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Complications of posterior vertebral column resection in spinal deformity

A systematic review

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Abstract

Background: Posterior vertebral column resection (pVCR) is widely used to correct severe spinal deformities. However, it is a complex surgery, and the complications associated with different indications remain unclear.

Methods: A systematic literature search was conducted in PubMed, MEDLINE, Scopus, EMBASE, and the Cochrane Library. Studies reporting clinical outcomes and complications of pVCR were included and descriptively analyzed according to underlying deformity etiology. The quality of evidence was assessed using the grading ofr ecommendationsa ssessment,d evelopment and evaluation framework.

Results: A total of 26 studies were included. Across different indications, pVCR demonstrated substantial deformity correction, with reported kyphosis correction rates generally ranging from approximately 44% to 95%. However, complication rates varied considerably by etiology. In posttraumatic kyphosis, overall complication rates ranged from 12% to 59%, with internal fixation-related complications being relatively common. In congenital spinal deformities, the overall complication rate appeared higher (17%–100%), with neurological complications reported in approximately 7% to 9% of cases and notable rates of revision surgery and instrumentation failure. In posttuberculous kyphosis, neurological complication rates of around 15% were reported, including severe deficits in a subset of patients. In severe, rigid deformities, nonneurological complications were frequently observed, with reported rates up to 23%, along with rare mortality events. These findings suggest that the type and frequency of complications may differ across indications.

Conclusions: pVCR may provide effective deformity correction in patients with severe spinal deformities; however, it is associated with a substantial and variable complication burden. The available evidence suggests that complication profiles differ by underlying etiology, with potentially higher risks in certain subgroups, such as congenital. Further high-quality, comparative research is required to better define the safety and indications of pVCR.

Abbreviations: IONM = intraoperative neuromonitoring, PSO = pedicle subtraction osteotomy, pVCR = posterior vertebral column resection, SRS = Scoliosis Research Society, VCR = vertebral column resection.

Keywords: complication, posterior vertebral column resection, spinal deformities, systematic review

1. Introduction

Spinal deformities, often resulting from congenital, traumatic, or infectious diseases, can lead to altered appearance, lower back pain, and neurological or cardiopulmonary impairments.[1] To address these deformities, surgical intervention is frequently required to correct the deformity, relieve nerve compression, and achieve sagittal and coronal balance.[2] Vertebral column resection (VCR), initially proposed by Professor Maclennan in 1922 for severe scoliosis correction, involves vertebral body osteotomy of the anterior, middle, and posterior columns of the spine.[3] In 2014, Professor Schwab classified osteotomies into 6 grades, with the 5th and 6th grades involving single-segment or 2-segment VCR.[4] Over the years, numerous innovations, including techniques like the eggshell method and pedicle subtraction osteotomy (PSO), have further refined spinal deformity correction, improving precision, safety, and postoperative outcomes.[5,6] However, these techniques often come with challenges such as prolonged surgery times and significant blood loss. In response, the posterior vertebral column resection (pVCR) technique has

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gained prominence for its reduced surgical difficulty and complication rates, particularly in treating severe spinal deformities like posttubercular and posttraumatic kyphosis.[7,8]

In 2002, Professor Suk et al.[7,8] proposed the technique of pVCR to reduce surgical difficulty and complication rates, which was first applied in spinal tumor resection surgeries in 1988.[9] In 2008, Wang et al.[10] combined pVCR with the eggshell technique to create multilevel modified vertebral column resection (MVCR), reducing blood loss and time. In 2009, Lenke et al.[11] promoted pVCR for severe spinal deformities. In 2011, Wang et al.[12] introduced vertebral column decancellation (VCD) for sharp angular deformities. In 2019, Luo et al.[13] applied pVCR to treat spinal extradural arachnoid cysts, and Gururaj Sangondimath et al.[14] used a VCR on a 19-month-old with Pott's kyphosis. In 2021, Zhang et al.[15] proposed deformed complex vertebral osteotomy (DCVO) for tuberculous spinal kyphosis, with better results than traditional VCR.

The posterior approach, which avoids the anterior thoracic cavity and pleural invasion, allows manipulation of both posterior and anterior columns through a posterior incision, significantly reducing operative time and intraoperative bleeding. Subsequently, multiple authors reported the application of the pVCR technique in treating severe spinal deformities, and indications for pVCR have expanded to include severe posttubercular kyphosis,[16–18] posttraumatic kyphosis,[19–22] congenital spinal deformities,[23–30] and severe rigid deformities.[31–33] However, with advancements in the pVCR technique and the expansion of its indications, the incidence of complications has correspondingly changed. This study aimed to assess the incidence of complications in pVCR through a literature review.

2. Methods

This systematic review was conducted in accordance with the Preferred Reporting Items for Systematic Reviews and Meta-Analyses guidelines. The study was approved by the Ethics Committee of Union Hospital of Tongji Medical College, Huazhong University of Science and Technology. Because all data were obtained from previously published studies, the requirement for informed consent was waived.

2.1. Literature search

A comprehensive literature search was performed in PubMed, MEDLINE, Scopus, EMBASE, and Cochrane Library databases to identify studies evaluating complication risks associated with pVCR, with the search deadline set for October 2025. The search strategy included the keyword "pVCR" along with related terms and medical subject headings (MeSH) where applicable. The search was limited to studies published in English without time restrictions.

2.2. Inclusion and exclusion criteria

Inclusion criteria: Involved patients undergoing pVCR for spinal deformities and reported data on radiographic correction rates and complications.

Exclusion criteria: Focused on patients undergoing pVCR for tumors or revision surgeries. Had insufficient patient numbers or lacked relevant outcome data (number of patients < 3). Had overlapping patient cohorts from the same institution (only the most comprehensive study was included).

2.3. Study selection and data extraction

Two independent reviewers screened the titles and abstracts of all identified studies. Full-text articles of potentially eligible studies were retrieved and assessed for final inclusion based on the predefined criteria. Disagreements were resolved through discussion or consultation with a third reviewer.

A standardized data extraction form was used to collect relevant information, including study characteristics, patient demographics, surgical details, complication rates, and radiographic outcomes.

2.4. Level of evidence

The quality of the included studies was evaluated independently by two authors using the GRADE framework. Each study was rated as high, moderate, low, or very low quality according to the GRADE criteria based on scores in five aspects: risk of bias, inconsistency, indirectness, imprecision, and other considerations. Kappa coefficients were calculated to determine inter-rater reliability for 2-author ratings.

2.5. Statistical analysis

All analyses for this systematic review were performed using SPSS 22.0 software. Continuous variables were presented as "mean ± SD." Categorical variables were presented in the form of "number/percentage."

2.6. Study selection process

The initial search yielded 302 studies. After removing duplicates and screening titles and abstracts, 38 full-text articles were assessed for eligibility. Among them, 7 studies were excluded for enrolling fewer than 3 patients, and to minimize potential overlap in patient cohorts, only the most comprehensive study from each institution was included in the final analysis. Ultimately, 26 studies were retained for final analysis (Fig. 1).

3. Results

The average ages of patients with uncategorized, posttraumatic, congenital, posttuberculous, and severe rigid deformities ranged from 13 to 39 years, 33 to 70 years,

4 to 22 years, 40 to 41 years, and 10 to 45 years, respectively. Surgical procedures primarily involved vertebral resection in the thoracic or lumbar spine. The duration of surgery varied by deformity type: for uncategorized cases, the average duration ranged from 250 to 600 min, with intraoperative blood loss between 1,300 and 3,500 mL; for post-traumatic cases, the duration ranged from 190 to 290 min, with blood loss of 800 to 2,100 mL; for congenital deformities, surgery took 170 to 660 min, with blood loss ranging from 300 to 3,000 mL; for posttuberculous kyphosis, surgery durations were 360 to 390 min, with blood loss between 1,400 and 2,600 mL; and for severe rigid deformities, the duration ranged from 410 to 620 min, with blood loss between 1,500 and 6,700 mL (Table 1).

3.1. Treatment of uncategorized spinal deformity with pVCR

The effectiveness of pVCR in correcting spinal deformities has been well-documented, with reported correction rates varying across studies. Overall, kyphotic correction rates range from 44% to 95%, with some studies achieving particularly high correction percentages. For example,

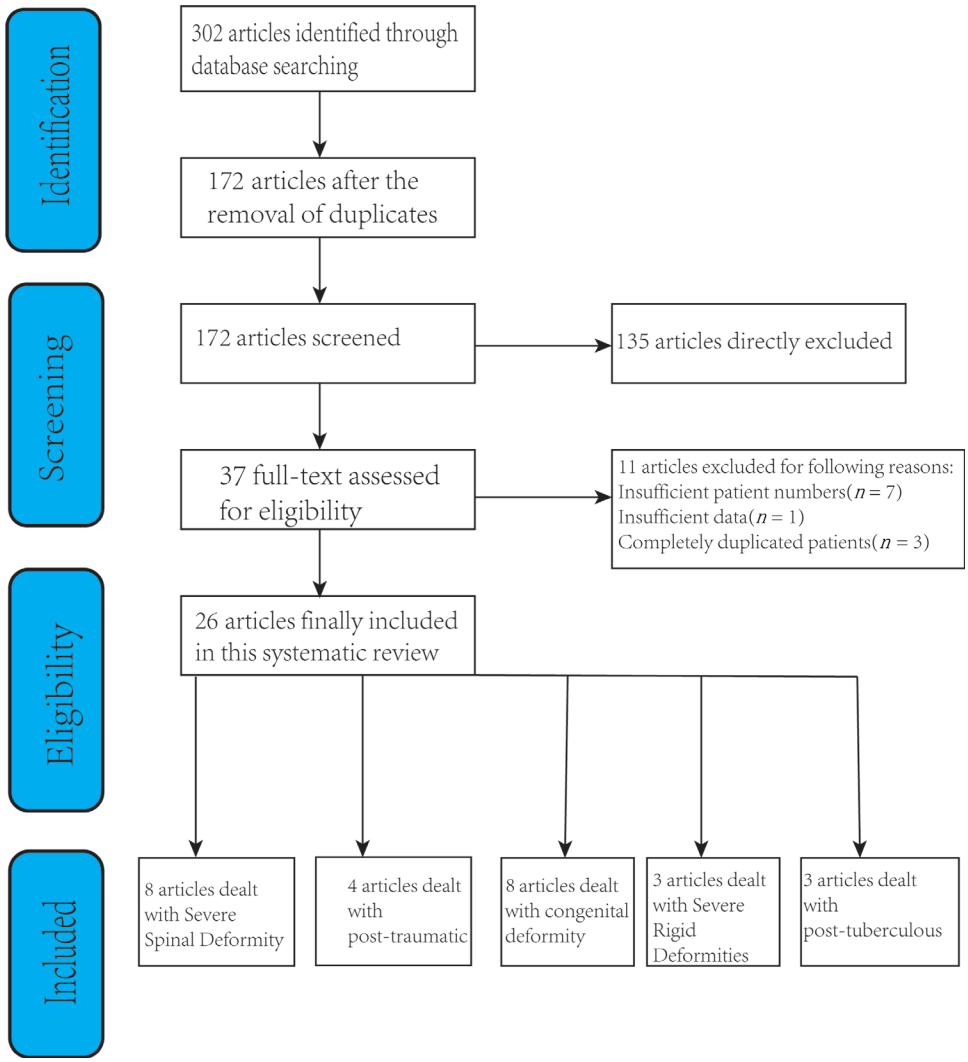


Figure 1. Flow diagram.

Table 1

Baseline and surgical characteristics of included studies by indication for pVC.

Indication	No. of studies	Total patients	Age (year)	Preoperative deformity	Operative time (min)	Blood loss (mL)
Uncategorized spinal deformity	8	900	13–39	50°–100°	370–450	1,300–4,800
Posttraumatic kyphosis	4	75	33–70	29°–49°	190–290	800–2,100
Congenital spinal deformity	8	145	4–22	71°–117°	170–660	300–3,000
Posttuberculous kyphosis	3	224	40–41	94°–113°	360–390	1,400–2,600
Severe rigid deformities	3	166	10–45	93°–109°	410–620	1,500–6,700

pVC = posterior vertebral column.

a large-scale study of 233 patients demonstrated a 95% correction of local kyphotic angles, reducing them from 51° to 3°, along with a 63% correction in thoracic kyphosis and a 68% correction in thoracolumbar/lumbar kyphosis.[34] Comparable correction magnitudes have also been reported in other cohorts. In a 102-case series, the coronal plane main curve improved from 102° to 38° (62% correction), while thoracic kyphosis decreased from 83° to 36° (57% correction).[35] In addition, a 5-year follow-up study of 54 patients showed sustained deformity correction in both age groups, with a higher correction rate in pediatric patients (62%) than in adults (54%).[36]

Postoperative complications remain a significant concern, with an overall incidence ranging from 2% to 47%. Neurological complications have been reported in 2% to 25% of patients, with severe cases including complete spinal cord injury.[37] In the study by Wang et al.[38], intraoperative spinal cord monitoring events occurred in up to 22% of cases, and 4% of patients developed new neurological deficits postoperatively. Notably, in a study involving 76 patients, 6 experienced transient neurological changes, but none suffered permanent paralysis or nerve root injury.[39] Across studies, the reported neurological risk varies considerably, ranging from 1.96% to 25.5%.[35,40]

Proximal junctional kyphosis is a common mechanical complication after pVCR, with reported incidences of 16% in pediatric patients and 35% in adults.[36] In addition, rod breakage is a concern, with some studies reporting an incidence of 14%.[41] The need for revision surgery within 5 years has been observed in 13% of cases, reflecting the long-term challenges associated with maintaining correction and stability [36] (Table 2, Fig. 2).

3.2. Treatment of posttraumatic kyphosis with pVCR

The application of pVCR has demonstrated remarkable efficacy in the correction of posttraumatic kyphosis, consistently achieving a segmental kyphotic angle correction rate exceeding 70% across all studies. Notably, Kang et al.[19] reported an impressive correction rate of 86%. Furthermore, no deterioration in neurological function was observed, and improvements were documented.

Neurological recovery was particularly significant in patients with pre-existing deficits. A pooled analysis of 38 patients revealed a Frankel grade improvement rate of 29% (11/38), with severely affected cases (grade A) showing functional improvements in continence (6/9).[21,22] In

Table 2

Descriptive data of included studies and incidence of complications of severe spinal deformity with pVCR.

Study	Country	*N*	Age (year)	Operative time (min)	Blood loss (mL)	Deformity correction	Rate	Complications
Hamzaoglu et al.[35]	Türkiye	102	37	–	–	72% Coronal plane 102° to 38° 71% Thoracic kyphosis 83° to 36°	2.0	Nerve root palsies 2
Kim S-S et al.[34]	Korea	233	34	–	–	Local kyphosis 51° to 3 ° Thoracic scoliosis 64° to 25° Thoracolumbar or lumbar scoliosis 50° to 17°	39	Postoperative neurologic deficit 33 Instrument failures 25 Dural tears 23 Hemothoraxes 6 Pleural effusions 2 Major abdominal ileus 1 Iliac donor site infection 1 Mortality case 1
Papadopoulos et al.[37]	USA	45	14	450	1,300	44% Correction of local kyphosis 108° to 60°	24	Nerve root injury 1 Wound infection 4 Pseudoarthrosis 3 Instrument failures 3
Xie et al.[39]	China	76	18	510	4,800	Scoliosis 110° to 38° Kyphosis 95° to 29°	7.9	Change of neurologic status 6
Sacramento-Domínguez et al.[40]	Spain	98	14	370	1,300	–	47	Major complications occurred in 46 patients (neurologic in 25)
Wang et al.[38]	China	202	26	–	1,500	Coronal correction was 63% Sagittal plane correction was 60%	2.5	Neurologic deficit 5
Wang et al.[41]	China	35	38	–	–	Correction rates of the main curve 69% Correction rates of segmental kyphosis 68%	14	Rod breakage 5
Riley et al.[36]	USA	109	13–39	–	–	61% Correction for the pediatric cohort and 54% correction for the adult cohort	4.6	PJK 16% for the pediatric cohort and 35% for the adult cohort Neurological deficits 5
Total		900					19.1	172

PJK = proximal junctional kyphosis, pVCR = posterior vertebral column resection.

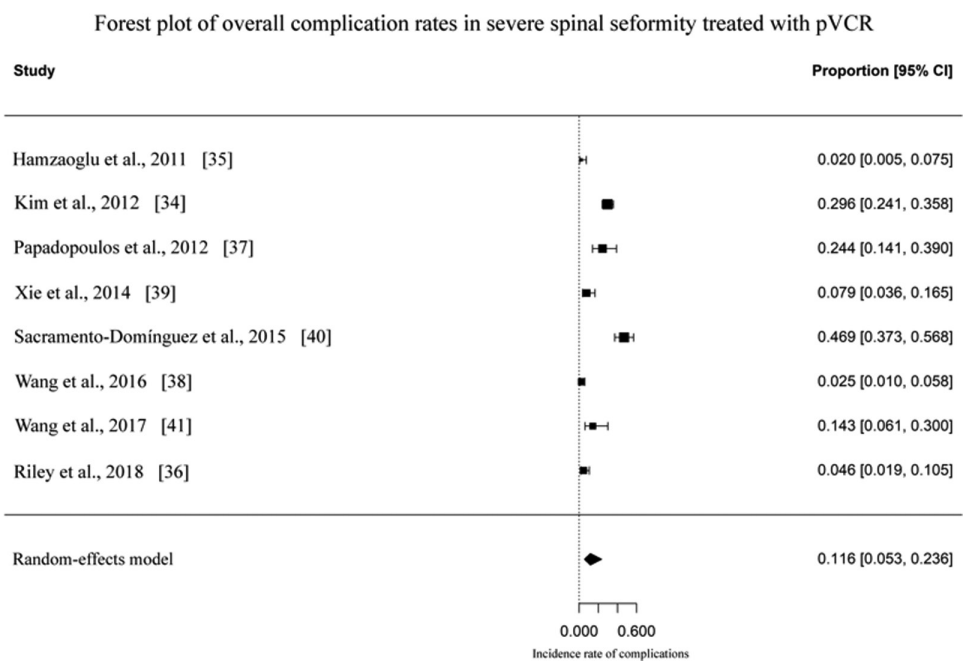


Figure 2. Forest plot of overall complication rates in uncategorized spinal deformity treated with pVCR. CI = confidence interval, pVCR = posterior vertebral column resection.

addition, solid spinal fusion was achieved in all cases, and patients experienced significant relief from lower back pain. Importantly, none of the studies reported any surgery-related neurological deterioration.

These findings underscore the strong corrective potential of pVCR in posttraumatic kyphosis and its positive impact on neurological symptoms. However, the relatively high complication rate (12%–59%) warrants careful consideration. Intraoperative complications such as deep vein thrombosis and dural tears were observed in approximately 11% of cases but were effectively managed without the need for surgical intervention.[21] Although joint fractures and dural-related complications were among the more common postoperative issues (10%), they were generally controllable.[20] Given these outcomes, pVCR remains a viable and effective surgical option for patients with posttraumatic kyphosis (Table 3, Fig. 3).

3.3. Treatment of congenital spinal deformity with pVCR

While pVCR has demonstrated substantial corrective potential in the treatment of congenital spinal deformities, its complication rate remains a critical concern. The reported correction rates vary widely across studies (36%–87%).[26,29] For instance, Wang et al.[27] documented a reduction in segmental kyphotic angle from 87° to 18°, along with an improvement in sagittal vertical axis (SVA) from 43 to 9 mm, significantly enhancing sagittal balance. In pediatric cases, Matsumura et al.[26] achieved an impressive 87% correction, underscoring the powerful realignment capacity of pVCR.

Despite its efficacy in spinal correction, the potential neurological risks associated with pVCR warrant careful evaluation. In congenital deformities, the incidence of neurological complications ranges from 7.4% to 8.9%. Garg et al.[23] reported a 7.4% incidence, with 3.7% of cases experiencing permanent neurological deficits. Similarly, in a cohort of 45 patients studied by Chang et al.[24], the neurological complication rate was 8.9%. However, long-term follow-up indicated that spinal alignment remained relatively stable postoperatively (patients under 10 years: 44° to 10°; patients over 10 years: 49° to 17°), with only minor progression (14° and 20°).

Beyond neurological risks, mechanical complications and revision surgery rates are also noteworthy concerns. The overall complication rate associated with pVCR in congenital deformity correction is substantial (32.4%), with significant variability across studies (17%–100%). For instance, Tanaka et al.[30] reported a 100% complication rate (rod breakage and/or surgical site infection) in a cohort of 3 patients over a mean follow-up of 9.3 years. Ould-Slimane et al.[25] reported a 31% revision rate in a cohort of 13 patients, with postoperative paralysis occurring in 7.7% of cases. These findings highlight the necessity for meticulous surgical planning, intraoperative neuromonitoring (IONM), and vigilant postoperative management to mitigate the risks associated with pVCR (Table 4, Fig. 4).

3.4. Treatment of posttuberculous kyphosis with pVCR

pVCR has demonstrated significant efficacy in correcting posttuberculous kyphosis, with reported local kyphotic angle correction rates ranging from 66% to 71%. Studies have shown substantial improvements in spinal alignment,

Table 3

Descriptive data of included studies and incidence of complications of post-traumatic kyphosis with pVCR.

Study	Country	*N*	Age (year)	Operative time (min)	Blood loss (mL)	Postoperative length of stay (day)	VAS	Deformity correction	Complication rate	Complications
Koepke et al.[20]	Germany	17	70 ± 10	290 ± 110	2,100 ± 1,400	21 ± 16	7.7 ± 2.8 to 3.0 ± 1.6	29 ± 14° to 8 ± 8°	59	Material loosening 4 Iatrogenic dura leak 2 Wound infection 3 Seroma 1
Kang et al.[19]	Korea	20	36–82	290 ± 30	–	–	7.9 ± 0.8 to 2.3 ± 1.0	48 ± 8° to 6 ± 4° (86% correction rate)	20	DJK2 PJK1 Screw loosening 1
Ma et al.[21]	China	26	58–74	210 ± 50	800 ± 200	10 ± 2	6.5 ± 1.5 to 2.6 ± 1.2	49 ± 7° to 10 ± 4°	12	Dural rupture 1 Cerebrospinal fluid leakage 2
Tang et al.[22]	China	12	33	190	1,600	–	–	–	17	Pleural injury 1 Intercostal nerve damage 1
Total		75							25.3	19

DJK = distal junctional kyphosis, PJK = proximal junctional kyphosis, pVCR = posterior vertebral column resection, VAS = visual analogue scale.

with preoperative kyphotic angles decreasing from 94°–113° to 32°–37° postoperatively. In addition, the sagittal vertical axis improved from approximately 43 mm preoperatively to 18 mm postoperatively.[18] Notably, pVCR has also been associated with enhanced pulmonary function, with postoperative computed tomography measurements indicating a 24% increase in lung volume.[17]

Despite these benefits, the risk of neurological complications remains a critical concern. The incidence of neurological deficits after pVCR for posttuberculous kyphosis is approximately 15%, with reported cases ranging from mild sensory impairments to severe motor deficits, including paraplegia.[18] While most studies indicate no significant deterioration in neurological function, severe complications such as complete or incomplete paraplegia have been observed in a small subset of cases.[16–18]

In addition to neurological risks, surgical complications such as fixation failure, cerebrospinal fluid leakage, and neurological deficits are among the most frequently reported issues. However, the high correction rates and potential functional improvements—including better postural balance and enhanced pulmonary

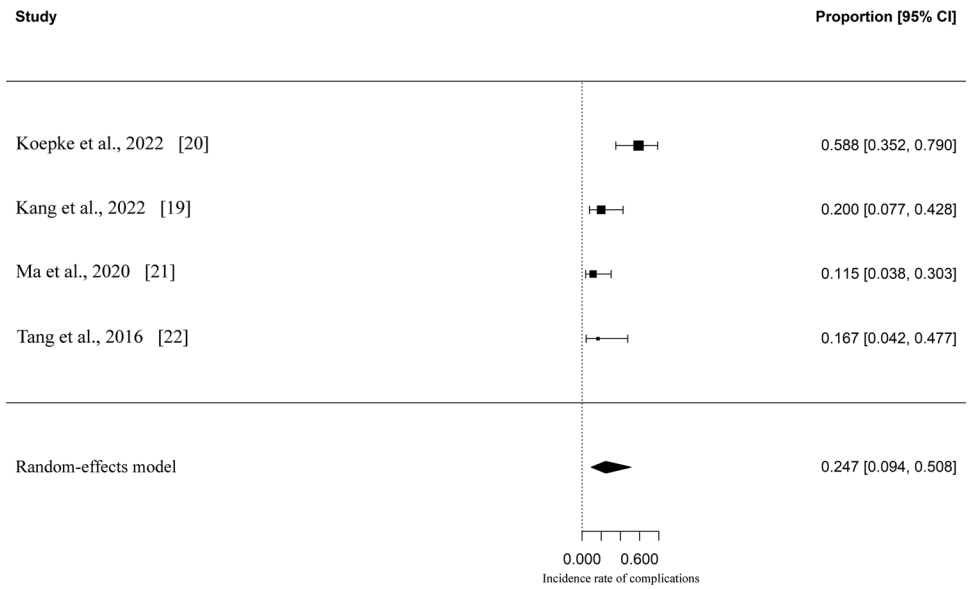


Figure 3. Forest plot of overall complication rates in posttraumatic kyphosis treated with pVCR. CI = confidence interval, pVCR = posterior vertebral column resection.

Table 4

Descriptive data of included studies and incidence of complications of congenital spinal deformity with pVCR.

Study	Country	Diagnosis	*N*	Age (year)	Operative Time (min)	Blood loss (mL)	Deformity correction	Rate	Complications
Wang et al.[29]	China	Achondroplasia	7	22 ± 13	–	1,800 ± 1,000	TLKs 73% ± 15% Main curves 87% ± 6%	100	Rod breakages 3 Neurological complications 2 Dural tears 1 Cerebrospinal fluid leaks 1 Proximal junction kyphosis 1
Tanaka et al.[30]	Japan	Achondroplasia	3	22	–	–	Kyphotic angle 117° (range: 103°–126°) to 37° (range: 14°–57°) 67%	100	Rod breakage and/or surgical site infection 3
Ould-Slimane et al.[25]	France	Congenital scoliosis	13	4 ± 3	410 ± 50	900 ± 200	74° (Mean correction was 64% postoperatively)	38	Transient monoplegia 1 non-unions requiring revision 4
Garg et al.[23]	India	Congenital kyphosis	27	14	180	700	Kyphotic angle 71° to 25° TK: -1° to 24°	22	Neurological complications 1 Nonneurological complications 5
Matsumura et al.[26]	Japan	Congenital kyphoscoliosis	12	9	370	400	Overall correction rate of main curve was 87%. Spontaneous correction rate in the cranial curve and caudal curve were calculated as 56% and 81%	17	Root irritation 1 Pedicle screw loosening 1
Wang et al.[27]	China	Congenital kyphosis	24	14	170–480	300–3,000	87° to 18°	17	Screw pullout because of pseudarthrosis 1 Proximal junctional kyphosis 1 Incomplete spinal cord injury 1 Root injuries 1
Zhang et al.[28]	China	Congenital scoliosis	17	11–23	420–660	1,400–2,900	91° (range: 72°–118°) to 58° (range: 43°–76°)	18	Dural laceration 2 Hemopneumothorax 1
Chang et al.[24]	Korea	Congenital scoliosis	45	7–15	190–250	1,300–2,400	44°–49° to 10°–17°	38	Early postoperative complications: postoperative transient neurologic deficits 4 Superficial wound infection 1 Late postoperative complications: screw malposition 1 Screw pull-out and/or metal failure 4 Adding-on deformity 5 late infections 2
Total			148					32.4	47

pVCR = posterior vertebral column resection, TLK = thoracolumbar kyphosis, TK = thoracic kyphosis.

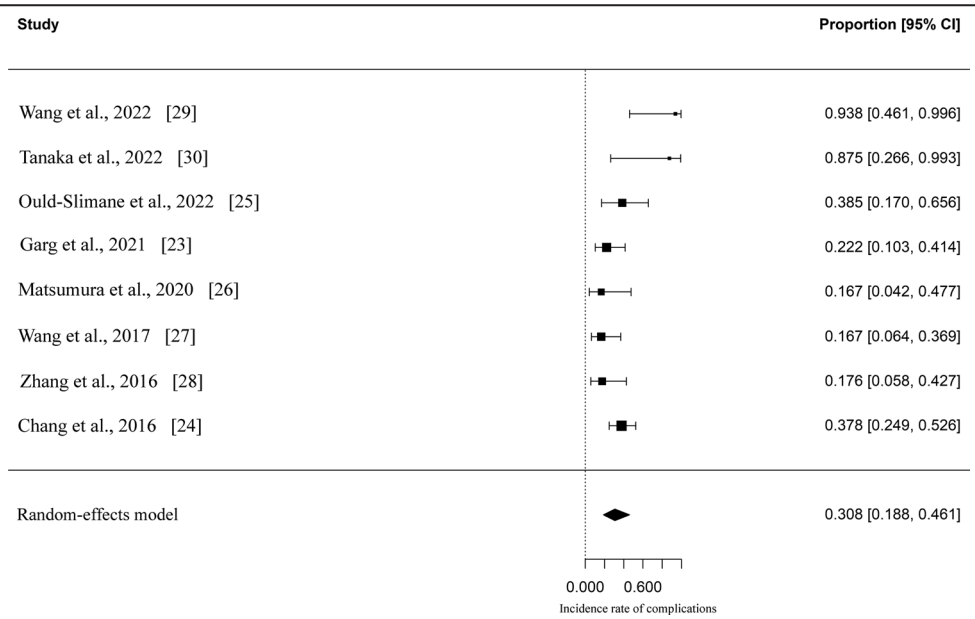


Figure 4. Forest plot of overall complication rates in congenital spinal deformity treated with pVCR. CI = confidence interval, pVCR = posterior vertebral column resection.

function—support the viability of pVCR as a treatment option for severe posttuberculous kyphotic deformities. These findings highlight the effectiveness of pVCR in spinal realignment while underscoring the importance of careful patient selection and IONM to mitigate neurological risks (Table 5, Fig. 5).

3.5. Treatment of severe rigid spinal deformities with pVCR

pVCR has demonstrated a high correction rate in the treatment of severe rigid scoliosis, with large-cohort studies consistently reporting significant improvements. In various studies, patients with severe, rigid spinal deformities had preoperative Cobb angles exceeding 90°, with postoperative corrections of more than 60°, yielding correction rates ranging from 59% to 67%. Notably, Bullmann et al.[33] reported a 49% correction in apical vertebral rotation, highlighting improvements in the 3-dimensional realignment of the deformity.

Despite its effectiveness in achieving substantial deformity correction, pVCR is associated with a high complication rate. Nonneurological complications have been reported in up to 23% of cases, with a mortality rate approaching 1%.[31] Neurological dysfunction, including ischemia-reperfusion injury, has also been observed, though complete recovery was achieved with appropriate management.[32] Interestingly, some studies have reported no incidence of neurological complications, deep infections, or pseudarthrosis, which may be attributed to variations in surgical techniques and perioperative management strategies.[32]

Table 5

Descriptive data of included studies and incidence of complications of post-tuberculous kyphosis with pVCR.

Study	Country	Diagnosis	*N*	Age (year)	Operative time (min)	Blood loss (mL)	Deformity correction	Rate	Complications
Lin et al.[17]	China	Posttubercular kyphosis	126	41 ± 8	360 ± 90	1,400 ± 500	LK: 113° ± 15° to 37° ± 6° LS: 21° ± 2° to 5.2° ± 2° EILV: 2.9 ± 0.8 to 3.6 ± 0.8 L	9.5	CSF: 5 Superficial wound infection 3 Transient neurological deficit 4
Ma et al.[16]	China	Posttubercular kyphosis	82	40 ± 8	370 ± 90	1,400 ± 600	Focal kyphosis: 109° ± 16° to 32° ± 5° Focal scoliosis: 21° ± 2° to 5° ± 2°	26	Temporary neurological deficit 2 CSF leakage 4 Lumbar nerve root injury 1 Superficial wound infection 4 Fixation failure 10
Hua et al.[18]	China	Posttubercular kyphosis	16	41	390 ± 50	2,600 ± 1,500	Kyphosis: 94° ± 14° to 32° ± 7°	13	Spinal cord injuries 2
Total			224					15.6	35

CSF = cerebrospinal fluid, EILV = end-inspiratory lung volume, LK = local kyphosis, LS = local scoliosis, pVCR = posterior vertebral column resection.

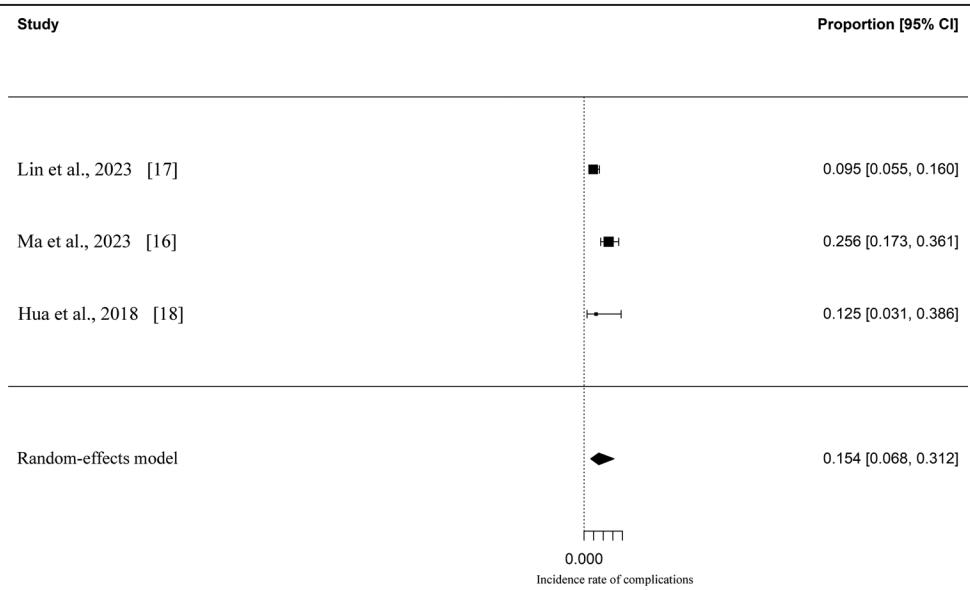


Figure 5. Forest plot of overall complication rates in posttuberculous kyphosis treated with pVCR. CI = confidence interval, pVCR = posterior vertebral column resection.

Given the powerful corrective potential of pVCR, its associated risks must be weighed carefully. However, compared with traditional combined approaches, pVCR offers advantages such as requiring only a single incision and reducing operative time. As a result, despite its inherent risks, pVCR remains a primary surgical option for the management of severe rigid spinal deformities (Table 6, Fig. 6).

4. Discussion

The pVCR surgery was proposed by Professor Suk in 2002, which mitigated the technical difficulty of anterior–posterior VCR.[7] Theoretically, pVCR offers numerous advantages over anterior–posterior VCR, including reduced surgery time and intraoperative blood loss, maintained stability throughout the spine osteotomy process, more reliable spinal reconstruction, fewer postoperative complications, and more effective correction.[42–45] Subsequent research has reported the application of the pVCR technique. However, a systematic evaluation of the application of pVCR in spinal deformity correction is still lacking.

In the current study, a systematic review of the literature was conducted, and 26 studies were included for

Table 6

Descriptive data of included studies and incidence of complications of severe rigid deformities with pVCR.

Study	Country	Diagnosis	*N*	Age (year)	Operative time (min)	Blood loss (mL)	Deformity correction	Rate	Complications
Wang et al.[31]	China	Severe rigid deformities	105	19 (Range: 10–45)	600 ± 130	4,700 ± 1,800	The major curve of scoliosis: 109° ± 26° to 37° ± 17° Segmental kyphosis: 90° ± 30° to 30° ± 15°	23	31 MNNCs in 24 patients: 16 Respiratory complications in 13 patients 9 Cardiovascular adverse events in 7 cases Malignant hyperthermia 1 Optic deficit 1 Wound infection 3 died 1
Xie et al.[32]	China	Severe rigid deformities	28	20	620 (range: 320–920)	6,700 (Range: 3,000–24,000)	Kyphotic Cobb angles: 96° to 30°	18	Late-onset paralysis 1 Thoracic nerve root pain 4
Bullmann et al.[33]	Germany	Severe and rigid idiopathic scoliosis	33	18 (Range: 11–39)	410 ± 80	1,500 ± 1,000 (Range: 300–4,500)	Cobb angle of the primary curve: 93° to 31°	9.0	Subileus 1 Torn wound drain 1 A fracture of the threaded VDS rod in the cephalad segment 1
Total			166					19.3	32

MNNC = major non-neurological complications, pVCR = posterior vertebral column resection, VDS = ventral derotation system.

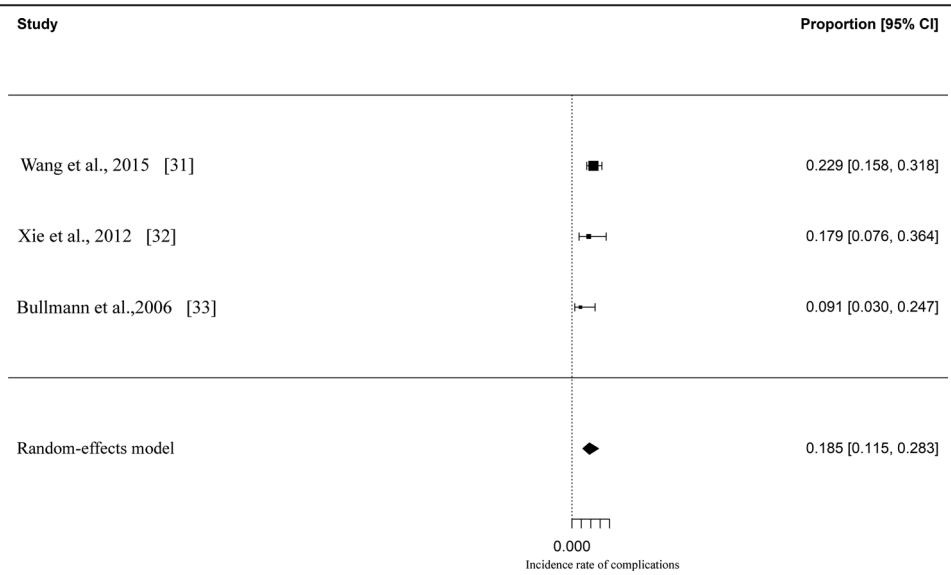


Figure 6. Forest plot of overall complication rates in severe rigid spinal deformities treated with pVCR. CI = confidence interval, pVCR = posterior vertebral column resection.

analysis. These studies were categorized into 5 groups: posttraumatic kyphosis, congenital spinal deformity, posttuberculous kyphosis, severe rigid deformities, and other unclassified etiologies. The average surgery time for posttraumatic kyphosis was 250 min, with an average intraoperative blood loss of 1,400 mL. Researchers improved the technique by performing the pVCR operation unilaterally. The main purpose of osteotomy for posttraumatic kyphosis is to provide space for anterior support rather than thorough decompression. The opening and resetting of the posterior rod can achieve better correction. For congenital spinal deformity, the average surgery time was 300 min, with an average intraoperative blood loss of 1,400 mL. The correction of deformity was 39° for scoliosis and 55° for kyphosis, with correction rates of 64% and 74%, respectively. Although thorough decompression was achieved, the stability of the spine was compromised, leading to an increased failure rate of internal fixation in the later stage. In addition, severe angular kyphosis was caused by late-stage tuberculosis, with an average surgery time of 370 min, intraoperative blood loss of 1,500 mL, scoliotic correction of 16°, kyphotic correction of 75°, and correction rates of 75% and 68%, respectively. What is more, for severe rigid deformities, the average surgery time was 570 min, with an average intraoperative blood loss of 4,400 mL. The correction of deformity was 60° for scoliosis and 69° for kyphosis, with correction rates of 55% and 75%, respectively. Another advantage of pVCR is the improvement of lung function. The latest two studies have shown significant improvement in lung function.[16,17] In addition, pVCR is the preferred method for correcting severe, rigid deformities.[46] Compared to Smith–Petersen osteotomy and PSO, pVCR can effectively correct severe rigid spinal deformities (Cobb angle exceeding 90° in the coronal or sagittal plane). By resecting 1 or more vertebrae and adjacent intervertebral discs, it allows for adequate decompression of the spinal cord.

However, any residual compression can lead to spinal cord or nerve root compression. In cases of severe, rigid spinal deformities, the proportion of nonneurological complications is relatively high and should be given significant attention.[31,47] The incidence of neurological complications during spinal deformity correction surgery ranges from 0.4% to 6.3%. In 1975, MacEwen et al. collected 7,885 cases of scoliosis surgery by distributing questionnaires to Scoliosis Research Society (SRS) members, revealing neurological complications in 87 cases, an incidence rate of 0.72.[48] In 2006, Coe et al.[49] reported that among 6,334 patients in the SRS database, the incidence rates of complications for anterior, posterior, and combined anterior–posterior approaches were 0.26%, 0.32%, and 1.75%, respectively. A retrospective analysis at Nanjing Drum Tower Hospital revealed a neurological complication rate of 0.73% among 8,870 cases of scoliosis correction surgery.[50] The incidence of neurological complications in pVCR is much higher than the above data, becoming its primary concern. In this study of 390 patients, the incidence of neurological complications was 8%, with spinal cord injury accounting for 2%. A total of 36 cases of neurological complications were recorded, including 10 cases of spinal cord injury. Undoubtedly, the risk of neurological complications and spinal cord injury in pVCR is very high.

4.1. Posttuberculous angular kyphosis

Patients with posttuberculous angular kyphosis show the highest incidence of neurological complications. Several factors may account for this finding. First, tuberculous kyphosis is infection-related, and chronic inflammation frequently leads to adhesions between the apical vertebrae and the dura, increasing the likelihood of dural tethering and spinal cord traction during decompression and osteotomy. Second, long-standing infection may compromise

segmental spinal cord perfusion at the kyphotic apex, thereby reducing spinal cord tolerance to intraoperative manipulation and transient ischemia. Third, the deformity is often severe and sharply angular, necessitating substantial angular correction and/or spinal column translation, which can increase the risk of cord kinking, stretch injury, and perfusion instability. Fourth, preoperative neurological deficits are relatively common in this population, suggesting that the spinal cord may already be near its physiological tolerance threshold. Importantly, prior work has shown that even in patients without overt neurological signs, diffusion tensor imaging may detect subclinical spinal cord injury, as reflected by reduced fractional anisotropy values.[51] In addition, patients with late-onset neurological deficits secondary to multisegment posttuberculous kyphosis are at elevated risk of further neurological deterioration during osteotomy, and outcomes remain comparatively poor.[7] Clinically, late progressive deficits in tuberculosis-associated severe angular kyphosis are often accompanied by multiple fused vertebrae, postinfectious fusion masses, and dural sac tethering.[6] Healed bony struts, calcified caseous material, fibrosis, and progressive deformity may exacerbate chronic compression and distraction, contributing to spinal cord ischemia and atrophy.[7] Collectively, these features underscore the need for particularly cautious, stepwise correction and meticulous release to minimize additional spinal cord injury.

4.2. Congenital spinal deformities

Most congenital deformities arise from failures of vertebral formation and are characterized by small, dysplastic vertebral bodies with abundant cartilaginous components around the apex. Although controlled translation may be tolerated in patients with a normal spinal cord, even transient intraoperative kinking can precipitate neurological injury, especially when correction is performed across a short, rigid apex. Moreover, neurological events during correction appear more likely in patients with preoperative neurological deficits.[27] Beyond neurological complications, the relatively high revision rate reported after pVCR in congenital deformity is largely attributable to instrumentation-related failure, particularly rod breakage, suggesting that postoperative mechanical demands and fusion reliability are critical concerns in this subgroup.

4.3. Posttraumatic kyphosis

In posttraumatic kyphosis, complications are predominantly perioperative and postoperative, whereas intraoperative complications are relatively less frequent. A plausible explanation is that the initial traumatic insult produces substantial structural disruption and soft-tissue injury, which may not necessarily translate into higher intraoperative technical complication rates but does predispose patients to postoperative adverse events related to impaired local biology, scar formation, altered vascularity, and the challenges of reconstructing stable spinal biomechanics.

4.4. Severe rigid spinal deformities

In severe, rigid deformities, complications are mainly nonneurological and occur at a relatively high frequency. These events are more common in patients with combined coronal and sagittal plane deformities than in those with isolated coronal deformities, which likely reflects the greater technical complexity and substantially prolonged operative time required to address multiplanar deformity. Longer procedures typically entail increased blood loss, extended anesthesia exposure, and higher cumulative cardiopulmonary and infectious risks, thereby shifting the complication spectrum toward systemic (nonneurological) events.

To further clarify the safety profile of pVCR, it is necessary to compare its complication risks with other high-level osteotomies, including PSO, conventional VCR, and other anterior, middle, and posterior columns of the spine. As a representative 4-column osteotomy, pVCR provides the strongest deformity correction capacity but is associated with longer operative time, greater intraoperative blood loss, and higher overall complication burden compared with PSO and Smith–Petersen osteotomy. In contrast to pVCR, conventional VCR requires a combined anterior–posterior approach, which offers wider surgical exposure but introduces thoracotomy-related morbidity and higher rates of pulmonary complications. According to a large cohort study,[52] VCR was associated with significantly higher medical complications than PSO; however, the rate of new neurological deficit was comparable between VCR and PSO.

Neurological-complication prevention in pVCR should be addressed as a perioperative package. Intraoperatively, temporary rod fixation with gradual, stepwise correction allows continuous assessment of dural sac tension and avoids abrupt translation. Excessive anterior distraction and uncontrolled posterior shortening should be avoided to reduce traction-related spinal cord injury, and a moderate correction strategy is advisable, particularly in patients with preoperative neurological deficits. In addition, strict IONM alarm algorithms are essential (i.e., immediate cessation of correction and partial reversal of the last step when alerts occur). Potential nonapical causes of neural compromise—such as adjacent-segment canal stenosis—should be identified preoperatively and decompressed before major correction to prevent postoperative deterioration despite an adequate apical decompression.[53,54]

Beyond these principles, two technical points are particularly relevant for lowering neurological risk. First, maintaining continuous spinal stability throughout the resection and correction is critical. In a large-curve pVCR series, segmental pedicle-screw fixation above and below the resection level, temporary stabilization, and sequential rod exchange with accurately precontoured definitive rods were used to keep the cranial and caudal segments mechanically coupled during correction, thereby minimizing uncontrolled translation at the osteotomy gap and reducing the risk of acute cord kinking/traction.[32] Second, controlled, timely shortening can

be used as a tension-reduction maneuver. Experimental work on acute shortening suggests that shortening within a limited range, performed under neurophysiologic monitoring with attention to spinal cord perfusion, may be tolerated and may even improve spinal cord blood supply.[55] Clinically, a pVCR mechanism study emphasized that correction is closely coupled to dural sac/spinal cord displacement, supporting the rationale for tension-aware correction and selective shortening to create "reserve" for subsequent steps.[56]

Beyond neurological concerns, pVCR is associated with other major complications that demand careful perioperative management, notably implant failure, vascular injury, and loss of correction. Implant-related complications, such as rod breakage and instability, are driven by immense mechanical stresses at the osteotomy site. Current evidence indicates that a larger residual segmental kyphotic angle and a higher body mass index are positively associated with implant failure, whereas the use of multirod constructs is negatively associated with failure, likely because it enhances construct stiffness and reduces stress concentration at the resection level. When implant failure occurs—especially if accompanied by pain or progressive deformity—revision surgery is typically required; in selected cases, this involves more extensive resection and reconstruction to adequately address the residual deformity and restore spinal stability.[57] Furthermore, although infrequent, vascular and visceral injuries can be catastrophic. In revision settings, particularly before performing repeat anterior exposure, obtaining high-quality preoperative imaging is mandatory to accurately delineate the spatial relation between previous anterior implants and adjacent vascular or visceral structures. Intraoperatively, these structures must be handled with extreme caution, using slow, meticulous, and preferentially blunt dissection to minimize the risk of inadvertent injury.[58] Finally, postoperative loss of correction, which often secondary to mechanical failure or pseudarthrosis, is generally managed through targeted reoperation to restore alignment and achieve solid fusion.[58]

Importantly, pVCR itself remains a high-risk procedure with substantial blood loss and a relatively high overall complication burden, including neurological events; therefore, patient selection should be cautious, and the procedure should be performed by experienced multidisciplinary teams.[59] To reduce reliance on aggressive single-stage correction, staged or preconditioning strategies can be considered for selected high-risk patients. Preoperative halo-gravity traction is the best-supported option: a systematic review and meta-analysis (7 studies, 189 patients) reported that traction reduced deformity magnitude (mean 27.28° in the coronal plane and 22.02° in the sagittal plane) and improved pulmonary function (mean increases of 6.62% in percentage of forced vital capacity and 8.24% in percentage of forced expiratory volume in 1 second, all $p < 0.001$).[60] A single-center series of 45 patients with severe rigid scoliosis/kyphoscoliosis reported an average 7.0% increase in predicted forced vital capacity during traction and noted that very rigid curves may not correct substantially without additional release, supporting a selective staged approach (traction ± release/definitive correction).[61] Collectively, integrating preoperative traction/staging, continuous mechanical stabilization with controlled rod exchange, and tension-aware correction (including selective shortening) under continuous IONM may help achieve adequate correction while reducing neurological and systemic complications.[53,54]

5. Limitations

This study also has limitations. First, differences in sample sizes among the included studies and the lack of standardized clinical outcome measures (for example, the mixed use of visual analog scale [VAS], oswestry disability index [ODI], Scoliosis Research Society-22 questionnaire [SRS-22]) may have introduced data heterogeneity and could reduce the reliability of comparisons of surgical prognosis and complication rates. Second, the focus on correction of local angular deformity rather than on global sagittal and coronal balance undoubtedly limits the assessment of the overall therapeutic effect of pVCR. Third, because of limitations in the original data, patients were grouped only by deformity etiology without accounting for individual differences (for example, age, comorbidities, or variations in surgical technique), which may have obscured subgroup-specific trends in complications. Fourth, relatively short follow-up in some studies may have prevented detection of certain long-term complications, potentially leading to an underestimation of complication rates. Fifth, it was not possible to quantify the impact of different surgical teams' technical skill and experience on outcomes; given the technical difficulty of pVCR, team experience is likely critical to surgical results and prognosis. Sixth, the definitions of temporary versus permanent complications (particularly neurological deficits) were not standardized across the included studies, and several studies did not clearly report the criteria used for this classification. This inconsistency, together with mixed patient populations, likely contributed to substantial heterogeneity and limits the interpretability of pooled estimates for permanent and nonpermanent complication rates. Seventh, although we conducted a comprehensive search of major bibliographic databases, we did not systematically search grey literature (for example, conference abstracts, dissertations, or preprints), which may have increased the risk of publication bias and could have led to the omission of relevant unpublished data.

6. Conclusion

Based on this systematic review of 26 eligible studies, the current low-certainty evidence suggests that pVCR can be an effective surgical approach for managing severe spinal deformities, contributing to notable radiographic correction across various etiologies. While narrative

observations suggest that pVCR might offer potential advantages over anterior or combined anterior–posterior approaches—such as utilizing a single incision and potentially reducing operative duration or bleeding risks—these comparative statements are drawn from highly heterogeneous, observational data and must be interpreted with caution.

Future research is necessary to better quantify complication risks and assess the long-term efficacy of pVCR across diverse patient populations. This requires large-scale, multicenter prospective studies using standardized complication definitions, global spinal alignment metrics, and patient-reported outcomes. In the interim, although iterative advancements in surgical techniques and intraoperative monitoring may help mitigate risks, the overall complication burden of pVCR remains substantial. Therefore, until stronger, high-quality comparative evidence becomes available, pVCR should be applied selectively, based on comprehensive, individualized patient evaluations. Its implementation demands profound expertise from experienced surgical teams capable of safely balancing the goals of complex deformity correction with the significant risks of perioperative complications.

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Ethical statement

Not applicable.

Conflicts of interest

Cao Yang, Associate Editor-in-Chief of *Spine Research*, was not involved in the peer-review processor in any editorial decisions regarding this manuscript. The peer-review process was handled independently by other qualified editors to minimize potential bias. The other authors have no conflicts of interest to disclose.

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Data availability statement

Data included in article/supplemental material/referenced in article.

Author contributions

LX, HF, MC, and CY contributed to the conceptualization and methodology. LX and KZ performed the formal analysis. All authors were involved in resources and data curation. LX, HF, MC, XZ, and KZ drafted the original manuscript. HF, LX, and CY reviewed and edited the manuscript. LX, CY, and XZ supervised the study.

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