Minimally invasive scoliosis surgery assisted by O-arm navigation for Lenke Type 5C adolescent idiopathic scoliosis: a comparison with standard open approach spinal instrumentation

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OBJECTIVE Recently, minimally invasive scoliosis surgery (MISS) was introduced for the correction of adult scoliosis. Multiple benefits including a good deformity correction rate and fewer complications have been demonstrated. However, few studies have reported on the use of MISS for the management of adolescent idiopathic scoliosis (AIS). The purpose of this study was to investigate the outcome of posterior MISS assisted by O-arm navigation for the correction of Lenke Type 5C AIS.

METHODS The authors searched a database for all patients with AIS who had been treated with either MISS or PSF between November 2012 and January 2014. Levels of fusion, density of implants, operation time, and estimated blood loss (EBL) were recorded. Coronal and sagittal parameters were evaluated before surgery, immediately after surgery, and at the last follow-up. The accuracy of pedicle screw placement was assessed according to postoperative axial CT images in both groups. The 22-item Scoliosis Research Society questionnaire (SRS-22) results and complications were collected during follow-up.

RESULTS The authors retrospectively reviewed the records of 45 patients with Lenke Type 5C AIS, 15 who underwent posterior MISS under O-arm navigation and 30 who underwent posterior spinal fusion (PSF). The 2 treatment groups were matched in terms of baseline characteristics. Comparison of radiographic parameters revealed no obvious difference between the 2 groups immediately after surgery or at the final follow-up; however, the MISS patients had significantly less EBL ($p < 0.001$) and longer operation times ($p = 0.002$). The evaluation of pain and self-image using the SRS-22 showed significantly higher scores in the MISS group ($p = 0.013$ and 0.046 , respectively) than in the PSF group. Postoperative CT showed high accuracy in pedicle placement in both groups. No deep wound infection, pseudarthrosis, additional surgery, implant failure, or neurological complications were recorded in either group.

CONCLUSIONS Minimally invasive scoliosis surgery is an effective and safe alternative to open surgery for patients with Lenke Type 5C AIS. Compared with results of the open approach, the outcomes of MISS are promising, with reduced morbidity. Before the routine use of MISS, however, long-term data are needed.

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KEY WORDS minimally invasive scoliosis surgery; O-arm navigation; Lenke Type 5C; adolescent idiopathic scoliosis; spine

SURGICAL correction of adolescent idiopathic scoliosis (AIS) has been greatly improved by the development of spinal instrumentation. With the introduction of Harrington instrumentation and subsequent Cotrel-Dubousset and pedicle screw instrumentation, posterior ap-

proaches have become commonly used for the treatment of AIS.^{2,11,22} Traditional posterior open techniques are typically performed using a long incision, thus leading to extensive blood loss, obvious pain, and a high risk of wound infection. In addition, the long incision is an immense

ABBREVIATIONS AIS = adolescent idiopathic scoliosis; AVR = apical vertebral rotation; AVT = apical vertebral translation; CB = coronal balance; EBL = estimated blood loss; LL = lumbar lordosis; MISS = minimally invasive scoliosis surgery; PSF = posterior spinal fusion; SRS-22 = 22-item Scoliosis Research Society questionnaire; SVA = sagittal vertical axis; T = Cobb angle of thoracic curve; TK = thoracic kyphosis; TL/L = Cobb angle of thoracolumbar/lumbar curve.

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cosmetic problem for adolescents with scoliosis. In 2011, Sarwahi et al.²⁰ first described the technique of posterior minimally invasive scoliosis surgery (MISS) for AIS, performed under fluoroscopy with limited incisions and less soft-tissue dissection. In addition to its satisfactory deformity correction rate, the technique had multiple benefits, including less blood loss and shorter hospital stays. These authors later compared the results of MISS with those of standard open posterior spinal fusion (PSF) and concluded that posterior MISS was a feasible option for deformity correction in patients with AIS.¹⁹ However, the accuracy of pedicle screw placements could not be guaranteed through the small incision under traditional fluoroscopy. Furthermore, repeated fluoroscopy would expose the surgeons and patients to more radiation.

O-arm navigation is a recent 3D fluoroscopy system that provides image quality similar to that of CT, which was first used in spinal surgery to guarantee the accuracy of pedicle screw placement.^{10,16,21} Another advantage with this imaging platform is the limited radiation exposure.^{1,8,10} Abdullah et al.¹ assessed radiation exposure in lumbar and thoracolumbar fusions using the O-arm imaging system and found that exposure is minimal to the surgical team. Grelat et al.⁸ compared the radiation exposure dose between the minimally invasive approach under the O-arm system and the traditional open approach under fluoroscopy in the treatment of degenerative lumbar diseases. Their results showed that O-arm navigation was a safe alternative that can significantly reduce surgeon exposure as compared with fluoroscopy. Jin et al.¹⁰ also confirmed that O-arm navigation minimized radiation exposure to both surgeons and patients in their study of pedicle screw placement under O-arm navigation or fluoroscopy.

From November 2012 to January 2014 in selected patients with Lenke Type 5C AIS at our center, O-arm-based navigation was used to assist in posterior MISS in order to decrease radiation exposure and ensure the accuracy of pedicle screw placement. To our knowledge, no previous study of the utilization of the posterior MISS technique assisted by O-arm navigation in AIS has been reported. Therefore, we conducted the present study to investigate the feasibility and effectiveness of MISS under navigation in patients with Lenke Type 5C AIS.

Methods

This retrospective study was approved by our local institutional review board. We searched a database for all patients with AIS who had been treated with either MISS or PSF between November 2012 and January 2014. The criteria for study inclusion were as follows: 1) diagnosis of AIS with Lenke Type 5C curve, 2) age between 14 and 18 years, 3) a minimum follow-up of 2 years, 4) curvature < 70°, and 5) curve flexibility > 50%. Patients and their parents were informed of both surgical techniques (MISS and open) during preoperative communications. The advantages and disadvantages of the 2 techniques were discussed with them in detail. The final surgical approach was determined by patients and their parents.

Surgical Technique

The minimally invasive surgical technique utilizes 2

FIG. 1. **A:** Two small (3–5 cm) midline skin incisions are used for the minimally invasive surgical technique. **B:** Intraoperative snapshot showing pedicle screw placement under navigational guidance. **C:** The rod is passed in a cephalocaudal manner with the assistance of screw extensions. **D:** Distraction and compression were performed with a special adjustable fulcrum, followed by final tightening. Figure is available in color online only.

small (3–5 cm) midline skin incisions (Fig. 1A). The facet is exposed by blunt dissection through the intermuscular cleavage plane between the longissimus and multifidus muscles.¹⁸ Facetectomy can be performed under direct vision, and adequate fusion can be ensured. After detachment of the surrounding musculature, a dynamic reference frame (tracker) for spinal navigation is placed on the spinous process. The tracker is placed as close as possible to the instrumented segment. Next, the 3D intraoperative images are recorded in a full 360° rotation of the radiation source and detector unit. These images are automatically reformed and visualized on the O-arm viewing station and then transferred to the navigation station (StealthStation S7 surgical navigation system, Medtronic).¹⁰ Pedicle screws are inserted bilaterally under O-arm navigation, with 2–3 screws inserted on each side per skin incision. With the assistance of a navigated screwdriver, the pedicle screw is advanced to a suitable depth (Fig. 1B). The rod that has been contoured in the normal sagittal profile is passed in a cephalocaudal manner²⁰ with the assistance of screw extensions (Fig. 1C). Distraction and compression maneuvers are performed with a special adjustable fulcrum (Fig. 1D). The set screw is then tightened, followed by removal of the rod holder and screw extension. In the MISS, fusion is facilitated with autograft composed of resected facet and allograft bone.

In the standard open posterior procedure, an appropriate midline incision is made, and the posterior elements of the spine, including the spinous processes, laminae, and transverse processes, are meticulously exposed. Pedicle screws are inserted free hand based on fluoroscopy. Standard correction maneuvers are then performed. Posterior fusion is accomplished with autograft composed of resected facet and allograft bone. All surgeries were performed by the same team using intraoperative neuroelectrophysiological monitoring in the 2 groups.

Radiographic and Clinical Assessment

Standing long-cassette anteroposterior and lateral ra-

diographs were obtained for assessment before surgery, 1 week after surgery, and at the last follow-up. Preoperative left and right supine side-bending radiographs were also obtained for curve flexibility evaluation.

The following radiographic parameters were measured according to the Spinal Deformity Study Group¹³ guidelines: Cobb angles of the thoracolumbar/lumbar (TL/L) and thoracic curves (T), side-bending Cobb angle, correction rate, flexibility, apical vertebral translation (AVT), apical vertebral rotation (AVR; Nash-Moe technique), coronal balance (CB), sagittal vertical axis (SVA), thoracic kyphosis (TK), and lumbar lordosis (LL). Coronal balance was measured (in mm) as the perpendicular distance between the C-7 plumb line and the central sacral vertical line. It was considered positive if the C-7 plumb line fell to the right of the central sacral vertical line. The SVA was measured as the distance from the C-7 plumb line to the posterior superior corner of the sacrum and was considered positive if the plumb line fell anterior to the posterosuperior corner of the sacrum and negative if it fell posterior to the posterosuperior corner of the sacrum. Specifically, the correction rate $[(\text{preoperative angle} - \text{postoperative angle}) / \text{preoperative angle} \times 100\%]$ and the flexibility rate $[(\text{preoperative standing angle} - \text{preoperative bending angle}) / \text{preoperative standing angle} \times 100\%]$ were calculated.

Postoperative axial CT images of the instrumented segments were used for analyzing pedicle perforations in both groups. Perforation was graded according to the Gertzbein classification.⁷ The images were obtained using a Brilliance CT 64-channel scanner (Philips Medical Systems) with the following specifications: 320 mAs, 120 kVp, and 5-mm thickness, with a 5-mm gap between slices. Additionally, Grade 0 and 1 penetrations were considered satisfactory, whereas Grade 2 and 3 were regarded as perforations. Data on intraoperative time, estimated blood loss (EBL), transfusions, and complications were collected. Blood loss estimation was based on aspirated blood and weighted sponges. The 22-item Scoliosis Research Society questionnaire (SRS-22) was given to the patients for assessment of health-related quality of life at the final follow-up. All radiographic and clinical data were collected by an independent observer who was not involved in the treatment of the patients.

Statistical Analysis

Data were analyzed using SPSS version 16.0 statistical software (SPSS Inc.). All data were presented as the mean $\pm$ standard deviation. A Student t-test was performed to assess the continuous and categorical variables between the 2 treatment groups at 3 time points (preoperatively, 1 week after surgery, and at the last follow-up). Analysis of variance was used for assessing the difference in radiographic data among the 3 time points in both groups. Chi-square analysis was applied to assess the accuracy of pedicle screw placement between the 2 groups. A *p* value < 0.05 was considered statistically significant.

Results

A total of 45 patients with Lenke Type 5C AIS were in-

TABLE 1. Demographic characteristics and clinical features of 45 patients with Lenke Type 5C AIS, according to treatment group

Variable	MISS Group	PSF Group	<i>p</i> Value
No. of patients	15	30	
Mean age at surgery (yrs)	16.5 $\pm$ 1.6	15.1 $\pm$ 1.7	0.064
Sex (female/male)	13/2	27/3	0.715
Preop primary Cobb angle ($^{\circ}$)	48.3 $\pm$ 4.2	50.9 $\pm$ 5.4	0.616
Flexibility of primary curve (%)	71.2 $\pm$ 8.7	73.3 $\pm$ 15.6	0.744
Preop secondary Cobb angle ($^{\circ}$)	24.0 $\pm$ 5.4	26.4 $\pm$ 6.6	0.345
Flexibility of secondary curve (%)	57.3 $\pm$ 12.1	69.7 $\pm$ 15.7	0.059
FU period (mos)	27.1 $\pm$ 4.0	32.9 $\pm$ 3.5	< 0.01

FU = follow-up.

cluded in the study, 15 who underwent MISS and 30 who underwent open PSF. There were 13 females and 2 males in the MISS group, with a mean age of 16.5 ± 1.6 years (range 14–18 years). There were 27 females and 3 males in the PSF group, with a mean age of 15.1 ± 1.7 years (range 13–18 years). As shown in Tables 1 and 2, the 2 groups were matched in terms of age, sex, Cobb angle, flexibility, and other radiographic parameters.

Table 3 summarizes the surgical information for the 2 groups. The average operation time in the MISS group was longer than that in the PSF group ($p = 0.002$), whereas the average EBL in the MISS group was lower ($p < 0.001$). No transfusions were performed in the MISS group, whereas 3 patients in the PSF group received a transfusion with an average volume of 233 ± 146 ml (range 200–300 ml). Assessments of pain and self-image using the SRS-22 revealed significantly higher scores in the MISS group ($p = 0.013$ and 0.046 , respectively) than in the PSF group. No obvious difference in any other assessment was observed between the 2 groups. Neither were fusion levels ($p = 0.087$) or density of implants ($p = 0.240$) significantly different between the groups.

In the MISS group, the correction rate of the main and secondary curves were $78.4\% \pm 8.3\%$ and $53.3\% \pm 8.7\%$ immediately after surgery. An obvious improvement was noted in terms of CB, AVT, AVR, and SVA (Table 2). After a mean follow-up of 27.1 ± 4.0 months, SVA was improved from -31.0 ± 24.2 mm to -12.0 ± 6.2 mm. As for CB, AVT, AVR, TK, and LL, no obvious changes were observed (Table 2 and Figs. 2 and 3).

Compared with the PSF group, the MISS group had similar correction rates of the main and secondary curves (Table 2). At the final follow-up, corrections in the 2 curves were well maintained in both groups (Figs. 2 and 3). After surgery and at the final follow-up, CB, AVT, and AVR were decreased significantly in each of the 2 groups ($p < 0.05$), whereas no obvious change in TK and LL was observed. Note, however, that the above parameters did not differ significantly between the 2 groups (Table 2). Similarly, SVA in each of the 2 groups also tended toward a forward shift after surgery and subsequently improved at the final follow-up. However, SVA showed no obvious difference between the 2 groups.

As shown in Table 4, a total of 145 screws were inserted

TABLE 2. Comparison of radiographic parameters in the coronal and sagittal planes between the MISS and PSF groups

Variable	MISS Group	PSF Group	p Value
No. of patients	15	30	
Cobb angle of main curve (°)			
Preop	48.3 ± 4.2	50.9 ± 5.4	0.616
Immediately postop	10.4 ± 3.8*	11.0 ± 3.4*	0.892
Last FU	11.1 ± 4.3	12.0 ± 3.1	0.789
Correction rate of main curve (%)			
Immediately postop	78.4 ± 8.3	78.3 ± 8.6	0.996
Last FU	77.1 ± 8.9	76.5 ± 7.0	0.832
Cobb angle of minor curve (°)			
Preop	24.0 ± 5.4	26.4 ± 6.6	0.345
Immediately postop	9.8 ± 2.9*	11.4 ± 4.2*	0.313
Last FU	10.3 ± 4.8	9.0 ± 3.8	0.442
Spontaneous correction rate of minor curve (%)			
Immediately postop	53.3 ± 8.7	55.2 ± 16.6	0.744
Last FU	57.0 ± 12.1	66.7 ± 12.9	0.074
CB (mm)			
Preop	29.5 ± 13.5	28.0 ± 10.8	0.767
Immediately postop	11.2 ± 8.6*	13.1 ± 9.7*	0.610
Last FU	6.2 ± 6.3	8.3 ± 6.2	0.406
AVT (mm)			
Preop	43.1 ± 11.3	49.3 ± 6.0	0.069
Immediately postop	13.9 ± 8.0*	14.3 ± 6.8*	0.887
Last FU	11.1 ± 4.3	10.8 ± 6.9	0.909
AVR			
Preop	2.6 ± 0.5	2.3 ± 0.5	0.286
Immediately postop	0.9 ± 0.5*	0.8 ± 0.3*	0.241
Last FU	1.0 ± 0.6	0.9 ± 0.3	0.322
TK (°)			
Preop	20.2 ± 6.1	16.5 ± 6.8	0.179
Immediately postop	24.3 ± 6.7	19.6 ± 5.9	0.071
Last FU	25.2 ± 6.2	22.9 ± 7.5	0.429
LL (°)			
Preop	50.1 ± 11.7	51.8 ± 6.9	0.632
Immediately postop	51.7 ± 6.4	51.7 ± 6.7	0.984
Last FU	50.8 ± 4.3	54.2 ± 7.3	0.205
Sagittal balance (mm)			
Preop	-31.0 ± 24.2	-36.3 ± 20.7	0.557
Immediately postop	-27.1 ± 19.8*	-25.7 ± 21.6*	0.876
Last FU	-12.0 ± 6.2*	-15.4 ± 12.1*	0.338

* Indicates a p value < 0.05 for the comparison among the different time points for the MISS group or PSF group.

in the MISS group and 335 screws in the PSF group. The accuracy of pedicle screw placement in both groups was evaluated on CT images. The satisfactory rate of pedicle screw placement was 93.8% in the MISS group and 95.5% in the PSF group, while the perforation rate was 6.2% and

TABLE 3. Comparison of surgical information and SRS-22 results between the MISS and PSF groups

Variable	MISS Group	PSF Group	p Value
No. of patients	15	30	
Operation time (mins)	252 ± 96	192 ± 30	0.002*
EBL (ml)	153 ± 97	418 ± 126	<0.001*
Transfusion (ml)	—	233 ± 146†	—
Levels of fusion	4.9 ± 0.5	5.7 ± 0.5	0.087
Density of implants (%)	98.6 ± 4.9	94.6 ± 7.6	0.240
SRS-22			
Functional/activity	4.3 ± 0.5	4.2 ± 0.5	0.292
Pain	4.6 ± 0.6	3.9 ± 0.7	0.013*
Self-image/appearance	4.3 ± 0.7	3.7 ± 0.6	0.046*
Mental health	4.1 ± 0.5	4.0 ± 0.5	0.347
Satisfaction w/ management	4.4 ± 0.6	4.2 ± 0.8	0.196

* Significant difference (p < 0.05).

† Only 3 patients in the PSF group received a transfusion.

4.5%, respectively, showing no significant difference between the 2 groups.

In the PSF group, 2 patients developed a superficial infection during the follow-up period. No deep wound infection, pseudarthrosis, additional surgery, implant failure, or neurological complications were observed in either group.

Discussion

Spinal deformity has been successfully managed with standard open anterior spinal fusion and PSF.^{11,14,15,25} In the past few years, MISS has been successfully applied in the correction of adult degenerative scoliosis. Previous studies have shown good deformity correction rates and fewer complications.^{3,4,17} However, in contrast to adult degenerative scoliosis, the deformity in 3 planes in AIS is characterized by larger curves and more obvious vertebral rotation. Therefore, it is a great technical challenge for surgeons to perform MISS in AIS patients.

Recently, Sarwahi et al.^{19,20} performed posterior MISS in 7 AIS patients for deformity correction. In their series, the scoliosis correction rate in the MISS group was 79.25%, which was comparable to the correction rate of 84.78% in the PSF group. In addition, multiple benefits such as less blood loss and shorter hospital stays were also obtained. Note that more fluoroscopic imaging was needed while using traditional fluoroscopy in their surgery, which could increase the radiation exposure of both surgeons and patients.^{3,14,17} As a new technique, O-arm navigation can produce intraoperative 3D images through a single radiated operation, which exposes the patients and surgeons to less radiation from the O-arm than that with traditional fluoroscopy.^{1,16} In the present study, we specifically investigated the outcome of posterior MISS assisted by O-arm navigation for the correction of selected Lenke Type 5C AIS patients.

Our data indicate that the posterior MISS technique in Lenke 5C AIS with curves < 70° and reasonable flexibility can achieve correction of the primary curve that is compa-

FIG. 2. A and B: Preoperative radiographs obtained in a 14-year-old girl with Lenke 5C AIS, showing a major TL/L curve of 51° and a minor T curve of 32°. Sagittal alignment was observed with a TK of 32° and an LL of 60°. **C and D:** The patient underwent posterior MISS from T-12 to L-4. Immediately after surgery, the main curve correction rate was 92.2% and the spontaneous minor curve correction rate was 75%. Thoracic kyphosis was corrected to 31°, and LL was corrected to 62°. **E and F:** At the last follow-up of 27 months, the main curve correction rate was 88.2%, and the spontaneous minor curve correction rate was 65.6%. Thoracic kyphosis was 30° and LL was 62°. **G and H:** The appearance of the patient 3 months after surgery. Figure is available in color online only.

able with that of the standard open approach. In addition, the correction rates were consistent with those reported in the previous literature.^{5,9} Hee et al.⁹ reported a correction rate of 71% in thoracolumbar curves and 39.3% in thoracic curves in 11 patients undergoing PSF. Wang et al.²⁴ performed a study in 34 Lenke Type 5C AIS patients and found 78.6% correction of main curves and 55.4% correction of secondary curves. High accuracy in pedicle screw placement in the MISS group was achieved through the navigation of the O-arm. Our results were similar to those

of Torres et al., whose accuracy in pedicle screw placement in minimally invasive transforaminal lumbar interbody fusion under 3D navigation was 91.0%.²³ Moreover, the overall satisfactory rate in the MISS group was comparable to that in the PSF group in our study. From this standpoint, MISS seems to achieve the goals of acceptable deformity correction and satisfactory accuracy in pedicle screw placement.

In addition to the radiographic outcomes comparable with those of PSF, we observed multiple benefits of the

FIG. 3. A and B: Images obtained in a 17-year-old girl diagnosed with Lenke Type 5C AIS with a main TL/L curve of 48° and a minor T curve of 34°. Sagittal malalignment was observed with a TK of 4° and an LL of 26°. **C and D:** The patient underwent posterior MISS from T-12 to L-4. Immediately after surgery, the correction rates of the main and minor curves were 75% and 64.7%, respectively. Thoracic kyphosis was corrected to 28° and LL was corrected to 42°. **E and F:** At the last follow-up of 25 months, the correction rates of the main and minor curves were 77.1% and 64.7%, respectively. Thoracic kyphosis was 28° and LL was 43°. **G and H:** The appearance of the patient 3 months after surgery. Figure is available in color online only.

TABLE 4. Accuracy of pedicle screw placement between the MISS and PSF groups

Variable	Grade 0	Grade 1	Grade 2	Grade 3	Satisfactory Placement Rate	Perforation Rate	Total
MISS	125 (86.2%)	11 (7.6%)	8 (5.5%)	1 (0.7%)	136 (93.8%)	9 (6.2%)	145 (100%)
PSF	287 (85.7%)	33 (9.1%)	9 (2.6%)	6 (1.8%)	320 (95.5%)	15 (4.5%)	335 (100%)
p value					0.425	0.425	

MISS technique. Our results showed that EBL in the MISS group was much lower than that in the PSF group. This finding was reasonable since small incisions and less dissection of tissue was performed in MISS. Sarwahi et al.¹⁹ performed posterior MISS in 7 patients with double structural curves and found that EBL in MISS was less than that in PSF. In the present study, patient quality of life was evaluated using the SRS-22. Assessments of pain and self-image were better in the MISS group than in the PSF group, which reached the minimal clinically important difference threshold.⁵ In Sarwahi et al.'s¹⁹ study, the MISS technique seemed not to have the advantage of better pain assessments (visual analog scale score) compared with PSF. That may be due to the extensive incision used to expose the facet in their technique.¹⁹ Our maneuver of blunt dissection through the intermuscular plane yielded less blood loss and postoperative pain. In addition, the minimal incision and better cosmetic appearance contributed to the better self-image assessment on the SRS-22.

Despite the advantage of good deformity correction with less blood loss and less pain, the MISS was found to be associated with longer operation times than the PSF. Sarwahi et al.¹⁹ also found longer operative times in MISS than in PSF. This was, to some extent, a reflection of the learning curve. The initial operative time of a posterior MISS was about 250 minutes, whereas an entire posterior MISS can now be finished within 180 minutes given the increased experience of surgeons.

Traditional minimally invasive pedicle screw placement was performed via a percutaneous procedure.^{3,6,12} Percutaneous pedicle screw placement with a stab incision not only creates immense cosmetic problems, but also limits adequate facetectomy and fusion, which is not preferable in AIS correction surgery. In our study, 2 limited incisions (3–5 cm) were used. The facet was exposed through the intermuscular plane between the erector spinae muscles and multifidus muscles with less dissection of soft tissue and spinal posterior structure. Facetectomy could be performed under direct vision and adequate fusion could be ensured. Two or 3 segments (4–6 pedicle screws) were instrumented per skin incision under O-arm navigation. As compared with traditional PSF surgery, in our opinion, the MISS is aimed at minimal invasion, which has more clinical significance than a minimal open incision. Currently, this technique is applied mainly to curves < 70° with flexibility > 50%. In our series, the deformity in both the coronal and sagittal planes could be corrected satisfactorily.

This is the first report to focus on the utilization of posterior MISS under O-arm navigation in Lenke Type 5C AIS patients. The advantage in our study lies in the utilization of O-arm navigation, which guaranteed the high accuracy in screw placement. Although favorable correc-

tion outcomes occurred following MISS in our study, the use of this technique is currently limited and its role in deformity correction of Lenke Type 5C AIS is still difficult to define. The primary limitation of our study was its small sample size, with only 15 patients in the MISS group and 30 in the PSF group. Because we restricted the use of posterior MISS to patients with Lenke Type 5C AIS with curves less than 70° and reasonable flexibility, only 15 patients were treated by use of this technique. We believe attention to appropriate case selection is the key to long-lasting good outcomes. Blood loss estimation was based on aspirated blood and weighted sponges. This does not take into account submuscular bleeding, which can occur in MISS as the spine is not exposed. Another limitation was the short-term follow-up. Further investigation with a longer follow-up and larger sample size is warranted to clarify the benefits of MISS for correction surgery in AIS.

Conclusions

In summary, posterior MISS is a feasible and effective alternative for Lenke Type 5C AIS patients with curves < 70° and reasonable flexibility. High accuracy in pedicle screw placement during MISS can be achieved through O-arm navigation. Compared with the open approach, MISS outcomes in the present study are promising with reduced morbidity. Before routine use of the technique, long-term data are needed.

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Disclosures

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Author Contributions

Conception and design: W Zhu. Acquisition of data: W Sun. Analysis and interpretation of data: Xu, X Sun, Liu. Drafting the article: W Zhu. Critically revising the article: W Zhu, Xu. Reviewed submitted version of manuscript: Z Zhu, Qiu. Approved the final version of the manuscript on behalf of all authors: Z Zhu.

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