OPERATIVE TECHNIQUE

Treatment of Scoliosis with One-Stage Posterior Pedicle Screw System by Paraspinal Intermuscular Approach: A Minimum of Two Years of Follow-Up

Qingxu Song, MD[1], Jiali Leng, MSN[2], Zhigang Qu, MD[1], Xinming Zhuang, MD[1], Yujian Wang, MBBS[1], Yi Liu, MD[1†], Zhenyu Wang, MD[1†]

Department of [1]Spinal Surgery and [2]Hospice, the First Hospital of Jilin University, ChangChun City, China

Abstract

Objective: To evaluate the clinical efficacy of the treatment of scoliosis with a pedicle screw system through paraspinal intermuscular approach (PIA).

Methods: This is a retrospective case series study. A total of 10 patients diagnosed with scoliosis had surgical indications and treated with a pedicle screw system in one-stage posterior surgery by PIA from March 2013 to April 2015 at the First Hospital of Jilin University were enrolled in this study. The average age of the patients was 14.9 years, including one male and nine females. The operative information and surgical results, including Cobb angle correction, correction loss, global balance (including Frontal Plane Balance [FPB] and Sagittal Plane Balance [SPB]), and fusion rate were reviewed. Functional outcomes including visual analog scale (VAS) back pain score, leg pain score, and Scoliosis Research Society-22 questionnaire (SRS-22) were used to evaluate the quality of life of patients preoperatively and at last follow-up.

Results: Each patient was followed up at least six times. The average follow-up time was 43.2 months. Mean scoliosis and kyphosis improved from $68.5° \pm 18.1°$to $18.7° \pm 11.8°$ and from $34.4° \pm 17.9°$to $24.0° \pm 6.7°$, respectively ($p < 0.05$); at last follow-up, it was 20.1° and 24.7°, respectively ($p > 0.05$). During the follow-up, mean coronal and sagittal correction loss was $1.4° \pm 1.2°$and $0.7° \pm 0.8°$, respectively ($p > 0.05$). Mean FPB improved from 32.7 to 11.7 mm ($p < 0.05$); Mean SPB changed from 0.3 to −0.7 mm ($p > 0.05$). No dural tears were observed during the corrective surgery or wound infection or implant-related complications. No pseudoarthrosis was identified according to the last follow-up three-dimensional (3D) CT scan. All the domains in SRS-22 questionnaire show statistically significant improvement at the last follow-up ($p < 0.05$). The VAS back pain scores improved from a mean preoperative score of 1.7 to a mean postoperative score of 0.2 ($p < 0.05$).

Conclusion: This original one-stage posterior PIA is safe and effective in the treatment of scoliosis, which is characterized with less blood loss, shorter operation time, and satisfactory bony fusion.

Key words: facet joint fusion; one-stage posterior approach; paraspinal intermuscular approach; pedicle screw system; scoliosis

Introduction

It is widely accepted that the primary goals of surgical correction for patients with scoliosis are effective correction of spinal deformity, safely prevention of curve progression, and restoration of the coronal and sagittal planes.[1–4] For structural thoracic scoliosis, this is most commonly done by

Address for correspondence Zhenyu Wang, MD, Department of Spinal Surgery, the First Hospital of Jilin University, No. 71, Xinmin St, Chaoyang District, ChangChun City, Jilin Province 130021, China. Email: zhenyu@jlu.edu.cn; Yi Liu, MD, Department of Spinal Surgery, the First Hospital of Jilin University, ChangChun City, Jilin Province, 130021, China. Email address: Email: successwzy@163.com
[†]Yi Liu and Zhenyu Wang contributed equally to this work.
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use of posterior spinal fusion technique with pedicle screws system.[5,6] However, surgical correction of structural scoliosis with a traditional posterior open approach has been associated with significant perioperative and postoperative morbidity, related to long incisions, stripping of paraspinal muscles over large segments, severe blood loss, and increased hospital stay.[7] In recent years, there has been a rapid development of minimally invasive surgery (MIS) for degenerative spinal disorders, including scoliosis.[4] From 1990s, Mack *et al.*[8] and Picetti *et al.*[9] reported the development of endoscopic approaches to the thoracic and thoracolumbar spine. Since then, minimally invasive surgery (MIS) for scoliosis has developed rapidly.[5,10–12] The MIS approach to spinal deformity is increasingly recognized as effective and safe; it reduces trauma to soft tissue, decreases intraoperative blood loss, and minimizes surgical site infections.[7,13–17] However, none of these studies described the anatomical approach in detail. In addition, usually laminar decortication or wide facetectomies were applied for bone graft fusion. Thus, even the application of so-called minimally invasive approaches or access tools could potentially damage the soft tissue during the approach.

Furthermore, Wiltse's approach is one of the MIS techniques that has been widely applied in various spinal diseases,[18–20] such as spinal fusion, especially lumbosacral spondylolisthesis in the lumbar or thoracolumbar spine.[21] Several studies have shown that injury to paraspinal muscles could significantly decrease with the Wiltse's approach.[22,23]

Although changes in the recent decades affecting the surgical treatment of scoliosis mainly focused on spinal stabilization and improvements in implants and instrumentation techniques, the ultimate goal of treatment is to achieve a solid and stable fusion.[24,25] Compared with previous instrumentation systems, the pedicle screw technique is advantageous. It provides stronger anchorage, achieves three-column fixation through a single posterior approach, and has better apical vertebral derotation, correction methods, high correction rate, long-term low loss of correction, and 3D correction.[26–30] Therefore, effective bony fusion is the key to the success of scoliosis correction surgery after accurate and safe placement of the pedicle screw.

In clinical practice, the present study aimed to investigate whether we can effectively treat scoliosis with a one-stage posterior pedicle screw system and facet joint fusion by paraspinal intermuscular approach (PIA), which was modified from Wiltse's approach. However, the Wiltse's approach is primarily applied in lumbar or thoracolumbar spinal surgery diseases. In thoracic region, due to the coverage of latissimus dorsi, trapezius, rhomboid and so on, the Wiltse's intermuscular cleavage plane is difficult to identify. So, the reason why this type of MIS technique has not been applied to thoracic spine surgery may be that the anatomical layers of thoracic paravertebral muscles are more complex, variable, and difficult to identify clearly. This kind of complexity may increase, especially in the presence of scoliosis. To the best of our knowledge, this type of MIS surgical approach for the treatment of scoliosis has not been reported. Therefore, it is not difficult to understand why few surgeons are willing to attempt this approach in the thoracic region. However, is it true? Therefore, the specific purposes of this study are: (i) to explore and elucidate a feasible, simple, and reproducible MIS surgical approach for pedicle screw insertion for the correction of scoliosis, especially in thoracic spine; (ii) to assess whether solid fusion can be achieved through this MIS approach; (iii) to evaluate the radiographic and clinical outcomes of a minimum 2-year follow-up.

Materials and Methods

Inclusion Criteria and Exclusion Criteria

The inclusion criteria were as follows: (i) scoliosis patients treated with surgery from March 2013 to April 2015 at the First Hospital of Jilin University; (ii) patients treated with one-stage posterior pedicle screw system and facet joint fusion by PIA and were followed up for more than 2 years; (iii) number of fusion segments, intraoperative blood loss, operation time, blood transfusion and number of pedicle screws, Cobb angle, correction loss, FPB, SPB, SRS-22 score, VAS back pain score, and VAS leg pain score were used for evaluation of the results of surgical treatment; and (iv) all the patients' outcomes were documented.

Exclusion criteria were: (i) pulmonary dysfunction, infections, psychiatric disorders, coagulation disorders, and other severe diseases, such as cardiovascular and cerebrovascular diseases, primary malignant vertebral tumors; (ii) Patients followed up <2 years.

All scoliosis patients treated with one-stage posterior pedicle screw system and facet joint fusion by PIA from March 2013 to April 2015 at the First Hospital of Jilin University were enrolled. The study was approved by the Ethics Committee of First Hospital of Jilin University (Application number: 2020–703), and written informed consent was obtained from the patients.

Preoperative Clinical Examination

Preoperative clinical examination included a thorough neurological and radiological examination. All patients were subjected to standard standing plain radiography of the whole spine (posterior–anterior and lateral positions) and side-bending radiographical examination. Coronal and sagittal curve measurements were made on the whole-spine radiograph images using the Cobb method. Spinal flexibility was evaluated using side-bending images.

Surgical Techniques

All patients were treated with one-stage posterior segmental pedicle screw instrumentation and spinal fusion by PIA. All the procedures were performed by the same surgical team with somatosensory evoked potential monitoring.

Anesthesia and Position
The patients received general anesthesia and were placed in the prone position on prone frames.

Exposure
The skin was prepared and draped in a routine orthopaedic manner. Then, the PIA was performed in the following manner. A posterior median incision was made along the spinous processes. The skin incision was carried down to the level of deep fascia, and the skin was retracted about 1–2 cm laterally on either side according to the preoperative magnetic resonance imaging (MRI) results in order to make an accurate fascial incision.

Lumbar Spine Region
In the lumbar spine region, the erector spinae aponeurosis was incised, and the potential space between the multifidus and longissimus muscles was developed to expose facet joints.

Upper Thoracic Spine Region
In the thoracic spine region, if the proximal fusion region includes T2–6, the trapezius and rhomboid major are severed from thoracic spinous processes and marked with tendon sutures and then retracted laterally to reveal the potential gap between longissimus cervicis and splenius cervicis (Figure 1). Through this gap, the thoracic transverse process and the lateral edge of the superior articular process and lamina could be accessed. Then, the subperiosteal dissection was performed to the medial side, and the splenius cervicis, the semispinalis cervicis, the semispinalis thoracis, and the multifidus muscle were retracted medially to reveal the facet joint (Fig. 2).

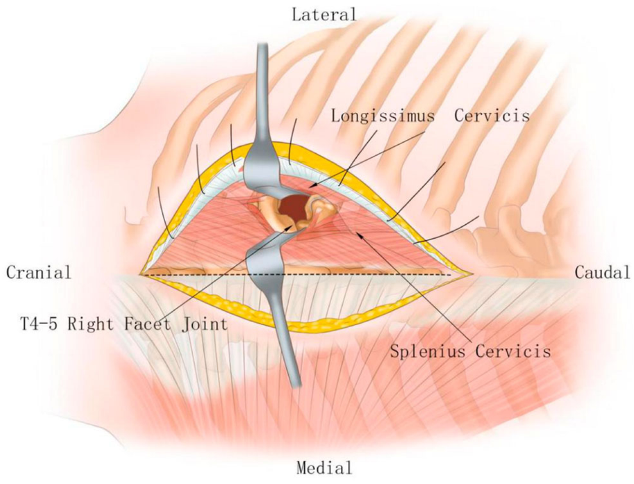

Fig. 1 Surgical diagram (hand drawing) for the anatomy of the paraspinal intermuscular approach of upper thoracic region

Lower Thoracic Spine Region
If the proximal end is fused to T7–12, the trapezius and latissimus dorsi should be severed from spinous process and marked to reveal potential gaps between the longissimus thoracis, semispinalis thoracis, and multifidus muscles (Fig. 3). In fact, because the potential gap between the longissimus muscle and the spinalis muscle is more recognizable, it is easier to expose the facet joint fusion area in the thoracolumar region. The facet joint is just located at the potential gap between the spinalis muscle and multifidus muscle (Fig. 4). In order to minimize the injury of soft tissue and blood supply, we only exposed limited laminar region.

Fixation, Correction, and Fusion
A total of nine patients were fused from one or two levels proximal to the upper-end vertebra to one or two levels distal to the lower end vertebra (EV + 1 or 2). The remaining

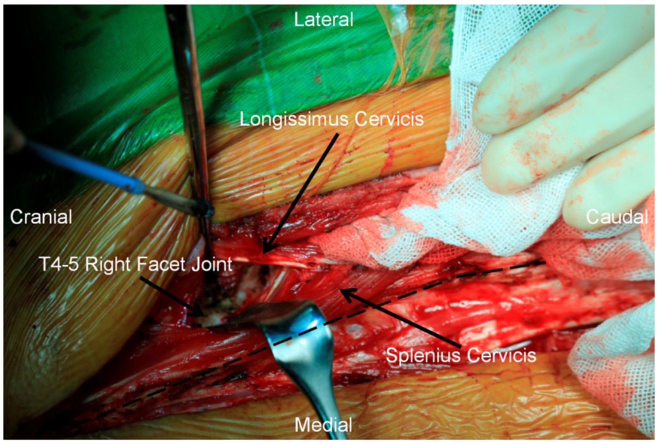

Fig. 2 No. 12 patient. Intraoperative photograph shows anatomy of surgical approach for upper thoracic region

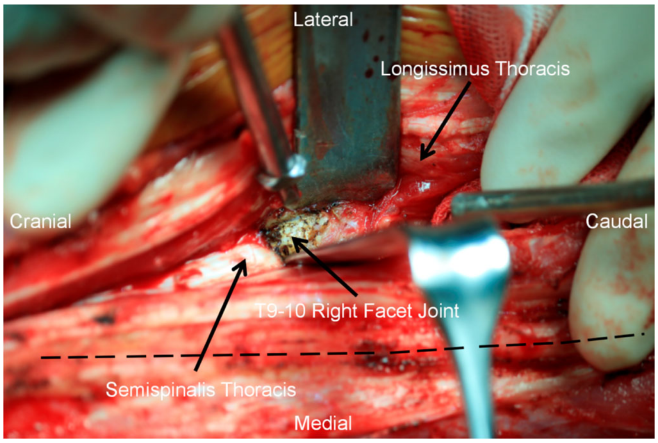

Fig. 3 No. 5 patient. Intraoperative photograph shows anatomy of surgical approach for lower thoracic region

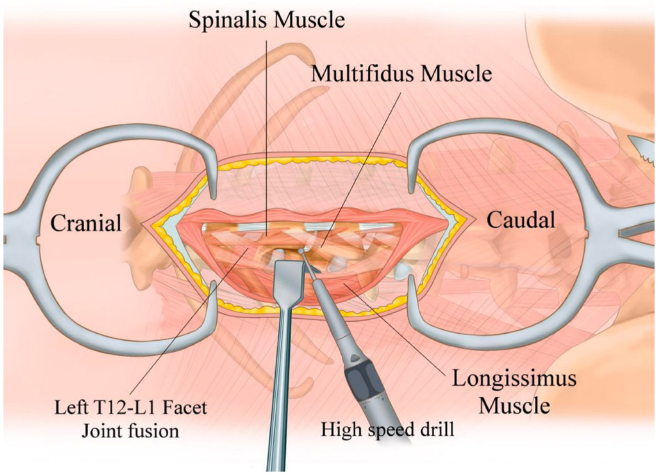

Fig. 4 Surgical diagram (hand drawing) for the anatomy of the paraspinal intermuscular approach of thoracolumbar region (T12-L1)

one patient (scoliosis of neurofibromatosis type 1) underwent fusion to the stable vertebra (SV) proximally and distally. The preselected surgical segment and correct pedicle screw insertions were confirmed by C-arm fluoroscopy. During surgery, the tails of the pedicle screws were connected through a temporary rod on one side (usually the concave side). After stabilization by the temporary rod, the abnormal spine was corrected through gradual segmental compression, distraction, and derotation. Next, we applied the final internal fixation after confirming the correction by intraoperative radiographic examination. The facet joints fusion was performed within the correction region with the PIA approach, leaving the supraspinalis and interspinal ligaments intact. High-speed drill was utilized to decorticate facet joints for fusion without wide facetectomy. Allogenic bone was applied to assist graft fusion. Operation time, blood loss, blood transfusion, and postoperative drainage volume were recorded.

Postoperative Image Evaluation

After surgical treatment, we investigated fusion segments using computed tomography (CT) (Philips, 256-slice, Brilliance iCT) to assess both preoperative bone quality and the severity of pedicle deformity; three-dimensional CT (3D-CT) was also used to assess the bony fusion rate after the surgery. The loss of correction of ≥10 was another indicator of nonunion or pseudarthrosis.[31–34] Before operation, all patients underwent pulmonary function testing and echocardiography to assess cardiopulmonary function and the presence of congenital cardiac malformations, respectively.

Postoperative Care

Antibiotics were administered routinely to prevent postoperative infections in 24 h. Typically, if the 24 h drainage volume is <50 ml postoperatively, the drainage tube can be removed. All patients left bed under the protection of brace 3 days after the surgery. The brace can be removed 3 weeks postoperatively.

Follow-Up

Each patient was followed up at least six times. Standard standing plain radiography of the whole spine (posterior–anterior and lateral positions) was taken at 5 days, 1 month, 3 months, 6 months, 1 year, and 2 years postoperatively, and then reviewed annually. The 3D-CT of spine was reviewed annually to access fusion. All patients were followed up for a minimum of 26 (mean: 43.2 [range, 26–52]) months.

Outcome Measures

Cobb Angle. The Cobb angle is the most widely used measurement to quantify the magnitude of spinal deformities. Dr. John Cobb invented this method in 1948.[35] Cobb suggested that the angle of curvature be measured by drawing lines parallel to the upper border of the upper vertebral body and the lower border of the lowest vertebra of the structural curve, then erecting perpendiculars from these

TABLE 1 Patient information

No.	Gender	Diagnosis	Operative age (years)	Course (month)	Pre-OP height (cm)	Pre-OP sitting Height (cm)	Follow-up (month)	Length of stay (day)
1	F	AIS	16	36	163	85	52	12
2	F	AIS	20	208	150	73	51	13
3	F	AIS	14	84	159	82	48	12
4	F	AIS	10	72	156	76	46	7
5	F	AIS	13	36	160	82	45	12
6	F	AIS	22	96	162	84	44	17
7	F	NFS	13	36	141	73.5	40	14
8	F	AIS	14	36	160	83	40	17
9	M	NMS	14	120	168	87	40	7
10	F	AIS	13	2	157	83	26	20
Mean			14.9	72.6	157.6	80.9	43.2	13.1

Abbreviations: AIS, adolescent idiopathic scoliosis; F, female; M, male; NFS, neurofibromatosis scoliosis; NMS, neuromuscular scoliosis; Pre-OP, pre-operative; Post-OP, postoperative.

lines to cross each other, the angle between these perpendiculars being the "angle of curvature."

Global Balance: Frontal Plane Balance and Sagittal Plane Balance. The concept and definition are quoted from the Scoliosis research society.

Frontal Plane Balance. Concept: The distance in the frontal plane between a vertical line dropped from the most cephalad vertebra and the vertical line passing through S_1.

Definition: The medial-lateral distance of a defined cephalad endpoint from the global axis system (origin at S_1). In practice, the defined cephalad endpoints are the T_1, C_7, or the inion. In our study, we defined the cephalad endpoints as C_7.

Sagittal Plane Balance. Concept: The distance in the sagittal plane between a vertical line dropped from the most cephalad vertebra and the vertical line passing through S_1.

Definition: The antero-posterior translation of a defined cephalad endpoint from the global axis system (origin at S_1). In practice, the defined cephalad endpoints are the T_1, C_7, or the inion. In our study, we defined the cephalad endpoints as C_7.

Functional Outcome

Scoliosis Research Society-22, SRS-22. The Scoliosis Research Society-22 (SRS-22) questionnaire is a patient-reported outcome instrument for the assessment of the health-related quality of life of patients with scoliosis. The SRS-22 questionnaire includes five domains. The domains and the number of questions in them are as follows: function/activity (5), pain (5), self-image/appearance (5), mental health (5), and satisfaction with management (2). The combination of the first four domains is labeled subtotal. The mental health questions are adapted with permission from SF-36. The scoring scale ranges from 5 as best to 1 as worst. SRS-22 was used to evaluate the quality of life of patients preoperatively and at last follow-up.

Visual Analog Scale. The Visual Analog Scale (VAS) is one of the most reliable and valid measurement tools for self-report of pain in children aged 8 and above. It is often used in epidemiological and clinical research to measure the intensity or frequency of various symptoms. In our study, VAS back pain score and leg pain were used to assess back pain preoperatively and at last follow-up.

Statistical Analysis

SPSS V.22 software (IBM) was used for statistical analysis. Paired *t*-test was used to compare outcomes at different time points. The measurement data (follow-up time, number of fusion segments, intraoperative blood loss, operation time, blood transfusion, number of pedicle screws, Cobb angle, correction loss, FPB, SPB, SRS-22 score, VAS back pain

TABLE 2 Surgery information

	Diagnosis	Date of surgery (yyyy/mm/dd)	Main scoliosis range	Apical vertebra	Fusion range	Fusion segments	Left pedicle screw	Right pedicle screw	Total pedicle screws	Operative time (min)	Blood loss (ml)	Blood transfusion (ml)	Postoperative drainage (ml)
1	AIS	2013/3/7	T10-L3	L1	T10-L4	7	T10, 11, L1, 3, 4	T10, 11, 12, L1, 2, 3, 4	12	215	140	0	50
2	AIS	2013/3/19	T9-L3	L1	T8-L4	9	T8, 9, 10, 11, 12, L1, 2, 3, 4	T8, 9, 10, 11, 12, L1, 2, 3, 4	18	270	210	0	30
3	AIS	2013/7/25	T7-L2	T11	T2-L3	14	T2, 3, 5, 7–12, L1-3	T2, 3, 7, 11, L2, 3	18	290	200	0	30
4	AIS	2013/9/29	T7-T11	T9	T6-T12	7	T6-12	T6, 9, 12	10	251	100	0	30
5	AIS	2013/10/25	T6-L1	T10	T5-L2	10	T5, 6, 8, 10, 12, L2	T5, 6, 8, 10, 11, L1, 2	13	345	80	0	20
6	AIS	2013/11/12	T5-T11	T8	T4-L1	9	T4-L1	T4-10, T12, L1	19	300	420	0	20
7	NFS	2014/2/13	T7-T11	T9	T3-L2	12	T3-L2	T3, 4, 9, L1, 2	17	483	680	400	20
8	AIS	2014/3/4	T8-L2	T11	T8-L3	8	T8, 10, 12, L2, 3	T8-L3	13	291	210	0	20
9	NMS	2015/2/6	T8-L1	T10-11	T6-L2	9	T6-L2	T6, 7, 10, L11, 2	14	360	310	0	20
10	AIS	2015/4/23	T4-T11	T8	T4-T12	9	T4, 5, 7, 9, 11, 12	T4, 5, 8, 11, 12	11	275	210	0	20
Mean						9.4			14.5	308	256	40	26

Abbreviations: AIS, adolescent idiopathic scoliosis; NFS, neurofibromatosis scoliosis; NMS, neuromuscular scoliosis.

TABLE 3 Correction information on coronal plane

No.	Diagnosis	Preoperative cobb angle (°)	Postoperative cobb angle (°)	Correction rate (%)	Last follow-up Cobb angle (°)	Correction loss (°)	Correction loss rate (%)
1	AIS	65	8	88	9	1	2
2	AIS	92	25	73	28	3	3
3	AIS	64	13	80	13	0	0
4	AIS	50	28	44	30	2	4
5	AIS	49	0	100	3	3	6
6	AIS	74	36	51	38	2	2
7	NFS	105	34	68	35	1	1
8	AIS	64	10	84	10	0	0
9	NMS	70	15	79	17	2	3
10	AIS	52	18	66	18	0	0
Mean		68.5	18.7	73.3	20.1	1.4	2.1

Abbreviations: AIS, adolescent idiopathic scoliosis; NFS, neurofibromatosis scoliosis; NMS: neuromuscular scoliosis.

TABLE 4 Correction information on the sagittal plane

No.	Diagnosis	Preoperative cobb angle (°)	Postoperative cobb angle (°)	Correction rate (%)	Last follow-up cobb angle (°)	Correction loss (°)	Correction loss rate (%)
1	AIS	26	23	12	23	0	0
2	AIS	21	17	19	17	0	0
3	AIS	28	21	25	22	1	4
4	AIS	38	35	8	35	0	0
5	AIS	36	32	11	33	1	3
6	AIS	55	26	53	28	2	4
7	NFS	68	25	63	27	2	3
8	AIS	9	17	89	17	0	0
9	NMS	45	29	36	30	1	3
10	AIS	18	15	17	15	0	0
Mean		34.4	24	33.3	24.7	0.7	1.7

Abbreviations: AIS, adolescent idiopathic scoliosis; NFS, neurofibromatosis scoliosis; NMS, neuromuscular scoliosis.

score, and VAS leg pain score) were expressed as mean ± SD ($x \pm s$). Two independent sample t tests were utilized for measurement data comparison. p-value <0.05 was considered statistically significant.

Results

General Results

A total of 10 patients were included in the final analysis. They included nine females and one male, with a mean age of 14.9 (range, 10–22) years at the time of surgery, mean follow-up of 43.2 (range, 26–52) months, and a mean length of stay of 13.1 (range, 7–20) days (Table 1). Of these, eight patients were diagnosed with idiopathic scoliosis. One patient was diagnosed with non-dystrophic neurofibromatosis type-1 scoliosis (NFS), and one was diagnosed with neuromuscular scoliosis (NMS) due to Chiari malformation, as revealed by MRI examination. No evident neurological complication was observed except the NFS patient who exhibited preoperative lower extremity weakness, defined as Grade 4 muscle strength. Cardiopulmonary function tests revealed no severe cardiac dysfunction.

Intraoperative Outcomes

In this study, a total of 145 pedicle screws were inserted accurately. No misplaced screw and invasion of nerves or blood vessels were found. During the follow-up, there was no decompensation. The mean intraoperative blood loss was 256 (range: 80–680) ml, and the mean operation time was 308 (range, 215–483) min (Table 2).

Radiographic Outcomes

The initial mean Cobb angle of scoliosis and kyphosis was 68.5° (range: 50°–105)° and 34.4° (range: 9°–68°), respectively. Postoperatively, the Cobb angle of scoliosis and kyphosis was reduced to 18.7° (range: 0°–36°) ($p < 0.05$) and 24° (range: 15°–35°) ($p < 0.05$), respectively. The scoliosis and kyphosis correction rates were 73.3% (range: 44%–100%) ($p < 0.05$) and 33.3% (range: 8%–89%) ($p < 0.05$), respectively. At the last follow-up, the mean Cobb angle of scoliosis was 20.1° (range: 3°–38°), and that for kyphosis was 24.7° (range: 15°–35°), respectively. Typically, the satisfactory improvement was obtained in both the coronal and sagittal planes (Tables 3 and 4). There was no significant loss of correction (1.4° [0–3]° and 0.7° [0–2]° in the coronal and sagittal planes, respectively, $p > 0.05$]). Mean FPB improved from 32.7 ± 10.9 to 11.7 ± 6.4 mm ($p < 0.05$); Mean SPB changed from 0.3 ± 7.7 to −0.7 ± 2.6 mm ($p > 0.05$) (Table 5). No patient had a loss of correction of ≥10° or experienced persistent pain or tenderness along the fusion

TABLE 5 Correction information of global balance

No.	Diagnosis	Preoperative FPB (mm)	Last follow-up FPB (mm)	Correction rate (%)	Preoperative SPB (mm)	Last follow-up SPB (mm)	Correction rate (%)
1	AIS	34.0	17.0	50.0	−3.0	−2.0	33.3
2	AIS	43.0	18.0	58.1	−5.0	−6.0	−20.0
3	AIS	33.0	17.0	48.5	−2.0	−3.0	−50.0
4	AIS	21.0	5.0	76.2	1.0	0.0	200.0
5	AIS	12.0	0.0	100.0	2.0	1.0	50.0
6	AIS	37.0	8.0	78.4	10.0	2.0	80.0
7	NFS	51.0	22.0	56.9	12.0	3.0	75.0
8	AIS	38.0	10.0	73.7	−13.0	−2.0	84.6
9	NMS	36.0	9.0	75.0	9.0	2.0	77.8
10	AIS	22.0	11.0	50.0	−7.0	−6.0	14.3
Mean		32.7	11.7	66.7	0.4	−1.1	44.5

Abbreviations: AIS, adolescent idiopathic scoliosis; FPB, frontal plane balance; NFS, neurofibromatosis scoliosis; NMS, neuromuscular scoliosis; SPB, sagittal plane balance.

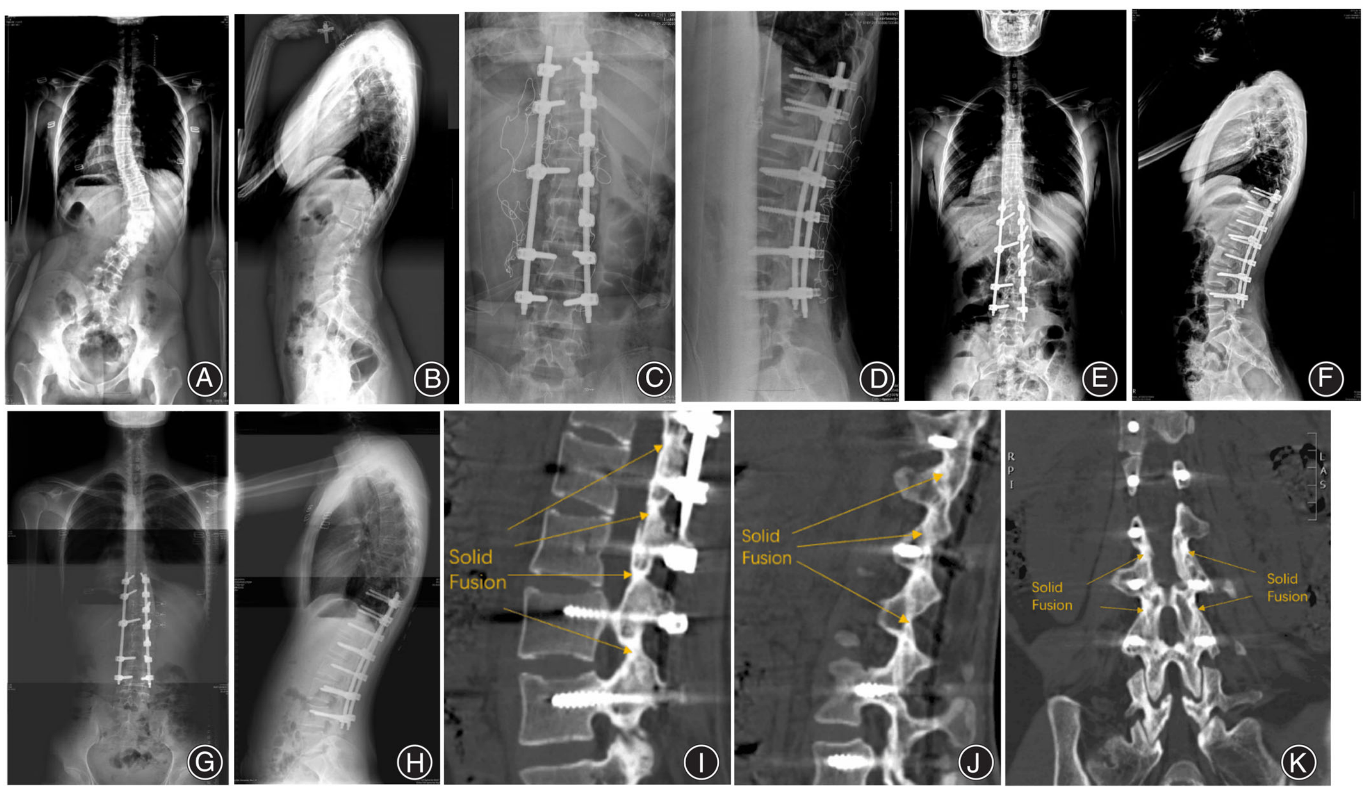

Fig. 5 No.1 patient. (A) Preoperative full spine anteroposterior X-ray image; (B) Preoperative full spine lateral X-ray image; (C) Intraoperative anteroposterior X-ray image; (D) Intraoperative lateral X-ray image; (E) Postoperative full spine anteroposterior X-ray image; (F) Postoperative full spine lateral X-ray image; (G) Last follow-up full spine anteroposterior X-ray image; (H) Last follow-up spine lateral X-ray image; (I, J) 3D-CT scans show solid fusion on sagittal plane at last follow-up; (K) 3D-CT scans show solid fusion on coronal plane at last follow-up

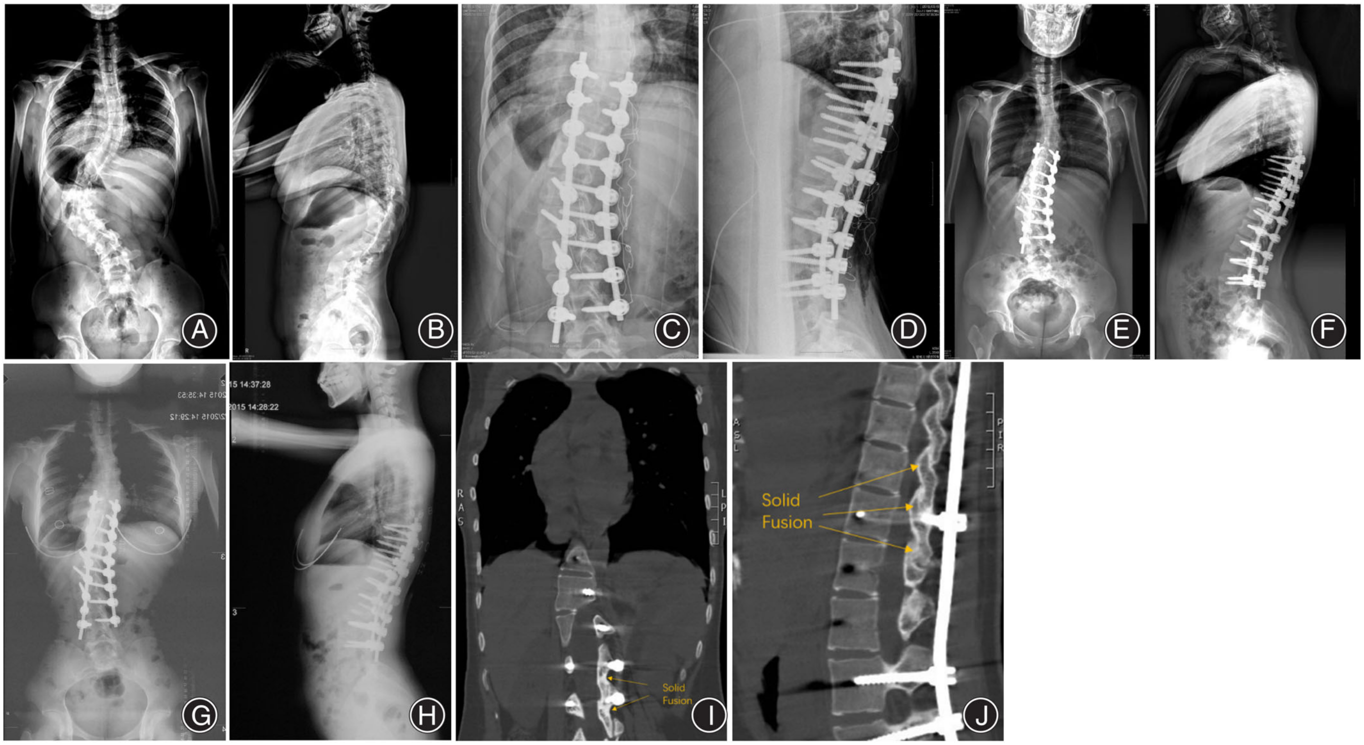

Fig. 6 No.2 patient. (A) Preoperative full spine anteroposterior X-ray image; (B) Preoperative full spine lateral X-ray image; (C) Intraoperative anteroposterior X-ray image; (D) Intraoperative lateral X-ray image; (E) Postoperative full spine anteroposterior X-ray image; (F) Postoperative full spine lateral X-ray image; (G) Last follow-up full spine anteroposterior X-ray image; (H) Last follow-up spine lateral X-ray image; (I) 3D-CT scans show solid fusion on coronal plane at last follow-up; (J) 3D-CT scans show solid fusion on sagittal plane at last follow-up

TABLE 6 Comparison of SRS-22 questionnaire preoperatively and at last follow-up

SRS-22 Domains	Pre-operation	Last Follow-up	*t* value	*p* value
Function/activity	4.2 ± 0.3	4.5 ± 0.2	−4.129	0.003*
Pain	4.1 ± 0.3	4.6 ± 0.2	−8.752	0.000*
Self-imge/appearance	2.7 ± 0.3	4.6 ± 0.3	−14.812	0.000*
Mental health	3.5 ± 0.3	4.5 ± 0.3	−19.202	0.000*
Satisfaction with management	—	4.66 ± 0.13	—	—

Abbreviation: SRS-22, the Scoliosis Research Society-22 questionnaire.; * Statistically significant if $p < 0.05$.

segments. Furthermore, we observed a continuous layer of fusion bone on 3D-CT scans of the fusion and instrumentation segments, and hence, did not find any pseudoarthrosis or nonunion during the follow-up (Fig. 5I,J,K and Fig. 6I,J). To date, no revision surgery has been performed. However, whether revision surgery is necessary depends on the continued follow-up results.

Functional Outcomes

The results of SRS-22 score were shown in Table 6. All the domains in SRS-22 questionnaire show statistically significant improvement at the last follow-up ($p < 0.05$). The score of self-image/appearance domain shows the most significant improvement rate of 42.2% (2.7 ± 0.3 preoperatively, 4.6 ± 0.3 at last follow-up). Mental health domain improved from 3.5 ± 0.3 to 4.5 ± 0.3 with the improvement rate of 23.0%. Although, the improvement rate was only 5.38% and 12.7%, statistically significant difference was still observed in the domain of function/activity (4.2 ± 0.3 preoperatively, 4.5 ± 0.2 at last follow-up) and mental health (3.5 ± 0.3 preoperatively, 4.5 ± 0.3 at last follow-up) respectively. The VAS back pain scores improved from a preoperative score of 1.7 ± 1.8 to a postoperative score of 0.2 ± 0.4 ($p < 0.05$). The mean preoperative and postoperative VAS left leg pain scores were 0.9 ± 1.5 and 0.1 ± 0.3, respectively ($p > 0.05$).

Complications

There were no dural tears during the corrective surgery or wound infection or implant-related complications.

Discussion

In this retrospective study on MIS with PIA in the treatment of scoliosis, there were three significant findings: (i) the exposure method through PIA accommodated pedicle screw insertion safely and effectively. No implant-related complications were found; (ii) facet joint fusion with PIA leaves most paraspinal muscles, the supraspinalis, and interspinal ligament intact, achieving strong fusion. No pseudoarthrosis was found at last follow-up; (iii) fairly good correction effects and well-balanced trunks while avoiding significant loss of correction were achieved with PIA. Mean scoliosis improved from 68.5°to 20.1° (70.7% improvement) at last follow-up. Mean coronal and sagittal correction loss was $1.4^\circ \pm 1.2^\circ$and $0.7^\circ \pm 0.8^\circ$, respectively. Mean FPB improved from 32.7 to 11.7 mm (64.2% improvement).

Advantages of PIA

Both PIA and the traditional posterior median approach use a posterior median incision, but the PIA method of exposure fully conforms to the concept of minimally invasive spinal surgery. The goals of PIA procedure are to reduce the approach-related morbidity associated with traditional posterior thoracic and lumbar approaches, and at the same time achieve all the surgical goals in an effective and safe manner. Traditional posterior thoracic and lumbar procedures through a midline incision requires extensive soft tissue dissection in order to expose the anatomic landmarks, perform screws insertion, and achieve posterior fusion. Multiple authors have documented the detrimental effects of extensive muscle dissection and retraction that normally occur during traditional procedures. The PIA exposure utilizes the natural and potential tissue planes of the erector spinae muscle between the sacrospinalis muscle medially and the longissimus and iliocostalis muscles laterally. As a result, it is possible to preserve important soft tissue and bony stabilizing structures, while at the same time accessing the starting points of pedicle screws and fusion region. Entering the surgical site through the paraspinal muscle space can retain the starting and ending points, blood vessels, and nerves of the muscles, effectively avoiding the loss of innervation of the paraspinal muscle and the occurrence of postoperative low back pain, which is conducive to postoperative recovery. At the same time, the large stripping range of the traditional posterior median approach leads to significant intraoperative blood loss, more postoperative drainage, and higher infection rate. Compared with the traditional approach, PIA reduces the steps of separating paraspinal muscles directly from the muscle space to the facet joint, allowing the surgery to be done "almost in one step" after incision of the superficial structure and effectively shortening the surgery duration.

Surgical Approach for Fusion

Posterior spine fusion (PSF) for scoliosis involves extensive muscle dissection,[36] which causes substantial blood loss (EBL) leading to 20% to 30% risk of blood transfusions.[37–40] In our study, only one NFS patient (10%) got blood transfusion during the operation. This was mainly due to the protection of paraspinal muscles through PIA and only the face joint fusion was applied without extensive lamina decortication. Reames *et al.*[41] reviewed the Scoliosis Research Society (SRS) 2004 to 2007 morbidity and mortality database and found 6.3% complication rate in AIS. In our study, no intraoperative or postoperative complications were found.

To the best of our knowledge, Wiltse's approach is used only in the treatment of thoracolumbar or lumbar spine diseases, but not in thoracic surgery or scoliosis correction surgery; this procedural approach has a few clinical applications. Since segmental pedicle screws are used in spinal deformity correction surgery, effective posterior bone graft fusion is considered to be one of the essential elements for the ultimate success of a surgery, while the posterior laminar decortication and bone grafting are found to be mandatory fusions. However, interarticular fusion through PIA also achieved satisfactory fusion results in this study. Follow-up results did not show any statistically significant loss of correction, indicating that the corrective surgery for scoliosis with the posterior procedure and effective posterior bone graft fusion are not only confined to methods of laminar decortication and fusion. Although safe pedicle screws placement and robust fusion through PIA may be sufficient, further large, randomized, and controlled clinical studies are warranted.

Fusion Level Selection

Fewer fusion segments preserve mobility of the lumbar spine, avoid early degeneration of distal segments, and reduce the possibility of back pain. With the rapid development of 3D correction techniques, distal fusion in idiopathic scoliosis may be limited to one or two vertebrae bodies beyond the terminal vertebral bodies.[28,42] In comparison to stable vertebra fusion,[25] this type of fusion segment selection can preserve one or two more mobile segments. Although several studies have been published regarding the selection of fusion and instrumentation levels in adolescent idiopathic scoliosis (AIS) through routine approach fusion, only a few studies have focused on correction surgery through PIA with only interarticular fusion.[37]

The classification systems of AIS facilitate surgical planning and comparison of postoperative results.[25,43,44] Nonetheless, the most appropriate identification of fusion levels remains a challenge in surgical planning for AIS.[45] There is currently no universally accepted classification system or standard surgical decision-making planning of scoliosis. In this study, the fusion-level selection, according to the Lenke classification system of AIS and characteristic of the curves, was based on both fusion and instrumentation methods. If the main curve was similar to Lenke types 2, 3, 4, 5, and 6 (especially whose lumbar spine modifier was defined as B or C),[45] which usually indicates severe deformities, poor flexibility, and difficulty in correction, the fusion region would include additional segments to avoid loss of correction and acquire robust instrumentation and fusion. Patients with non-dystrophic neurofibromatosis type 1 meeting these criteria underwent SV fusion. Nine patients underwent EV 1 or 2 fusion and did not experience decompensation in follow-up visits.

Limitation

Only 10 cases were included in this retrospective study because the application of the new surgical approach must obtain the informed consent of the patients, and reliable, good, and complete clinical case data need long-term accumulation and follow-up. This retrospective study is our preliminary exploration and is limited by the small number of cases and the lack of a control group. For future studies, a prospective design, an addition of a control group, and a large number of cases should be included. Additionally, in our study, all case data were from a single institution, therefore future studies should aim to involve more institutions.

Conclusions

Idiopathic scoliosis and well-selected non-idiopathic spinal deformities may be treated with one-stage posterior correction surgery with interarticular fusion through posterior paraspinal intermuscular approach (PIA). The decreased intraoperative and postoperative bleeding, shortened operative time, zero blood transfusion, and satisfactory bony fusion might be achieved by PIA.

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