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Safety and efficacy of posterior vertebral column resection in complex pediatric deformities

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Abstract

Background: Vertebral column resection (VCR) is a well-known technique used for correction of complex spinal deformities. VCR could be done through a posterior only approach (Pvcr), or a combined anteroposterior approach, with almost comparable results. Early studies of Pvcr have reported high rates of complications, while subsequent studies have reported a reasonable complication rate. In this study, the authors represent and evaluate the initial results of using the Pvcr technique to correct complex pediatric deformities.

Objective: To evaluate the safety and efficacy of performing Pvcr to correct complex pediatric deformities.

Methods: Retrospective cohort study of data was collected from the database of pediatric deformity patients who were operated for correction of their deformities using posterior instrumentation and Pvcr at a single institution from 2015 to 2019.

Results: Twenty-one pediatric patients with a mean age 15.2 ± 3.5 years were enrolled in this study. The mean follow-up period was 26.3 ± 3.1 months. The mean Cobb angle has been decreased significantly from 82.9 ± 23.9 degrees to 28.8 ± 14.2 immediately after correction (correction rate 66.9 ± 10.8%, $p < 0.001$) with slight increase to 30.2 ± 14.9 after 24 months of follow-up (correction loss 4.3 ± 3.1%). The mean kyphotic angle has decreased significantly from 74.1 ± 15.9 to 25.4 ± 4.5 immediately after correction (correction rate 65.4 ± 2.9%, $p < 0.001$) with slight increase to 26.7 ± 5.2 after 24 months of follow-up (correction loss 4.8 ± 3.5%). The mean estimated blood loss was 2816.7 ± 1441.5 ml. The mean operative time was 339 ± 84.3 min. Self-image domain (part of SRS-22 questionnaire) has significantly improved from a mean preoperative of 2.3 ± 0.5 to a mean postoperative of 3.9 ± 0.4 after 24 months of correction ($p < 0.001$). As regards complications, chest tubes were inserted in 17 cases (81%), one case (4.8%) had suffered from deep wound infection and temporary respiratory failure, while 3 cases (14.3%) had neurological deficits.

Conclusion: Posterior vertebral column resection is considered a highly effective release procedure that aids in the correction of almost any type of complex pediatric deformities with a correction rate reaching 66.9 ± 10.8%. However, Pvcr is a challenging procedure with high estimated blood loss and risk of neurological deficits, so it must be done only by experienced spine surgeons in the presence of good anesthesia and neuromonitoring teams.

Keywords: Vertebral column resection, Deformities, Neuromonitoring

Introduction

Vertebral column resection is a three-column osteotomy procedure used for correction of severe and rigid deformities. It allows for shortening the length of the vertebral column and aids in the process of translation needed to correct and balance the spine in multiple

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planes [1]. The procedure of combined posterior instrumentation and spinal shortening for deformity correction was first described by Luque in 1983, which is then modified later in 1987, by Bradford who described a modification of Luque technique through anterior column resection in rigid curves [2, 3]. Although the outcome of combined anterior–posterior technique was satisfactory [3, 4], but vertebral column resection through a posterior only approach (Pvcr) has been initialized and popularized by many authors in recent years. The development of Pvcr technique has aimed at decreasing the operative time, technical challenges, and morbidity associated with the traditional anterior–posterior vertebral column resection. Early studies regarding Pvcr technique have reported high morbidity rates, while following studies have reported a much less complication rate [5, 6].

The main aim of this study is to assess the safety and efficacy of performing Pvcr to correct complex pediatric deformities. The results of this study could be added to the recent reports regarding the Pvcr technique in order to help spine surgeons choosing the best approach for deformity correction.

Patients and methods

The authors conducted a retrospective cohort study of data collected from the database of pediatric deformity patients who were operated for correction of their deformities using posterior instrumentation and Pvcr at a single institution from 2015 to 2019 (Table 1). Investigations for this study were done at Alexandria University hospitals.

The aim was to evaluate the safety and efficacy of performing Pvcr to correct complex pediatric deformities. A total of 21 pediatric patients with complex deformities were enrolled in the study. The deformities were assessed by whole spine plain X-rays (anteroposterior, lateral, bending views) and CT scan. Neural tube abnormalities were assessed by whole spine MRI including the craniocervical junction. All the patients were operated for correction of their spine deformities using the posterior approach. All the involved patients were neurologically intact before correction.

Inclusion criteria:

1. Age: pediatric age up to 19 years.
2. Deformity: Rigid non flexible deformities (bending films showed less than 50% correction of the major curve).
3. Patients with follow-up period ≥ 2 years.

Adult deformities, flexible curves, and patients losses with less than 2 years of follow-up were excluded from the study.

There were 14 female cases and 7 male cases. The mean age was 15.2 ± 3.5 years with a range from 5 to 19 years. There were 7 cases of adolescent idiopathic scoliosis, 6 cases of congenital kyphoscoliosis, 4 cases of congenital scoliosis (associated with fully segmented hemivertebra), 3 cases of neuromuscular scoliosis, and one case of post-laminectomy kyphoscoliosis. All patients were operated by senior spine surgeons. Pvcr at the apex and correction using pedicle screws were done in all cases. Postoperative radiological evaluation was done by PXR and/or CT scans. Evaluation of the patients was done via clinical and radiological follow-up every 6 months, for at least 24 months.

Outcome measures

Self-image domain (part of SRS-22 questionnaire) was used to assess the clinical outcome. The self-image domain is one out of four main domains included in the SRS-22 questionnaire; a patient outcome questionnaire (available in different languages without permissions or licensing at the official SRS website https://www.srs.org/professionals/online-education-and-resources/patient-outcomequestionnaires). This domain describes the mean score of 5 questions that best describe the patients' appearance and feelings regard their back condition. The best score is 5 while the least is one. The authors used the Arabic version of Scoliosis Research Society-22 (SRS-22r) Questionnaire. Radiological assessment was obtained via plain X-rays AP and lateral views of the whole spine including the pelvis and/or CT scanning for more detailed evaluation. Safety of the procedure was assessed by analysis of Pvcr complications.

Data were fed to the computer and analyzed using IBM SPSS software package version 20.0. (Armonk, NY: IBM Corp). The Kolmogorov–Smirnov test was used to verify the normality of distribution of variables. Comparisons between groups for categorical variables were assessed using chi-square test (Fisher's exact or Monte Carlo correction). Student t-test was used to compare two groups for normally distributed quantitative variables, while ANOVA with repeated measures was used to compare between more than two periods for normally distributed quantitative variables and followed by post hoc Test (Bonferroni adjusted) for pairwise comparisons. Mann–Whitney test was used to compare between two groups for not normally distributed quantitative variables and Wilcoxon signed ranks test was assessed for comparison between different two periods for not normally distributed quantitative variables. While Friedman test was used to compare between more than two periods and

Table 1 The epidemiological and clinical characteristics of 21 pediatric deformity patients

	Age	Sex	Pathology	Preop Cobb/Kyph*	Postop Cobb/Kyph*	2 y post op Cobb/Kyph*	Bl. loss*	Apex	M*	Op. time*	Self-image domain (1–5)	FU*	Complication
1	10	M	Congenital scoliosis	45	9	10	400	D12–L1	No	200	3.2–4.2	24	No
2	5	M	Postlaminectomy kyphoscoliosis	74/93	9/29	10/31	500	D5–6	No	240	1.6–4.2	24	Chest tube
3	12	M	Congenital scoliosis	33	9	9	600	L2–3	No	200	3.2–4.4	30	No
4	14	F	Congenital scoliosis	67	7	7	350	L1–2	No	200	2.8–3.8	24	No
5	17	M	Congenital kyphoscoliosis	70/66	28/23	30/24	4000	D8	No	390	3–3.6	30	Unilateral flail foot (Grade D ASIA scale), Chest tube
6	14	F	Congenital kyphoscoliosis	140/100	62/33	65/35	4200	D7	No	440	1.6–3	26	UMN Paraplegia (Grade A ASIA scale), Chest tube
7	18	M	Congenital kyphoscoliosis	80/73	31/27	33/29	3200	D11	No	400	1.8–4.4	36	Chest tube
8	11	F	Congenital kyphoscoliosis	88/60	40/23	40/25	4000	D2	No	410	2–3	24	UMN Paraplegia (Grade A ASIA scale), Chest tube
9	18	F	AIS	97	29	30	3200	D11	Yes	350	3–4	24	Chest tube
10	18	F	AIS	70	27	28	3100	D9	Yes	360	2.8–3.8	25	Chest tube
11	17	F	Neuromuscular scoliosis (tethered cord)	90	28	30	3000	D6	Yes	300	2.2–3.8	26	Chest tube
12	16	F	AIS	105	35	37	3000	D9	Yes	360	2.2–4	25	Chest tube
13	17	F	Congenital kyphoscoliosis	94/64	44/20	45/20	3500	D7	Yes	400	2–4	28	Chest tube
14	16	M	Congenital kyphoscoliosis	74/63	27/23	28/23	3600	D6	Yes	390	1.8–4.4	31	Chest tube
15	15	F	Neuromuscular scoliosis (Chiari type 1)	112	40	43	3700	D7	Yes	380	2–4.4	26	Chest tube
16	17	F	AIS	90	32	34	2900	D9	Yes	375	2.4–4.2	25	Chest tube
17	19	M	AIS	96	38	40	3000	D8	Yes	425	2.2–3.8	24	Chest tube
18	19	F	Congenital scoliosis	49	7	7	700	D4–5	Yes	180	3–4	26	No
19	14	F	Neuromuscular scoliosis (congenital myopathy)	101	35	37	5500	D12	Yes	430	1.6–3.8	25	Respiratory, infectious, Chest tube
20	19	F	AIS	76	28	29	3200	D7–8	Yes	350	2–4.2	24	Chest tube
21	14	F	AIS	90	40	43	3500	D8	Yes	340	2–3.8	26	Chest tube

*Preop Cobb/Kyph, preoperative Cobb/Kyphosis; postop Cobb/Kyph, postoperative Cobb/Kyphosis; 2y postop Cobb/Kyph, 2 years postoperative Cobb/Kyphosis; Bl.loss, mean estimated blood loss; M, neuromonitoring; Op.time, mean operative time in minutes; FU, follow-up in months followed by post hoc test (Dunn's) for pairwise comparisons, significance of the obtained results was judged at the 5% level.

An approval from the research ethics committee of the Faculty of Medicine, Alexandria University [serial number 0305059], was obtained in 18/2/2021.

Surgical technique

Anesthesia: General
Positioning: Prone
Incision: Midline back incision.
Technique: After skin incision and sub-periosteal dissection of the paraspinal muscles, the bony vertebral column was adequately exposed and pedicle screws were inserted in all the desired levels excluding the apex of the curve using the free hand technique aided by fluoroscopy. Smith-Peterson osteotomies were done in all the levels before insertion of the screws to facilitate instrumentation (via pedicle palpation from inside the spinal canal) and to augment fusion (via obtaining an adequate amount of autologous bone graft and removing any soft tissues overlying the bony surface of the instrumented levels). Smith-Peterson osteotomy was done by removing the ligaments (interspinous ligament, supraspinous ligament, and the ligamentum flavum) and opening the intervertebral foramina bilaterally by removing the inferior facets and part of the superior facets. Wound cleaning was done by saline and gentamycin to wash out the excess debris, and then the procedure of posterior vertebral column resection (Pvcr) was started. The main aim of Pvcr was to remove the apex of the major curve in order to correct the existing deformity safely with minimal stress on the existing hardware. The approach was started by removing one or two rib heads at the level of the apex on the convex side. This was followed by coagulation and sharp dissection of the neurovascular bundle. Sharp dissection helps to avoid indirect traction on cord by traction on the segmental roots. Then, blunt dissection of the parietal pleura/or the psoas muscle (in case of lumbar apex) from the lateral side of the body of the apex was done to reach the anterior longitudinal ligament. Blunt dissection along the lateral side of the body down to the anterior longitudinal ligament helps to spare the aorta and the other great vessels lying ventral to the anterior longitudinal ligament. In cases associated with congenital hemivertebra, the dissection is easier and usually we do not have to reach the anterior longitudinal ligament, as ventral end of the hemivertebra may end before reaching the ligament. After dissection was complete, a temporary rod was inserted on the concave side that usually include 3 levels above and 3 levels below the apex (at least 2 levels above and below the apex must be included). This was followed by wide laminectomy at the level of the apex, besides one level above and one level below the apex, to expose the dural sac and the segmental roots on both sides. One or two segmental dorsal roots on the convex side were sacrificed (in case of lumbar apex, preservation of lumbar roots was done). This was followed by removal of the pedicle and the body from the convex side by a combination of drilling, osteotomes and rongeurs. The intervertebral disks above and below the site of the osteotomy were also removed after removal most of the apical body. The process of osteotomy was continued as much as possible from lateral to medial while preserving a thin shell just beneath the dural sac to protect the neural structures from any manipulation. This part adjacent to the neural tissue is the last part to be removed when performing the Pvcr procedure, and better to remove it using the high speed drill. At this stage, another temporary rod was inserted on the working side with the removal of the contralateral temporary rod followed by the removal of the pedicle and the remaining part of the body from the concave side in the same fashion till the cord became circumferentially exposed. A permanent rod was inserted on the convex side with gradual controlled compression at the region of the apex till the gap between two bony surfaces at the osteotomy site was closed. Closure of the gap was done from below to above and from above to below, in an equal alternating manner, for a better alignment result. Replacement of the temporary rod on the concave side by another permanent one was done with slight distraction at the osteotomy side. Correction of the deformity was done by a combination of compression at the convex side to close the osteotomy gap, slight distraction at the concave side, and cantilever techniques. Convex-side compression is safer than concave side distraction, to minimize the risk of cord stretch injury. The process of osteotomy gap closure should be done in a gradual controlled manner, guided by neuromonitoring. Keeping the mean arterial blood pressure at the highest normal readings during the process of osteotomy, osteotomy gap closure, and deformity correction is crucial. Anterior fusion by autologous bone graft at the region of the apex was done if there was any remaining gap, in addition to posterior fusion along the whole construct. Copious lavage by saline and gentamycin antibiotic was done followed by hemostasis and closure in layers. Patients were admitted to postoperative ICU for at least 5 days to optimize the general medical and hemodynamic conditions.
Note: In cases with neuromuscular scoliosis, correction was done after surgical management of the primary neurological conditions if applicable (cord untethering in tethered cord, foramen magnum decompression in Chiari type 1).

Results

Follow-up period

The mean follow-up was 26.3 months ± 3.1.

Radiological data

Most cases had a dorsal apex (17 cases), 2 cases had a lumbar apex, and two cases had a dorsolumbar apex. The mean Cobb angle has decreased significantly from 82.9 ± 23.9 degrees to 28.8 ± 14.2 immediately after correction (correction rate 66.9 ± 10.8%, $p < 0.001$) with slight increase to 30.2 ± 14.9 after 24 ms of follow-up (correction loss 4.3 ± 3.1%). The mean kyphotic angle has decreased significantly from 74.1 ± 15.9 to 25.4 ± 4.5 immediately after correction (correction rate 65.4 ± 2.9%, $p < 0.001$) with slight increase to 26.7 ± 5.2 after 24 months of follow-up (correction loss 4.8 ± 3.5%).

Perioperative data

The mean estimated blood loss was 2816.7 ± 1441.5 ml. The mean operative time was 339 ± 84.3 min. Neurophysiological monitoring was used in 13 out of 21 cases included in the study. Self-image domain (part of SRS-22 questionnaire) has improved from a mean preoperative of 2.3 ± 0.5 to a mean postoperative of 3.9 ± 0.4 after 24 months of correction (Tables 2, 3).

Complications (Table 4)

Chest tube insertion was encountered in 17 cases out of 21 cases included in our study (81%). Pleural disruption during Pvcr on the convex side of the curve was a universal finding in our series, and all chest tubes were inserted intraoperatively, via a cardiothoracic surgeon. Chest tubes were inserted in all cases with dorsal apex down to D12 except in cases with congenital hemivertebrae where plural dissection was much easier. This may be due to the fact that we could not deflate the lung during the process of Pvcr as we do not use the double-lumen endotracheal tube.

Infectious and medical complications

One case (4.8%) suffered neuromuscular scoliosis had deep wound infection that necessitated wound debridement. Meanwhile, the same case had suffered from temporary respiratory failure that needed artificial ventilation for one month till complete respiratory cure.

Neurological complications

Three cases with congenital kyphoscoliosis (14.3%) had experienced permanent neurological deficits. Neurological deficits were assessed using ASIA Impairment Scale [7]. There were 2 cases of complete cord injury (Grade A ASIA Impairment Scale) and one case of incomplete cord injury (Grade D ASIA Impairment Scale).

Table 2 Statistical analysis of the epidemiological and clinical characteristics of 21 pediatric deformity patients

	Total ($n = 21$)
Sex	
Male	7 (33.3%)
Female	14 (66.7%)
Age (years)	
Mean ± SD.	15.2 ± 3.5
Median (Min.–Max.)	16 (5–19)
Pathology	
Congenital scoliosis	4 (19%)
Congenital kyphoscoliosis	6 (28.6%)
AIS	7 (33.3%)
Neuromuscular scoliosis	3 (14.3%)
Postlaminectomy kyphoscoliosis	1 (4.8%)
COBB	
Preoperative	
Mean ± SD.	82.9 ± 23.9
Median (Min.–Max.)	88 (33–140)
Postoperative	
Mean ± SD.	28.8 ± 14.2
Median (Min.–Max.)	29 (7–62)
2 years postoperative	
Mean ± SD.	30.2 ± 14.9
Median (Min.–Max.)	30 (7–65)
Estimated blood loss	
Mean ± SD.	2816.7 ± 1441.5
Median (Min.–Max.)	3200 (350–5500)
Monitoring	
No	8 (38.1%)
Yes	13 (61.9%)
Operative time (min)	
Mean ± SD.	339 ± 84.3
Median (Min.–Max.)	360 (180–440)
Follow-up (months)	
Mean ± SD.	26.3 ± 3.1
Median (Min.–Max.)	25 (24–36)
Self-image domain	
Preoperative	
Mean ± SD.	2.3 ± 0.5
Median (Min.–Max.)	2.2 (1.6–3.2)
Postoperative	
Mean ± SD.	3.9 ± 0.4
Median (Min.–Max.)	4 (3–4.4)
t_0 (p)	**11.892 (< 0.001*)**

p value is bold because it is the only test of the significance in the table

t_0: paired *t*-test

p: *p* value for comparing between preoperative and postoperative self-image domain

*Statistically significant at $p \leq 0.05$

Table 3 Comparison between preoperative and postoperative angles (Cobb and Kyphosis)

	Preoperative	Postoperative		Test of Sig.
		Immediate	After 2 years	
COBB (21 cases)				
Mean ± SD.	82.9 ± 23.9	28.8 ± 14.2	30.2 ± 14.9	Fr = 39.975*
Median (Min.–Max.)	88 (33–140)	29 (7–62)	30 (7–65)	
Significance between periods	$p_1 < 0.001^*$, $p_2 < 0.001^*$			
Correction rate and correction loss %	**66.9 ± 10.8** **4.3 ± 3.1**			
KYPHOSIS (7cases)				
Mean ± SD.	74.1 ± 15.9	25.4 ± 4.5	26.7 ± 5.2	$F = 118.964^*$
Median (Min.–Max.)	66 (60–100)	23 (20–33)	25 (20–35)	
Significance between periods	$p_1 < 0.001^*$, $p_2 < 0.001^*$			
Correction rate and correction loss %	**65.4 ± 2.9** **4.8 ± 3.5**			

Correction rate and loss are bold because as they are the most important information in the table

F: F test (ANOVA) with repeated measures, significance between periods was done using post hoc test (adjusted Bonferroni)

Fr: Friedman test, Sig. bet. periods was done using post hoc test (Dunn's)

p_1: p value for comparing between preoperative and immediate postoperative period

p_2: p value for comparing between preoperative and 2-year postoperative period

*Statistically significant at $p \leq 0.05$

Table 4 Distribution of the studied cases according to complication ($n = 21$)

	No. (%)
Complication	
No	4 (19%)
Chest tube	17 (81%)
Neurological	3 (14.3%)
Respiratory	1 (4.8%)
Infectious	1 (4.8%)

Discussion

Correction of complex deformities by VCR was first described by MacLennan in 1922 [8]. The combined anterior–posterior approach was the standard approach to perform VCR. The combined approaches have the advantages of anterior release and the ability to correct the coronal deformity significantly [9–11]. However, the antero-posterior approaches have major disadvantages as regards the increased operative time and the morbidity associated with the thoracotomy procedure, in addition to the technical difficulty to reach the apex in severe and focal kyphotic deformities [9–12].

Since 2002, the procedure of posterior vertebral column resection has been initialized by Suk, but with a relatively high mean blood loss and high complication rate [5]. Since 2009, Lenke has popularized the procedure with a more reasonable complication rate and less mean blood loss [6]. However, this procedure is still technically demanding and still has significant complications [6, 13]. The main aim of this study is to assess the safety and efficacy of performing Pvcr to correct complex pediatric deformities.

This study included 21 pediatric deformity cases, 14 females and 7 males, with a mean age of 15.2 ± 3.5 years. Different pathologies were included in the study; adolescent idiopathic scoliosis (AIS) (7 cases), congenital kyphoscoliosis (6 cases), congenital scoliosis associated with fully segmented hemivertebrae (4 cases), neuromuscular scoliosis (3 cases), and one case of postlaminectomy kyphoscoliosis.

The current series of pediatric patients was operated by senior spine surgeons to correct their deformities. The process of Pvcr was performed mostly in the thoracic region, with only 2 cases of congenital scoliosis associated with congenital hemivertebra having a lumbar apex (Fig. 1). The mean follow-up period was 26.3 ± 3.1 months.

Radiological correction

A significant correction rate (66.9 ± 10.8%, $p < 0.001$), from a mean Cobb angle of 82.9 ± 23.9 degrees to 28.8 ± 14.2 degrees, was obtained within the first 6 months of follow-up. Meanwhile, The mean kyphotic angle has decreased significantly from 74.1 ± 15.9 to 25.4 ± 4.5 after 3 months of follow-up (correction rate 65.4 ± 2.9%, $p < 0.001$). A minor correction loss

Fig. 1 CT scan with 3 D reconstruction showing a case of congenital scoliosis in 14-year-old female patient. A congenital hemivertebra is found at the level of L1–L2 (lumbar apex)

(4.3 ± 3.1% for Cobb angle, 4.8 ± 3.5 for Kyphotic angle) was observed after 24 months of follow-up.

This significant correction rate (65.4 ± 2.9% correction rate) is comparable with the published correction rates (between 51 and 60% with dorsal VCR) for the various subtypes of deformities [6, 14].

This powerful correction capability is due to the circumferential removal of one or more vertebrae. This allows for the necessary translation and shortening needed to correct complex rigid deformities (Fig. 2).

Self-satisfaction

The self-image domain (elicited from SRS-22) had increased significantly from a mean preoperative of 2.3 ± 0.5 points to a mean 2 years postoperative of 3.9 ± 0.4 points (Paired t-test = 11.892, $p < 0.001$). The significant increase in this domain among the operated patients deflects the increased self-image after deformity correction.

The radiological and clinical outcome of Pvcr as evidenced by the significant Cobb angle correction and the increased self-image score among the operated patients could prove the efficacy of performing such a technique in difficult and complex pediatric deformities (Fig. 3).

Blood loss

Pvcr is a challenging technique with a relatively high mean estimated blood loss and high morbidity rate. The mean estimated blood loss in procedures associated with VCR in the literature varies from 820 to 3071 ml [14–16].

In our cohort, the mean estimated blood loss was 2816.7 ± 1441.5 ml, and although being a relatively high mean, but is well within the range found in the literature. The reduction in intraoperative blood loss during the process of VCR continues to be a prime challenge for the anesthesia and surgical team. Some authors advocate the use of hypotensive anesthesia to decrease the mean estimated blood loss, although this may add a significant neurological risk if the spinal cord perfusion is affected [1, 5, 17]. We avoided the use of hypotensive anesthesia during the process of osteotomy and correction to guard against cord hypoperfusion, while using it during exposure and screws insertion. We used tranexamic acid during the operation as it may help to control the blood loss during the procedure of VCR [14, 16]

Complications

The published complication rates associated with Pvcr range from 25 to 64% [5, 6, 13, 16]. The complication rate in this cohort is 81%. This relatively high complication rate is due to chest tube insertion in most cases included in the study (17 out of 21 cases).

The complications associated with Pvcr include the following:

1. Medical complications: The rate of medical complications associated with Pvcr ranges from 12 to 15% [5, 18]. Medical complications may include cardiac problems, respiratory problems, or seizures. In our cohort, temporary respiratory failure that needed artificial ventilation was encountered in one patient (4.8%) with neuromuscular scoliosis due to congenital myopathy. Immediate postoperative CT chest in that patient showed complete lung atelectasis on one side. Chest tube was also inserted during the operation in the contralateral chest cavity due to pleural disruption during Pvcr. Complete weaning from mechanical ventilation was achieved after inflation of both lungs within 1 month. The suboptimal respiratory function in neuromuscular scoliosis patients is a risk factor that could lead to postoperative respiratory problems [19].
2. Chest tube insertion: Although uncommonly reported in the literature [1, 5, 13], chest tube was inserted in all cases in our series, except in cases with congenital scoliosis associated with hemivertebra (81%). Nevertheless, no sequelae were reported as all chest tubes were removed within the first 2 weeks of

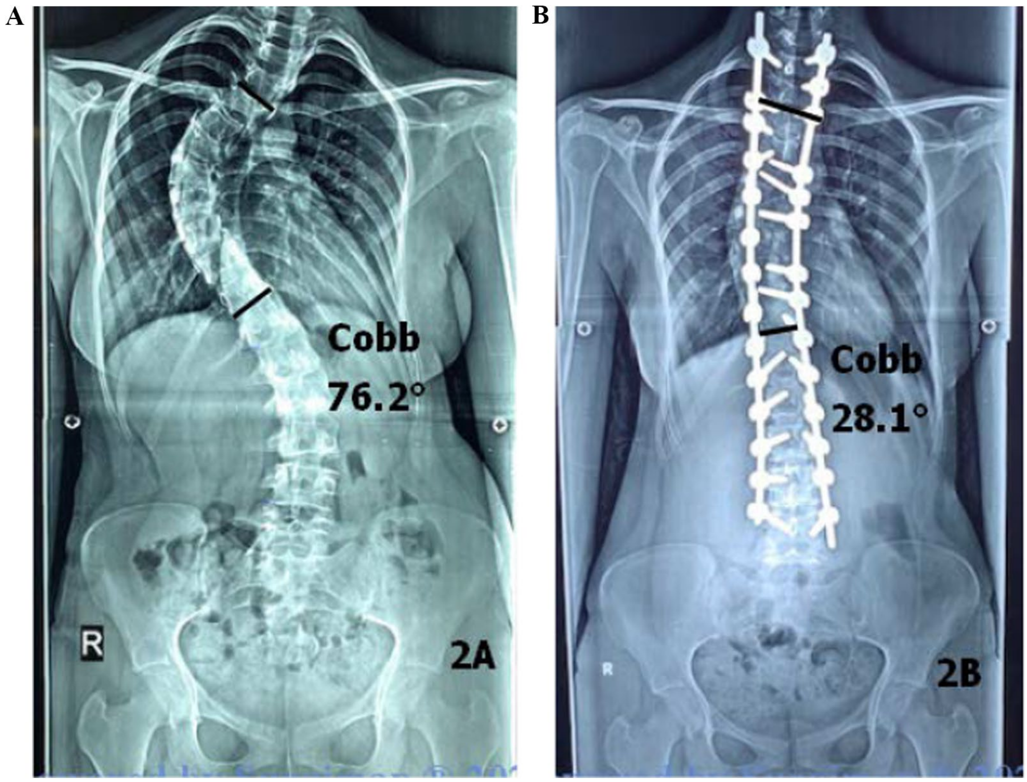

Fig. 2 **A** Plain X-ray (AP view) of the whole spine showing a main thoracic curve angle measures 76 degrees, in a 19-year-old female AIS Lenke type 1 A. **B** Postoperative plain X-rays (AP views) of the same case after 3 months showing correction of the main thoracic curve down to 28 degrees after Pvcr of the apex at D7

the postoperative period, except in one case, where the chest tube was removed after 1 month as this case was artificially ventilated.

3. Wound infection: Few infectious complications were reported in the literature in association with Pvcr [5, 13, 20–22]. In one series four cases (8.9%), out of 45 cases operated for correction of severe kyphosis with PVCR, developed deep wound infections [1]. In this series, one patient (4.8%) with neuromuscular scoliosis had developed deep wound infections that required debridement and drainage. This case was completely cured after surgical debridement and antibiotherapy based on culture and sensitivity. The poor tissue quality and the decreased nutritional reserves in neuromuscular scoliosis cases are potential risk factors that could lead to postoperative infectious complications [19].

Neurological complications: The rate of neurological insults after thoracic VCR ranges from 11.1 to 22%, with approximately 2.8% being permanent insults [1, 5, 6, 13, 23]. Neurological insults are amongst the most catastrophic complications following thoracic VCR [1]. The most common neurological deficit following Pvcr is nerve root injury, although permanent and complete deficits may occur [5, 6, 13, 20–22]. Permanent cord injuries could be attributed to thoracic cord hypoperfusion [5]. Authors recommended avoiding hypotensive anesthesia and preserving the neurovascular bundle on one side when performing Pvcr [24]. In this series, we avoided the use of hypotensive anesthesia during osteotomy and correction, while using it during exposure and screws insertion. Also, we sacrificed the neurovascular bundle at the apical vertebra only on the convex side of the deformity. We had reported 3 cases (14.3%) with permanent neurological deficits, 2 cases of complete cord injury (Grade A ASIA Impairment Scale), and one case of incomplete cord injury (Grade D ASIA Impairment Scale). This high rate of neurological deficits may be due to the relatively small sample size.

Data analysis of cases suffered from neurological deficits had revealed the following (Table 5):

1. Deformity type: Three out of 6 cases (50%) with congenital rigid kyphoscoliosis had developed neurological deficits. Although this percentage failed to reach

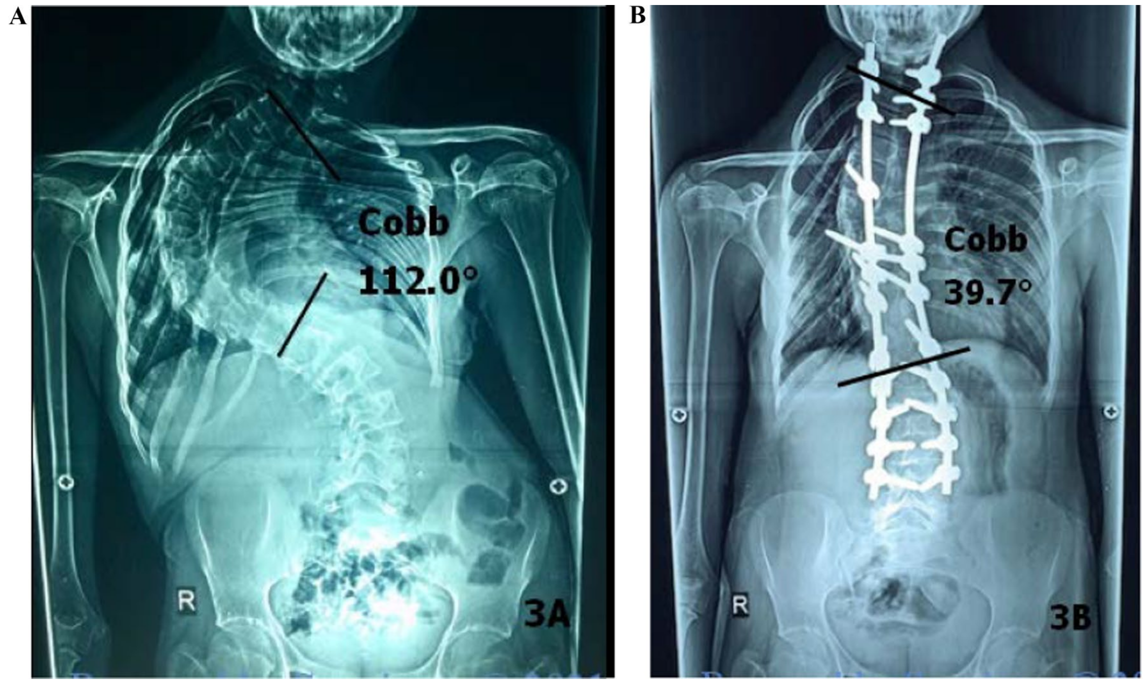

Fig. 3 **A** Plain X-ray (AP view) of the whole spine showing a main thoracic curve angle measures 112 degrees, in a 15-year-old female patient suffering from neuromuscular scoliosis (associated with Chiari type 1). **B** Postoperative plain X-rays (AP views) of the same case after 6 months showing correction of the main thoracic curve down to 40 degrees after Pvcr of the apex at D7

statistical significance (Chi square test $\chi^2 = 6.265$, Monte Carlo test $p = 0.098$), but meanwhile, no neurological complications were encountered among other deformity types. Iatrogenic neurological deficits are the most common complications encountered during surgical correction of rigid kyphoscoliosis. The characteristics of rigid kyphoscoliosis that render the patients at more risk to suffer from neurological deficits are the severe stiffness of the thoracic curve and the sensitivity of the thoracic cord to hypoperfusion [25].

2. Cobb angle: A higher preoperative Cobb angle values (102.67 ± 32.58) were noticed in patients who experienced neurological complications versus lower Cobb angle values (79.61 ± 21.67) in non-complicated cases. This difference also was not statistically significant (Mann–Whitney test = 18.0, $p = 0.412$).
3. Blood loss: Cases with neurological deficits had a marked higher amount of mean estimated blood loss (3800.0 ± 529.15 ml) compared to other cases (2652.78 ± 1487.44 ml), but this difference failed to reach the value of statistical significance (Mann–Whitney test = 9.500, $p = 0.080$). Blood transfusion data for these cases revealed that each case had received at least 4 units of packed RBCs and 2 units of fresh frozen plasma during surgery. Higher amount of blood loss during surgery may predispose to cord hypoperfusion. The literature data revealed that cord hypoperfusion is one of the main possible causes of functional cord compromise [18, 25].
4. Mean operative time: Cases experienced neurological complications had a statistically significant higher mean operative time (416.67 ± 20.82 min) compared to cases without neurological complications (326.11 ± 84.11 min) Mann–Whitney test = 4.500*, $p = 0.017$. A higher mean operative time could lead to a more hemodynamic stress resulting from the increased amount of blood loss and the increased anesthesia time.
5. Neuromonitoring: Our data had revealed that 3 (37.5%) out of 8 cases operated without monitoring had experienced neurological complications (statistically significant, chi-square test $\chi^2 = 5.688$, Fisher's exact $^{FE}p = 0.042$). Meanwhile, no neurological complications have been encountered in the 13 cases operated with intraoperative neuromonitoring. We used both somatosensory evoked potentials (SEPs) and motor evoked potentials (MEPs) to monitor the neurological function during surgery. The process of Pvcr followed by the process of deformity correction could be effectively monitored by somatosensory evoked potentials (SEPs) and motor evoked poten-

Table 5 Relation between neurological complication and different parameters ($n=21$)

	Neurological complication		Test of Sig.	p
	No ($n=18$)	Yes ($n=3$)		
Pathology				
Congenital scoliosis	4 (100%)	0 (0%)	$\chi^2=6.265$	$^{MC}p=0.098$
Congenital kyphoscoliosis	3 (50%)	3 (50%)		
AIS	7 (100%)	0 (0%)		
Neuromuscular scoliosis	3 (100%)	0 (0%)		
Postlaminectomy kyphoscoliosis	1 (100%)	0 (0%)		
Preoperative Cobb				
Mean ± SD.	79.61 ± 21.67	102.67 ± 32.58	$U=18.0$	0.412
Median (Min.–Max.)	83 (33–112)	88 (80–140)		
Blood loss				
Mean ± SD.	2652.78 ± 1487.44	3800.0 ± 529.15	$U=9.500$	0.080
Median (Min.–Max.)	3050 (350–5500)	4000 (3200–4200)		
Monitoring				
No (8 cases)	5	3	$\chi^2=5.688^*$	$^{FE}p=0.042^*$
Yes (13 cases)	13	0		
Operative time (min)				
Mean ± SD.	326.11 ± 84.11	416.67 ± 20.82	$U=4.500^*$	0.017*
Median (Min.–Max.)	355 (180–430)	410 (400–440)		

χ^2, Chi square test; MC, Monte Carlo; FE, Fisher's exact; U, Mann–Whitney test; p, p value for Comparing between the 2 groups

*Statistically significant at $p \le 0.05$

tials (MEPs) [25]. The challenges of screw insertion, osteotomy, osteotomy gap closure, and deformity correction could increase the risk of perioperative neurological complications. Intraoperative neuromonitoring has the advantage of continuous real-time monitoring of spinal cord functions with high sensitivity, hence the ability to pick up any minor deficits to give the chance to reverse the neurological compromise without any permanent sequelae [25–28]. Intraoperative monitoring changes mostly occur during osteotomy and osteotomy gap closure and less commonly during screws insertion and correction [14, 23, 25, 29]. In this study, almost all monitored cases had monitoring changes during different phases of surgery, from exposure to final correction. However, all these changes were completely reversible. Monitoring changes during exposure were almost always due to hypotension or hypothermia. Meanwhile, monitoring changes during pedicle screws insertion, osteotomies, osteotomy gap closure, or correction were mainly due to surgical manipulation, in addition to hypotension and hypothermia. Timely surgical responses after monitoring data loss had made these changes reversible.

Authors' suggestions for patients undergoing Pvcr

1. Keeping the mean arterial blood pressure at the highest normal readings during the process of osteotomy, osteotomy gap closure, and deformity correction. The aim is to maintain adequate spinal cord perfusion during the critical phases of surgery.
2. Wide laminectomy including one level above and one level below the apex must be done before the beginning of the osteotomy procedure. The aim is to give an extra-space for the cord to withstand the process of cord manipulation during the osteotomy stage. Also, the wide laminectomy process aids to avoid buckling of the spinal cord during the stage of osteotomy gap closure.
3. Sharp dissection of the neurovascular bundle on the convex side at the apex, while keeping the contralateral neurovascular bundle intact. The aim is to minimize the risk of cord ischemia.
4. The use of high speed drill is better than the use of osteotomes to remove the last part of apical body adjacent to the cord (the thin shell just beneath the dural sac). The aim is to minimize the effect of cord manipulation and concussion.

5. The insertion of a temporary rod on the contralateral side of the osteotomy aiming to prevent the osteotomy ends subluxation and cord injury.
6. Osteotomy gap closure in a gradual controlled manner, guided by neuro-monitoring, to minimize the risk of cord buckling and bony compression on the spinal canal.
7. Convex-side compression is safer than concave side distraction, to minimize the risk of cord stretch injury.
8. Blood loss control and adequate replacement during surgery are crucial to avoid hypovolemia and cord hypoperfusion.
9. Neuromonitoring is an essential tool that must be available during the whole surgery to minimize the risk of permanent neurological deficits.

Study limitations

The small number of the cohort group and the relatively short follow-up period are the main limitations of this study.

Conclusion

Vertebral column resection through a posterior only approach is considered a highly effective release procedure that aids in the correction of almost any type of complex pediatric deformities with a correction rate reaching $66.9 \pm 10.8\%$. However, posterior vertebral column resection is a challenging procedure with high estimated blood loss and risk of neurological deficits, so it must be done only by experienced spine surgeons in the presence of good anesthesia and neuromonitoring teams.

Abbreviations

Pvcr: Posterior vertebral column resection; AIS: Adolescent idiopathic scoliosis.

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Authors' contributions

IS designed the study and wrote the initial manuscript. AAF assisted in the final preparation of the manuscript. AME has participated in the final revision of the manuscript. All authors have contributed to this study and approved the final version of the manuscript. All authors read and approved the final manuscript.

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Availability of data and materials

All data used are available from the corresponding author on request.

Declarations

Ethics approval and consent to participate

An approval from the research ethics committee of the Faculty of Medicine, Alexandria University [serial number 0305059], was obtained in 18/2/2021. Furthermore, being a retrospective study, patients' consents for participation was not applicable.

Consent for publication

Not applicable.

Competing interests

The authors had no competing interest to report.

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References

1. Papadopoulos EC, Boachie-Adjei O, Hess WF, Sanchez Perez-Grueso FJ, Pellise F, Gupta M, et al. Early outcomes and complications of posterior vertebral column resection. Spine J. 2015;15(5):983–91.
2. Luque E. Vertebral column transposition. Orthop Trans. 1983;7:29–32.
3. Boachie-Adjei O, Bradford DS. Vertebral column resection and arthrodesis for complex spinal deformities. J Spinal Disord. 1991;4(2):193–202.
4. Bradford DS, Tribus CB. Vertebral column resection for the treatment of rigid coronal decompensation. Spine (Phila Pa 1976). 1997;22(14):1590–9.
5. Suk SI, Kim JH, Kim WJ, Lee SM, Chung ER, Nah KH. Posterior vertebral column resection for severe spinal deformities. Spine (Phila Pa 1976). 2002;27(21):2374–82.
6. Lenke LG, O'Leary PT, Bridwell KH, Sides BA, Koester LA, Blanke KM. Posterior vertebral column resection for severe pediatric deformity: minimum 2-year follow-up of thirty-five consecutive patients. Spine (Phila Pa 1976). 2009;34(20):2213–21.
7. Committee M, Burns S, Biering-Sorensen F, Donovan W, Graves DE, Jha A, et al. International standards for neurological classification of spinal cord injury, revised 2011. Top Spinal Cord Inj Rehabil. 2012;18(1):85–99.
8. MacLennan A. Scoliosis. Br Med J. 1922;2:864–6.
9. Bridwell KH. Decision making regarding Smith–Petersen versus pedicle subtraction osteotomy versus vertebral column resection for spinal deformity. Spine (Phila Pa 1976). 2006;31(19 Suppl):S171–8.
10. Ren C, Liu L, Song Y, Zhou C, Liu H, Li T. 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(6):1237–43.
11. Zeng Y, Chen Z, Guo Z, Qi Q, Li W, Sun C. The posterior surgical treatment for focal kyphosis in upper–middle thoracic spine. Eur Spine J. 2014;23(11):2291–8.
12. Daubs MD. Commentary: Is a two-staged anterior-posterior vertebral column resection (VCR) safer than a posterior-only VCR approach for severe pediatric deformities? Spine J. 2013;13(5):487–8.
13. Wang Y, Zhang Y, Zhang X, Huang P, Xiao S, Wang Z, et al. A single posterior approach for multilevel modified vertebral column resection in adults with severe rigid congenital kyphoscoliosis: a retrospective study of 13 cases. Eur Spine J. 2008;17(3):361–72.
14. Lenke LG, Sides BA, Koester LA, Hensley M, Blanke KM. Vertebral column resection for the treatment of severe spinal deformity. Clin Orthop Relat Res. 2010;468(3):687–99.
15. Li X, Zhang J, Tang H, Lu Z, Chen S, Hong Y. Closing–opening wedge osteotomy for thoracolumbar traumatic kyphosis. Eur J Med Res. 2014;19:59.
16. Xie J, Wang Y, Zhao Z, Zhang Y, Si Y, Li T, et al. Posterior vertebral column resection for correction of rigid spinal deformity curves greater than 100 degrees. J Neurosurg Spine. 2012;17(6):540–51.
17. Rajasekaran S, Vijay K, Shetty AP. Single-stage closing-opening wedge osteotomy of spine to correct severe post-tubercular kyphotic deformities of the spine: a 3-year follow-up of 17 patients. Eur Spine J. 2010;19(4):583–92.
18. Suk SI, Chung ER, Lee SM, Lee JH, Kim SS, Kim JH. Posterior vertebral column resection in fixed lumbosacral deformity. Spine (Phila Pa 1976). 2005;30(23):E703–10.
19. Reames DL, Smith JS, Fu KM, Polly DW Jr, Ames CP, Berven SH, et al. Complications in the surgical treatment of 19,360 cases of pediatric scoliosis: a review of the Scoliosis Research Society Morbidity and Mortality database. Spine (Phila Pa 1976). 2011;36(18):1484–91.

20. Shimode M, Kojima T, Sowa K. Spinal wedge osteotomy by a single posterior approach for correction of severe and rigid kyphosis or kyphoscoliosis. Spine (Phila Pa 1976). 2002;27(20):2260–7.
21. Kawahara N, Tomita K, Baba H, Kobayashi T, Fujita T, Murakami H. Closing-opening wedge osteotomy to correct angular kyphotic deformity by a single posterior approach. Spine (Phila Pa 1976). 2001;26(4):391–402.
22. Hamzaoglu A, Alanay A, Ozturk C, Sarier M, Karadereler S, Ganiyusufoglu K. Posterior vertebral column resection in severe spinal deformities: a total of 102 cases. Spine (Phila Pa 1976). 2011;36(5):E340–4.
23. Zhang BB, Zhang T, Tao HR, Wu TL, Duan CG, Yang WZ, et al. Neurological complications of thoracic posterior vertebral column resection for severe congenital spinal deformities. Eur Spine J. 2017;26(7):1871–7.
24. Winter RB, Lonstein JE, Denis F, Leonard AS, Garamella JJ. Paraplegia resulting from vessel ligation. Spine (Phila Pa 1976). 1996;21(10):1232–3 (**discussion 3–4**).
25. Huang ZF, Chen L, Yang JF, Deng YL, Sui WY, Yang JL. Multimodality intraoperative neuromonitoring in severe thoracic deformity posterior vertebral column resection correction. World Neurosurg. 2019;127:e416–26.
26. Devlin VJ, Schwartz DM. Intraoperative neurophysiologic monitoring during spinal surgery. J Am Acad Orthop Surg. 2007;15(9):549–60.
27. Sloan TB, Janik D, Jameson L. Multimodality monitoring of the central nervous system using motor-evoked potentials. Curr Opin Anaesthesiol. 2008;21(5):560–4.
28. Krassioukov AV, Sarjeant R, Arkia H, Fehlings MG. Multimodality intraoperative monitoring during complex lumbosacral procedures: indications, techniques, and long-term follow-up review of 61 consecutive cases. J Neurosurg Spine. 2004;1(3):243–53.
29. Wang S, Yang Y, Zhang J, Tian Y, Shen J, Wang S. Frequent neuromonitoring loss during the completion of vertebral column resections in severe spinal deformity surgery. Spine J. 2017;17(1):76–80.

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