life of patient after the second operation (RASD)

fixation, and prefer to maintain a small range of lumbar mobility reducing the trauma and risk of the operation.

Whether it can only be fixed to L5 should rely on the changes of L5-S1 intervertebral discs caused by the operation, and whether adjacent segment degeneration will occur in the lower reserved segment and result in related clinical symptoms. Polly *et al.* have conducted a 6-year follow-up of 34 patients with normal L5-S1 disk who accepted the long-segment fixation and fusion to L5. They found that 61% of the patients had L5-S1 disc degeneration, while only four patients needed reoperation.²⁰ In another study, Edwards *et al.* pointed out that patients with L5-S1 disc degeneration, L5 spondylolisthesis, L5-S1 spinal stenosis, too large L5 inclination angle, and surgical history of this segment are more likely to have clinical symptoms related to the segment in the early postoperative period, and S1 is more appropriate for lower instrumented fixation and fusion selection.²¹ Thus, the long-segment strategy requires essential preoperative evaluation and planning, while there is still much controversy on the key issues, as a slight move in one part may affect the situation. In the absence of a recognized and unified consensus to guide surgical planning and prognostic prediction, it often depends on the surgeon's experience with spinal degeneration and deformity.

This study showed that the implant-related complications of long-segment strategy were significantly higher than those of short-segment and that there were also problems with the adjacent segment. Furthermore, even if some cases of implant failure did not develop pseudarthrosis or related clinical symptoms due to solid bone fusion, there is always a risk of spinal degeneration. With advancing age, this hidden danger can lead to new symptoms and spinal cord injury at

any time. At that point, revision surgery with increased trauma and higher risk will be unavoidable (Fig. 1).

Short-segment Surgical Strategy: Limited Intervention with Higher Reoperation Rate?

Fixed and fused segment extension increased the risks associated with surgery, but did not equivalently improve the patient's outcome, whereas in our study, the short segment strategy was found to limit surgery with regular follow-up and a targeted remedy that balanced the contradiction. Although the incidence of adjacent segment degeneration in short-segment surgery was higher than that in long-segment, it did not increase the reoperation rate and showed no difference in the symptom assessment of patients in the two groups. This also suggests that not all the adjacent segment degenerations diagnosed by X-ray caused clinical symptoms, and surgical intervention was not required for all the adjacent segment degenerations with clinical symptoms. Moreover, the number of adjacent segment degeneration increased gradually over time. Whether the main reason is the destruction of tissue structure, increased spinal stress after surgical intervention, or the unstoppable progression of natural degeneration, more analyses and research are needed.²²⁻²⁴ (Figs 4 and 5).

A study conducted by Boden *et al.* showed that the incidence of lumbar MRI abnormalities in asymptomatic volunteers over 60 years old was 57%, suggesting that the abnormalities in X-ray are common in elderly patients.²⁵ Another prospective study conducted by Elfering *et al.* indicated that 41% of asymptomatic patients with lumbar disc herniation diagnosed by MRI had lumbar degenerative progression after 5 years, while showing a low correlation

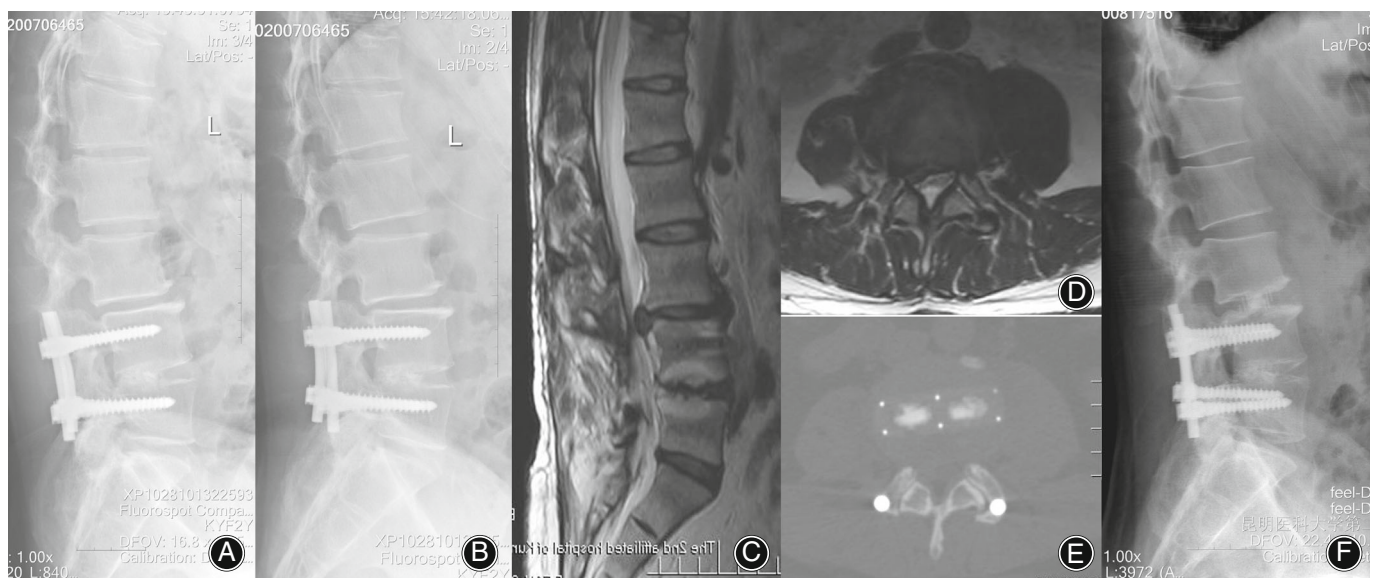


Fig. 5 A 55-year-old male underwent L4-5 fusion because of spinal stenosis, 3 years later, the patient came to the clinic because of low back pain and lower limb radiation pain. A&B, L3-4 instability. C&D, the lumbar disk herniated laterally and posteriorly. E&F, OLIF post-op. (CASD)

between clinical symptoms and imaging changes.²⁶ In addition, the degree of lumbar disc herniation, lack of activity and occupation type were the risk factors for degenerative progression. Therefore, it is concluded that radiographic changes caused by natural degeneration of the spine are widely present in the elderly and have no significant correlation with low back pain or radiation pain in the lower extremities. This is a common phenomenon rather than a disease.

Similarly, Ramirez-Villaescusa *et al.* also paid attention to this issue by dividing adjacent segment degeneration into RASD and CASD.¹⁶ After an average follow-up of 3.8 years, they found that 7.2% of the patients had adjacent segment-related symptoms but no radiographic findings and 37.3% of the patients had imaging findings but no clinical symptoms. Another meta-analysis, including 94 studies and 34,716 patients who underwent spinal fusion surgery, showed that the incidence of RASD ranged from 4.8% to 92.2%, and the incidence of CASD ranged from 0 to 30.3%. The incidence of RASD gradually increased over time, with 21.8% in 0.5–2 years, 33.6% in 2–5 years, and 37.4% in 5–10 years after surgery. The incidence of CASD will reach a peak in 2–5 years and then gradually decrease, with 6.5% in 0.5–2 years, 12.1% in 2–5 years, and 3.2% in 5–10 years after surgery.²⁷ It could result from spinal compensation in the 2–5 years following surgery and the development of new degeneration-inducing factors, which accelerated the degeneration process. This process tends to stabilize after 5 years and gradually return to the pathophysiological process dominated by natural degeneration.

Our results are consistent with the above conclusions, and we found in the mid- and long-term follow-up that the proportion of reoperation due to CASD is not high.

Limitations

The study has several limitations. First, the allocation of patients between the two groups was not randomized. Furthermore, although we adjusted the baseline data of imaging parameters and VAS scores to a comparable range, the age and comorbidities between the groups still differed (patients

in the short segment group had worse conditions overall). In addition, we are unable to choose a more comprehensive functional assessment method, such as the Oswestry Disability Index (ODI) or Short Form 36 (SF-36), due to the limited statistical tests, considering the wide age range and time span of the study. Nevertheless, this is a non-inferiority result and does not preclude the limited intervention from being a valid palliative therapy as the population is becoming longer-lived.

Conclusion

Considering the risks and complications, rehabilitation pathway and costs of long-segment radical surgery, limited intervention with regular follow-up and targeted intervention is a more appropriate strategy and may benefit patients when radical reconstruction surgery cannot achieve ideal efficacy. The short-segment limited intervention addresses adjacent segmental disease through regular follow-up and targeted remediation rather than by preventive intervention at the time of the initial operation, significantly reducing the risks for patients and surgeons. Moreover, its long-term efficacy is non-inferior to that of the long-segment surgery. At present, the biggest challenge is how to avoid the onset of CASD too early and too quickly through technical improvement. This is also a direction worthy of attention and further research in the future.

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Author Contributions

Zhibo Song and Yingsong Wang designed the research; Zhaoquan Zhang and Xiaochen Yang collected the data; Zhi Zhao and Tao Li performed the research; Zhibo Song and Ni Bi wrote the paper. All authors read and approved the final version of the manuscript for publication.

References

- Diebo BG, Shah NV, Boachie-Adjei O, et al. Adult spinal deformity. *Lancet*. 2019;394:160–72.
- Aebi M. The adult scoliosis. *Eur Spine J*. 2005;14:925–48.
- Lakomkin N, Stannard B, Fogelson JL, Mikula AL, Lenke LG, Zuckerman SL. Comparison of surgical invasiveness and morbidity of adult spinal deformity surgery to other major operations. *Spine J*. 2021;21:1784–92.
- Pellisé F, Serra-Burriel M, Vila-Casademunt A, et al. Quality metrics in adult spinal deformity surgery over the last decade: a combined analysis of the largest prospective multicenter data sets. *J Neurosurg Spine*. 2021;1–9.
- Silva FE, Lenke LG. Adult degenerative scoliosis: evaluation and management. *Neurosurg Focus*. 2010;28:E1.
- Berjano P, Lamartina C. Classification of degenerative segment disease in adults with deformity of the lumbar or thoracolumbar spine. *Eur Spine J*. 2014;23:1815–24.
- Wong E, Altaf F, Oh LJ, Gray RJ. Adult degenerative lumbar scoliosis. *Orthopedics*. 2017;40:e930–9.
- Phan K, Xu J, Maharaj MM, Li J, Kim JS, di Capua J, et al. Outcomes of short fusion versus long fusion for adult degenerative scoliosis: a systematic review and meta-analysis. *Orthop Surg*. 2017;9:342–9.
- Charosky S, Guigui P, Blamoutier A, Roussouly P, Chopin D. Complications and risk factors of primary adult scoliosis surgery: a multicenter study of 306 patients. *Spine*. 2012;37(8):693–700.
- Glassman SD, Berven SH, Shaffrey CI, Mummaneni PV, Polly DW. Commentary: appropriate use criteria for lumbar degenerative scoliosis: developing evidence-based guidance for complex treatment decisions. *Neurosurgery*. 2017;80:E205–12.
- Virk SS, Niedermeier S, Yu E, Khan SN. Adjacent segment disease. *Orthopedics*. 2014;37:547–55.
- Helgeson MD, Bevevino AJ, Hilibrand AS. Update on the evidence for adjacent segment degeneration and disease. *Spine J*. 2013;13:342–51.
- Ha K-Y, Kim Y-H, Ahn J-H. Is it real adjacent segment pathology by stress concentration after limited fusion in degenerative lumbar scoliosis? *Spine*. 2014;39(13):1059–66.
- Glattes RC, Bridwell KH, Lenke LG, Kim YJ, Rinella A, Edwards C II. Proximal junctional kyphosis in adult spinal deformity following long instrumented posterior spinal fusion: incidence, outcomes, and risk factor analysis. *Spine*. 2005;30(14):1643–9.

- 15.** Nguyen NL, Kong CY, Hart RA. Proximal junctional kyphosis and failure-diagnosis, prevention, and treatment. *Curr Rev Musculoskelet Med.* 2016;9:299–308.
- 16.** Ramirez-Villaescusa J, López-Torres Hidalgo J, Martín-Benlloch A, Ruiz-Picazo D, Gomar-Sancho F. Risk factors related to adjacent segment degeneration: retrospective observational cohort study and survivorship analysis of adjacent unfused segments. *Br J Neurosurg.* 2019;33:17–24.
- 17.** Shen FH, Mason JR, Shimer AL, Arlet VM. Pelvic fixation for adult scoliosis. *Eur Spine J.* 2013;22:265–75.
- 18.** Jain A, Hassanzadeh H, Strike SA, Menga EN, Sponseller PD, Kebaish KM. Pelvic fixation in adult and pediatric spine surgery: historical perspective, indications, and techniques: AAOS exhibit selection. *J Bone Jt Surg.* 2015;97:1521–8.
- 19.** Esmende SM, Shah KN, Daniels AH. Spinopelvic fixation. *J Am Acad Orthop Surg.* 2018;26:396–401.
- 20.** Polly DW Jr, Hamill CL, Bridwell KH. Debate: to fuse or not to fuse to the sacrum, the fate of the L5–S1 disc. *Spine.* 2006;31(19 Suppl):S179–84.
- 21.** Edwards CC, Bridwell KH, Patel A, Rinella AS, Berra A, Lenke LG. Long adult deformity fusions to L5 and the sacrum a matched cohort analysis. *Spine.* 2004; 29(18):1996–2005.
- 22.** Scemama C, Magrino B, Gillet P, Guigui P. Risk of adjacent-segment disease requiring surgery after short lumbar fusion: results of the French spine surgery society series. *J Neurosurg Spine.* 2016;25:46–51.
- 23.** Okuda S, Yamashita T, Matsumoto T, Nagamoto Y, Sugiura T, Takahashi Y, et al. Adjacent segment disease after posterior lumbar interbody fusion: a case series of 1000 patients. *Global Spine J.* 2018;8:722–7.
- 24.** Hashimoto K, Aizawa T, Kanno H, Itoi E. Adjacent segment degeneration after fusion spinal surgery—a systematic review. *Int Orthop.* 2019;43:987–93.
- 25.** Boden SD, Davis DO, Dina TS, Patronas NJ, Wiesel SW. Abnormal magnetic-resonance scans of the lumbar spine in asymptomatic subjects. A prospective investigation. *J Bone Joint Surg, Am.* 1990;72:403–8.
- 26.** Elfering A, Semmer N, Birkhofer D, Zanetti M, Hodler J, Boos N. Young investigator award 2001 winner: risk factors for lumbar disc degeneration: a 5-year prospective MRI study in asymptomatic individuals. *Spine.* 2002;27(2): 125–34.
- 27.** Xia X-P, Chen H-L, Cheng H-B. Prevalence of adjacent segment degeneration after spine surgery: a systematic review and meta-analysis. *Spine.* 2013;38(7): 597–608.