Surgical Treatment of Scoliosis Lenke Type 5, Anterior Versus Posterior, Which Approach is Better?

A Systematic Review and Meta-Analysis

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Study Design. Systematic review and meta-analysis.

Objective. This study aimed to compare the radiographical and clinical outcomes between anterior spinal fusion (ASF) and posterior spinal fusion (PSF) in Lenke type 5 adolescent idiopathic scoliosis.

Summary of Background Data. PSF has been the standard operation for adolescent idiopathic scoliosis. ASF can also achieve a good curve correction effect with fewer fusion segments and minor invasion of paraspinal structures.

Materials and Methods. A systematic literature research was conducted in PubMed, Embase, Cochrane Library, and Web of Science. Use meta-analysis to compare the changes of thoracolumbar/lumbar and thoracic curves and other important outcomes between ASF and PSF.

Results. A total of 427 ASF and 392 PSF patients from 12 studies were included. There was no significant difference in the correction degree of thoracic curve at postoperation ($P>0.05$), except for PSF had more compensatory correction degree of thoracic curve at postoperation ($P<0.05$). Besides, the loss of correction in thoracic curve in PSF at the last follow-up was significantly less than that in ASF ($P<0.05$). PSF presented larger change values of thoracic kyphosis and lumbar lordosis at the last follow-up ($P<0.05$). PSF showed a better effect in correcting trunk shift distance at the postoperation ($P<0.05$) but less trunk shift distance correction from postoperation to last follow-up ($P<0.05$). There was no significant difference in the incidence of proximal junctional kyphosis and estimated blood loss between the two approaches ($P>0.05$). Moreover, ASF showed fewer fusion segments, but longer operation and hospital stay time ($P<0.05$).

Conclusion. ASF is capable of achieving similar correction in coronal curve and balance as PSF with fewer fusion segments. Spine surgeons should select an appropriate approach tailored to individual patients needs while considering procedural risks and benefits.

Key words: Lenke type 5, adolescent idiopathic scoliosis, anterior spinal fusion, posterior spinal fusion, long-term follow-up, meta-analysis

Level of Evidence. 2

Spine 2023;48:E223–E234

Adolescent idiopathic scoliosis (AIS) is one of the most common types of spinal deformity in teenagers, which has attracted the attention of many researchers.¹ Lenke type 5 AIS refers to the thoracolumbar/lumbar (TL/L) curve with a nonstructural thoracic curve.² At present, selective spinal fusion, including anterior and posterior, is commonly used in Lenke type 5 AIS correction, which only fixed and fused the TL/L curve to save the mobility of the thoracic curve.

With the popularization of pedicle screw technology, posterior spinal fusion (PSF) has become the mainstream correction operation of AIS and adult spinal deformity.³,⁴ However, there is a lack of consensus on coronal plane correction of TL/L and thoracic curves by anterior spinal fusion (ASF) and PSF in Lenke type 5 AIS.⁵,⁶ In the long-term follow-up, most studies showed that PSF had a larger...
or equal correction degree for the TL/L curve versus ASF.\textsuperscript{6} In contrast, a few studies suggested that ASF might have a larger correction degree for the TL/L curve.\textsuperscript{7} Since most spine surgeons are more familiar with the PSF, the operation time through the posterior approach is significantly shorter than that of ASF.\textsuperscript{8} The current development of robot-assisted screw placement and 3D-printed drill guide template technology makes PSF more accurate and efficient.\textsuperscript{9,10} Moreover, ASF has the advantage of being more minimally invasive, with fewer fusion segments and minor damage to paraspinal structures.\textsuperscript{11} Therefore, it is still controversial which of the two approaches is superior for treating Lenke type 5 AIS.

In addition to the TL/L curve correction of Lenke type 5, studies should also pay attention to the compensatory thoracic curve and trunk shift (TS) correction to evaluate the overall correction of the coronal plane.\textsuperscript{6} Studies had shown no significant difference in the compensatory thoracic curve correction of Lenke type 5 AIS between the ASF and PSF.\textsuperscript{8,12} We should also focus on the changes in thoracic kyphosis (TK) and lumbar lordosis (LL) post-ASF or PSF. The changes in sagittal parameters such as TK and LL after spinal fusion also influenced the long-term efficacy. A study with more than 10-year follow-ups showed that patients with a more considerable loss in TK and LL were more likely to develop flatback syndrome after spinal fusion. The loss in TK degrees was also closely related to the occurrence of proximal junctional kyphosis (PJK).\textsuperscript{13} In addition, neurological complications such as spinal cord injury, nerve root injury and muscle weakness also occur after correction surgery, which should arouse sufficient attention from scholars.\textsuperscript{14–16}

Previous meta-analyses had evaluated some surgical outcomes of ASF and PSF in Lenke type 5 AIS, mainly including the correction rate of TL/L curve, fusion segments, blood loss, etc.\textsuperscript{5,6} However, they did not directly compare the effects of the two approaches on compensatory thoracic curve correction, loss of correction of the TL/L and thoracic curves, as well as no involvement in coronal balance parameters in the long-term follow-up. Therefore, we conducted this meta-analysis study to comprehensively compare the radiographical and clinical outcomes of ASF and PSF for the treatment of Lenke type 5 AIS during long-term follow-up.

**MATERIALS AND METHODS**

This meta-analysis was performed according to Cochrane Handbook for Systematic Reviews of Interventions, and the article structure was presented based on the Preferred Reporting Items for Systematic Reviews and Meta-analyses (PRISMA) guidelines.\textsuperscript{17}

**Search Trials**

We conducted a systematic literature search in databases including PubMed, Embase, Cochrane Library, and Web of Science for articles published from 2001 to 2021. The terms used to identify relevant studies were: “anterior,” “posterior,” “adolescent idiopathic scoliosis,” “Lenke type 5,” “thoracolumbar/lumbar scoliosis,” “fusion, spinal,” “selective fusion,” “instrumented fusion,” “screw instrumentation.” We used MeSH terms including “scoliosis” and “spinal fusion.” Search results were exported into EndNote software (United States) for processing. Besides, the reference lists of the included studies were checked for more relevant studies.

**Selection Criteria**

The eligible articles were included according to the following inclusion and exclusion criteria:

1. Target population: patients diagnosed with Lenke type 5 AIS; patients who previously received spinal surgeries were excluded.
2. Interventions and controls: the study should include both ASF and PSF groups for comparison with 1-year minimum follow-up.
3. Outcomes: the primary outcomes of the study were to compare the curve correction between ASF and PSF based on radiographical data (change values of TL/L and thoracic curves at postoperation and the last follow-up, loss of correction at the last follow-up). Moreover, we assessed the change values of TS (the distance between C7PL and CSVL) distance, TK, LL, incidence rate of PJK, fusion segments, operation time, estimated blood loss, and hospital stay time between the two approaches.
4. Article types: any clinical research articles published in a peer-reviewed journal, excluding case reports and review articles. We excluded duplications, non-clinical studies, non-Lenke type 5 AIS studies, inconsistent subject studies, non-English studies, and studies without available data and controls.

**Data Extraction**

Using a predefined data extraction form, two reviewers (W. S.L. and B.H.) independently extracted the following data from all included studies: first author, publication year, AIS classification, study design, follow-up duration, demographic information (number, sex, and age), radiographical parameters (Cobb angle of TL/L curve, Cobb angle of thoracic curve, TK, LL, and TS distance), number of fusion segments, rod type, the incidence rate of PJK, estimated blood loss, operation time, and hospital stay time. Any disagreement was settled by mutual agreement or consulting the third reviewer (Y.H.).

**Risk of Bias and Methodological Quality Assessment**

The evidence of the included studies was assessed using previously published guidelines.\textsuperscript{18} The risk of bias for each included study was assessed by the following seven items using the Cochrane risk-of-bias tool (Review Manager 5.4): random sequence generation, allocation concealment,
blinding of participants and personnel, blinding of outcome assessment, incomplete outcome data, selective reporting, and other bias. The nonrandomized controlled clinical studies were assessed according to the Newcastle-Ottawa scale (NOS). The NOS scoring included three aspects (nine items): selection (four points), comparability (two points), and exposure (three points). A study awarded seven or more points were considered high quality. All the above assessments for the included studies were assessed by two reviewers independently (W.S.L. and D.S.), and any disagreement was resolved by consensus or consulting the third reviewer (Y.H.).

**Statistical Analysis**

All data analyses were conducted using Stata 12.0 (United States). The odds ratio and 95% confidence interval (CI) were computed for the categorical variables, and the weighted mean difference (WMD) and 95% CI were calculated for the continuous variables. The heterogeneity among studies was determined by using Q tests (\(P \leq 0.1\) representing substantial heterogeneity) and \(I^2\) test (\(I^2 > 0\%), > 50%, and > 75% representing mild, moderate, and considerable heterogeneity, respectively). Random-effect models were used with high heterogeneity (\(I^2 \geq 50\%) and \(P\) value for \(Q\) test \(\leq 0.1\)); fixed-effect models were used with low heterogeneity (\(I^2 < 50\%) and \(P\) value for \(Q\) test \(> 0.1\)). Egger test was applied to evaluate the studies’ publication bias, and \(P < 0.1\) was defined as a significant publication bias. Due to the acceptable heterogeneity of primary outcomes in the included studies, we did not conduct the meta-regression and subgroup analysis to find the potential sources of the heterogeneity.

In some included studies, the change values for some outcomes between postoperation and the last follow-up were not reported. We conducted a statistical transformation to get change values, and the transformation formula we adopted was recommended by the Cochrane Handbooks’ version 5.1.0.5 In this study, change values of one outcome in different period = (postoperation value–preoperation value) or (last follow-up value–preoperation value) or (last follow-up value–postoperation value).

**RESULTS**

**Study Selection**

There were 2286 potentially eligible articles in the initial search from PubMed (n = 574), Embase (n = 772), Cochrane Library (n = 20), and Web of Science (n = 920). After removing 1116 duplicates, 1170 were screened by reading titles and abstracts. Eventually, 12 studies2,11,12,19–27 were included in the meta-analysis after conducting a full-text review of the remaining 43 studies. Detailed results of the selection process are shown in Figure 1.

**Study Characteristics**

The characteristics of the included studies are summarized in Table 1. A total of 819 patients consisted of 427 patients treated with ASF, and 392 patients treated with PSF were investigated from the 12 included studies. The patients’ mean age was 14.88 years in the ASF group, while the mean age was 14.87 years in the PSF group. The preoperative TL/L curve in 12 studies showed an average Cobb angle of 47.27° in the ASF group and 46.98° in the PSF group. Average fusion segments were 4.70 in the ASF group and 6.06 in the PSF group. The level of evidence of all included studies, five prospective cohort studies were rated level I, II, and another seven retrospective cohort studies were rated level II, and another seven retrospective cohort studies were rated level II.

**Risk of Bias and Methodological Quality Assessment**

The risk of bias in the included studies is summarized in Fig. 2. Only two of 12 studies had a high risk of bias of random sequence generation and allocation concealment items (16.7%). Four studies had a high risk of reporting bias, and one had a high risk of other bias. According to the NOS for cohort studies, the included 12 cohort studies’ quality was evaluated, as shown in Table 2. The results showed that all six studies were rated as high quality, with ten studies scoring nine and two scoring eight. Therefore, the pooled results of included studies have good reliability and can be processed for further meta-analysis.

**Change Values of Thoracolumbar/Lumbar Curves**

The changes values of Cobb angle (representing correction degree) of TL/L curve from preoperation to postoperation were available in eight studies, and the data from preoperation to the last follow-up were available in all 12 studies (Fig. 3). From postoperation to the last follow-up, changes values of Cobb angle of TL/L curve representing loss of correction were available in seven studies. The heterogeneity was considerable in the change values of TL/L curve at postoperation (\(I^2 = 77.4\%, P\) value for \(Q\) test \(< 0.1\)) and the last follow-up (\(I^2 = 81.6\%, P\) value for \(Q\) test \(< 0.1\)), so the results were summarized using a random-effect model. A fixed-effect model was used to summarize the changes values of loss of correction because the heterogeneity was low (\(I^2 = 10.9\%, P\) value for \(Q\) test \(> 0.1\)). In Figure 3, the pooled results showed no significant difference in correction degree of TL/L curve between the ASF and PSF group at postoperation (WMD = 1.93, 95% CI: –0.53 to 4.41, \(P > 0.05\)) and the last follow-up (WMD = 1.93, 95% CI: –0.15 to 4.01, \(P > 0.05\)). Moreover, the ASF group showed a significantly larger loss of correction of TL/L curves from postoperation to the last follow-up (WMD = 1.17, 95% CI: 0.21–2.13, \(P < 0.05\)).

**Change Values of Thoracic Curves**

The change values of Cobb angle (representing correction degree) of thoracic curves from preoperation to postoperation or the last follow-up were reported in two or three studies, respectively (Fig. 4). The change values of Cobb angle of thoracic curve representing loss of correction were available in two studies. A random-effect model was...
used to summarize the change values of thoracic curve at the last follow-up because the heterogeneity was moderate among the three studies ($I^2 = 57.3\%$, $P$ value for $Q$ test < 0.1); and a fixed-effect model was used to pool the results of change values of postoperative thoracic curve and the loss of correction, for there is low ($I^2 = 32.1\%$, $P$ value for $Q$ test > 0.1) or no heterogeneity ($I^2 = 0.0\%$, $P$ value for $Q$ test > 0.1) among these studies. Compared with the ASF group, the PSF group showed larger compensatory thoracic curve correction at postoperation ($WMD = 3.79$, 95% CI: 1.42–6.15, $P$ < 0.05) (Fig. 4). However, the two groups showed no statistically significant difference in the correction degree of thoracic curve at the last follow-up ($WMD = 0.74$, 95% CI: −2.27 to 3.75, $P > 0.05$). There was no statistically significant difference in the loss of correction of thoracic curve between the two approaches ($WMD = −1.72$, 95% CI: −4.34 to 0.90, $P > 0.05$), from postoperation to the last follow-up (Fig. 4).

**Change Values of TK and LL**

In the analysis of change values of TK, data were extracted from seven studies. A fixed-effect model was used to pool the results for no heterogeneity among the seven studies ($I^2 = 0.0\%$, $P$ value for $Q$ test > 0.1). The pooled results showed a larger increased change value of TK in the PSF group compared with the ASF group ($WMD = −3.99$, 95% CI: −5.57 to −2.41, $P < 0.001$) (Fig. 5). Data on the change values of LL was available in seven studies, and a fixed-effect model was used for the low heterogeneity among the seven studies ($I^2 = 41.6\%$, $P$ value for $Q$ test > 0.1). The result showed that the PSF group obtained a larger increased Cobb angle of LL compared with the ASF group ($WMD = −6.12$, 95% CI: −8.03 to −4.21, $P < 0.001$) (Fig. 5).

**Change Values of TS Distance**

As shown in Figure 6, all three outcomes regarding the TS were reported in two of the 12 studies. A fixed-effect model was used to pool the change values of TS distance from preoperation to postoperation (representing TS distance correction) and the change values of TS distance from postoperation to the last follow-up, for there is low ($I^2 = 45.5\%$, $P$ value for $Q$ test > 0.1) and no heterogeneity ($I^2 = 0.0\%$, $P$ value for $Q$ test > 0.1) among these studies,
| References     | Classification | Design   | Follow-up (y) | Group   | Number | Male/Female | Age (y)       | TL/L Curve (°) | Fused Segments | Rod Type | Level of Evidence |
|----------------|----------------|----------|---------------|---------|--------|-------------|---------------|----------------|----------------|----------|-------------------|
| Li et al²⁹     | Lenke 5        | Prosp    | ≥ 10          | ASF     | 25     | 0/25        | 14.2 ± 1.5    | 50.8 ± 12.4    | 4.7 ± 0.6      | Single  | Level II          |
| V'O'Donnell et al²⁶ | Lenke 5        | Prosp    | ≥ 2           | ASF     | 98     | 8/90        | 14.8 ± 2      | 48.2 ± 8.6     | 4.6 ± 0.7      | Single  | Level II          |
| Miyani et al²² | Lenke 5C       | Prosp    | ≥ 2           | ASF     | 69     | 15/54       | 15.5 ± 1.8    | 45.2 ± 7.1     | 4.7 ± 0.9      | Dual    | Level II          |
| Li et al²⁸     | Lenke 5        | Retro    | ≥ 5           | ASF     | 40     | 5/35        | 14.80 ± 2.1   | 45.5 ± 4.6     | 5.3 ± 0.5      | Single  | Level III         |
| Dong et al²¹   | Lenke 5C       | Retro    | ≥ 2           | ASF     | 17     | 3/14        | 14.8 ± 1.8    | 41.4 ± 5.9     | 4.2 ± 0.8      | Single  | Level III         |
| Abel et al²²   | Lenke 5C       | Prosp    | ≥ 2           | ASF     | 39     | 3/33        | 14.5 ± 2.1    | 44.3 ± 7.4     | 6.4 ± 1.3      | Dual    | Level II          |
| Geck et al²³   | Lenke 5C       | Retro    | ≥ 2           | ASF     | 21     | 15 ± 1.7    | 49.8 ± 6.3    |                |                | Single  | Level III         |
| Tao et al²⁴    | Lenke 5        | Retro    | ≥ 2           | ASF     | 23     | 1/22        | 13.95 ± 1.26  | 49.74 ± 6.85   | 5 ± 0.6       | Single  | Level III         |
| Yu et al²⁵     | Lenke 5        | Retro    | ≥ 1           | ASF     | 26     | 26/152      | 13.64 ± 1.6   | 50.31 ± 7.09   | 6.57 ± 0.5     | Dual    | Level III         |
| Li et al²⁶     | Lenke 5C       | Retro    | ≥ 2           | ASF     | 22     | 1/25        | 13.73 ± 1.32  | 50.18 ± 7.52   |                | Single  | Level III         |
| Geck et al²⁷   | Lenke 5C       | Retro    | ≥ 2           | ASF     | 31     | 15.6 ± 2.3  | 49 ± 6.6      | 4.3 ± 0.8      | Dual    | Level III         |
| Wang et al¹¹   | Lenke 5C       | Prosp    | ≥ 2           | ASF     | 16     | 1/15        | 15.38 ± 1.54  | 42.56 ± 7.04   |                | Single  | Level II          |

ASF indicates anterior spinal fusion; Prosp, prospective study; PSF, posterior spinal fusion; Retro, retrospective study; TL/L, thoracolumbar/lumbar.
respectively. A random-effect model was used to summarize the change values of TS distance from preoperation to the last follow-up because of the considerable heterogeneity among the two studies ($I^2 = 72.3\%$, $P$ value for $Q$ test < 0.1). Compared with the ASF group, the PSF group showed a larger TS distance correction from preoperation to postoperation ($WMD = 6.21$, $95\%$ CI: 1.39–11.03, $P < 0.05$) (Fig. 6). However, from preoperation to the last follow-up, the two groups showed no significant difference for the TS distance correction ($WMD = 0.18$, $95\%$ CI: −8.31

### Table 2. Quality Assessment for the 11 Cohort Studies According to Newcastle-Ottawa scale (NOS)

| References  | S1 | S2 | S3 | S4 | C1 | C2 | E1 | E2 | E3 | Total Score |
|-------------|----|----|----|----|----|----|----|----|----|-------------|
| Lim et al11  | *  | *  | *  | *  | *  | *  | *  | *  | *  | 9           |
| O’Donnell et al7 | *  | *  | *  | *  | -  | *  | *  | *  | *  | 8           |
| Miyani et al12 | *  | *  | *  | *  | *  | *  | *  | *  | *  | 9           |
| Li et al20 | *  | *  | *  | *  | *  | *  | *  | *  | *  | 9           |
| Dong et al21 | *  | *  | *  | *  | *  | *  | *  | *  | *  | 9           |
| Abel et al22 | *  | *  | *  | *  | *  | *  | *  | *  | *  | 9           |
| Geck et al23 | *  | *  | *  | *  | *  | *  | *  | *  | *  | 9           |
| Tao et al24 | *  | *  | *  | *  | *  | *  | *  | *  | *  | 9           |
| Yu et al25 | *  | *  | *  | *  | -  | *  | *  | *  | *  | 8           |
| Li et al26 | *  | *  | *  | *  | *  | *  | *  | *  | *  | 9           |
| Geck et al27 | *  | *  | *  | *  | *  | *  | *  | *  | *  | 9           |
| Wang et al11 | *  | *  | *  | *  | *  | *  | *  | *  | *  | 9           |

*C* indicates comparability; *C*1, comparability of controls for most important factor; *C*2, comparability of controls for other factors; *E*, exposure; *E*1, assessment of outcome; *E*2, was follow-up long enough for outcomes to occur; *E*3, adequacy of follow-up of cohorts; *S*, selection; *S*1, representativeness of the exposed cohort; *S*2, selection of the nonexposed cohort; *S*3, ascertainment of exposure; *S*4, demonstration that outcome of interest was not present at start of study.

Figure 2. Review authors’ judgments about each risk of bias item for each included study. A, Risk of bias summary. B, Risk of bias graph presented as percentages.
to 8.68, \( P = 0.97 \) (Fig. 6). Besides, the originally included results revealed that both ASF and PSF increased the TS correction after surgery. The pooled results revealed ASF corrected more TS distance compared with the PSF group (WMD = −5.76, 95% CI: −9.51 to −1.92, \( P < 0.05 \)), from postoperation to the last follow-up (Fig. 6).

Incidence Rate of Proximal Junctional Kyphosis
The incidence rate of PJK was extracted from five studies, and a fixed-effect model was used for the low heterogeneity (\( I^2 = 29.6\% \), \( P \) value for Q test > 0.1) (Fig. 7). According to the pooled results, no significant difference was found between the ASF and PSF groups in the incidence rate of PJK at the last follow-up (odds ratio = 0.87, 95% CI: 0.34–2.24, \( P > 0.05 \)) (Fig. 7).

The Number of Fusion Segments
In Figure 8, a random-effect model was used to pool the data of number of fusion segments from five studies due to the considerate heterogeneity (\( I^2 = 89.5\% \), \( P \) value for Q test < 0.1). The results revealed that the number of fusion segments in the ASF group was less than that in the PSF group (WMD = −1.21, 95% CI: −1.65 to −0.77, \( P < 0.001 \)) (Fig. 8).

Operation Time, Estimated Blood Loss, and Duration of Hospital Stays
As shown in Figure 8, the data on operation time was extracted from five studies. Due to the low heterogeneity (\( I^2 = 33.4\% \), \( P \) value for Q test > 0.1) among these studies, a fixed-effect model was used. According to the statistical analysis, the PSF group presented a shorter operation time than the ASF group (WMD = 64.49, 95% CI: 53.17–75.81, \( P < 0.001 \)). Besides, seven studies reported data on estimated blood loss. Since there was no heterogeneity among these studies (\( I^2 = 0.0\% \), \( P \) value for Q test > 0.1), a fixed-effect model was used. The pooled results showed no significant difference in the estimated blood loss between the two groups (WMD = −20.76, 95% CI: −52.37 to 10.85, \( P > 0.05 \)) (Fig. 8). As for the duration of hospital stay, a random-effect model was used for considerable heterogeneity among the six included studies (\( I^2 = 97.1\% \), \( P \) value for Q test < 0.1). The ASF group represented a longer duration of hospital stay than the PSF group (WMD = 1.63, 95% CI: 0.54–2.71, \( P < 0.05 \)) (Fig. 8).

Publication Bias
According to the analysis results of Egger test, there was no significant publication bias in the change values of TL/L curves or thoracic curve at the postoperation (\( P > 0.05 \) and
the last follow-up \( (P > 0.05) \), as well as the loss of correction of TL/L curve \( (P > 0.05) \) and thoracic curve \( (P > 0.05) \) at the last follow-up.

**DISCUSSION**

The ASF and PSF are still controversial in which approach is better in treating Lenke type 5 AIS. Previous studies mainly focused on correction rates of TL/L curve, coronal and sagittal parameter changes, and some other surgical outcomes in Lenke type 5 AIS. Furthermore, many studies reported the loss of correction between postoperation and final follow-up in the two approaches. Two previous published meta-analyses have focused on the same topic as this study. However, they do not thoroughly analyze the outcomes mentioned above in the long-term follow-up, such as the loss of correction in the TL/L and thoracic curves and changes in the coronal and sagittal balance parameters. This study systematically investigated the correction of TL/L and thoracic curve in Lenke type 5 AIS, and also paid attention to the change values of TS distance, sagittal parameters and fusion segments, etc. Furthermore, we evaluated the loss of correction of TL/L and thoracic curve between the postoperation and the last follow-up to investigate the long-term benefits of patients after surgery.

**Thoracolumbar/Lumbar Curve Correction**

PSF has been the standard surgical approach for AIS to achieve a more stable fusion with the help of the pedicle screw system. Current studies showed ASF could also achieve a good correction rate for the TL/L curve as PSF in
Lenke type 5 AIS. Although there is a variation in the correction rate of the TL/L curve using ASF or PSF reported in different studies. Most studies showed no significant difference in the correction rate of the TL/L curve using the two approaches. Hee et al found that the correction degrees of the thoracolumbar curve between ASF and PSF were not statistically different in Lenke type 5 AIS, which was consistent with our results. In the eight included studies, both at postoperation and the last follow-up, the correction degree of the TL/L curve in the ASF and PSF groups were not statistically different. However, in the last follow-up, the results showed a less loss of correction in the TL/L curve in the PSF group. This finding may be associated that the transpedicle fixation had a better ability to control the spine’s three-column through the posterior approach. Although the correction effect of the TL/L curve was not significantly different in the two groups, the PSF group presented a more stable correction effect with less loss of correction in the last follow-up.

Compensatory Thoracic Curve Correction
One of the main goals of Lenke type 5 scoliosis correction surgery is to achieve a well-balanced spine. Both the TL/L curve correction and the compensatory thoracic curve correction play an important role in restoring spine balance and correcting overall coronal and sagittal alignment of Lenke type 5 AIS patients. Huitema et al did a minimum two-year follow-up in Lenke type 5 AIS patients and found that compensatory correction of thoracic curves was significantly associated with the correction of thoracolumbar curves. The present study showed that the compensatory correction of the thoracic curve was greater in the PSF group at postoperation, but no significant difference between the two groups at the last follow-up. And there was no significant difference in the loss of compensatory correction of the thoracic curves between the two groups. The above findings indicated that the long-term compensatory correction of the thoracic curve of Lenke type 5 by ASF and PSF was nearly equal; this may be directly associated with the approximate correction of the TL/L curve in the long-term follow-up.

Sagittal Parameters Changes
The static spine balance of AIS patients is worse than that of healthy people, and the static balance is mainly related to sagittal balance versus coronal balance. Restoring sagittal alignment and balance is an important goal of correction surgery. It was reported that ASF could achieve a better sagittal alignment restoration than PSF. This may be
because ASF allows anterior column shortening through the discectomy so that appropriate sagittal contours can be achieved. The restoration of TK in spinal fusion was correlated with the LL changes. It is reported that loss of LL post-PSF could result in pain and was associated with dysfunctional flatback syndrome in scoliosis patients. In this study, the pooled results showed a larger increased Cobb angle of TK and LL in the PSF group at the last follow-up. However, the pooled changes of the TK and LL do not mean that the TK and LL of these values will be restored to the direction of the normal scale. Since Lenke classification is designed for evaluating the coronal plane, the baseline of TK and LL of Lenke type 5 patients included in different studies is not uniform. The nonuniform inclusion criteria for sagittal parameters may also be the risk of bias for the pooled changes of the TK and LL in the present study. Therefore, including theLenke type 5 patients with the same inclusion criteria of the sagittal sequence is the direction of further improvement.

**TS Correction**

TS is a critical parameter commonly used to measure scoliosis patients’ coronal balance conditions. In addition to spontaneous TS, various surgical factors can lead to the occurrence of TS. The incidence of TS caused by iatrogenic factors in AIS patients after spine correction surgery is up to 8.8%, and it is of great clinical significance to observe the changes of TS in long-term follow-up. It was reported that under-correction of the lumbar curve might be a potential risk factor for the Lenke type 1 or 2 curves; other factors such as thoracic correction, coronal balance, and location of the lowest instrumented vertebra were not the risk factors. Our study found that the PSF group showed more TS correction at postoperation, but this significant difference disappeared at the last follow-up. The pooled results with a minimum two-year follow-up showed that the ASF group obtained more TS correction distance compared with the PSF group. As far as the results at present, it seems that there was no significant difference in the long-term correction of TS between the two approaches.

**Incidence of Proximal Junctional Kyphosis**

Preventing postoperative PJK is essential in restoring and maintaining the correction effect of the sagittal alignment. Im et al. found that LL correction greater than PI might achieve a better clinical outcome without increasing the risk of PJK. As PJK has a multifactorial etiology and pathology, no evidence indicated that ASF or PSF approaches would increase the risk of PJK. In our study, there was no significant difference in the incidence of PJK between the ASF and PSF at the last follow-up. Since most included studies reporting the incidence of PJK were the studies of more than
2-year follow-up, it is of greater significance to observe the studies with longer long-term follow-up (such as > 5 y) to investigate the incidence of PJK following the two approaches.

The Number of Fusion Segments
It has been well-recognized that the ASF fused fewer segments than PSF in the surgical treatment of Lenke type 5 AIS.6 This finding was consistent with our pooled results, which showed ASF saved about one segment compared with PSF. The shorter fusion segments of ASF may be due to the recommendations of many studies that ASF do not need to fix the stable vertebrae other than the main TL/L curve as PSF does in Lenke type 5 AIS.7,38 In addition, the increased number of fusion segments for PSF may also be related to the upper instrumented vertebrae, as it is easier to add fusion segments from the posterior approach than from the anterior approach.27 In the included studies, both single and dual rods were commonly used in ASF. Previous studies have shown no significant difference between single and dual rods in the curve correction and complication incidence.39,40 Direito-Santos et al.41 reported that a single rod could achieve a relatively satisfactory fusion rate, and the last level nonunion rate was 15.4% to 20% in a minimum two-year follow-up. As far as the above findings are concerned, there was no obvious evidence proving that dual rods performed better than single rods in the clinical outcomes. It is necessary to make a direct comparison in future studies on whether double rods have a more stable fixation effect and can reduce the incidence of nonunion.

Operation Time, Duration of Hospital Stays and Estimated Blood Loss
The present study found a longer operation time and hospital stay time in the ASF group. The relatively longer operation time of ASF might be associated with that posterior approach is more familiar and convenient to spine surgeons.8 Another possible reason may be due to the complicated contact and separation of major vessels during the operation.23,42 Many studies showed that the Lenke type 5 AIS patients who underwent ASF needed more time to recover, which may contribute to the prolonged hospital stay time.6 Our results indicated that the blood loss of the two groups was not significantly different. Although ASF has fewer fusion segments and minor trauma without damaging the posterior muscle-ligament complex may be likely to reduce blood loss.43 The prolonged operation time in ASF operation may contribute to the increase of blood loss to get an approximate blood loss as PSF.

Current Limitations
This study has several limitations. First, the included studies were prospective or retrospective cohort studies, so the level of evidence in these studies was relatively low. More RCT studies regarding the comparison of ASF and PSF are needed. In addition, due to the lack of corresponding data, the present study did not conduct a meta-analysis about the fusion rate, neurological function score, and incidence of postoperative complications other than PJK. Finally, the long-term benefits of patients who underwent ASF or PSF surgery need to be further evaluated due to only a few studies with a more than five-year follow-up. More relevant research with high evidence level focused on long-term follow-up results of comparing the two approaches is needed.

CONCLUSION
In the present study, the pooled results demonstrated that the correction of TL/L and compensatory thoracic curves of Lenke type 5 AIS using ASF and PSF were not significantly different in long-term follow-up, although ASF demonstrated greater loss of correction at final follow-up. The use of ASF was associated with fewer fusion segments, but resulted in longer operation time and length of hospital stay compared with PSF. The anterior and posterior approaches each have their advantages. Spine surgeons should select an appropriate approach tailored to individual patients needs while considering procedural risks and benefits.

Key Points
- ASF is capable of achieving similar correction in coronal curve and balance as PSF with fewer fusion segments.
- ASF demonstrated greater loss of correction at final follow-up.
- PSF demonstrated similar TS correction and larger TK and LL changes at final follow-up.
- The use of ASF was associated with fewer fusion segments, but resulted in longer operation time and length of hospital stay compared with PSF.

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