Am J Transl Res 2025;17(1):622-633
www.ajtr.org /ISSN:1943-8141/AJTR0161004

Original Article

Comparison of pedicle subtraction osteotomy and vertebral column resection in adolescent congenital kyphoscoliosis and the influencing factors on intraoperative hemorrhage: a retrospective study

Baina Shi, Xiaofeng Pan, Weiguang Lu, Nengfang Zheng, Guangcai Zhu, Jun Yang

Department of Spinal Orthopaedics, Orthopaedic Centre, Yingtan 184 Hospital, Yingtan 335000, Jiangxi, China

Received October 8, 2024; Accepted December 26, 2024; Epub January 15, 2025; Published January 30, 2025

Abstract: Objective: To explore the efficacy of different methods of osteotomy in the treatment of severe Winter type I adolescent congenital kyphoscoliosis (CKS) and to analyze the influencing factors of massive intraoperative hemorrhage in these patients. Methods: A retrospective analysis was conducted on the clinical data of 47 patients with severe CKS admitted to our hospital from October 2016 to December 2022. According to different surgical methods, they were divided into a PSO group and a VCR group. All patients in the PSO group were treated with multi-segment pedicle subtraction osteotomy (PSO), n=24. All patients in the VCR group were treated with single-segment vertebral column resection (VCR), n=23. The surgical status (including operation time, intraoperative blood loss, and days of hospitalization), surgical correction situation (including coronal Cobb angle, global kyphosis (GK), visual analogue scale (VAS) score, and Oswestry disability index (ODI)), and the occurrence of complications were analyzed and compared between the two groups of patients. The occurrence of massive intraoperative bleeding in patients was assessed, and a multivariate Logistic analysis was performed to identify the independent influencing factors of massive intraoperative hemorrhage in all patients. Results: The operation time of the PSO group was longer than that of the VCR group (P<0.05). No statistical differences were found in the comparison of coronal Cobb angle, GK, VAS score and ODI score between the PSO group and the VCR group before surgery (all P>0.05). After surgery, the coronal Cobb angle, GK, VAS score, and ODI score of patients in both groups were significantly improved compared with those before surgery (all P<0.05). Moreover, the improvements in coronal Cobb angle, GK and ODI score in the PSO group were more significant than those in the VCR group (all P<0.05). All patients were followed up for more than 18 months. During the follow-up period, the incidence of complications in the VCR group was higher than that in the PSO group, but with no statistically significant difference (P>0.05). According to the occurrence of massive intraoperative hemorrhage, the patients were divided into a hemorrhage group (n=19) and a normal group (n=28). Univariate analysis showed that there were statistically significant differences in the number of fixed segments, the osteotomy site, ESR, coronal Cobb angle, GK and the number of osteotomy segments between the hemorrhage group and the normal group (all P<0.05). The results of multivariate logistic regression analysis showed that the number of fixed segments, osteotomy site, coronal Cobb angle, and the number of osteotomy segments were independent influencing factors for massive intraoperative hemorrhage in patients with CKS. Conclusion: Both multi-segment PSO and VCR have good correction outcomes on CKS. In comparison, although multi-segment PSO has a longer operation time, its correction outcomes are better than that of VCR, and it does not significantly increase the risk of surgical complications. In addition, the number of fixed segments, osteotomy site, coronal Cobb angle, and the number of osteotomy segments are independent influencing factors for massive intraoperative hemorrhage.

Keywords: Pedicle subtraction osteotomy, vertebral column resection, congenital kyphoscoliosis, intraoperative hemorrhage, influencing factors

Introduction

Congenital kyphoscoliosis (CKS) is a complex disease caused by congenital vertebral body dysplasia, and with the aggravation of the disease, it can endanger the life of patients [1]. Currently, the Winter classification is one of the main pathological classifications of CKS. Winter

https://doi.org/10.62347/LPX09425

I is a failure of vertebral formation, which will lead to hemivertebra deformity if it is poorly formed completely, and wedge-shaped vertebra will be formed if it is only partially poorly formed; Type II is incomplete vertebral body segmentation; and Type III is a combination of the first two pathological types [2]. Due to the characteristics of children's bone growth and development, the development of the vertebral body is blocked, and the posterior appendages are constantly developing, which leads to the continuous progressing trend of Winter I CKS. For example, the Cobb angle of the main curvature can be aggravated by 5-10 degrees every year, so it is necessary to treat CKS as soon as possible [3]. At present, the primary clinical treatment for CKS is surgical correction, usually posterior spinal osteotomy. Among them, multi-segmental pedicle vertebral osteotomy (PSO) and single-segmental total vertebral osteotomy (VCR) are common surgical procedures in spinal osteotomy, and their surgical indications overlap to some extent, which are both suitable for the treatment of severe spinal deformity. PSO is a surgical method used for treating spinal deformities. Its basic principle is to remove part of the spinal bone to change the geometry of the spine, thereby correcting spinal deformities. For example, in the case of kyphosis or scoliosis deformities, precise osteotomy can rearrange the spine and restore the normal physiological curvature. VCR is a more radical surgical procedure for correcting spinal deformities. It mainly involves the resection of a single spinal vertebra, including most or all of the vertebral body as well as the adjacent intervertebral disc tissues. VCR is mainly used to treat severe and localized spinal deformities, such as severe congenital hemivertebra deformities and vertebral destruction caused by severe spinal tuberculosis. For cases where the deformity is concentrated in a single vertebra and cannot be effectively corrected by other conservative treatments or mild surgical interventions, VCR can provide a thorough solution.

Currently, both VCR and PSO are used in the treatment of a variety of spinal diseases, such as ankylosing spondylitis and adult complex spinal deformities. Although single-segment PSO is suitable for kyphotic spinal deformities not exceeding 40°, the correction outcomes of patients can be significantly improved after multi-segment PSO, achieving a correction outcome similar to that of VCR [4, 5]. Clinically, the selection of surgical methods for adolescent patients with CKS is complex. Many patients can be treated with both multi-segment PSO and VCR. In these cases, the choice of surgical method depends on the subjective experience and judgment of clinicians. Therefore, a systematic comparison of the correction outcomes of the two can provide a scientific reference to help the selection of surgical plans.

In addition, in some literature reports [6, 7], massive intraoperative hemorrhage is a common complication in surgeries for patients with severe spinal deformities and is closely related to surgical success rate, surgical complications and patient prognosis. Due to its surgical characteristics, the complexity and blood loss of VCR are often higher than those of single-segment PSO. However, when multi-segment PSO is performed on patients, although theoretically it can achieve a correction outcome similar to that of VCR, the complexity of the surgery and surgical damage also increase substantially. Currently, there are few studies comparing the differences in surgical damage and benefits brought by multi-segment PSO and single-segment VCR for patients with severe CKS. Therefore, this study explored the efficacy of multi-segment PSO and single-segment VCR in adolescents with CKS and analyzed the influencing factors of massive intraoperative hemorrhage, aiming to provide references for optimizing the clinical surgical ideal for CKS.

Materials and methods

Patients

The clinical data of CKS patients admitted to the Spinal Orthopedics Center of the 184th Hospital in Yingtan, Jiangxi Province, China from October 2016 to December 2022 were collected and retrospectively analyzed. Inclusion criteria: (1) patients who met the diagnostic criteria for adolescent CKS, and were diagnosed by imaging [8]; (2) those with severe spinal deformity (coronal Cobb angle >40°); (3) those aged 12 to 18 years; (4) those who underwent multi-segment PSO or single-segment VCR via a posterior approach; (5) those with pathological classification of Winter type I, and hemivertebra with complete formation failure, with 1 to 3 deformities; (6) those with complete clinical data; (7) patients who were

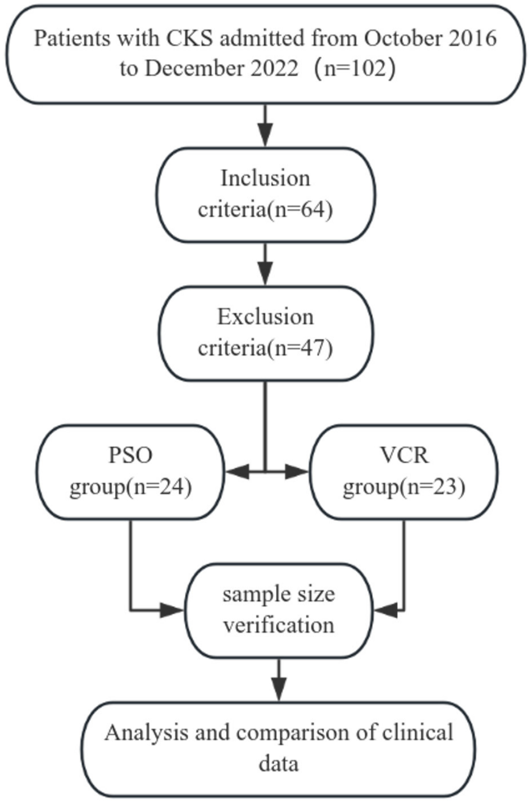

Figure 1. Flow diagram of patient inclusion. CKS: congenital kyphoscoliosis; PSO: pedicle subtraction osteotomy; VCR: vertebral column resection.

followed-up for at least 18 months; (8) patients who possessed the surgical indications for both multi-segment PSO and single-segment VCR. Exclusion criteria: (1) those with malignant tumors; (2) those with rigid spinal deformity with spinal flexibility <30%; (3) those with severe organ dysfunction or other secondary diseases; (4) those with neurological symptoms or preoperative detection suggesting neurological malformations; (5) those without complete medical record data or relevant testing indicators; (6) those with contraindications for PSO or VCR. This study was approved by the Ethics Committee of Yingtan 184 Hospital.

Grouping

A total of 47 CKS patients were included. Among them, 24 patients underwent multi-segment PSO, and 23 patients underwent VCR. According to the different surgical methods, they were divided into a PSO group and a VCR group, and sample size verification was carried out (**Figure 1**). The sample size was calculated using non-inferiority testing. After literature review and comparison of existing data, the clinically significant difference in surgical efficacy between the two groups was 5%. With β=0.2 and α=0.025, the expected sample size of both groups should exceed 20 cases. The sample size of this study meets the requirements of non-inferiority research.

Collecting the observation indicators

The operation time, intraoperative blood loss, days of hospitalization, surgical correction situation, intraoperative blood loss, and occurrence of postoperative follow-up complications were collected and statistically analyzed between the two groups of patients.

The surgical correction conditions were observed in the two groups of patients, including the coronal Cobb angle (the scoliosis angle between the upper and lower vertebral lamina of the main curvature, which is an important parameter to evaluate the severity of coronal spinal deformity), global kyphosis (GK) (the angle between the tangent of the upper endplate of the most inclined vertebral body and the caudal lower endplate in a standing position, which is an important parameter to evaluate the severity of sagittal spinal deformity), pain degree, and spinal function before and after surgery. The degree of pain was assessed by the self-reported visual analogue scale (VAS), with a score of 0 meaning no pain, and a score of 10 representing unbearable pain. Spinal function was evaluated by the Oswestry disability index (ODI). The scale consists of a total of 11 items, representing the impact of spinal function on various aspects of the patient's daily life. Higher scores indicate worse recovery of the patient's spinal function. The above-mentioned postoperative indicators was measured at the third week after the surgery.

The intraoperative blood loss was recorded. When the patient's blood loss is ≥30% of their estimated blood volume, a blood transfusion is required. Therefore, massive intraoperative hemorrhage was defined as blood loss ≥30% of the estimated blood volume. Calculation of blood loss: total blood loss = weight of blood-soaked gauze - weight of dry gauze + blood volume in the suction bottle. The preoperative total blood volume was calculated according to the Nadler equation: preoperative total blood volume = K1*height (m) + K2*weight (kg) + K3. For men, K1=0.3669, K2=0.03219, and K3= 0.6041. For women: K1=0.3561, K2=0.0331, K3=0.1833. All patients were divided into a hemorrhage group and a normal group according to whether massive intraoperative hemorrhage occurred. The relevant clinical data of the two groups of patients were analyzed, and multivariate analysis was carried out to determine the risk factors for intraoperative massive bleeding. The relevant clinical data include sex, age, weight, body mass index (BMI), number of fixed segments, osteotomy site, hemoglobin, platelet count, prothrombin time (PT), activated partial thromboplastin time (APTT), international normalized ratio (INR), fibrinogen, erythrocyte sedimentation rate (ESR), coronal Cobb angle, GK, VAS, ODI, and number of osteotomy segments.

Therapeutic methods

All patients underwent routine examinations before surgery, including full-spine X-ray examination, spinal CT plain scan and three-dimensional reconstruction, neurological MRI, and cardiopulmonary function examination to clarify the anatomical structure of the deformity and the patient's physical conditions. Patients were given nutritional support before surgery, and they were encouraged to perform pulmonary function training. One week before surgery, bed rest and defecation training were carried out. According to the patient's imaging data, the surgical osteotomy and fixation methods were determined. All patients were treated by the same surgeon in the spinal surgery center of our hospital, and posterior Ponte osteotomy was supplemented for correction according if necessary. According to the recovery situation, the postoperative patients wore protective braces and were followed up every 3 months to observe the occurrence of complications.

Multi-segment PSO: The apical vertebra area of the kyphotic curve was typically selected as the upper osteotomy vertebra, while the lower osteotomy vertebra was chosen at least two vertebrae below the upper site. During PSO, the upper and lower parts of the lamina, the attached ligamentum flavum, and the bilateral upper and lower facet joints were excised. For thoracic osteotomy, the costal head and costotransverse process were removed as well. Pedicle screws were inserted bilaterally at the pedicles of the diseased vertebra and secured with connecting rods. A transverse incision was made at the hemivertebra to be resected, exposing the anterior surface. Using tools such as a grinding drill or curette, the anterior cortical bone of the hemivertebra was removed and progressively deepened. The same procedure was applied to the posterior of the hemivertebra, ensuring complete removal. Pedicle screws were implanted in the upper and lower adjacent vertebrae, and a connecting rod was installed for stabilization. An osteotomy was performed at the predetermined site using tools like a laminar rongeur or curette. After osteotomy, the connecting rods of the upper and lower vertebrae were fixed together. The procedure for subsequent osteotomy levels mirrored the first, maintaining consistency in technique. Throughout the operation, somatosensory evoked potential (SEP) monitoring was employed to ensure spinal cord function integrity. Routine autologous blood transfusion was conducted, and a wake-up test was performed postoperatively to confirm normal spinal cord function. A simple illustration is shown in **Figure 2**.

Single-segment VCR: The apical vertebra of the primary curve was selected as the osteotomy site. First, osteotomy was performed on the convex side of the curve. Using rongeurs, the pedicle on the convex side was resected down to its base, along with the transverse process. For thoracic vertebra, the costal head connected to the vertebra was also removed. The periosteum was stripped from the lateral base of the pedicle to the anterior edge of the vertebra, exposing the surgical field. Entry was made through the space created after pedicle removal, and the vertebral body, along with its anterior and lateral cortical bones, were excised. The intervertebral disc tissues above and below the vertebral body were chiseled off, retaining only a thin posterior wall of the vertebral body beneath the dura mater. Then upper and lower vertebrae adjacent to the resected vertebral body on the convex side were then stabilized using a fixation rod. On the concave side, the vertebral body and its associated structures were removed in the same manner. A pre-bent temporary fixation rod was applied to stabilize the concave side. After securing the screws, appropriate compression was applied to both fixation rods. The temporary fixation rod on the convex side was then loosened, and a connect-

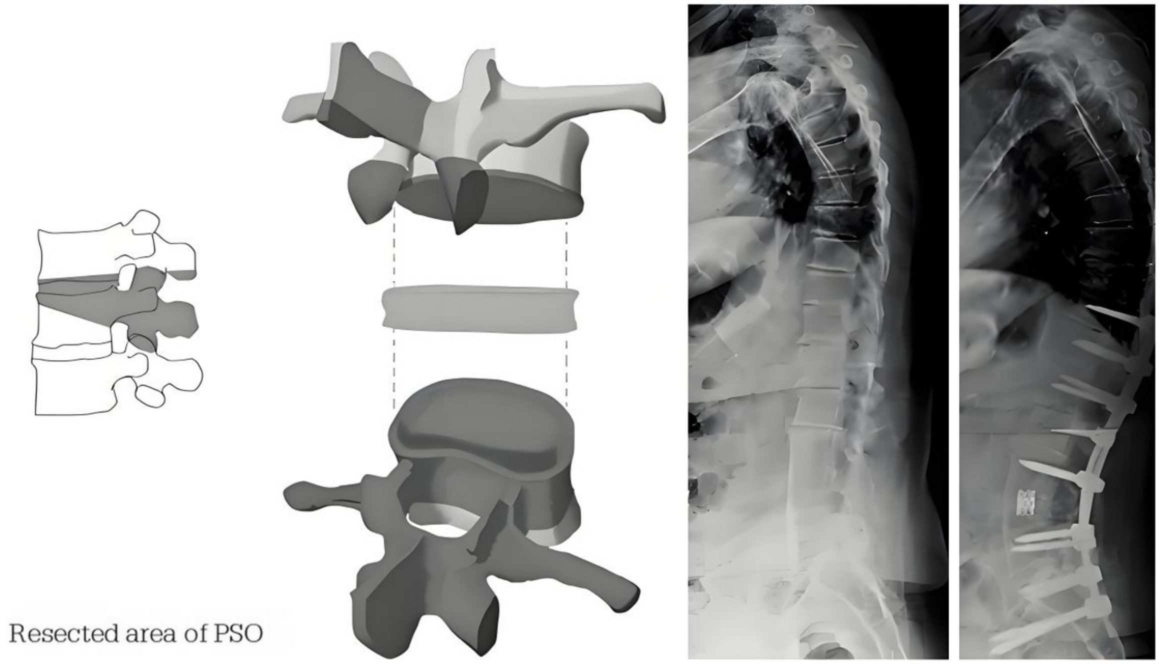

Figure 2. PSO operation method. PSO: pedicle subtraction osteotomy.

ing rod of suitable length, pre-bend to match the physiological spine curvature was prepared. In a sequential manner from proximal to distal, the rod was connected through compression screws. Once adequate compression was applied, the rod was locked into place. Then the temporary fixation rod was removed on the concave side. Subsequently, the temporary fixation rod on the concave side was removed, and a pre-bent rod of appropriate length was connected and fixed. Bilateral compression was gradually applied to bring the osteotomy ends together. Alternating distraction and compression maneuvers were performed to restore the balance in the coronal and sagittal planes as much as possible. Throughout the procedure, SEP monitoring was used to ensure spinal cord integrity. Routine autologous blood transfusion was conducted, and a wake-up test was performed postoperatively to confirm normal spinal cord function. A simple illustration is shown in **Figure 3**.

Statistical analysis

Data processing was performed using SPSS 22.0 software. Measurement data are expressed as mean ± standard deviation (SD), and count data were expressed as (%). Pairwise comparisons were performed using the t-test, and count data were analyzed using the chi-square test. Image measurements were independently conducted by two attending physicians, and the results were tested for consistency using the intra-class correlation coefficient (ICC). Multivariate analysis was performed using a multiple Logistic regression model. The significance level was set at $\alpha=0.05$, with $P<0.05$ indicating statistical significance.

Results

Comparison of general information between the PSO group and the VCR group

There were no statistically significant differences between the two groups of patients in the comparison of general information such as sex, age, the number of hemivertebra deformities, and BMI ($P>0.05$), as shown in **Table 1**.

Comparison of surgical situations between the PSO group and the VCR group

The operation time of the PSO group was longer than that of the VCR group, and the difference was statistically significant ($P<0.05$) (**Figure 4A**). However, there was no statistically significant difference in intraoperative blood loss and days of hospitalization between the two groups ($P>0.05$) (**Figure 4B** and **4C**).

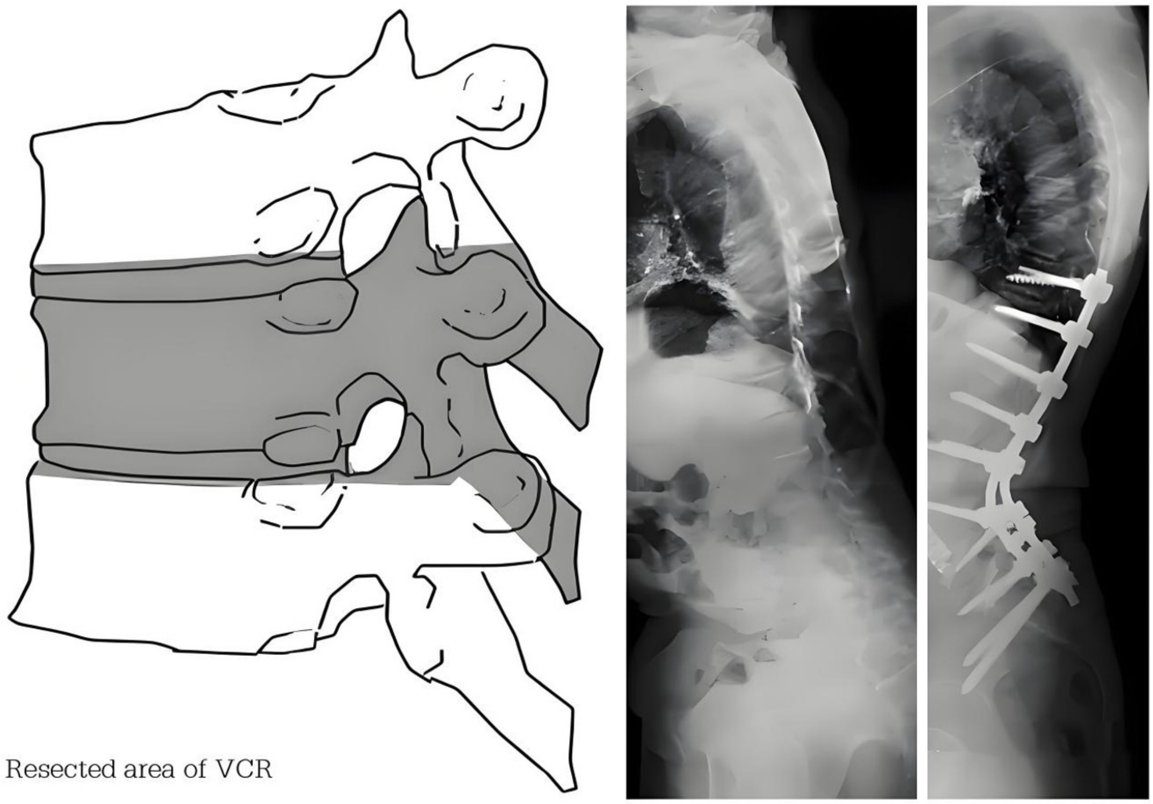

Figure 3. VCR operation method. VCR: vertebral column resection.

Table 1. Comparison of general information

Group	Sex		Age (year)	Number of hemivertebra deformities			BMI (kg/m²)
	Male	Female		1	2	3	
PSO group (n=24)	13	11	15.28±3.33	4	16	4	19.67±3.91
VCR group (n=23)	12	11	15.01±3.55	2	15	6	19.53±3.85
t/χ^2 value	0.019		0.468	1.078			0.124
P value	0.891		0.642	0.583			0.902

Note: PSO: pedicle subtraction osteotomy; VCR: vertebral column resection.

Comparison of deformity correction results between the PSO group and the VCR group

There were no statistical differences in the comparison of coronal Cobb angle, GK, VAS score, and ODI score between patients in the PSO group and the VCR group before surgery (P>0.05). After surgery, the coronal Cobb angle, GK, VAS score, and ODI score of patients in both groups were significantly improved compared with those before surgery. Moreover, the improvements in coronal Cobb angle, GK, and ODI score in the PSO group were more significant than those in the VCR group, and the differences were statistically significant (P<0.05). There was no statistical difference in the VAS scores after surgery between the two groups (P>0.05). See **Table 2**.

Comparison of the occurrence of postoperative complications between the PSO group and the VCR group

All patients were followed up for at least 18 months. During the follow-up period, the incidence of complications in the VCR group was higher than that in the PSO group. However, there was no statistically significant difference between the two groups (P>0.05) (**Figure 5A-C**).

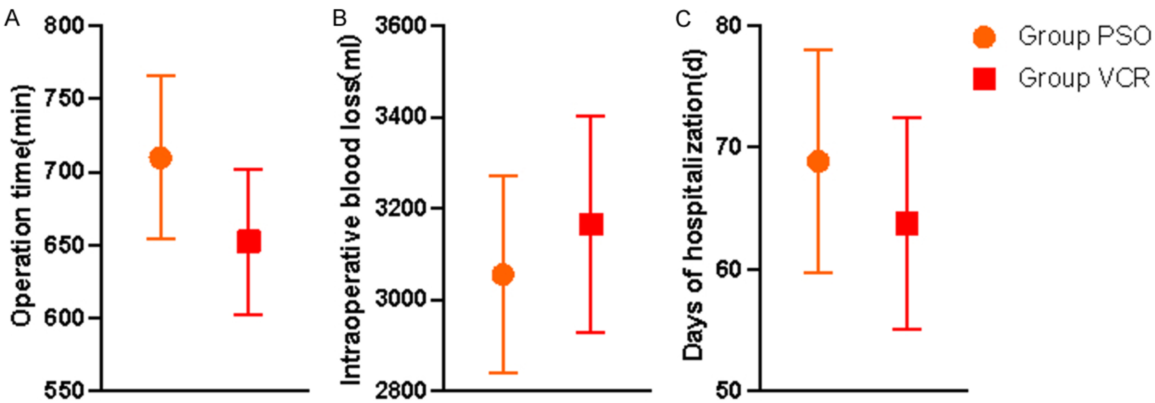

Figure 4. Comparison of surgical situations. A: Comparison of operation durations, P<0.05; B: Comparison of intraoperative blood loss, P<0.05; C: Comparison of days of hospitalization, P<0.05.

Table 2. Comparison of deformity correction results

Group	Coronal Cobb angle (°)		GK (°)		VAS (point)		ODI (point)	
	preop	postop	preop	postop	preop	postop	preop	postop
PSO group (n=24)	86.54±23.16	19.34±13.21*	71.84±17.23	42.87±13.76*	6.45±2.37	3.09±1.53*	75.83±6.97	15.86±7.26*
VCR group (n=23)	81.83±25.37	27.86±10.83*	73.42±16.45	53.31±15.42*	6.83±1.82	3.01±1.88*	74.82±7.55	20.04±5.43*
t/χ^2 value	0.665	2.412	0.321	2.451	0.784	0.203	0.606	2.509
P value	0.509	0.020	0.750	0.018	0.436	0.839	0.546	0.031

Note: Compared with the pre-treatment, *P<0.05; PSO: pedicle subtraction osteotomy; VCR: vertebral column resection; GK: global kyphosis; VAS: visual analogue scale; ODI: Oswestry disability index.

Comparison of clinical data of between patients with or without massive intraoperative hemorrhage

According to the occurrence of massive intraoperative hemorrhage, the patients were divided into a hemorrhage group with 19 cases and a normal group with 28 cases. Univariate analysis showed that there were statistically significant differences in the number of fixed segments, osteotomy site, ESR, coronal Cobb angle, GK, and the number of osteotomy segments between the hemorrhage group and the normal group (P<0.05). See **Table 3**.

Analysis of independent influencing factors for massive intraoperative hemorrhage

Taking the number of fixed segments, osteotomy site, ESR, coronal Cobb angle, GK, and the number of osteotomy segments as independent variables for logistic regression analysis. The results showed that the number of fixed segments, osteotomy site, coronal Cobb angle, and the number of osteotomy segments were independent influencing factors for massive intraoperative hemorrhage (P<0.05). See **Table 4**.

Discussion

In addition to its own disease symptoms, the long-term existence of spinal deformity in CKS is also likely to lead to the atrophy of surrounding soft tissues, which can further affect lung expansion and the cardiopulmonary function of patients. It has important impacts on the growth and development, quality of life, and survival time of patients [9, 10]. Therefore, according to the patient's condition, choosing an appropriate surgical method to correct spinal deformity as soon as possible is of great significance. Adopting surgical correction during adolescence is an effective approach for treating CKS. PSO is currently a widely used orthopedic surgical method. Its main indications are angular kyphosis and lateral kyphosis of the spine (spinal sagittal imbalance of 10-12 centimeters), and the degree of correction in each osteotomy gap is about 30°. It is mainly used to resect the posterior accessory structures of the deformed apical vertebra. The single-segment PSO surgical method is characterized by minimal trauma, fast bone graft fusion, and little spinal cord injury. At the same time, due to its relatively anterior center of rotation, this method achieves superior corrective out-

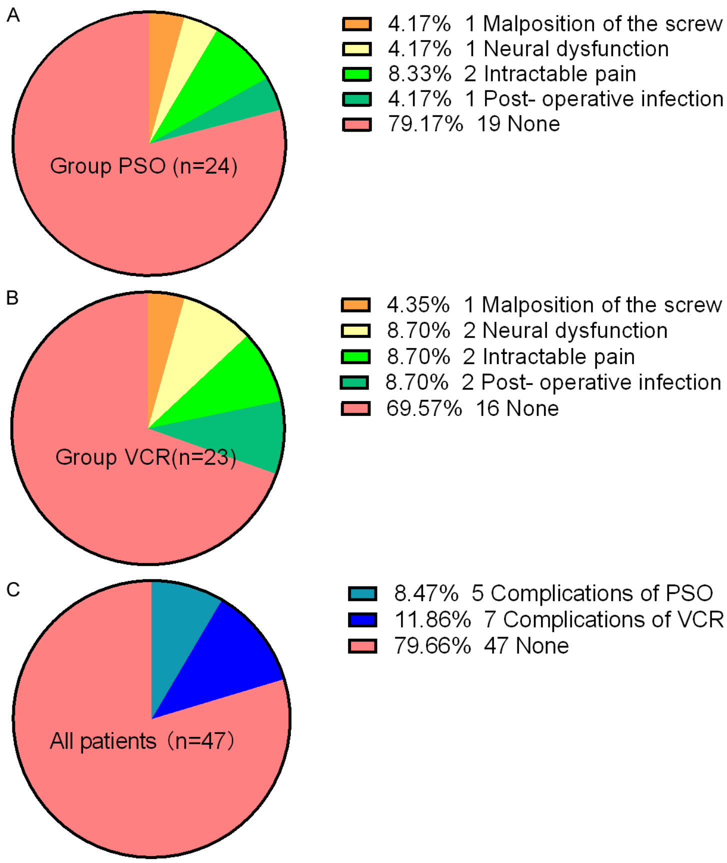

Figure 5. Comparison of the occurrence of postoperative complications. A: Occurrence of complications in the PSO group; B: Occurrence of complications in the PSO group; C: Occurrence of complications in all patients. PSO: pedicle subtraction osteotomy; VCR: vertebral column resection.

comes, particularly for mild to moderate spinal deformities [11, 12]. However, single-segment PSO is limited in severe spinal deformities. In these cases, multiple segments are often required to achieve the expected correction outcomes. Different from single-segment PSO, multi-segment PSO requires pedicle resection and spinal osteotomy at multiple segments, followed by correction and fixation. Due to the involvement of multiple segments, the surgical difficulty and risk of multi-segment PSO are greater [13]. The osteotomy range of VCR includes two complete intervertebral discs above and below the vertebral body. At present, it is mostly used in the treatment of severe spinal deformities and spinal tumors. Some studies [14, 15] have reported that VCR has a good orthopedic effect on spinal deformities in either the coronal plane or the sagittal plane. However, as the surgical orthopedic effect increases, the complications caused by surgical trauma also increase significantly, including spinal cord injury and wound infection.

Both PSO and VCR are osteotomy surgeries applied in various spinal diseases. Through the treatment research on ankylosing spondylitis and adult complex spinal deformities, it has been found that the orthopedic effect and disease adaptability of VCR are significantly better than those of PSO. However, this is accompanied by an increased risk of surgical complications, especially the occurrence of nerve damage. However, apart from the more complex VCR surgery, the disease itself may also be one of the relevant factors [16]. However, the above advantages and disadvantages are all obtained through the comparison between the application of single-segment PSO for mild-to-moderate spinal deformities and the application of VCR for severe spinal deformities. Due to the limitation of cases and the influence of the complex conditions of CKS, the comparison of the efficacy of multi-segment PSO and single-segment VCR in the treatment of severe spinal deformities is currently very scarce. For example, Karami et al. [17] conducted a long-term follow-up on children with CKS who underwent VCR, and they showed that VCR had a good effect on CKS and did not cause major risks to nerve roots, but there was a possibility of sagittal compensation and insufficient correction. Similarly, most of the current studies are discussions on a single surgical method, lacking the comparison of the advantages and disadvantages of multiple surgical methods. In addition, compared to adult complex spinal deformities, Winter type I CKS without secondary diseases presents a relatively straightforward condition, minimizing variable interference in experimental comparisons. Therefore, we evaluated the advantages and disadvantages of multi-segment PSO and single-segment VCR for adolescent CKS. This analysis is of great sig-

Table 3. Comparison of clinical data of patients with massive intraoperative hemorrhage

Influencing factors		Hemorrhage group (n=19)	Normal group (n=28)	t (χ^2) value	*P* value
Sex (male)		13	12	0.172	0.688
Age (year)		14.98±3.97	15.37±3.31	0.231	0.631
Weight (kg)		45.62±12.39	43.81±13.27	0.159	0.893
BMI (kg/m^2)		19.89±3.76	19.35±4.01	0.464	0.645
Number of fixed segments	≥5	13	8	7.272	0.007
	<5	6	20		
Osteotomy site	T1-T6	3	10	2.981	0.037
	T7-T12	13	6		
	L1-L5	3	12		
Operation mode	PSO	10	14	0.031	0.859
	VCR	9	14		
Hemoglobin (g/L)		137.94±18.23	136.75±17.96	0.483	0.541
Platelet count (×10^9/L)		221.87±34.56	237.49±41.83	1.343	0.256
PT (s)		15.36±1.21	15.66±1.42	0.697	0.598
APTT (s)		39.26±3.84	38.99±3.15	0.606	0.545
INR		1.01±0.03	1.02±0.02	0.136	0.8932
Fibrinogen (mg/dl)		3.98±0.76	4.02±0.98	1.087	0.239
ESR		17.96±5.21	10.83±5.92	3.057	0.022
Coronal Cobb angle		106.52±24.76	74.46±25.31	4.299	0.000
GK		80.36±16.74	69.54±17.65	2.013	0.035
VAS (point)		6.75±1.92	6.63±1.48	1.186	0.103
ODI (point)		75.43±8.65	75.27±7.91	0.290	0.891
Number of osteotomy segments	≤2	3	15	11.632	0.003
	2-3	9	12		
	>3	7	1		

Note: PSO: pedicle subtraction osteotomy; VCR: vertebral column resection; PT: prothrombin time; APTT: activated partial thromboplastin time; INR: international normalized ratio; ESR: erythrocyte sedimentation rate; GK: global kyphosis; VAS: visual analogue scale; ODI: Oswestry disability index.

Table 4. Independent influencing factors for massive intraoperative hemorrhage

Influencing factors	B	SE	Sig.	OR (95% CI)
Number of fixed segments	1.423	0.896	0.032	3.868 (1.243-2.389)
Osteotomy site	1.138	0.423	0.015	3.093 (1.138-5.947)
ESR	1.336	0.564	0.451	3.632 (0.376-6.755)
Coronal Cobb angle	1.131	0.428	0.001	3.074 (1.003-5.992)
GK	1.567	0.514	0.059	4.260 (0.987-8.968)
Number of osteotomy segments	1.332	0.581	0.000	3.621 (2.136-5.755)

Note: ESR: erythrocyte sedimentation rate; GK: global kyphosis.

nificance for optimizing correction outcomes in adolescent CKS patients while reducing the risk of complications. The results of this study showed that the time required for multi-segment PSO was longer than that of single-segment VCR, but there were no statistically significant differences in intraoperative blood loss and postoperative hospital stay between the two groups. These results indicate that in terms of surgical complexity, as the number of operated on vertebrae increases, the surgical complexity gradually increases. In this study, there were patients with two-segment PSO and three-segment PSO, and the three-segment PSO surgery significantly increased the operation time of the PSO group. The surgical complexity and time-consumption of two-segment PSO is roughly similar to that of VCR. In the comparison of correction outcomes, the coronal Cobb angle, GK, pain degree, and spinal function of patients in both groups were significantly improved compared to before treatment, and the improvements of the coronal Cobb angle was more obvious. This indicates that both PSO and VCR have good correction outcomes on congenital severe spinal deformities, and the improvement of coronal plane deformities is more obvious. Further comparison found that the coronal Cobb angle, GK, and spinal function of patients undergoing multi-segment PSO were better than those of patients undergoing VCR, while there was no significant difference in pain degree between the two groups, indicating that in terms of the correction outcomes on CKS, multi-segment PSO is more effective. Therefore, this study reveals that for patients with severe CKS, the corrective ability of various osteotomy methods in the coronal plane from low to high is single-segment SPO, two-segment PSO or VCR, and three-segment PSO, showing that the more segments of surgery, the better the correction outcomes.

Neurological dysfunction is a common complication in spinal deformity correction surgeries [18]. In this study, the incidence of postoperative complications in patients who underwent VCR was higher than that in patients who underwent PSO, but there was no statistical significance between the two groups. Some studies [19, 20] have reported that VCR is more likely to lead to the occurrence of postoperative complications in patients. However, in this study, the patients in the VCR group did not show a significant increase in complication rate. This may be related to the single condition of the CKS patients included in this study. In addition, compared with single-segment PSO, multi-segment PSO may only increase the surgical complexity and operation time without significantly increasing the risk of complications. This shows that the advantage and the risk of complications of single-segment PSO is less than that of VCR.

Our research found that there were statistical differences in the number of fixed segments, osteotomy sites, ESR, coronal Cobb angle, GK, and the number of osteotomy segments between patients in the hemorrhage group and the normal group. Further Logistic analysis showed that the number of fixed segments, osteotomy sites, coronal Cobb angle, and the number of osteotomy segments were independent influencing factors for massive blood loss during the operation. Analyzing the reasons, intraoperative blood loss occurring in osteotomy often comes from the vertebral body itself, and operation time and surgical complexity are also relevant influencing factors [21]. When VCR is adopted or the patient has a larger kyphotic angle, more vertebral bodies and related tissues often need to be resected, increasing the exposure area, and it is more likely to cause active bleeding and oozing. However, as the number of PSO-operated vertebral bodies increases, the blood loss was significantly more than those of single-segment PSO and was comparable to VCR. Therefore, in this study, the surgical method did not become an influencing factor for massive intraoperative blood loss in patients. In addition, compared with single-segment osteotomy, multi-segment osteotomy, with an increased number of fixed segments and a larger exposure area, raises the risk of vertebral vein rupture. In such instances, bleeding can be challenging to control, increasing the likelihood of massive intraoperative blood loss [22, 23]. According to the surgeon's experience, operation time is also extremely important for reducing the occurrence of massive intraoperative blood loss. The risk of massive blood loss in patients undergoing three-segment PSO surgery was higher than that in other patients. For patients undergoing the same surgical procedure, as the operation time is shortened, especially the time required to close the osteotomy surface is shortened, the intraoperative blood loss of patients will also be reduced accordingly.

For some patients with CKS, both PSO and VCR surgical methods can be applied, but there will be certain differences in the final curative effects. The innovation of this study lies in the comparison of the application effects of the two surgical regimens, rather than the previous comparison between single-segment PSO and VCR. There are still some limitations in this study. For example, the number of patients is limited, so more cases and long-term close follow-up are needed. The condition of CKS is too complex to fully ensure the consistency of variables. Depending on the different conditions of each patient, it is difficult to ensure that only PSO or VCR is used during the operation. To ensure the orthopedic effect, PONTE osteotomy or SPO is often additionally performed in other segments. However, in this study, we made efforts to minimize their application to maintain the objectivity of the experimental results.

In summary, both multi-segment PSO and VCR yield effective correction outcomes for CKS. In comparison, multi-segment PSO, despite having a longer operation time, provides superior correction outcomes compared to VCR and does not significantly increase the risk of surgical complications. In addition, the number of fixed segments, osteotomy site, coronal Cobb angle, and the number of osteotomy segments are independent factors influencing the risk of massive intraoperative hemorrhage.

Acknowledgements

This study was funded by the Military Medical Science and Technology Youth Cultivation Programme (No. 13QNP049); Nanjing Military Region Medical Science and Technology Innovation Key Project (No. 15ZD023); Key projects of the 'Twelfth Five-Year' All-Army Logistics Research Programme (No. BNJ13J003), and the Jiangxi Province Yingtan Science and Technology Bureau Achievement Promotion Programme (No. YKS20210068).

Disclosure of conflict of interest

None.

Address correspondence to: Jun Yang, Department of Spinal Orthopaedics, Orthopaedic Centre, Yingtan 184 Hospital, Yingtan 335000, Jiangxi, China. E-mail: yangjun184gk@163.com

References

[1] Ha AS, Lee N, Blake R, Mathew J, Cerpa M and Lenke LG. Can spinal deformity patients maintain proper arm positions while undergoing full-body X-ray? Spine Deform 2021; 9: 387-394.

[2] Hu Z, Liu D, Zhu Z, Qiu Y and Liu Z. Using satellite rod technique in patients with severe kyphoscoliosis undergoing three-column osteotomy: a minimum of 2 years' follow-up. Orthop Surg 2021; 13: 83-89.

[3] Ha AS, Cerpa M and Lenke LG. State of the art review: vertebral osteotomies for the management of spinal deformity. Spine Deform 2020; 8: 829-843.

[4] Huang Z, Sui W, Huang H, Deng Y, Li J, Liu L, Yang J and Yang J. Quantitative determining of pre-operative osteotomy plan for severe spinal deformity: an analysis of 131 consecutive Yang's a type cases from single center. Eur Spine J 2021; 30: 3200-3208.

[5] Dong Y, Tang N, Wang S, Zhang J and Zhao H. Risk factors for blood transfusion in adolescent patients with scoliosis undergoing scoliosis surgery: a study of 722 cases in a single center. BMC Musculoskelet Disord 2021; 22: 13.

[6] Zhong W, Chen Z, Zeng Y, Sun C, Li W, Qi Q and Guo Z. Two-level osteotomy for the corrective surgery of severe kyphosis from ankylosing spondylitis: a retrospective series. Spine (Phila Pa 1976) 2019; 44: 1638-1646.

[7] Ding H, Hai Y, Zhou L, Liu Y, Zhang Y, Han C and Zhang Y. Clinical application of personalized digital surgical planning and precise execution for severe and complex adult spinal deformity correction utilizing 3D printing techniques. J Pers Med 2023; 13: 602.

[8] Negrini S, Aulisa AG, Aulisa L, Circo AB, de Mauroy JC, Durmala J, Grivas TB, Knott P, Kotwicki T, Maruyama T, Minozzi S, O'Brien JP, Papadopoulos D, Rigo M, Rivard CH, Romano M, Wynne JH, Villagrasa M, Weiss HR and Zaina F. 2011 SOSORT guidelines: orthopaedic and rehabilitation treatment of idiopathic scoliosis during growth. Scoliosis 2012; 7: 3.

[9] Sato T, Takahashi I, Watanabe Y, Yokoyama D and Shimokawa N. Congenital kyphoscoliosis: analysis of vertebral abnormalities using model animals (Review). Exp Ther Med 2024; 28: 416.

[10] Börekci A, Ekşi MŞ, Osama M, Tunçkale T, Yılmaz M, Koban O, Öğrenci A and Dalbayrak S. Circumferential approach to congenital kyphoscoliosis with hemivertebra: adding on rather than resecting could be a better option in older adolescents. World Neurosurg 2023; 180: 22-28.

[11] Abdaliyev S, Yestay D and Baitov D. Correction of a congenital kyphoscoliosis associated with diastematomyelia. J Surg Case Rep 2024; 2024: rjae153.

[12] Miyazaki S, Suzuki T, Yurube T, Kakutani K, Nishida K and Uno K. Postoperative sagittal alignment of congenital thoracolumbar to lumbar kyphosis or kyphoscoliosis: a minimum 10-year follow-up study. Spine Deform 2020; 8: 245-256.

[13] Lau D and Ames CP. Three-column osteotomy for the treatment of rigid cervical deformity. Neurospine 2020; 17: 525-533.

[14] Crostelli M, Mazza O, Mariani M, Mascello D, Tundo F and Iorio C. Hemivertebra resection

and spinal arthrodesis by single-stage posterior approach in congenital scoliosis and kyphoscoliosis: results at 9.6 years mean follow-up. Int J Spine Surg 2022; 16: 194-201.

[15] Agrawal A, Dhawale T, Kaur V and Passi GR. Case report of congenital kyphoscoliosis with myotonic dystrophy type 1: perioperative and anesthetic considerations. J Pediatr Neurosci 2021; 16: 281-284.

[16] Xue X, Zhao S, Miao F, Li K and Zhao B. Long-term results after the one-stage posterior-only surgical correction of thoraco-lumbar kyphoscoliosis in congenital spine deformity caused by two ipsilateral hemi-vertebrae. BMC Musculoskelet Disord 2021; 22: 327.

[17] Karami M, Zandi R, Hassani M and Elsebaie HB. Thoracolumbar and lumbar posterior vertebral resection for the treatment of rigid congenital spinal deformities in pediatric patients: a long-term follow-up study. World Neurosurg X 2022; 16: 100130.

[18] Koller H, Ansorge A, Hostettler IC, Koller J, Hitzl W, Hempfing A and Jeszenszky D. Center of rotation analysis for thoracic and lumbar 3-column osteotomies in patients with sagittal plane spinal deformity: insights in geometrical changes can improve understanding of correction mechanics. J Neurosurg Spine 2021; 36: 440-451.

[19] Boachie-Adjei O, Duah HO, Sackeyfio A, Yankey KP, Lenke LG, Sponseller PD, Samdani AF, Sucato DJ, Sides BA, Newton PO, Shah SA, Akoto H and Gupta MC; Fox Pediatric Spinal Deformity Study. Surgical outcomes of severe spinal deformities exceeding 100° or treated by vertebral column resection (VCR). Does implant density matter?: an observational study of deformity groupings. Spine Deform 2022; 10: 595-606.

[20] Chen JL, Xu Y, Wan L and Yao GX. Surgical choice of posterior osteotomy way for senile osteoporotic thoracolumbar fracture with kyphosis. Zhongguo Gu Shang 2020; 33: 121-6.

[21] Maio M, Carvalho A, Pinho A, Serdoura F and Veludo V. What factors can influence massive blood loss in the surgical treatment of neuromuscular scoliosis? Rev Bras Ortop (Sao Paulo) 2020; 55: 181-184.

[22] Mihara Y, Chung WH, Chiu CK, Hasan MS, Lee SY, Ch'ng PY, Chan CYW and Kwan MK. Perioperative outcome of severe idiopathic scoliosis (Cobb angle ≥ 90°): is there any difference between "daytime" versus "after-hours" surgeries? Spine (Phila Pa 1976) 2020; 45: 381-389.

[23] Liu H, Li D, Zhang X, Qi X, Guo D, Bai Y and Tian M. Predictors of perioperative blood loss in primary posterior hemivertebra resection for pediatric patients with congenital scoliosis. J Pediatr Orthop B 2022; 31: 565-571.