



OPEN Radiologic and clinical outcomes of combining pedicle subtraction osteotomy and Smith–Peterson osteotomy in correcting severe ankylosing spondylitis kyphosis

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The aim of this study was to explore the validity and safety of the combination of one-level pedicle subtraction osteotomy (PSO) and one-level Smith–Peterson osteotomy (SPO) in correcting severe ankylosing spondylitis kyphosis. Twenty-five AS patients undergoing one-level PSO and one-level SPO with a minimum of 2-year follow-up were included. Radiographical analyses included T5–T12 kyphosis (TK), L1–S1 lordosis (LL), global kyphosis (GK), osteotomized vertebral angle (OVA), sagittal vertical axis (SVA) and pelvic parameters. The computed tomographic (CT) scans of the spine were used to measure the aortic diameter and length. Clinical outcomes were evaluated by Oswestry Disability Index (ODI) questionnaire. The mean correction of OVA at PSO level and SPO level was $33.6^\circ \pm 9.2^\circ$ and $26.0^\circ \pm 13.2^\circ$ respectively. An average correction of $69.3^\circ \pm 23.2^\circ$ in GK was achieved. The mean operation time was 372.6 ± 60.1 min and the estimated blood loss averaged 1790.4 ± 953.3 ml. The mean increase of aortic length after surgery was 3.6 cm. An average decrease of 0.25 cm in aortic diameter at the PSO level was observed after surgery. There was no significant difference in aortic diameter at the SPO level between pre- and post-operation. ODI was improved from 30.2 ± 19.3 before surgery to 15.5 ± 13.9 at the last visit. The combination of one-level SPO and one-level PSO could achieve satisfactory correction outcomes in AS patients with severe kyphosis ($GK \geq 80^\circ$) needing a correction of $> 60^\circ$.

Keywords Ankylosing spondylitis, Thoracolumbar kyphosis, Two-level osteotomy, Pedicle Subtraction osteotomy, Smith–Peterson osteotomy

Ankylosing spondylitis (AS) is an inflammatory arthritis of the axial skeleton that predominantly affects young men^{1,2}. HLA-B27 has been proved to be the major genetic risk factor in AS³. In the advanced stage of AS, sagittal deformity, which mainly manifests in thoracolumbar kyphosis leading to a downward and forward shift in the patient's truncal body center is common⁴. To restore the erect posture and improve the quality of life, corrective spinal osteotomy surgery is usually required⁴.

Smith–Peterson osteotomy (SPO) and pedicle subtraction osteotomy (PSO) are most commonly used in the treatment of kyphotic deformity in AS, which are also named as opening wedge osteotomy (OWO) and closing wedge osteotomy (CWO), respectively^{5–7}. Van Royen and De Gast conducted a meta-analysis and revealed a mean correction of 40.3° for OWO, and 36.5° for CWO⁴. That means both operative techniques can achieve substantial correction. Yet still, for patients with severe kyphosis requiring a correction of $> 60^\circ$, one-level osteotomy usually cannot obtain enough correction and two-level PSO is recommended⁸. OWO isn't commonly used in correcting severe kyphosis in patients with AS, as the concern of stretching the major vessels anterior to the spine and leading to rupture and aneurysms⁹. However, two-level PSO is more challenging with more blood loss, longer operative time, and more technically demanding^{8,10,11}, which make it difficult for many surgeons to conduct the treatment of AS patients with severe kyphotic deformity.

In our practice, the two-level PSO can be avoided in some patients with severe kyphosis (global kyphosis, $GK \geq 80^\circ$) needing a correction of $> 60^\circ$. We performed one-level PSO and one-level SPO to reduce the operation difficulty without sacrificing the correcting outcomes. To our best knowledge, no studies had especially reported

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the efficacy and safety outcomes of this procedure for correcting severe kyphotic deformity in AS. Therefore, the purpose of this investigation was to document the effects of the combination of PSO and SPO in correcting severe thoracolumbar kyphotic deformity in AS.

Patients and methods

Patient population

Consecutive AS patients with thoracolumbar kyphotic deformity achieving spinal correcting surgery from January 2017 to January 2021 were retrospectively reviewed. The inclusion criteria were as follows: the diagnosis of AS was made by radiographic features, laboratory tests, and clinical features according to New York standards¹²; patients with severe thoracolumbar kyphosis with $GK \geq 80^\circ$; one-level PSO and one-level SPO were performed; availability of the radiographs of the entire spine including the X-ray and CT scans; and a minimum of 2-year follow-up. Patients with Anderson lesion, vertebral fracture, and history of previous spine surgery were excluded. Informed consent was obtained from all participants prior to their involvement in the study, which was approved by the Ethics Review Board at our hospital and conducted in accordance with the Declaration of Helsinki.

Radiographic and clinical evaluation

All patients were analyzed radiographically using long-cassette standing posteroanterior and lateral radiographs before operation, 2 weeks after surgery and at the latest follow-up. Radiographical analyses included T5–T12 kyphosis (TK), L1–S1 lordosis (LL), GK, osteotomized vertebral angle (OVA, for PSO, OVA was defined as the angle formed by the superior and inferior endplates of the osteotomized vertebrae; for SPO, OVA was defined as the angle between the superior endplate of the upper vertebra and the inferior endplate of the lower vertebra at the osteotomy level), pelvic tilt (PT), pelvic incidence (PI), sacral slope (SS) and sagittal vertical axis (SVA) (Fig. 1). For sagittal parameters, positive values mean kyphosis. Value of the SVA is negative if the C7 plumb line is posterior to the posterosuperior corner of S1. The corrections of these parameters were calculated by subtracting the magnitude of early postoperative (2 weeks after surgery) measurement from the magnitude of preoperative measurement. Correction loss was defined as last follow-up measurement minus the postoperative measurement.

The operation time and blood loss were well documented. The Oswestry disability index (ODI) questionnaire was completed by patients before surgery and at the last follow-up, which was used for clinical outcomes assessments. Any complications occurred postoperatively were recorded as well as additional surgeries.

CT scan measurements

Concerning the risk of aortic injury led by SPO, change of aortic length and diameter after two-level osteotomy (one-level PSO and one-level SPO) were investigated using CT scans according to the methods reported by previous studies¹³. Aortic length was assessed on the sagittal reconstruction CT scan. From the upper



Fig. 1. A 32-year-old male AS patient with severe thoracolumbar kyphosis underwent L1 PSO and L3/L4 SPO. (**A1,A2**). The preoperative radiograph showed: $GK = 97^\circ$, $LL = 26^\circ$, $SVA = 26.3\text{ cm}$, $SS = 7^\circ$, $PSO\text{-}OVA = 11^\circ$, $SPO\text{-}OVA = 7^\circ$. **B1,B2** Postoperatively, the $PSO\text{-}OVA$ and $SPO\text{-}OVA$ were corrected to -21° and -29° , respectively. The correction of GK was 74° . The LL , SVA and SS were improved to -49° , 4.5 cm and 22° , respectively.

instrumented vertebra to the L4, the point of intersection of the line parallel to the superior endplate and the anterior edge of aorta was marked. A line parallel to the inferior endplate of L4 was also drawn, the intersection of this line and the anterior edge of aorta was linked to the other marked points one by one, sum of the length of all line segments was defined as the aortic length. Only the aortic diameter at the osteotomy level was measured on the axial CT scan, which was defined as the maximum distance between the anterior and posterior wall of the aorta. All measurements were taken by an experienced radiologist using the picture archiving and communication system (PACS). Duplicate measurements were taken for each parameter, and the average of the 2 measurements was used. (Fig. 2)

Surgical decision making

Pre-op planning tool of Surgimap® software (Version 2.3.0.1, New York 2019) was used for simulating and predicting patients outcomes. Goal of the correction surgery was to retrieve spinal alignment, horizontal vision, and whole sagittal and coronal balance. If the desired correction was $>60^\circ$, two-level osteotomy was planned and simulated on the Surgimap®. We did not consider SPO in patients with atheromatous deposits and calcification in the aortic wall according to preoperative CT scans. Otherwise, one-level SPO and one-level PSO were considered. T12 and L1 are usually the apex of the thoracolumbar kyphosis in patients with AS, so the PSO sites were usually chosen at T12 or L1. We preferred L1 for that it was relatively safer. The location of SPO was usually at L3/L4 as L3 was the apex of lumbar lordosis in normal subjects.

Surgical technique

After general anesthesia was applied, the patient was positioned prone on a big sponge mat placed on the surgical table, leaving the abdomen free from compression. Our surgeons would preshape the sponge mat to accommodate the severe kyphotic spine the day before. A standard posterior longitudinal midline incision was used. The posterior elements were exposed by subperiosteal dissection as far laterally as the transverse processes. Transpedicular screws were inserted at least four levels proximal to the upper osteotomy area and at least three levels distal to the lower osteotomy area. SPO was performed first. A unilateral temporary short rod was placed across the osteotomy site. The posterior elements including posterior ligaments, bilateral facet joints and the part of the lamina were resected. Kyphosis correction was achieved by inflating the air bag below the lower limbs to elevate the lower extremities and coupled with pressing the distal vertebra downward. Then, bilateral pre-curved long rods took the place of the temporary short rod and were placed across the SPO side and the planned PSO level.

With regard to the PSO level, laminectomy and facetectomy were done. The transverse processes were excised and both pedicles were removed. Decancellation of the vertebral body was performed to create a V-shaped cavity. Before closing the osteotomy side, bilateral fixed rods cranial to the PSO level were loosen and re-curved with in situ rod bender. Then, shoulders were elevated with the assistance of two colleagues to gradually close the osteotomy side and the rods on both sides were fixed.

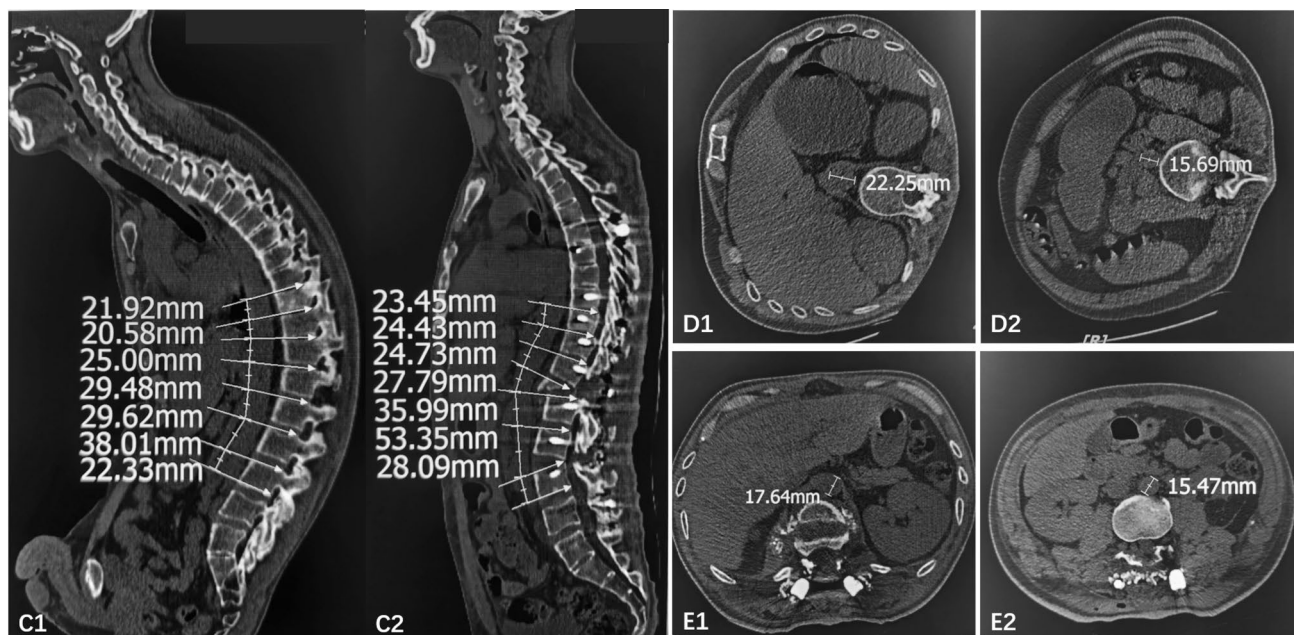


Fig. 2. C1, C2 After surgery, the length of the aorta increased from 18.7 cm to 21.8 cm. D1, E1 The aortic diameter at the site of PSO was decreased from 22.25 mm (D1) preoperatively to 17.64 mm (E1) postoperatively. D2, E2 But the aortic diameter at the site of SPO almost kept unchanged before or after the surgery.

Variables	Mean	Rang
Age at surgery (y)	39.6 ± 10.3	26–62
Gender (male/female)	25/0	–
Levels instrumented	9.0 ± 0.7	9–13
Duration of follow-up (m)	26.2 ± 2.5	24–30
Operation time (min)	372.6 ± 60.1	280–511
Osteotomy site (PSO/SPO)		
L1/L3–L4	22	–
L1/L4–L5	1	–
T12/L2–L3	2	–
Estimated blood loss (ml)	1790.4 ± 953.3	800–4500

Table 1. Demographic and surgical data of the subjects. *PSO* pedicle subtraction osteotomy, *SPO* Smith–Petersen osteotomy.

Radiographic parameters	Preoperative	Postoperative	Final follow-up	Correction	Loss of correction
TK (deg)	44.6 ± 18.3	41.3 ± 17.7	46.7 ± 16.9	3.3 ± 10.1	5.4 ± 9.2
LL (deg)	10.4 ± 21.6	−46.4 ± 15.3*	−47.3 ± 15.3	56.7 ± 17.7	−1.0 ± 9.3
GK (deg)	99.8 ± 21.4	30.5 ± 16.1*	29.7 ± 19.6	69.3 ± 23.2	−0.8 ± 12.8
PSO-OVA (deg)	9.6 ± 5.6	−24.0 ± 9.6*	−21.3 ± 9.4	33.6 ± 9.2	2.7 ± 6.4
SPO-OVA (deg)	5.3 ± 10.5	−20.7 ± 8.2*	−20.1 ± 11.0	26.0 ± 13.2	0.6 ± 14.3
PI (deg)	42.5 ± 9.3	48.4 ± 14.1	43.8 ± 5.6	−4.2 ± 12.2	−4.6 ± 9.1
PT (deg)	35.7 ± 16.6	24.5 ± 15.3	23.1 ± 10.3	9.0 ± 26.2	−1.4 ± 13.4
SS (deg)	6.7 ± 9.9	23.9 ± 8.9*	20.7 ± 7.5	−20.2 ± 12.6	−3.2 ± 9.7
SVA (mm)	235.1 ± 123.8	62.9 ± 46.1*	51.5 ± 37.5	173.0 ± 112.0	−11.4 ± 56.1

Table 2. Comparison of pre- and postoperative radiographic outcomes. *Compared with preoperative values, $P < 0.05$. *TK* T5–T12 kyphosis, *LL* L1–S1 lordosis, *GK* global kyphosis, *PSO* pedicle subtraction osteotomy, *SPO* Smith–Petersen osteotomy, *OVA* osteotomized vertebral angle, *PI* pelvic incidence, *PT* pelvic tilt, *SS* sacral slope, *SVA* sagittal vertical axis.

Shortly after the conduction of two-level osteotomies, a wake-up test was performed. Continuously combined motor- and somatosensory-evoked potential monitoring was applied during the procedure.

Statistical analysis

The Statistical Package for the Social Sciences (version 19.0; SPSS, Inc., Chicago, IL) was used for data analysis. Distributions of variables were given as a mean and standard deviation ($\pm$). Paired-samples *t* tests were conducted to analyze possible differences between pre- and postoperative parameters. A *p*-value of < 0.05 was considered statistically significant.

Results

Demographic and surgical data

Totally, 25 patients (25 male and 0 female) with a mean age of 39.6 ± 10.3 years (range 26 to 62 years) were enrolled in this study. The mean number of fused levels was 9.0 ± 0.7 (range 9 to 13). The osteotomy site (PSO/SPO) was L1/L3–L4 in 22 cases, L1/L4–L5 in 1 case and T12/L2–L3 in 2 cases. The mean duration of follow-up was 26.2 ± 2.5 months (range 24 months to 30 months). The mean operation time was 372.6 ± 60.1 min (range 280 min to 511 min) and the estimated blood loss averaged 1790.4 ± 953.3 ml (range 800 ml to 4500 ml). (Table 1).

Radiographic and clinical outcomes

A significant improvement of LL, GK, SS and SVA was observed after surgery ($P < 0.05$, Table 2). The mean correction of OVA at PSO level and SPO level was $33.6^\circ \pm 9.2^\circ$ and $26.0^\circ \pm 13.2^\circ$ respectively. An average correction of $69.3^\circ \pm 23.2^\circ$ in GK was achieved in these patients. ODI was significantly improved from 30.2 ± 19.3 before surgery to 15.5 ± 13.9 at the last visit.

Aortic radiographic assessment

The aortic length increased from 209.8 ± 29.2 mm (range 158.3 mm to 296.1 mm) preoperatively to 245.6 ± 31.8 mm (range 194.3 mm to 339.8 mm) postoperatively, resulting in an average increase of 36 mm ($P < 0.001$) (Table 3). The mean aortic diameter at the PSO level decreased from 18.9 ± 2.4 mm (range 15.2 mm to 22.9 mm) preoperatively to 16.4 ± 2.3 mm (range 12.6 mm to 23.0 mm) postoperatively ($P < 0.001$). No significant difference was found between pre- and postoperative aortic diameter at the SPO level.

Parameters	Preoperation	Postoperation	P value
Aortic traversing length (mm)	209.8 ± 29.2	245.6 ± 31.8*	< 0.001
Aortic diameter at the PSO level (mm)	18.9 ± 2.4	16.4 ± 2.3*	< 0.001
Aortic diameter at the SPO level (mm)	15.8 ± 1.6	15.3 ± 1.7	0.173

Table 3. Radiographic assessment of the aorta. *Compared with preoperative values, $P < 0.001$. PSO pedicle subtraction osteotomy, SPO Smith–Petersen osteotomy.

Complication type	N
Cerebrospinal fluid leak	4
Paralytic ileus	2
Subluxation of the osteotomy site	3
Wound infection	1
Pleural effusion	3
Incomplete neurological injury	1
Complication type	N

Table 4. Complications.

Complications

For all patients, no vascular complication was observed. Cerebrospinal fluid leak occurred in 4 cases and resolved with pressure dressing. Two patients developed paralytic ileus, which resolved with bowel rest and parenteral nutrition. Subluxation of the PSO site was observed in 3 cases and neither neurologic nor vascular complications were found. One patient experienced deep wound infection at 6 months after surgery and achieved surgical debridement along with antibiotic therapy. Pleural effusion was detected in 3 cases and resolved with thoracic close drainage. Incomplete neurological injury was found in one patient, of which the grade of left dorsal flexors strength decreased from 5 preoperatively to 2 postoperatively. The strength returned to normal after rehabilitation training at 6 months follow-up (Table 4).

Discussion

Thoracolumbar kyphotic deformity is a disabling condition affecting more than 30% of patients with AS. The complaint of patients include inability to walk or stand erectly and lie flat, cannot maintain horizontal gaze, low back pain owing to muscle fatigue, and poor appearance^{1,2}. The main osteotomy technique used to repair AS thoracolumbar kyphosis are OWO and CWO^{5–7}. Normally, a single-level osteotomy can achieve optimal outcome in most AS patients^{14,15}. Schwab et al.¹⁶ reported that successful realignment was achieved in 77% cases undergoing one-level PSO, whereas realignment failed in patients with larger preoperative SVA, larger PT, larger PI and greater PI-LL mismatch, in which the two-level PSO was advised.

Compared to single PSO, two-level PSO can theoretically provide more than 60° of correction^{11,17–22}. Xu et al.¹¹ reported a mean kyphosis correction of 60.6° in 27 patients receiving two-level PSO. Chen et al.²⁰ showed an average overall correction of 62.6° in 14 patients that received two-level PSO. Kiaer et al.²¹ reported that the correction was 50.8° in 15 patients, slightly less than that reported in previous research. Moreover, Huang et al.⁸ conducted a comparison of correction outcome between one-level PSO and two-level PSO in AS patients with $GK \geq 80^\circ$, which found that the postoperative correction of LL, OVA, PT, SS, femoral obliquity angle, GK and SVA was significantly greater in two-level PSO group. Besides, more harmonious and close to normal spinal alignment could be achieved by two-level PSO for improving the thoracic kyphosis and restoring lumbar lordosis at the same time.

However, two-level PSO could result in significantly longer operative time, higher blood loss, more fusion levels and also higher technical requirements^{8,10,11}. Huang et al.⁸ comparative study found that the mean blood loss and operative time were significantly increased in two-level PSO group compared with one-level PSO group, which was 3261 ml, 525 min and 1740 ml, 288 min, respectively. Moreover, a meta-analysis conducted by Li et al.¹⁰ showed that the operative time ranged from 3.87 h to 6.03 h and the blood loss ranged from 0.537 L to 1.525 L for one-level group, both were significantly less than two-level group, in which ranged from 4.7 h to 8.88 h and 1.132 L to 3.26 L, respectively. As for the complication rate, neural complications, dural tears and systemic complications were found more common in two-level group. Overall, these studies indicated that the safety of two-level PSO was compromised. To ensure enough correction without sacrificing operation safety, two-level osteotomy including one-level SPO and one-level PSO was performed in our center and reviewed in this study. The mean operation time was 372.6 min and the mean blood loss was 1790.4 ml in our patients, which is much less than those reported in patients achieving two-level PSO.

Besides, the results of our study showed that the correction outcome of our two-level osteotomy (one-level SPO and one-level PSO) was comparable to that of two-level PSO. An average correction of $69.3^\circ \pm 23.2^\circ$ in GK was achieved in the present study. Zhang et al.¹⁸ reported a mean correction of 67.9° for two-level PSO in nine patients. Xu et al.¹¹ reported that the average total correction was 60.6° for the two-level PSO group including

Study	Number of the patients	Average age	Osteotomy sites	Operation time (min)	EBL (ml)	LL correction (deg)	SS correction (deg)	GK correction (deg)	SVA correction (cm)
Zheng (2016) ²²	10 (1 F/9 M)	33	T12/L2 in 4 L1/L3 in 6	292 ± 47	2132 ± 837	42.0	− 24.3	71	14.3
Zhang (2014) ¹⁸	9 (1 F/8 M)	41.4 ± 5.7	T12/L3 in 9	402.8 ± 50.3	3311 ± 523.1	33.2 ± 2.4	–	54.0 ± 14.8	23.9 ± 4.4
Huang (2021) ⁸	21 (4 F/17 M)	34.3 ± 9.9	L1/L4 in 10 L2/L5 in 9 T12/L3 in 1 L2/L4 in 1	525 ± 71	3261 ± 1559	77.7 ± 15.4	− 25.3 ± 8.4	79.7 ± 14.6	19.4 ± 6.7
Zhong (2019) ¹⁷	10 (0 F/10 M)	36.8 ± 11.2	T12/L3 or L1/L4	460 ± 75	2560 ± 1109	37.0 ± 17.4	− 17.2 ± 8.8	69.9 ± 14.9	16.8 ± 6.7
Xu (2015) ¹¹	23 (2 F/21 M)	41 ± 11.6	T12/L2 in 2 T12/L3 in 7 L1/L3 in 14	282 ± 43	2202 ± 737	53.3	–	60.6 ± 19.1	23.6 ± 10.2
This study	25 (0 F/25 M)	39.6 ± 10.3	L1/L3–L4 in 22 L1/L4–L5 in 1 T12/L2–L3 in 2	372.6 ± 60.1	1790.4 ± 953.3	56.7 ± 17.7	− 20.2 ± 12.6	69.3 ± 23.2	17.3 ± 11.2

Table 5. Comparison with previous studies reporting two-level PSO. *EBL* estimated blood loss, *LL* L1–S1 lordosis, *SS* sacral slope, *GK* global kyphosis, *SVA* sagittal vertical axis, *PSO* pedicle subtraction osteotomy.

23 patients. Liu et al.²³ reported that 33 two-level PSO patients achieved a mean correction of 61.8°. Huang et al.⁸ reported that the postoperative GK correction averaged 79.7° in 21 patients who underwent two-level PSO. Moreover, when it comes to the improvement of LL, SS and SVA, there was no significant dissimilarity between our correction results and those reported by earlier studies (Table 5).

This finding was also reported by Zhong et al.¹⁷ They compared two different combinations between PSO + SPO and PSO + PSO in patients with severe AS kyphosis. No intergroup significant difference in the correction of kyphosis angle, LL, SS and SVA was found after surgery. As well, the surgical time was longer in the two-level PSO group than in the PSO + SPO group. Still, their study was limited in a small sample size (10 in two-level PSO group and 9 in PSO + SPO group). In contrast to our exclusion of patients with pseudarthrosis, most patients achieving PSO + SPO in Zhong et al.'s study were diagnosed with pseudarthrosis. They concluded PSO + SPO could be a good option for patients with pseudarthrosis. Our results were based on a relatively larger sample size (25 in PSO + SPO group) and further confirmed that even in patients without pseudarthrosis, the combination of one-level PSO and one-level SPO was effective and safe.

The main concern of this operational style was the potential risk of aortic injury caused by SPO^{9,13,24}. Previous studies have shown that vascular complications may occur when performing OWO at levels above L2–L3, because of the violent elongation of the aorta¹³. Ji et al.¹³ investigated the change in aortic length in AS patients after achieving closing-opening wedge osteotomy at L1 or L2 and found an average increase of 2.2 cm in aortic length and an average decrease of 0.41 cm in aortic diameter at the osteotomy level. No vascular complications were observed. Similarly, Liu et al.²⁴ investigated these changes in AS patients after undergoing CWO at L1 or L2 and found that the aortic markedly lengthened by an average of 2.0 cm and the aortic diameter at the CWO site significantly decreased by an average of 0.4 cm after surgery. No clinical manifestations associated with stenosis of the aorta were found. Our operation way combined the OWO and CWO. The mean increase of aortic length after surgery was 3.6 cm in this study. The more increase in aortic length than previous reports could be attributed to the more correction achieved by two-level osteotomy. One interesting finding is that there was no significant difference in aortic diameter at the SPO level between pre- and post-operation. An average decrease of 0.25 cm in aortic diameter at the PSO level was observed after surgery. Overall, change of the aortic diameter at the site of the osteotomy was smaller in our two-level osteotomy patients than in those patients achieving one-level osteotomy as previous studies reported. There are several possible explanations for this result. Firstly, we performed SPO at L3/L4 in most patients and the aorta has been proved to be far away from the vertebral body at L3 level²⁵, which minimized the pressure exerted on the artery wall by the opening wedge osteotomy. Then, although more correction led to more elongation of the aorta in our study, we could not infer the existence of a tighter aorta for that the aorta was more tortuous in patients with severer kyphosis. No vascular complications or devastating neurological complications were observed in the present study. Our findings showed that two-level osteotomy combining one-level PSO and one-level SPO was safe and effective without additional risk of aortic and neurological injury.

Potentially contraindication to use PSO + SPO was severe arterial calcification at the SPO level, as the risk of aortic injury during the opening of the anterior disc spaces. Two-level PSO could be considered in patients with atheromatous deposits and severe calcification in the aortic wall according to preoperative CT scans. Outside of this condition, PSO + SPO could be used in most severe AS kyphosis patients for overcoming some limitations of two-level PSO.

The results of this study are limited by the retrospective design and lack of a comparative control group including patients undergoing two-level PSO. Besides, radiographical assessment of the aortic was conducted based on the 2-dimensional CT scan, aortic morphology requires further investigation using 3-dimensional reconstruction. On the other hand, no females and only 25 patients were included in our study, this result is a preliminary result. Further work is needed to determine whether the findings of this study will be applicable to

female AS patients. Finally, it must be cautioned that these findings are interim, further research conducted over longer follow-up periods is required.

Conclusion

The results of this study demonstrated that the two-level PSO can be avoided in some AS patients with severe kyphosis ($GK \geq 80^\circ$) needing a correction of $> 60^\circ$. The combination of one-level SPO and one-level PSO was safe and effective in correcting severe thoracolumbar kyphotic deformity in AS patients. Compared to two-level PSO, this operational style presented less blood loss and operative time without sacrificing the correction outcomes.

Data availability

The datasets used and analysed during the current study available from the corresponding author on reasonable request.

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Author contributions

D.J. wrote the main manuscript text, D.Z. and Z.R. analyzed the data, Z.Z. and Z.H. reviewed the manuscript.

Declarations

Competing interests

The authors declare no competing interests.

Ethical approval

This is a retrospective study. This article does not contain any studies with human participants or animals

performed by any of the authors. Approval was granted by the Ethic Committee of our hospital (No. 61816508).

Consent to participate

Informed consent was obtained from all individual participants included in the study.

Device status/drug statement

The Manuscript submitted does not contain information about medical device(s)/drug(s).

Additional information

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