OBJECTIVE: We sought to determine whether a posterior vertebral resection on congenital deformities of thoracolumbar and lumbar vertebrae leads to more complications and provides less correction.

METHODS: Twenty-three patients underwent a posterior vertebral resection for a rigid congenital spinal deformity, which included scoliosis (13 patients), kyphoscoliosis (6 patients), and pure kyphosis (4 patients). The surgeries involved removing 1 to 2 vertebrae using multiaxial pedicle screws in all but 2 of the patients. All surgeries were performed under intraoperative spinal cord monitoring. Thoracic curve, lumbar lordosis, focal kyphosis, shift, and sagittal vertical axis were collected at baseline and during the last follow-up (taking place after at least 3 years) and were then statistically analyzed.

RESULTS: The major curve correction was about 55% in cases of scoliosis, with focal kyphosis improving from 54.3 ± 19.1 degrees to 21.3 ± 15 degrees. Two patients experienced intraoperative neuromonitoring changes, with data returning to baseline without any surgical intervention. Sensory or motor palsy after the surgery was not reported in patients.

Despite improving sagittal or coronal deformities, 8 patients experienced excessive sagittal decompensation during follow-up, 1 of whom underwent revision surgery. Sagittal decompensation was by far the most common complication. Larger kyphoscoliosis or focal kyphosis angles were preoperative risk factors for postoperative sagittal imbalance (P value < 0.05).

CONCLUSIONS: Using a lumbar or thoracolumbar posterior vertebral resection enables surgeons to correct rigid curves in the pediatric population without major risk to nerve roots. The primary complications would be sagittal decompensation and the likelihood of undercorrection, which requires mindful addressing during the preoperative planning stages.

INTRODUCTION

One of the major dilemmas in the treatment of spinal deformities is correcting rigid and complex curves. Various treatment methods and strategies have been introduced to address these, from preoperative or intraoperative skeletal traction to different spinal osteotomies. These introduced osteotomies provide diverse correction percentages and are chosen according to criteria such as the rigidity, location, and plane of the curves, etiology, and complexity of the disease. Vertebral column resection (VCR) is a procedure that has been used to correct complex deformities. Nascent VCR has been used initially using combined anterior and posterior approaches, which were later modified to correct the deformities through a posterior-only approach, as this has been determined to be safer than the traditional combined approach. In addition, it allows correction in multiple planes including rotational or translational planes.
Although involving a steep learning curve, posterior VCR (PVCR) has been widely employed by spinal surgeons around the globe to address severe, rigid curves. In order to gain access to the deformity site, sacrificing nerve roots is necessary to adequately expose the deformity site and remove stiff columns of the spine. Physician expertise is crucial when tiny motor nerve roots ought to be preserved in lumber or thoracolumbar regions or when approaching a complex curve in pediatric patients. In this study, pediatric rigid congenital thoracolumbar, lumbar, or lumbosacral curves were managed using posterior vertebral resection (PVCR included) to demonstrate its efficacy and safety without compromising nerve roots’ continuity.

MATERIALS AND METHODS
This investigation consisted of a retrospective review of 23 pediatric patients who had a severe spinal deformity, which was treated through a posterior vertebral resection. All patients who were included in the study had a thoracolumbar/lumbar or lumbosacral rigid curve (a rigid curve with >20 degrees’ kyphosis and/or >30 degrees’ scoliosis, demonstrating <10% flexibility). All patients had a congenital malformation of the spinal column. In 3 patients, spinal dysraphism had been diagnosed, for whom a diastematomyelia resection was performed before the index surgery. Two additional patients had the previous spinal procedure—1 involving convex hemiepiphysiodesis and the other undergoing a growing rod procedure with multiple lengthening. The patients were evaluated by a multidisciplinary team, incorporating multiple stakeholders who were managing patients during or after surgery.

Standing radiographs, a multiaxial reconstruction computed tomography scan, and magnetic resonance imaging were obtained from all patients preoperatively. Sagittal and coronal curves’ Cobb angles, thoracic kyphosis, lumbar lordosis, sagittal vertical axis, and coronal shift were each measured by a spinal surgeon using

**Figure 1.** (A) Following posterior exposure of spine, the medial end of the ribs is resected. (B) Pedicle screws are inserted above and below the osteotomy site. Extensive laminectomy is done to expose dura and nerve roots. Malleable or spoon retractors are subperiosteally placed over the vertebral bodies’ anterior aspect. The concave side pedicles and vertebral bodies are removed with appropriate instruments. (C) The concave temporary rod is inserted to avoid spinal cord damage due to an unstable spine. After completing convex side osteotomy and removing posterior vertebral bodies’ wall, a mesh cage is passed between nerve roots in a horizontal direction. (D) The correction of the deformity is commenced on the concave temporary rod and then on the convex permanent rod using in-situ benders, a compressor, or a distractor device. (E) Switching temporary rod to a permanent rod and final radiograph to check the position of the cage and to avoid coronal decompensation.
Surgimap for Windows (version 2.2.12.1). Each patient received prophylactic tranexamic acid at a loading dose of 30 mg/kg and a maintenance dose of 10 mg/kg/hr during the procedure. Intraoperative nerve monitoring was performed for all patients. Blood loss and intraoperative nerve monitoring changes were recorded. Postoperatively, patients were neurologically evaluated after extubating and at their final follow-up visits. Postoperative complications (e.g., paralysis, infection, instrumentation failure, pseudoarthrosis) were also documented.

A partial neurologic deficit (long tract upper motor signs as exaggerated reflexes and positive Babinski) was present in 1 of the patients who presented with spinal dysraphism preoperatively. In this study, PVCR was used when the complete removal of 1 or more vertebrae from the vertebral column was required. Otherwise, a simple posterior vertebral resection was used to remove a hemivertebra.

The study was approved by our institutional review board, and informed consent was obtained from all parents after explaining the procedure along with its advantages and disadvantages. Analyses were conducted using the statistical software environment R, version 4.1.2, using mean, standard deviation, median, and nonparametric Wilcoxon tests to compare the differences before and after surgery, with 95% confidence intervals for point estimates.

Surgical Method

The number of vertebrae that needed to be removed was determined by the senior surgeon, according to the preoperative radiographs and computed tomography scan images and using Surgimap. The patient was positioned on a regular radiolucent table after receiving general anesthesia and setting up neuro-monitoring. Through the standard posterior subperiosteal approach, the spinal lamina and transverse processes were exposed (Figure 1A). Polyaxial pedicle screws were inserted using a freehand technique to at least 1 level above and below the deformity in posterior vertebral resections and 2 levels above and below in conventional PVCR (Figure 1B). A wide V-shaped laminectomy and foraminectomy were performed to adequately expose dura and nerve roots at the apex. Epidural veins were cauterized using bipolar cautery. After cutting and removing transverse processes and/or medial 3–4 cm of the lower ribs in thoracolumbar curves, vertebral bodies were subperiosteally exposed and malleable retractors were used to protect retroperitoneal vessels (Figure 1B).

Next, concave pedicles and vertebral bodies were removed using a power Burr, osteome, and/or angled curettes. A temporary rod was inserted on the concave side to stabilize the resected site during vertebral resection. Convex pedicles and vertebral bodies were then resected in a similar manner. The wall of the posterior vertebral body was impacted down, away from the spinal canal while respecting dural content. In cases of kyphosis correction or severe scoliosis, a corpectomy mesh cage was used to construct the anterior column. The bone graft—loaded cage was passed horizontally between the nerve roots to prevent their damage. After passing the cage (Figure 1C), it was then rotated into a vertical position and placed between vertebral end plates, in the resected space (Figure 1D). Deformity correction was performed using sagittal and coronal planes in-situ benders (Medtronic Sofamor Danek Inc., Memphis, TN) placed on the concave temporary rod and then on the final rods (Figure 1D). Compression and distraction maneuvers were also used according to the type of deformity. Short-segment fusion (1 level above and below) was used only for hemivertebra resection in scoliosis cases; otherwise, longer fusion was preferred (Figure 1E). An intraoperative radiograph was obtained to evaluate the whole construct, cage position, final correction, and lateral decompensation. Postoperatively, a rigid brace was used for the patients who received a short-segment fusion.

RESULTS

There were 15 females and 8 male consecutive patients, with a mean age of 10.5 ± 4.1 (range 3–18) years at the time of the procedure. Thirteen patients (56.5%) presented with failure of formation of the vertebra, 2 patients (8.7%) revealed the failure of segmentation, and 8 patients (34.8%) showed a mixed type of congenital spinal deformity (Table 1). The mean follow-up was 46 ± 10 months (range: 36–75). Two patients (8.7%) had intracanal pathology, which included diastematomyelia plus syringomyelia in 1 patient.

### Table 1. Patients’ Characteristics and Operative Parameters (Mean ± Standard Deviation [Range] or Number)

| Characteristics                  | Patients (N = 23) |
|----------------------------------|-------------------|
| Age (year)                       | 10.5 ± 4.1 (3–18) |
| Female/Male                      | 15 (65.2%)/8 (34.8%) |
| Operation time (minutes)         | 185 ± 56 (105–285) |
| Blood loss (mL)                  | 765 ± 393 (300–1800) |
| Follow-up (months)               | 46 ± 10 (36–75)   |
| Types of congenital deformity    |                   |
| Failure of formation             | 13 (56.5%)        |
| Failure of segmentation          | 2 (8.7%)          |
| Mixed deformities                | 8 (34.8%)         |
| Types of spinal curvature        |                   |
| Scoliosis                        | 18 (78.3%)        |
| Kyphosis                         | 4 (17.4%)         |
| Kyphoscoliosis                   | 1 (4.3%)          |
| Spinal deformities’ location     |                   |
| Thoracic                         | 5 (21.7%)         |
| Thoracolumbar                    | 6 (26.1%)         |
| Lumbar                           | 9 (39.1%)         |
| Lumbosacral                      | 3 (13%)           |
| Osteotomies’ location            |                   |
| T11, T12, L1                     | 11 (47.8%)        |
| L2, L3, L4                       | 8 (34.8%)         |
| L5                               | 4 (17.4%)         |

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and split cord syndrome in the other patient. In these cases, the former patient had undergone diastematomyelia surgery before the index surgery, while the latter required no additional neurosurgical intervention. The curve morphologies involved scoliosis in 18 patients (78.3%), kyphosis in 4 patients (17.4%), and kyphoscoliosis in 1 (4.3%) patient. The location of the curves was lumbar in 9 patients (39.1%), thoracolumbar in 6 patients (26.1%), thoracic in 5 patients (21.7%), and lumbosacral in 3 patients (13%) (Table 1). Preoperatively, the main scoliotic curve averaged 41.1 degrees (range: 31–75), thoracic kyphosis averaged 37.6 ± 23.1 degrees (range: 2–87), and focal kyphosis averaged 54.3 ± 19.1 degrees (range: 30.2–92.3) (Table 1). The site of the osteotomy was on T11 in 5 patients (21.7%), T12 or L1 in 6 patients (26.1%), and lumbar vertebrae (L2, L3, L4) in 8 patients (34.8%), and L5 in 4 patients (17.4%) (Table 1). The construct was all pedicle screws in 21 patients and hybrid (hook + pedicle screw) in 2 patients. The mean operation time was 185 ± 56 minutes (range: 105–285). The average blood loss was 765 ± 393 mL (range: 300–1800), which was equal to 29.6 ± 10.7 percent of expected blood volume (EBL) (range: 12.4–49.7).

A posterior vertebra resection (including hemivertebra resection) was performed for 12 patients while the other 11 patients

Figure 2. Demonstrating partial posterior vertebral column resection (PVCR) or hemivertebrectomy in a 3-year, 7-month old patient, who had a congenital kyphosis with a posterior hemivertebra [A–C]; through a posterior approach, L1 was removed and a T11-L3 fusion was done (D).
underwent a conventional PVCR (Figure 2). Vertebral osteotomy was done in 18 (58.3%) patients without inserting an anterior cage, while others received a mesh cage through the same approach (Figure 3). One or two vertebrae were removed (average 1.2 vertebrae), and 1–10 levels were fused (average, 2.2 levels).

Temporary motor evoked potential amplitude loss (about 50% of the original potentials) was observed in 2 patients (8.7%) during the surgery, which returned to normal once the patient’s blood pressure increased. As such, no wake-up test was performed for these patients. Nerve root deficit did not occur during or after the procedure. The patient with preoperative long-tract symptoms (1 of the original potentials) was observed in 2 patients (8.7%) during the follow-up period. Nerve root decompensation increased. As such, no wake-up test was performed for the patients.

At the last follow-up visit, the main scoliotic curve averaged 18.4 ± 13.8 degrees (range: 0–47), thoracic kyphosis averaged 41 ± 15.2 degrees (range: 6–65), and focal kyphosis averaged 21.3 ± 15 degrees (range: 2–48) (Table 2).

The average corrections for the coronal and sagittal main curves were 55.3% and 60.7%, respectively. Regarding the correction of the curves, there were no significant differences in the location of the curve; diagnosis (kyphosis, scoliosis, or kyphoscoliosis); osteotomy levels; or fusion levels. While lumbar sacral curves and older ages were initially expected to show more resistance to a surgical correction, the location of the curve and age of the patients have had no statistically significant impact on the correction nor complication rates.

No infections, pseudarthrosis, or implant failures were revealed during the follow-up period. Despite improving preoperative sagittal and coronal parameters, 8 patients (34.8%) demonstrated excessive sagittal imbalance during follow-up visits, 1 of whom underwent revision surgery (Figure 4). From the sagittal balance perspective, there was a significant correlation with the larger preoperative kyphoscoliosis ($P = 0.005$) and kyphosis angles ($P = 0.02$) with postoperative sagittal decompensation. Postoperatively, residual kyphosis and an excessive lumbar lordosis ($P = 0.03$) were early signs of further deterioration of the sagittal decompensation. Although longer fusion has been used in kyphotic patients ($P = 0.02$), sagittal decompensation was the most common complication. Coronal decompensation of >20 mm was also detected in 2 patients (8.6%), though neither case was clinically significant to the patients.

### DISCUSSION

A posterior vertebral resection has been identified as a standard procedure to treat rigid spinal deformities in both adult and pediatric patients and has been popularized by Suke et al and Lenke et al. In their meta-analysis, Saifi et al concluded that the procedure needed to be stratified into adult and pediatric series to better outline the outcomes and complications. The procedure includes the transection of nerve roots (at minimum on the concave side) to increase the exposure to the vertebral rigid area. In pediatric patients with lumbar or thoracolumbar curves, in particular, tiny motor nerve roots may compromise the technique and increase the likelihood of the undercorrection of the deformity or cause further complications.

Few studies have demonstrated VCR results in the pediatric population. Lenke et al reported a multicenter study based on 147 consecutive pediatric VCR procedures. However, their congenital deformity cases involved only 28 patients. As such, the results of their congenital cases can be compared with our cohort. The average age of their patients was about 13.7 years (from newborn to 21 years of age). Our patients’ average age was about 10.5 years, ranging from 3 to 18 years, younger than Lenke’s patient cohort. Their multicenter study highlighted the number of vertebra resected ranging from 1 to 5, with an average of 1.6 levels. Our average number of resected vertebrae was 1.2 levels. The mean operation time was nearly 3 hours, with a maximum of about 5 hours. The average blood loss was 779.5 mL (30% of EBL), with a high of 1800 mL. The complexity of the curve and blood loss can affect operation time. Lenke

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### Table 2. Preoperative and Last Follow-up Curve Characteristics in Pediatric Patients

|                         | Preoperative Mean ± SD (Range) | Last Follow-up Mean ± SD (Range) | $P$ Value |
|-------------------------|-------------------------------|----------------------------------|-----------|
| Upper thoracic curve (degrees) | 31 ± 15.6 (10–60)             | 18.4 ± 10.8 (5–35)               | 0.017*    |
| Main thoracic curve (degrees)   | 41 ± 11.1 (31–75)             | 18.4 ± 13.8 (0–47)               | 0.0001*   |
| Lower thoracic curve (degrees)   | 26.9 ± 10 (14–44)             | 10 ± 11.8 (1–35)                 | 0.018*    |
| Thoracic kyphosis (degrees)     | 37.6 ± 23.1 (2–87)            | 41 ± 15.2 (6–65)                 | 0.879     |
| Lumbar lordosis (degrees)       | 36.1 ± 31.4 (–43–95)          | 40.7 ± 19.5 (–15–75)             | 0.295     |
| Focal kyphosis (degrees)        | 54.3 ± 19.1 (30.2–92.3)       | 21.3 ± 15 (2.7–48)               | 0.008*    |
| Shift (millimeters)             | 23.2 ± 17.6 (5.3–63.9)        | 9.14 ± 8.7 (0–32.6)              | 0.025*    |
| SVA absolute value (millimeters)| 54.6 ± 38.4 (1–132)          | 26.1 ± 31.9 (0–130)              | 0.006*    |

Values in parentheses are ranges.

SVA, sagittal vertical axis.

*Significant at 0.05 level, Wilcoxon test.
et al6 reported an average operative time of nearly 9 hours in their pediatric cohort, with an average blood loss of more than 1600 mL. Only longer operation times were significantly associated with the staged procedures. In comparison, our study’s improved operative metrics were likely due to including hemivertebrectomy in the study and using a high dose of prophylactic tranexamic acid.

In terms of curve correction, Lenke et al6 showed an average preoperative major scoliosis curve of 84 degrees corrected to 35 degrees for a correction rate of 58%. The mean preoperative major kyphosis angle of 90 degrees corrected to 42 degrees, with an average correction rate of 54%. Looking precisely at their congenital cases, the average preoperative coronal Cobb angle was 47 degrees, which was corrected by 22 degrees on average (correction rate of 46%). The mean preoperative kyphosis angle was 56 degrees, which was reduced by 24 degrees on average (correction rate of 43%). Regarding the curves’ parameters in our study, preoperatively, the main sciotic and kyphosis Cobb angles averaged 41 degrees and 54 degrees, respectively. At the last follow-up visit, the main coronal and sagittal curves averaged 18 degrees and 21 degrees, correspondingly. The correction rate for the main sciotic curve and focal kyphosis were 55% and 62%, respectively. The correction rates of our study were higher than those reported by Lenke et al.6 The younger age of our patients and location of the curves could have improved the results.

In terms of complications, previous studies have reported various rates of complications related to etiology, age, deformity type, bleeding volume, operative time, location and extent of the osteotomy, and preoperative neurologic condition.1,6–11 Zhang et al12 reported about 16% neurologic complications, which correlated with age ≥18 years, pulmonary dysfunction, and an EBL >500 mL. Lenke et al6 reported complications in 86 patients (58%) within their 147 pediatric cohort. Complications during surgery have been reported in 68 patients, and postoperative complications were revealed in 43 patients. The most common intraoperative complication was loss of spinal cord monitoring data or actual spinal cord or nerve root deficits. The second most common complication was an EBL of >2 L. The most common early postoperative complications were pulmonary related.6 Ould-Slimane et al5 reported 13 PVCR pediatric patients, with significant evoked potential changes in 4 patients (25%). Two had complete recovery without construct modification, and 1 experienced unilateral evoked potential drop, which was followed by spontaneous recovery after 6 weeks. The fourth case needed unilateral sectioning of the L2 root to complete PVCR procedure.7 In our series, temporary neuromonitoring changes happened in 2 patients (8%) and excessive EBL (>1500 mL) occurred in 1 patient. No nerve root was cut during the procedure, and no postoperative pulmonary obstacles, infections, or death have been observed. This lower rate of complications might be related to the younger age of the patients, reporting hemivertebra resection cases in our study, and the excellent care provided by our amply equipped pediatric intensive care unit. However, the most common late postoperative complication was sagittal plane decompensation, which was observed in 8 patients (34%), and coronal decompensation, which was observed in 2 patients (8%). Revision of the construct has been made in 1 patient due to an exaggerated sagittal imbalance during follow-up (Figure 4). Larger kyphoscoliosis or severe kyphosis was a preoperative risk factor for postoperative sagittal imbalance. Postoperative

![Figure 4](https://example.com/figure4.jpg)
residual kyphosis and an excessive lumbar lordosis are also risk factors that can aggravate postoperative sagittal decompensation during follow-up ($P < 0.05$).

**CONCLUSION**

PVCR is a demanding procedure, requiring surgical and anesthesiology experts. The challenge grows when considering the procedure in order to address a rigid spinal deformity in pediatric patients, particularly those with a thoracolumbar or lumbar curve. Preserving nerve roots can lead to the less correction of the curves. Loss of sagittal balance was one of the concerning complications that should be addressed by proper preoperative planning.

**CRediT AUTHORSHIP CONTRIBUTION STATEMENT**

Mohsen Karami: Conceptualization, Methodology, Treatment, Formal analysis, Writing — original draft, Writing — review & editing, Read and approved the final manuscript. Reza Zandi: Writing — original draft, Read and approved the final manuscript. Mohammad Hassani: Treatment, as a cardiovascular Surgeon, Writing — original draft, Read and approved the final manuscript. Hazem B. Elsebaie: Writing — original draft, Writing — review & editing, Read and approved the final manuscript.

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