

Comparison of Overall Complication Rates in VCR-Based vs Non-VCR-Based Corrective Techniques in Severe Rigid Kyphoscoliosis Patients: A Systematic Review and Meta-Analysis

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Abstract

Study Design: Systematic review and meta-analysis.

Objective: Compilation of complication outcomes data from the surgical management of severe rigid kyphoscoliosis patients using VCR-based vs non-VCR-based corrective maneuvers is lacking. This meta-analysis aimed to compare complication outcomes between those classified osteotomy approaches.

Methods: Thorough literature review and meta-analysis were conducted between January 2000 and September 2021. The selection criteria were studies: i) reporting major curve Cobb angle of $\geq 80^\circ$ and flexibility of $<25\%$ or 30% ; ii) comparing VCR or $\geq$ Type V Schwab osteotomy defined as VCR-based vs [non-VCR-based] techniques, (any osteotomy or technique other than VCR); iii) published in English with ≥ 10 patients; iv) reporting complication rates; and v) having minimum of 2-year follow-up.

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Odds ratios (ORs) and 95% confidence intervals (CIs) were calculated. Significance level was set at ($P < .05$).

Results: Of the 174 patients included, 52.30% ($n = 91$) and 47.70% ($n = 83$) were VCR-based and non-VCR-based, respectively. The incidence of dural tears/nerve injuries/significant intraoperative-neuromonitoring changes was significantly higher; [OR = 6.78, CI = (1.75 to 26.17), I² = 0%, ($P = .006$)] in the VCR-based group than the non-VCR-based group. The 'overall surgical and medical' complication rate was significantly higher in the VCR-based group, [OR = 1.94, CI = (1.02 to 3.67), I² = 31%, ($P = .04$)].

Conclusion: Both VCR-based and non-VCR-based surgical techniques for management of severe rigid scoliosis and kyphoscoliosis patients pose comparable overall surgical complication rates, while a significantly higher perioperative neurological complication incidence was associated with VCR-based technique compared to the non-VCR-based techniques. The VCR-based technique was associated with 6.78 times higher incidence of neurological complications compared to non-VCR-based techniques.

Keywords

severe rigid scoliosis, kyphoscoliosis, vertebral column resection surgery, neurological complications, perioperative complications, comparative studies

Introduction

In the spine literature, severe rigid scoliosis or kyphoscoliosis has been reportedly defined as severe spinal curves in the coronal plane with Cobb angle of $\geq 80^\circ$ and angular curves in the sagittal plane of more than 50° and flexibility of $<25\%$ or 30% .¹⁻⁷ Etiologies of these severe deformities include congenital, syndromic, neuromuscular, as well as idiopathic, the latter of which less commonly become severe.⁸⁻¹¹ Regardless of the etiology of scoliosis or kyphoscoliosis, patients clinically presenting with acutely progressive or symptomatically severe rigid spinal deformities require timely surgical intervention to halt progression, achieve correction, restore global spinal alignment, and improve back pain or neurological deterioration, as well as cosmetic and quality of life outcomes.¹²⁻¹⁵

Currently employed surgical approaches include posterior-only, antero-posterior, with various osteotomies or three-column osteotomies including resection of at least one full vertebra with its rostral and caudal intervertebral discs, otherwise known as vertebral column resection (VCR), while surgery may be staged or non-staged.^{10,16-19} During surgical planning and decision-making, surgical techniques for management of severe rigid scoliosis or kyphoscoliosis can be complex and clinically challenging. Most often, due to the rigidity and severity of these curves, aggressive surgical corrective cantilever maneuvers and osteotomy techniques are embraced to allow adequate and maximum correction of the scoliotic or kyphoscoliotic curves.^{6,20-26} The advancement of technology, anesthetic care, intraoperative neuromonitoring, and instrumentation systems have allowed for the advancement of complex osteotomy techniques in treatment of severe rigid spinal deformities.²⁷⁻²⁹

Vertebral column resection typically permits as much as 45° to 60° of curve correction usually at the apex of the major curve.³⁰⁻³² Even though VCR-based technique acknowledges maximum correction amongst the osteotomy phenotypes, it is

associated with a higher incidence of complications including neurological deterioration.³³⁻³⁵ There are non-VCR-based techniques for achieving satisfactory corrective and patient outcomes in severe rigid spinal deformity, including posterior column osteotomies (PCOs), also known as such as Smith-Petersen osteotomy (SPO) and Ponte osteotomy (PO), or pedicle subtraction osteotomy (PSO), bone-disc-bone osteotomy (BDBO), anterior release, internal distraction, among others.^{36,37} To assess the safety outcomes of VCR-based vs non-VCR-based surgical techniques, it is critical to identify comparative studies that compared complication outcomes of VCR-based and non-VCR-based surgical techniques in the surgical treatment of patients with severe rigid scoliosis or kyphoscoliosis.

Comparative studies discussing the perioperative complication outcomes of VCR-based vs non-VCR-based techniques for correction of severe rigid scoliosis or kyphoscoliosis have not been reported in the spine literature to date in a systematic comparison of the entirety of the literature. It is of pertinent importance that we identify and weigh the risks associated with these techniques and determine where the risk trade-offs may be unacceptable especially in cases in which lower complexity procedures resulting in reliable corrections are reported to be equivalent between either of these techniques when appropriately selected.³⁸

Our review team, therefore, aimed to conduct a systematic review and meta-analysis of perioperative complication rates reported in comparative studies of VCR-based and non-VCR-based surgical techniques in the management of severe rigid scoliosis or kyphoscoliosis.

Methodology

Search Strategy and Study Selection Criteria

This systematic review was performed and reported in observance to the Preferred Reporting Items for Systematic Reviews

and Meta-Analyses (PRISMA) Statement in addition to the current recommendations of the Cochrane Collaboration.³⁹⁻⁴¹

Search Strategy

Relevant comparative studies comparing vertebral column resection, [VCR-based] and other corrective maneuvering or osteotomy, [non-VCR-based] techniques were acquired through a comprehensive electronic literature search from 5 electronic databases: PubMed, EMBASE, MEDLINE, Google Scholar, and Cochrane library databases from January 1st, 2000, until October 31st, 2021. The search terminology included “severe rigid scoliosis”, “severe rigid kyphoscoliosis”, “surgical management”, “vertebral column resection”, or “comparative study”.

Selection of Studies

Studies were selected by 4 independent authors who screened the titles and abstracts of the retrieved studies for their eligibility of inclusion and excluded any unrelated studies. In the case that eligibility could not be assessed from the title or abstract alone, the entire text of the respective study was retrieved and further reviewed for relevancy and eligibility on the premise of the study aim to ensure the best-formulated synthesis of data and information. Furthermore, the references of the studies were searched for other potential studies. If an article was deemed relevant, the full text was obtained for review and for potential consideration of inclusion through further screening.

Inclusion and Exclusion Criteria

Studies were considered qualified if they had fulfilled the following inclusion criteria: (1) patients diagnosed with severe rigid scoliosis or kyphoscoliosis defined with average Cobb angle of $\geq 80^\circ$ and flexibility of $<25\%$ or 30% , and with or without sagittal plane deformities; (2) patients primarily managed with only VCR or $\geq$ Type V Schwab osteotomy (defined as VCR), [VCR-based] vs any osteotomy types or corrective techniques other than VCR, [non-VCR-based]; (3) studies published English that included at least 10 patients; (4) studies reporting perioperative complication rate outcomes; (5) studies with 2-year minimum follow-up period. Conversely, articles were mutually culled and excluded if they met any of the following exclusion criteria: (1) if article compared between any 2 VCR-based techniques; (2) if article included modified VCR-based technique; (3) if article included etiology of global-only kyphosis or infection-induced kyphosis in the [VCR-based] vs [non-VCR-based] compared patient cohorts, and (4) if the etiology in each of the compared group was degenerative. We did not apply a criterion for screening the level of evidence and whether a study was randomized controlled trial, prospective or retrospective in nature with the sole aim to maximize the patient pool. Discussions between

the 4 main authors resolved any disagreements about inclusion and exclusion criteria.

Outcome Measures

The main outcome measures were generally reported perioperative medical and surgical complication rate outcomes between [VCR-based] vs [non-VCR-based] techniques for the surgical treatment of rigid scoliosis or kyphoscoliosis. These perioperative complications included complication of cardio-pulmonary complications; dural tear/nerve injury/significant intraoperative neuro-monitoring changes; surgical site infections/wound complications; implant/cage-related issues; postoperative intensive care unit (ICU) admission; re-operation within 2-years following corrective surgery; and overall surgical complication outcomes reported across the 4 included studies.

Data Extraction

Data extraction was conducted in adherence to a custom data extraction table created for documenting all relevant details from the included articles. The 4 main authors were tasked to independently extract data from each article, including the first author's name, publication year, patient demographics, severe rigid scoliosis or kyphoscoliosis diagnosis, baseline characteristics, type of surgical intervention, thus comparing VCR or $\geq$ Type V Schwab osteotomy defined as [VCR-based] vs [non-VCR-based] techniques, (any osteotomy or technique other than VCR), follow-up period, results on perioperative complication outcome of interest, and the quality assessment score of each included study. Our initial goal was to screen for Level I or II comparative studies inclusion, but if no published reports were found, we intended to further screen for Level III comparative studies inclusion as a strategy to maximize the captured patient pool due to the rarity of reported comparative studies outcomes on corrective techniques in severe rigid scoliosis or kyphoscoliosis patients.

Quality and Risk of Bias Assessment

The 4 main authors independently evaluated the quality and risk of bias of each included comparative study in accordance with the Methodological Index for Non-Randomized Studies (MINORS) tool, and the McGuinness and Higgins' Risk-of-bias VISualization (robvis) tool, which includes the following criteria: bias resulting from the randomization process, bias due to deviations from intended interventions, bias due to missing outcome data, bias in outcome measurement, and bias in selecting the reported result.⁴²

In each included comparative article, every criterion was classified as among low risk, with some concerns, or high risk of bias. The quality of each study was classified into 1 of 3 levels: “low risk of bias” (all items were classified as low risk), “some concerns of risk of bias” (at least 1 item was classified

with some concerns), or “high risk of bias” (at least 1 item was classified as high risk). Any conflicts pertaining to the risk of bias assessment were solved by discussion between the 4 main authors.

Statistical Analyses

For each study, outcomes included in our analysis were effective number. Data were reported as odds ratios, (ORs) and 95% confidence intervals (CIs). Statistical heterogeneity was evaluated by the I^2 test. If the I^2 value was $>25\%$, the random effects model was employed. Conversely, if the I^2 value was $<25\%$, the fixed-effects model was used. Any potential explanations for heterogeneity were initially investigated by a random-effects model of the meta-analysis. The meta-analysis significance level was set at ($\alpha = .05$). *Stata version 17.0* (Stata Corp LLC, College Station, TX) and *RevMan version 5.4.1* statistical software packages were utilized for all meta-analyses.

Results

Search Results and Study Selection

The literature search resulted in 1216 publications related to the treatment of severe rigid scoliosis. Out of them, 455 articles were identified as eligible for inclusion, then 432 were excluded due to duplicate records, nonconformity, or non-comparative nature of studies, leaving 23 full-text studies that were further screened for satisfying the specific qualitative criteria for this systematic review and meta-analysis. A total of 4 comparative studies were finally observed.^{6,43-45} All four (4) comparative studies were included in the qualitative analysis according to PRISMA guidelines (Figure 1). They were comparative studies that related [VCR-based] vs [non-VCR-based] techniques for the surgical treatment of patients with severe rigid scoliosis or kyphoscoliosis. These 4 studies also assessed the perioperative medical and surgical complication incidence of treated patients between [VCR-based] and [non-VCR-based] approaches.

Characteristics of Included Studies

Among all 4 comparative studies, we observed a total of 174 patients. A total of 91 patients underwent VCR-based technique (female: $n = 57$, male: $n = 34$) and a total of 83 patients underwent non-VCR-based techniques (female: $n = 59$, male: $n = 24$) with a minimum follow-up period of 2 years. All the included studies treated scoliosis or kyphoscoliosis patients with the VCR-based technique as the conventional group and those with the non-VCR-based technique as the exploratory group to assess the complication rates and safety of the procedure when deformity correction is purportedly assumed equal between the 2 osteotomy techniques. Chunpeng et al.⁴³ compared 43 (VCR-based, $n = 26$ vs non-VCR-based, $n = 17$)

patients with severe rigid scoliosis or kyphoscoliosis; Hengwei et al.⁴⁴ compared 45 (VCR-based, $n = 31$ vs non-VCR-based, $n = 14$) patients with severe and stiff thoracic kyphoscoliosis; Zhou et al.⁴⁵ compared 48 (VCR-based, $n = 22$ vs non-VCR-based, $n = 26$) patients with severe rigid scoliosis; and Zhang et al.⁶ compared 38 (VCR-based, $n = 12$ vs non-VCR-based, $n = 26$) patients with severe rigid scoliosis. The comparisons between the included studies were as follows: anteroposterior VCR [APVCR] vs anterior release plus posterior spinal fusion [AR+PSF] in Chunpeng et al.'s⁴³ study; non-extended VCR [Non-Ext_VCR] vs extended pedicle subtraction osteotomy [Ext_PSO] in Hengwei et al.'s⁴⁴ study; anteroposterior VCR [APVCR] vs anteroposterior spinal fusion [APSF] in Zhou et al.'s study⁴⁵; and posterior-only VCR [PVCR] vs multiple asymmetrical Ponte osteotomy [MAPO] in Zhang et al.'s⁶ study. The incidence of gender, averages of age, preoperative curve Cobb angles, operative time, estimated blood loss and final follow-up curve Cobb angles of each study comparison were illustrated in (Table 1). Generally reported perioperative medical and surgical complication incidences between the 2 surgical techniques were then meta-analyzed.

Methodologic Quality and Risk of Bias Estimation

All the 4 comparative cohorts of the included studies had patients who were allocated to either VCR-based or non-VCR-based surgical techniques. Comparative studies were considered of high quality, and the risk of bias across and within all the included studies was determined to be low based on Cochrane collaboration, ‘McGuinness and Higgins’ Risk-of-bias VISualization (robvis),⁴² (Figure 2) and MINORS assessment tools (Table 2), respectively.⁴⁶

Medical Complications

There were 2 generally reported perioperative medical complications, which were a) cardiopulmonary complications and b) non-routine surgical intensive care unit (SICU) admission. All four (4) comparative studies^{6,43-45} reported on cardiopulmonary complications, but only 2; Chunpeng et al.⁴³ and Zhou et al.⁴⁵ reported on non-routine SICU admission outcomes, (Figure 3).

Cardiopulmonary Complications. There was $n = 10/91$ (11.0%) vs $n = 5/83$ (6.0%) incidence of cardiopulmonary events observed between the VCR-based vs non-VCR-based patient groups, respectively, from all four (4) studies,^{6,43-45} and no statistical significance was observed, [OR = 1.38, CI= (.43 to 4.50), $I^2 = 0\%$, ($P = .59$)], (Figure 3).

Surgical Intensive Care Unit Admissions. There was $n = 2/48$ (4.2%) vs $n = 1/43$ (2.3%) incidence of non-routine SICU admissions observed between the VCR-based and non-VCR-based patient groups, respectively, from two (2) studies:

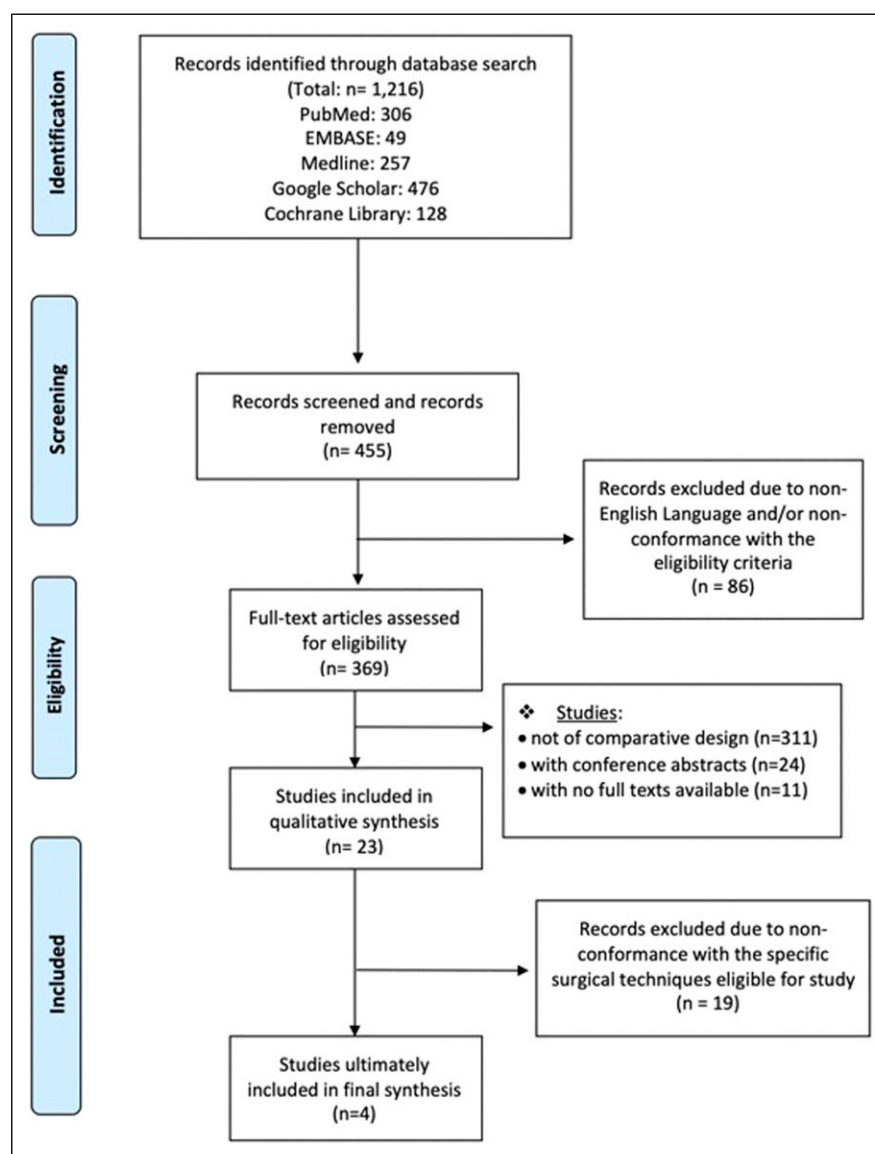


Figure 1. PRISMA Flow diagram of the search strategy and the yield of eligible studies.

Chunpeng et al⁴³ and Zhou et al,⁴⁵ and no statistical significance was observed, [OR = 1.51, CI= (.18 to 12.77), $I^2 = 0\%$, ($P = .71$)], (Figure 3).

Surgical Complications

There were 4 generally reported perioperative surgical complications, which were: 1) dural tears/nerve injury/significant intraoperative neuromonitoring changes; 2) surgical site infections/wound complications; 3) implants/cage-related issue; and 4) re-operation within 2 years of index corrective surgery.

Dural Tears/Nerve Injury/Significant Intraoperative Neuromonitoring Changes. There was $n = 28/43$ (65.12%) vs $n = 7/40$

(17.5%) incidence of durotomy, nerve injury, or significant neuromonitoring changes observed from two (2) studies: Hengwei et al⁴⁴ and Zhang et al⁶ between the VCR-based vs non-VCR-based patient groups, respectively, and was statistically significant, [OR = 6.78, CI = (1.75 to 26.17), $I^2 = 0\%$, ($P = .006$)], (Fig. 3).

Surgical Site Infections/Wound Complications. There was $n = 2/69$ (2.9%) vs $n = 4/57$ (7.0%) incidence of surgical site infections/wound complications respectively observed between the VCR-based vs non-VCR-based patient groups from three (3) studies: Chunpeng et al⁴³ reported 2 patients with wound complications in their non-VCR-based cohort, Hengwei et al⁴⁴ reported 1 patient with deep surgical site infection (SSI) in their non-VCR-based patient cohort, and

Table 1. Characteristic Features of Included Comparative Studies.

Study No.	Author, Year	Type of Clinical Study	Sample Size		Female, (%)	Average Age, (years)		Average Preoperative Curve Cobb (°)		Operative Time, (min)		Blood Loss Volume, (mL)		Average Final Follow-Up Curve Cobb (°)	
			VCR/Non-VCR	VCR		VCR/Non-VCR	VCR	VCR/Non-VCR	VCR	VCR/Non-VCR	VCR	VCR/Non-VCR	VCR	VCR/Non-VCR	VCR
1	Chunpeng et al, 2014	Retrospective comparative studies	26/17		65/53	15.10/17.70		101.3 ± 10.3/104.8 ± 12.27		552.20/590.60		1712.50/1319.10		32.9 ± 12.7/26.5 ± 12.0	
2	Hengwei et al, 2017	Retrospective comparative studies	31/14		42/64	22.00/21.90		127.7 ± --/133.9 ± --		543.70/517.10		2855.90/2789.60		60.8 ± --/60.6 ± --	
3	Zhou et al, 2018	Retrospective comparative studies	22/26		77/77	17.20/17.70		101.4 ± 11.7/103.3 ± 8.1		539.50/499.40		1895.50/1546.20		35.1 ± 12.7/50.3 ± 9.1	
4	Zhang et al, 2019	Retrospective comparative studies	12/26		83/81	27.92/26.65		108.91 ± 16.56/98.52 ± 16.50		326.67/285.58		1333.33/842.31		56.98 ± 189.36/44.87 ± 18.22	

Abbreviations: VCR: vertebral column resection

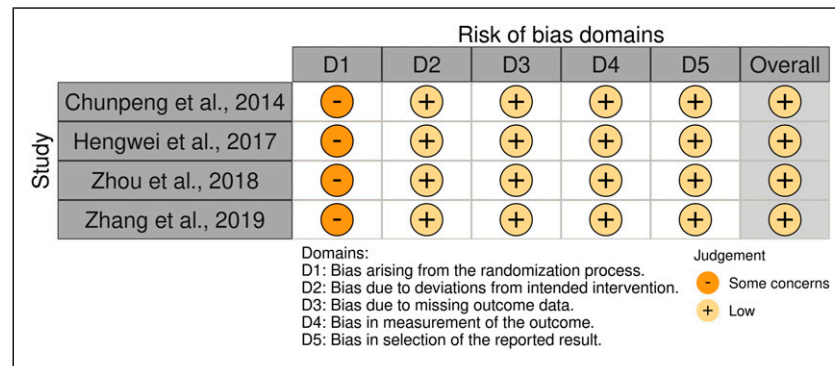


Figure 2. Risk of bias assessment.

Table 2. Individual MINORS Scoring Outcomes of Included Studies.

MINORS Criteria	Author and Year			
	Chunpeng et al, 2014	Hengwei et al, 2017	Zhou et al, 2018	Zhang et al, 2019
Clearly stated aim	2	2	2	2
Inclusion of consecutive patients	2	2	2	2
Prospective data collection	2	2	2	2
Endpoints appropriate to study aim	2	2	2	2
Unbiased assessment of study endpoint	0	0	0	0
Follow-up period appropriate to study aim	2	2	2	2
<5% lost to follow-up	0	0	0	0
Prospective calculation of study size	0	0	0	0
Adequate control group	2	2	2	2
Contemporary groups	2	2	2	2
Baseline equivalence of groups	1	1	2	2
Adequate statistical analyses	2	2	2	2
Total score	17/24	17/24	18/24	18/24

Zhang et al⁶ reported 2 patients with deep SSI in the VCR-based cohort and 1 patient with superficial SSI in the non-VCR-based patient cohort, while no statistical significance was observed, [OR = .52, CI= (.04 to 6.70), I^2 = 0%, (P = .61)], (Fig. 3).

Implants/Cage-Related Issues. There was $n = 4/48$ (8.3%) vs $n = 4/43$ (9.3%) incidence of implants/constructs-related issues observed between the VCR-based and non-VCR-based patient groups, respectively, from two (2) studies: Chunpeng et al⁴³ reported one incidence of pedicle screw mispositioning in 1 patient in the VCR-based group. Zhou et al⁴⁵ reported 1 incidence of pedicle screw mispositioning in 1 patient and titanium mesh cage mispositioning in 2 patients in the VCR-based group while 4 patients were detected with a screw breach each on postoperative postero-anterior radiographs, and no statistical significance was observed, [OR = 1.03, CI= (.24 to 4.39), I^2 = 0%, (P = .97)], (Fig. 3).

Re-Operation Within 2 years of Following Corrective Surgery. There was $n = 5/43$ (11.6%) vs $n = 0/40$ (.0%) incidence of re-operation within 2 years of primary corrective surgery observed from two (2) studies: Hengwei et al⁴⁴ reported 1 case of re-operation within 2 years due to rod breakage in the VCR-based group and Zhang et al⁶ reported 4 total cases of re-operation the VCR-based patient groups (2 patients for deep incisional debridement, 1 patient for internal fixation adjustment, and 1 patient for thoracoplasty, and no statistical significance was observed between VCR-based vs non-VCR-based group, [OR = 6.75, CI= (.36 to 126.01), I^2 = 42%, (P = .20)], (Fig. 3).

Overall Surgical Complications

All four (4) comparative studies^{6,43-45} reported complication outcomes between the VCR-based vs non-VCR-based patient groups. Overall, $n = 43/91$ (47.3%) vs $n = 21/83$ (25.3%) surgical complication incidence was observed

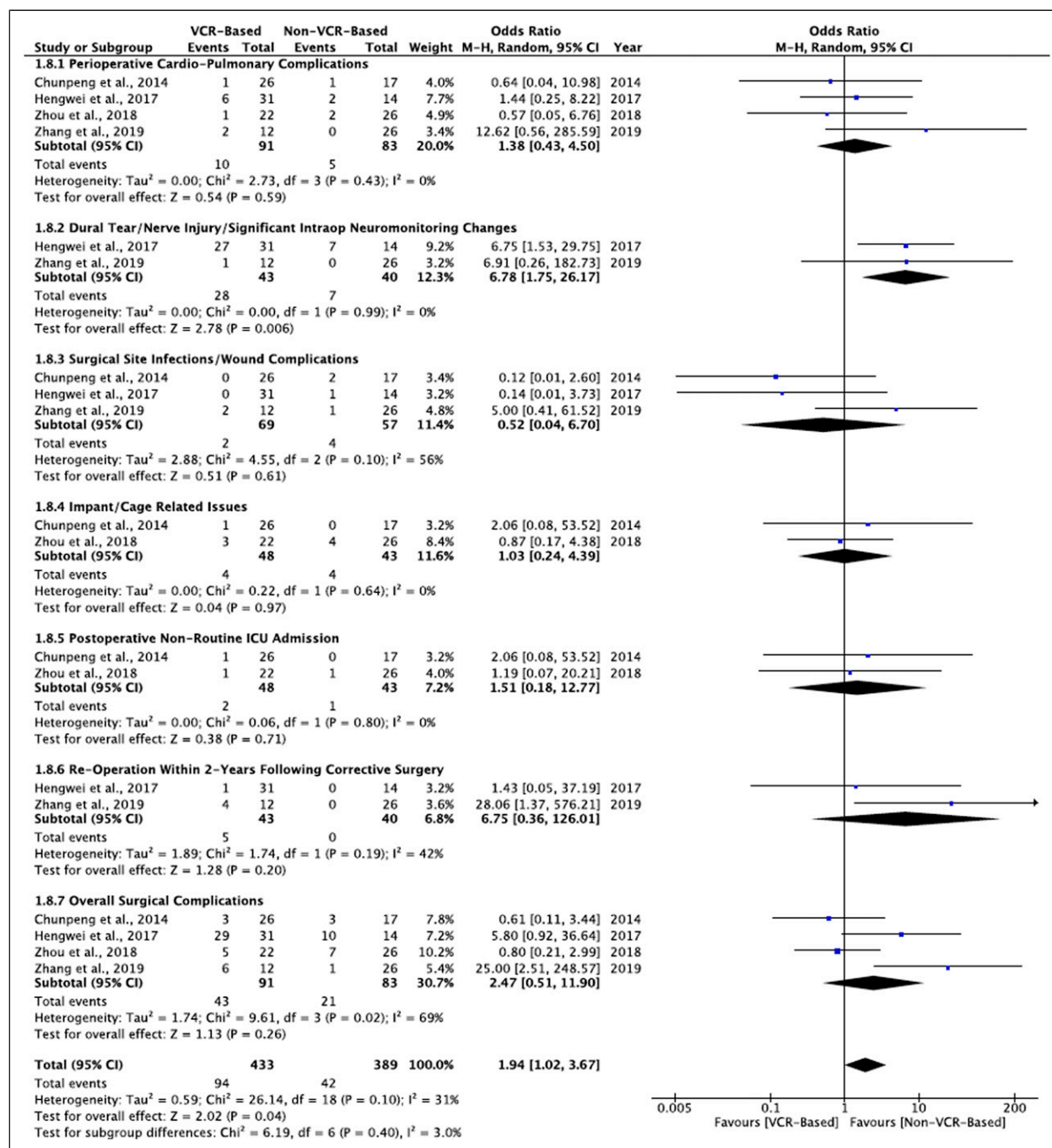


Figure 3. Generally reported postoperative complications.

between the 2 techniques, but no statistical significance was observed, [OR = 2.47, CI= (.51 to 11.90), $I^2 = 69\%$, ($P = .26$)], however, we found significant difference between VCR-based and non-VCR-based techniques for 'overall combined medical and surgical' complication incidence, [OR = 1.94, CI= (1.02 to 3.67), $I^2 = 31\%$, ($P = .04$)], (Fig. 3).

Risk of Bias Across Studies

The risk of bias outcomes between the included studies were as follows: the comparisons of anteroposterior VCR [APVCR] vs anterior release plus posterior spinal fusion [AR+PSF] in Chunpeng et al.'s⁴³ study demonstrated a MINOR score of 17/24; of non-extended VCR [Non-Ext_VCR] vs extended pedicle subtraction osteotomy [Ext_PSO] in

Hengwei et al.'s⁴⁴ study demonstrated a MINOR score of 17/24; of anteroposterior VCR [APVCR] vs anteroposterior spinal fusion [APSF] in Zhou et al.'s study⁴⁵ demonstrated a MINOR score of 18/24; and of posterior-only VCR [PVCR] vs multiple asymmetrical Ponte osteotomy [MAPO] in Zhang et al.'s⁶ study demonstrated a MINOR score of 18/24, (Table 2).

Discussion

The authors of this meta-review study sought to compare perioperative complication incidence in comparative studies of VCR-based vs non-VCR-based techniques utilized in surgical treatment of severe rigid scoliosis or kyphoscoliosis. In cases of severe rigid spinal deformities, VCR-based surgery is an effective corrective technique; nevertheless, it is also associated with a noteworthy risk of major perioperative morbidity and neurological complications.^{34,35} This practically means that VCR-based spinal surgery is a technically demanding skill that even the most experienced surgeons find challenging. It is seldom utilized in most spinal deformity patients and should be utilized only when other safer and less technically demanding osteotomy techniques are rather considered not plausible. Our study, the first meta-analysis of comparative studies assessing complications in VCR-vs non-VCR-based procedures for spinal deformity, points to the higher rates of neurological injury associated with VCR.

Surgical maneuvers other than VCR for correcting severe rigid spinal deformities to accomplish spinal alignment, curve correction, and satisfactory patient outcomes do exist.^{6,36,37,47,48} Due to the very high risk of perioperative and neurologic complications associated with VCR-based technique,^{34,35} outcomes of aggregated studies on the premise of VCR-based vs non-VCR-based surgery would serve as a basis of reference in assessing safety during surgical technique and decision making and to enhance value-based outcomes of severe deformity patients. In 2007, Lenke et al.⁴⁹ reported a 20.0% complication rate in a study of 43 adult and pediatric PVCR patients. Also in 2013, Lenke et al.¹⁵ reviewed a large VCR-based multicenter case series of 147 spinal deformity patients that comprised of circumferential VCRs (including staged and non-staged procedures) and the authors observed 68 intraoperative events and 43 postoperative events with an overall 58.5% complication incidence.

In other published studies, Ayvaz et al.⁵⁰ reviewed 18 adolescent congenital kyphoscoliosis patients with curves ranging from 31° to 116°, in which the surgeons applied posterior all-pedicle screw instrumentation combined with multiple posterior column (SRS-grade-2) osteotomies and concave rib resections. No neurological complications were observed in their cohort of non-VCR-based procedures. They observed perioperative complication incidence of only 11.1% (1 pneumothorax and 1 pneumonia) and

achieved satisfactory corrective outcomes. More recently, Sacramento-Dominiguez et al.,⁵¹ reviewed 72 patients with severe rigid curves >100°, who were safely treated with multiple posterior column osteotomies (MPCOs) and posterior fusion following halo-gravity traction while reporting an overall perioperative complication rate of 22.2%. They also attained satisfactory results in their patient cohort. These complication rates were low and consistently comparable with the overall complication rate of 25.3% observed in the non-VCR-based cohort. It is becoming more evident that utilization of milder osteotomy grades, such as PCOs, in the management of severe rigid spinal curves when feasible results in lower complication rates. Nevertheless, the ultimate decision of choice of osteotomy technique is solely reliant on the nature of the pathology, the surgeon's armamentarium in terms of training and experience, and comfort with the osteotomy technique, and other clinical and patient factors that dictate perioperative clinical outcomes.

In this current study, we observed a significant overall complication incidence of 47.3% associated with the VCR-based technique compared to a 25.3% overall complication incidence in non-VCR-based patient group. Albeit comparison between the 2 techniques was statistically insignificant regarding the overall surgical complication rates, an overview of each perioperative event stemming from the VCR-based surgeries compared against that of the non-VCR-based surgeries in this study is certain to demonstrate higher overall perioperative complication rates in the VCR-based surgeries in these severe rigid scoliosis or kyphoscoliosis patients. Clearly, we observed significantly higher rates of incidence of 'dural tears/nerve injury/significant neuromonitoring changes' in the VCR-based patient group and those patients were 6.78 times at risk higher than the non-VCR-based patient group. These findings corroborate evidence from cohort studies surrounding neurological complication rates following VCR-based procedures.^{34,52,53} In the service of minimizing complications while optimizing outcomes and advancing value-based care in healthcare delivery, it is of great importance that safety is prioritized during surgical decision-making, especially when non-VCR-based options may be efficacious in managing these severe rigid spinal deformity patients. The premise of clinical safety and value-based outcomes in surgical approaches to spinal deformity correction is rapidly becoming a global trend and concern in spine practice.³⁸

Strengths and Limitations

To our knowledge, this is the first ever reported study on comparison of complication incidence between VCR-based and non-VCR-based techniques in the surgical treatment of severe rigid scoliosis or kyphoscoliosis. Although the value of approaches not involving VCR are suggested by this review, this study is also undoubtedly limited by the lack of included prospective or randomized controlled studies and hence may

reflect underreported complication incidence. Further, the total pool of patients within each comparative group or subset is small with a limited number of studies to choose from (4). Another limitation is that one of the included studies, thus, Hengwei et al⁴⁴ compared patient outcomes that included pedicle subtraction osteotomy (PSO) or a Schwab-SRS grade 3-4 in the non-VCR group vs VCR (grade 5-6). Essentially this is a comparison of greater and lesser complexity three-column osteotomies (3COs).³⁶ This may cloud the delineation between complications associated with lesser grade PCOs and true VCR (grade 5-6 osteotomies). We believe in order to decisively inform the spinal deformity practice; it would be beneficial to study the complication-reported outcomes of each type of 3CO [grades 3-6] to weigh the risks associated with extended or non-extended application of the type of 3CO. This study niche is under feasibility evaluation by our study team.

Conclusion

The evidence generated from this study indicates that the overall surgical complication rate surrounding non-VCR-based surgical techniques appears comparable to rates observed in VCR-based patient groups for the treatment of severe rigid spinal deformities. In this current meta-review, we ultimately observed that severe rigid scoliosis or kyphoscoliosis patients managed by VCR-based surgical techniques are 6.78 times significantly at higher risk of incidence of 'dural tears/nerve injury/significant neuromonitoring changes' compared to patients managed with non-VCR-based surgical techniques. The outcome of this study conclusively warrants the spine practice to employ lesser grades of corrective osteotomies and perhaps in combination with halo-gravity traction (HGT) in these severe rigid scoliosis or kyphoscoliosis patients when feasible, especially when comparable and satisfactory major curve corrective outcomes can be achieved.

Authors' Contributions

N.V. and Y.H. conceptualized and designed the study; N.V., N.N.A., K.M., M.K.M., W.H.H., W.C.C., M.B.M., Z.Y.Y., N.R.S., Y.P.Z., A.X.P., K.G., and X.Y.C., acquired data; N.V., N.N.A., M.K.M., K.G., N.R.S., Y.P.Z., K.M., and Y.H. analyzed and interpreted data; N.V. and B.L. drafted the article; N.N.A., K.M., M.K.M., Y.P.Z., A.X.P., S.S.K., A.A., B.L., Y.H., and N.V. critically revised the article; all authors reviewed submitted version of the article; A.A., B.L., Y.H., and N.V. approved the final version of the article; N.V., K.M., N.N.A., K.G., M.B.M., W.C.C., W.H.H., Z.Y.Y. and N.R.S. provided technical and material support. Y.H. and N.V. spearheaded the study and Y.H., A.A., and B.L. supervised the entire study.

Declaration of Conflicting Interests

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References

1. Suk SI, Chung ER, Lee SM, et al. Posterior vertebral column resection in fixed lumbosacral deformity. *Spine*. 2005;30: E703-E710. doi:10.1097/01.brs.0000188190.90034.be.
2. Bullmann V, Halm HF, Schulte T, et al. Combined anterior and posterior instrumentation in severe and rigid idiopathic scoliosis. *Eur Spine J*. 2006;15:440-448. doi:10.1007/s00586-005-1016-1.
3. Di Silvestre M, Bakaloudis G, Lolli F, et al. Posterior fusion only for thoracic adolescent idiopathic scoliosis of more than 80°: pedicle screws vs hybrid instrumentation. *Eur Spine J*. 2008;17: 1336-1349. doi:10.1007/s00586-008-0731-9.
4. Kulkarni AG, Shah SP. Intraoperative skull-femoral (skeletal) traction in surgical correction of severe scoliosis (>80°) in adult neglected scoliosis. *Spine*. 2013;38:659-664. doi:10.1097/BRS.0b013e318277c874.
5. Kandwal P, Vijayaraghavan GP, Nagaraja UB, et al. Severe rigid scoliosis: Review of management strategies and role of spinal osteotomies. *Asian Spine J*. 2017;11:494-503. doi:10.4184/asj.2017.11.3.494.
6. Zhang Y, Tao L, Hai Y, et al. One-stage posterior multiple-level asymmetrical Ponte osteotomies vs single-level posterior vertebral column resection for severe and rigid adult idiopathic scoliosis: A minimum 2-year follow-up comparative study. *Spine*. 2019;44: e1196-e1205. doi:10.1097/brs.00000000000003101.
7. Librianto D, Saputra R, Djaja YP, et al. Preoperative skull tongs-femoral traction vs cotrel longitudinal traction for rigid and severe scoliosis: Cohort study. *Ann Med Surg (Lond)*. 2021;63: 102177. doi:10.1016/j.amsu.2021.02.023.
8. Altaf F, Gibson A, Dannawi Z, et al. Adolescent idiopathic scoliosis. *BMJ*. 2013;346:f2508. doi:10.1136/bmj.f2508.
9. Shakil H, Iqbal ZA, Al-Ghadir AH. Scoliosis: Review of types of curves, etiological theories and conservative treatment. *J Back Musculoskelet Rehabil*. 2014;27:111-115. doi:10.3233/bmr-130438.
10. Burnei G, Gavrilu S, Vlad C, et al. Congenital scoliosis: An up-to-date. *J Med Life*. 2015;8:388-397.
11. Karol LA. The natural history of early-onset scoliosis. *J Pediatr Orthop*. 2019;39:S38-s43. doi:10.1097/bpo.0000000000001351.
12. Alanazi MH, Parent EC, Dennett E. Effect of stabilization exercise on back pain, disability and quality of life in adults with scoliosis: A systematic review. *Eur J Phys Rehabil Med*. 2018; 54:647-653. doi:10.23736/s1973-9087.17.05062-6.

13. Kuznia AL, Hernandez AK, Lee LU. Adolescent idiopathic scoliosis: Common questions and answers. *Am Fam Physician*. 2020;101:19-23.
14. Zhong R, Hu Z, Zhao D, et al. Shoulder imbalance treated with scapuloplasty surgery in scoliosis patients: A clinical retrospective study. *J Orthop Surg Res*. 2020;15:149. doi:10.1186/s13018-020-01676-9.
15. Lenke LG, Newton PO, Sucato DJ, et al. Complications after 147 consecutive vertebral column resections for severe pediatric spinal deformity: A multicenter analysis. *Spine*. 2013;38:119-132. doi:10.1097/BRS.0b013e318269fab1.
16. Pateder DB, Kebaish KM, Cascio BM, et al. Posterior only versus combined anterior and posterior approaches to lumbar scoliosis in adults: A radiographic analysis. *Spine*. 2007;32:1551-1554. doi:10.1097/BRS.0b013e318067dc0e.
17. Shamji MF, Isaacs RE. Anterior-only approaches to scoliosis. *Neurosurgery*. 2008;63:139-148. doi:10.1227/01.Neu.0000325486.92090.DA.
18. Helenius I. Anterior surgery for adolescent idiopathic scoliosis. *J Child Orthop*. 2013;7:63-68. doi:10.1007/s11832-012-0467-2.
19. Mirzashahi B, Moosavi M, Rostami M. Outcome of posterior-only approach for severe rigid scoliosis: A retrospective report. *Int J Spine Surg*. 2020;14:232-238. doi:10.14444/7032.
20. Mermer MJ, Boachie-Adjei O, Rawlins BA, et al. Comprehensive analysis of cantilever, translational, and modular corrective techniques in adults with scoliosis treated with surgery to the sacropelvis. *J Spinal Disord Tech*. 2006;19:513-522. doi:10.1097/01.bsd.0000211214.36189.27.
21. Suh SW, Modi HN, Yang J, et al. Posterior multilevel vertebral osteotomy for correction of severe and rigid neuromuscular scoliosis: A preliminary study. *Spine*. 2009;34:1315-1320. doi:10.1097/BRS.0b013e3181a028bc.
22. Chang KW, Cheng CW, Chen HC, et al. Correction hinge in the compromised cord for severe and rigid angular kyphosis with neurologic deficits. *Spine*. 2009;34:1040-1045. doi:10.1097/BRS.0b013e31819c105f.
23. Richter A, Quante M, Macherei A, et al. [Modified primary stable ventral derotation spondylodesis with Halm-Zielke instrumentation for the treatment of idiopathic scoliosis]. *Oper Orthop Traumatol*. 2010;22:164-176. doi:10.1007/s00064-010-9040-7.
24. Jones KE, Hunt MA, Martin CT, et al. Controlled pedicle subtraction osteotomy site closure using flexible hinge-powered operating table. *Oper Neurosurg (Hagerstown)*. 2019;17:e214-e218. doi:10.1093/ons/opy397.
25. Libranto D, Aprilya D. Cantilever method for severe kyphotic deformity correction in spondylitis tuberculosis: A technical note and literature review. *Ann Med Surg (Lond)*. 2021;69:102764. doi:10.1016/j.amsu.2021.102764.
26. Girod PP, Kögl N, Molliqaj G, et al. Flexing a standard hinge-powered operating table for lumbosacral three-column osteotomy (3-CO) site closure in 84 consecutive patients. *Neurosurg Rev*. 2022;45:517-524. doi:10.1007/s10143-021-01559-5.
27. Cheng JC, Castelein RM, Chu WC, et al. Adolescent idiopathic scoliosis. *Nat Rev Dis Primers*. 2015;1:15030. doi:10.1038/nrdp.2015.30.
28. Overley SC, Cho SK, Mehta AI, et al. Navigation and robotics in spinal surgery: where are we now? *Neurosurgery*. 2017;80:S86-s99. doi:10.1093/neuros/nyw077.
29. Ali A, Fontanari V, Fontana M, et al. Spinal deformities and advancement in corrective orthoses. *Bioengineering (Basel)*. 2020;8. doi:10.3390/bioengineering8010002.
30. Han C, Hai Y, Yin P, et al. In vivo deformation of the spine canal before and after surgical corrections of severe and rigid kyphoscoliosis. *J Orthop Translat*. 2020;23:1-7. doi:10.1016/j.jot.2020.03.009.
31. Teixeira da Silva LE, de Barros AG, de Azevedo GB. Management of severe and rigid idiopathic scoliosis. *Eur J Orthop Surg Traumatol*. 2015;25(Suppl 1):S7-S12. doi:10.1007/s00590-015-1650-1.
32. Zhang Z, Hui H, Liu T, et al. Two-staged correction of severe congenital scoliosis associated with intraspinal abnormalities. *Clin Spine Surg*. 2016;29:E401-E405. doi:10.1097/bsd.000000000000175.
33. Kelly MP, Lenke LG, Shaffrey CI, et al. Evaluation of complications and neurological deficits with three-column spine reconstructions for complex spinal deformity: A retrospective Scolio-RISK-1 study. *Neurosurg Focus*. 2014;36:E17. doi:10.3171/2014.2.FOCUS1419.
34. Papadopoulos EC, Boachie-Adjei O, Hess WF, et al. Early outcomes and complications of posterior vertebral column resection. *Spine J*. 2015;15:983-991. doi:10.1016/j.spinee.2013.03.023.
35. Iyer S, Nemani VM, Kim HJ. A review of complications and outcomes following vertebral column resection in adults. *Asian Spine J*. 2016;10:601-609. doi:10.4184/asj.2016.10.3.601.
36. Schwab F, Blondel B, Chay E, et al. The comprehensive anatomical spinal osteotomy classification. *Neurosurgery*. 2014;74:112-120. discussion 120. doi:10.1227/NEU.0000000000000182o.
37. Kose KC, Bozduman O, Yenigul AE, et al. Spinal osteotomies: Indications, limits and pitfalls. *EFORT Open Rev*. 2017;2:73-82. doi:10.1302/2058-5241.2.160069.
38. Yilgor C, Kindan P, Yucekul A, et al. Osteotomies for the treatment of adult spinal deformities: A critical analysis review. *JBJS Rev*. 2022;10. doi:10.2106/jbjs.Rvw.21.00226.
39. Liberati A, Altman DG, Tetzlaff J, et al. The PRISMA statement for reporting systematic reviews and meta-analyses of studies that evaluate health care interventions: Explanation and elaboration. *PLoS Med*. 2009;6:e1000100. doi:10.1371/journal.pmed.1000100.
40. Higgins JP, Altman DG, Gotzsche PC, et al. The cochrane collaboration's tool for assessing risk of bias in randomised trials. *BMJ*. 2011;343:d5928. doi:10.1136/bmj.d5928.
41. Cumpston M, Li T, Page MJ, et al. Updated guidance for trusted systematic reviews: A new edition of the cochrane handbook for systematic reviews of interventions. *Cochrane Database Syst Rev*. 2019;10:ED000142. doi:10.1002/14651858.ED000142.

42. McGuinness LA, Higgins JPT. Risk-of-bias VISualization (robvis): An R package and Shiny web app for visualizing risk-of-bias assessments. *Res Synth Methods*. 2021;12:55-61. doi:10.1002/jrsm.1411.
43. Ren C, Liu L, Song Y, et al. Comparison of anterior and posterior vertebral column resection versus anterior release with posterior internal distraction for severe and rigid scoliosis. *Eur Spine J*. 2014;23:1237-1243. doi:10.1007/s00586-014-3270-6.
44. Hengwei F, Xueshi L, Zifang H, et al. Is vertebral column resection necessary in correcting severe and rigid thoracic kyphoscoliosis? A single-institution surgical experience. *World Neurosurg*. 2018;116:e1-e8. doi:10.1016/j.wneu.2017.10.002.
45. Zhou C, Liu L, Song Y, et al. Comparison of anterior and posterior vertebral column resection versus anterior and posterior spinal fusion for severe and rigid scoliosis. *Spine J*. 2018;18:948-953. doi:10.1016/j.spinee.2017.10.001.
46. Kim SY, Park JE, Lee YJ, et al. Testing a tool for assessing the risk of bias for nonrandomized studies showed moderate reliability and promising validity. *J Clin Epidemiol*. 2013;66:408-414. doi:10.1016/j.jclinepi.2012.09.016.
47. Smith-Petersen MN LC, Aufranc OE. Osteotomy of the spine for correction of flexion deformity in rheumatoid arthritis. *Clin Orthop Relat Res*. 1969;66:6-9.
48. Ponte A, Orlando G, Siccardi GL. The true ponte osteotomy: by the one who developed it. *Spine Deform*. 2018;6:2-11. doi:10.1016/j.jspd.2017.06.006.
49. Lenke LG, O'Leary PT, Bridwell KH, et al. Posterior vertebral column resection for severe pediatric deformity: Minimum 2-year follow-up of thirty-five consecutive patients. *Spine*. 2009;34:2213-2221. doi:10.1097/BRS.0b013e3181b53cba.
50. Ayvaz M, Olgun ZD, Demirkiran HG, et al. Posterior all-pedicle screw instrumentation combined with multiple chevron and concave rib osteotomies in the treatment of adolescent congenital kyphoscoliosis. *Spine J*. 2014;14:11-19. doi:10.1016/j.spinee.2012.10.016.
51. Sacramento-Domínguez C, Cynthia N, Yankey KP, et al. One-stage multiple posterior column osteotomies and fusion and pre-op halo-gravity traction may result in a comparative and safer correction of complex spine deformity than vertebral column resection. *Spine Deform*. 2021;9:977-985. doi:10.1007/s43390-021-00289-4.
52. Ozturk C, Alanay A, Ganiyusufoglu K, et al. Short-term X-ray results of posterior vertebral column resection in severe congenital kyphosis, scoliosis, and kyphoscoliosis. *Spine*. 2012;37:1054-1057. doi:10.1097/BRS.0b013e31823b4142.
53. Kim SS, Cho BC, Kim JH, et al. Complications of posterior vertebral resection for spinal deformity. *Asian Spine J*. 2012;6:257-265. doi:10.4184/asj.2012.6.4.257.