Spine

SPINE Volume 41, Number 21, pp E1271–E1278

Pediatric Posterior Vertebral Column Resection (PVCR): Before and After Ten Years of Age

Greater Than 10-Year Follow-Up

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Study Design. A retrospective study.

Objective. To compare the surgical outcomes of posterior vertebral column resection (PVCR) and its long-term effects on the deformity correction for congenital scoliosis in children less than 18 years of age.

Summary of Background Data. There have been no reports on surgical outcomes that pertain to the timing of surgery for congenital scoliosis in children under age 18 years with long term follow-up.

Methods. Forty-five congenital scoliosis patients (N = 45) under age 18 at the time of surgery were treated by PVCR. These cases were retrospectively studied and had a minimum 10-year follow-up. We assigned patients into two groups: Group 1 (N = 19) patients who had surgery before 10 years of age, Group 2 (N = 26) patients who had surgery after 10 years of age.

Results. In Group 1, the mean Cobb angle of the main curve was 44° before surgery, 10.2° after surgery, and 14.2° at last follow-up. In Group 2, the mean Cobb angle of the main curve was 48.7° before surgery, 17.2° after surgery, and 20.4° at the last follow-up. The mean operative time was 189 minutes in Group 1 and 245 minutes in Group 2. The mean estimated blood loss (EBL) per kilogram was 52.9 mL/kg in Group 1 and 48.1 mL/kg in Group 2. There were 22 complications for PVCR and the overall prevalence of complications was 48.9%.

Conclusion. PVCR is an effective procedure for the management of congenital scoliosis under age 18. PVCR for congenital scoliosis before the age of 10 years had significantly better deformity correction compared with the group after the age of 10 years and did not cause crankshaft phenomenon.

Key words: congenital scoliosis, crankshaft phenomenon, growing spine, hemivertebra, pedicle screw fixation, posterior vertebral column resection.

Level of Evidence: 4

Spine 2016;41:E1271–E1278

Congenital scoliosis results from abnormal vertebral development that may lead to asymmetric growth of the spine.[1–5] A complete unilateral failure of formation creates a hemivertebra that is the most frequent cause of congenital scoliosos.[1–3]

Surgical treatment is frequently necessary in patients with severe spinal deformities and progressive curves. Therefore, the treatment of congenital scoliosis focuses on early diagnosis and appropriate surgical management before the development of severe deformity of primary and compensatory curves.[6–10]

The usual method of hemivertebra resection has been combined anterior and posterior surgery in 1 or 2 stages.[11–15] The best permanently corrective surgery may be removal of the hemivertebra. Recently, posterior vertebral column resection (PVCR) has been reported with successful results in the treatment of congenital scoliosis.[16–30]

There have been no reports in the literature regarding surgical outcomes by the age at the time of surgery in children under age 18 years for congenital scoliosis. The purpose of this study is to compare the surgical outcomes by the age at the time of surgery undergoing PVCR and fusion with pedicle screw fixation (PSF) and the long-term effects on deformity correction in congenital scoliosis in children under age 18.

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Acknowledgment date: December 14, 2015. First revision date: February 5, 2016. Acceptance date: March 21, 2016.

The manuscript submitted does not contain information about medical device(s)/drug(s).

No funds were received in support of this work.

No relevant financial activities outside the submitted work.

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DOI: 10.1097/BRS.0000000000001623

TABLE 1. Demographic and Operative Data*

Demographics/Operative	Group 1 (N = 19)	Group 2 (N = 26)	*P*
Age (yr)	6.9 (2.4–10)	14.6 (11.4–18)	**<0.000**
Follow-up (yr)	12.9 (10.2–17.3)	12.7 (10.1–18.2)	0.842
Fused segments	3.3 (1–10)	4.6 (1–13)	0.121
Number of case used	0	4	**<0.000**
Operative time (min)	189 (70–405)	245 (80–395)	**0.019**
Estimated blood loss (mL)	1285 (270–3000)	2376 (600–6000)	**0.006**
Estimated blood loss (mL)/kg	53 (13–130)	48 (14–123)	0.570

**Data all represent mean values for each group.*
Significant differences are typed in bold and are accepted for P value <0.05.

MATERIALS AND METHODS

Patients

Sixty-six patients with a diagnosis of a congenital scoliosis due to a hemivertebra who underwent PVCR with posterior fusion using PSF in our institution between 1997 and 2004, were retrospectively reviewed for deformity correction and the long-term effects on the growing spine in the treatment of congenital scoliosis. The minimum follow-up was 10 years. Institutional Review Board approval of our hospital was obtained before data collection and analysis. The inclusion criteria were as follows: (A) congenital spinal deformity requiring surgical treatment (curve magnitude: greater than 25° with fast progression: this included documented progression of the curve of more than 5° in a 6-month follow-up and/or failure of conservative treatment); (B) PVCR with bilateral pedicle screw instrumentations; (C) age at surgery less than 18 years, and (D) minimum 10-year follow-up.

All our cases in this study were treated with PVCR. Cases with simple excision of hemivertebra and/or pedicle and vertebral body without disc excision were excluded in this study.

Among 66 patients, 20 patients were lost to follow-up and one patient was excluded due to a vague margin of anatomic markers. Therefore, 45 patients met our criteria. We divided them into those who had surgery before 10 years of age (Group 1, N = 19) and those who had surgery after 10 years of age (Group 2, N = 26) (Table 1).

Etiologic diagnosis was seen in Table 2. There were 11 cases of single hemivertebra in Group 1 and 13 cases of single hemivertebra in Group 2. The level of hemivertebra was T9 in 3, T11 in 1, T12 in 2, L1 in 1, L4 in 4 in Group 1 and T11 in 5, T12 in 1, L1 in 2, L2 in 2, L3 in 1, L4 in 1, L5 in 1 in Group 2, respectively. Fifty-four (54) cases of PVCR were performed; in the thoracic spine (T1–T9) in 11 cases, the thoracolumbar region (T10–L2) in 34 cases, and the lumbar spine (L3–L5) in 9 cases.

Radiographic Measurements

Whole spine anteroposterior and lateral radiographs were reviewed preoperatively, 4 week postoperatively and last follow-up to assess deformity correction and spinal balance.

The magnitude of the curve was measured for curve parameters. Coronal balance (CB), sagittal balance (SB), segmental kyphosis (SK), thoracic kyphosis (TK), and lumbar lordosis (LL) were measured for balance paramenters.[16,17,26–29] The magnitudes of both main and compensatory curves were measured by the Cobb method using the end vertebrae that was determined on the preoperative standing radiographs.

To minimize interobserver measurement error, all radiographs were measured by two authors who did not participate in the operation. The means of the measurements were used for analysis. We calculated the intraclass correlation coefficient (ICC). ICC values for all radiographic parameters exceeded 0.90.

Statistical Analysis

A repeated-measures ANOVA test was performed for comparisons between each dependent variable. *T* test was performed at each time-point as a within-subject variable. A comparison was considered significant at $P < 0.05$.

RESULTS

Deformity Correction

Preoperative radiographic parameters of main curve were not statistically different between the two groups ($P = 0.635$). In Group 1, the preoperative main curve of

TABLE 2. Etiologic Diagnosis

Etiology	Group 1 (N = 19)	Group 2 (N = 26)
Single hemivertebra	11	13
Double hemivertebra	2	2
Multiple hemivertebra	4	7
Hemivertebra with block vertebra	0	2
Hemivertebra with unsegmented bar	2	2

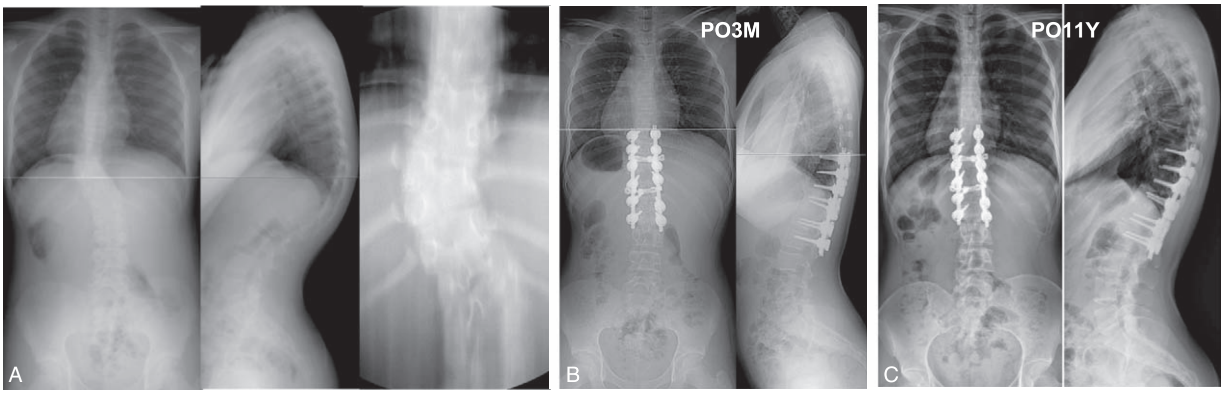

Figure 1. (**A**) A 9-year-old female who had congenital hemivertebra of T11and T12 with 40° of left thoraco-lumbar scoliosis and segmental kyphosis of 54°. (**B**) Postoperative 3 months radiographs showed that the main curve improved to 6° with satisfactory deformity correction. (**C**) Eleven years follow-up radiographs showed that the main curve maintained 7° without curve progression. The preoperative unequal coronal and sagittal balance improved after surgery and were maintained during follow-up period.

44° improved to 10.2° (76.8%) postoperatively and 14.2° (67.7%) at last follow-up (Figure 1A–C). In Group 2, the preoperative main curve of 48.7° improved to 17.2° (64.7%) postoperatively and 20.4° (58.1%) at last follow-up (Figure 2A–C). There was a loss of correction of 9.1% and 6.6% at last follow-up compared with the postoperative values, respectively. There was a significant difference in the correction of the main curve immediate postoperatively ($P=0.029$) and at last follow-up ($P=0.035$) between the two groups (Table 3).

Preoperative radiographic parameters of compensatory cranial curves were statistically different between the two groups ($P=0.027$). There was significant improvement after surgery in both groups. There was a significant difference of the compensatory cranial curve postoperatively ($P=0.002$) but no significant difference at last follow-up ($P=0.123$) in either of the two groups.

Preoperative radiographic parameters of compensatory caudal curve were not statistically different between the two groups ($P=0.658$). For the compensatory curve, there was significant improvement after surgery, and significant difference of compensatory caudal curve postoperatively ($P=0.018$) but no significant difference at last follow-up ($P=0.166$) when comparing the two groups. In both groups, the compensatory cranial curve was less corrected when compared with the compensatory caudal curve postoperatively and at last follow-up, respectively.

Coronal and Sagittal Balance

Preoperative CB and SB were not statistically different in the two groups (Table 4). There was no significant difference of CB and SB postoperatively ($P=0.408$, 0.337) or at last follow-up ($P=0.815$, 0.286), respectively, between the two groups. In both groups, the CB was less influenced by the surgery when compared with SB. CB was maintained during follow-up period, but SB deteriorated during the follow-up period.

Sagittal Plane (Segmental Kyphosis, Thoracic Kyphosis, and Lumbar Lordosis)

All the hemivertebra showed kyphotic deformity (positive value) before surgery (Table 5). There was no significant

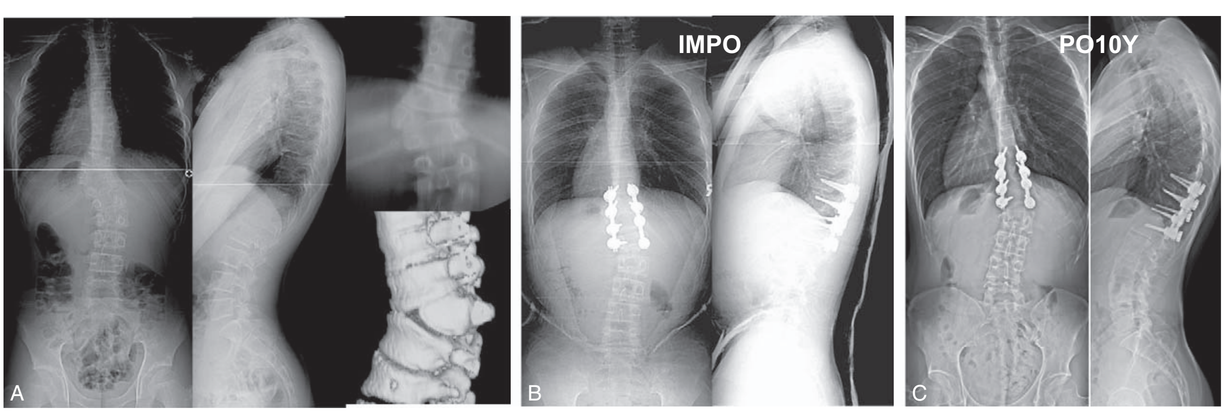

Figure 2. (**A**) A 12-year-old male who had congenital hemivertebra of T11 with 43° of left thoraco-lumbar main curve. Posterior vertebral column resection and bilateral pedicle screw insertion were performed on both T9 and L1. (**B**) Immediate postoperative radiographs showed that the main curve improved to 14°. (**C**) Ten years follow-up radiographs showed that the main curve was changed to16°.

TABLE 3. Main Curve and Compensatory Curve*

Radiographics	Group 1 (Corr)	Group 2 (Corr)	*P*
Main curve (°)			
Preoperative	44.0 ± 15.8	48.7 ± 15.5	0.635
IMPO	10.2 ± 7.1 (76.8 %)†	17.2 ± 7.8 (64.7 %)†	**0.029**
Last follow-up	14.2 ± 9.3 (67.7 %)	20.4 ± 7.4 (58.1 %)	**0.035**
Compensatory cranial curve (°)			
Preoperative	15.9 ± 7.5	24.9 ± 14.2	**0.027**
IMPO	4.9 ± 2.4 (69.2 %)†	11.8 ± 7.9 (52.6 %)†	**0.002**
Last follow-up	7.7 ± 4.6 (51.6 %)	13.1 ± 8.1 (47.4 %)	0.123
Compensatory caudal curve (°)			
Preoperative	22.8 ± 11.4	25.5 ± 10.5	0.658
IMPO	4.7 ± 4.4 (79.4 %)†	9.1 ± 5.9 (64.3 %)†	**0.018**
Last follow-up	7.9 ± 5.0 (65.4 %)	10.9 ± 8.5 (57.3 %)	0.166

*Data represents the mean values for each group.
†Significantly changed from the value of previous time-point.
Significant differences are typed in bold and are accepted for P value <0.05.
Corr indicates correction rate; IMPO, immediate postoperative.*

difference of SK immediate postoperatively ($P = 0.492$) and at last follow-up ($P = 0.741$) between the two groups.

There was no significant difference of TK and LL postoperatively ($P = 0.469$, 0.452) and at last follow-up ($P = 0.868$, 0.734), respectively, between the two groups. In both groups, the preoperative LL and TK was within normal range and this was maintained postoperatively and at last follow-up and showed no significant changes during the follow-up period. The values of the TK and LL were less influenced by the hemivertebra resection because of the compensation within the adjacent segments.[6]

Operative Data

Operative data pertaining to study group was reported in Table 1. There was a significant difference in operative time between the two groups. Estimated blood loss (EBL) was much higher in Group 2 (2379 mL) than in Group 1 (1285 mL). However, EBL per kilogram was not significant different between the two groups (Group 1: 53 mL/kg *vs.* Group 2: 48 mL/kg).

Complications

There were 22 complications in 16 patients and the overall incidence of complications was 48.9% (Table 6). There were four cases of postoperative transient neurologic deficits (one case in Group 1 and three cases in Group 2) that recovered within 3 months. Two of them were caused by hematoma, which was evacuated immediately. There was one case of superficial wound infection that was treated by incision and drainage in Group 2. There was 1 case of screw malposition in Group 2 but no major vascular or permanent neurological complications related to the pedicle screws inserted, in either group.

There were several late postoperative complications as follows. (A) Four cases of screw pull-out and/or metal failure (one case in Group 1 and three cases in Group 2)

TABLE 4. Coronal and Sagittal Balance*

Radiographics	Group 1 (N = 19)	Group 2 (N = 26)	*P*
Coronal balance (mm)			
Preoperative	9.8 ± 8.3	12.7 ± 9.4	0.390
IMPO	7.8 ± 4.8	10.9 ± 13.8	0.408
Last follow-up	9.4 ± 5.9	8.8 ± 7.7	0.815
Sagittal balance (mm)			
Preoperative	−1.5 ± 28.5	8.7 ± 22.5	0.490
IMPO	6.3 ± 17.3	1.1 ± 21.8	0.337
Last follow-up	24.7 ± 24.2†	16.3 ± 19.5†	0.286

*Data represents the mean values for each group.
†Significantly changed from the value of previous time-point.
IMPO indicates immediate postoperative.*

TABLE 5. Sagittal Plane*			
Radiographics	Group 1 (N = 19)	Group 2 (N = 26)	*P*
Segmental kyphosis (°)			
Preoperative	25.0 ± 12.1	36.2 ± 20.6	0.086
IMPO	6.8 ± 10.6†	10.0 ± 14.4†	0.492
Last follow-up	7.0 ± 10.2	8.3 ± 14.1	0.741
Thoracic kyphosis (°)			
Preoperative	25.9 ± 14.1	23.5 ± 19.2	0.700
IMPO	19.6 ± 0.0	22.7 ± 12.0	0.469
Last follow-up	24.8 ± 5.5	24.3 ± 11.2	0.868
Lumbar lordosis (°)			
Preoperative	43.9 ± 16.6	41.9 ± 20.6	0.777
IMPO	35.0 ± 14.2	38.6 ± 12.2	0.452
Last follow-up	42.3 ± 12.5	40.7 ± 13.7	0.734

Data represents the mean values for each group.

†Significantly changed from the value of previous time-point.

IMPO indicates immediate postoperative.

which consisted of a broken rod with distal screw pull-out of which two cases were treated by revision surgery. (B) Five patients (three cases in Group 1 and two cases in Group 2) showed adding-on deformity with a progression of the curve. Of these five patients, two were treated by brace (Figure 3A–C) and three were treated by revision surgery. (C) There were two cases of late infections who were treated by implant removal (1 case in Group 1 and 1 case in Group 2). (D) There were no cases of crankshaft phenomenon at the most recent follow-up in either of the group.

DISCUSSION

Congenital scoliosis due to a hemivertebra usually creates a wedge-shaped deformity, which progresses and causes severe spinal deformity during the growth spurt and compensatory curves develop to preserve trunk balance. Because of the predicted poor prognosis of most hemivertebra, early surgical treatment is recommended in most cases.[13–15,30–32] Delayed treatment of this kind of deformity will necessitate long fusion with a high risk of neurologic complications. Therefore, treatment for congenital scoliosis due to a hemivertebra may include early diagnosis and appropriate surgical management to prevent further progression.

PVCR was first reported by Suk *et al*[18] who introduced the technique of vertebral column resection through a posterior-only approach for fixed lumbar deformities and severe rigid scoliosis.[9,10] Many authors reported series of PVCR sequentially. The development of the PVCR technique has aimed at the reduction of technical difficulties, operation time, and complications of the traditional anterior-posterior vertebral column resection (VCR) whether performed as a single procedure or in a staged fashion.[32]

Pedicle subtraction osteotomies (hemivertebra excision) remove the pedicle and vertebral body (hemivertebra) with no touch of discs above and below. However, PVCR resects

TABLE 6. Complications		
Complications	Group 1 (N = 19)	Group 2 (N = 26)
Early complications		
Transient neurologic deficit	1	3
Dura tear	1	2
Hematoma	1	1
Wound infection, superficial	0	1
Wound infection, deep	0	0
Screw malposition	0	1
Major vascular injury	0	0
Late complications		
Permanent neurologic deficit	0	0
Metal failure or screw pull-out	1	3
Curve progression or adding-on	3	2
Wound infection	1	1
Crankshaft phenomenon	0	0

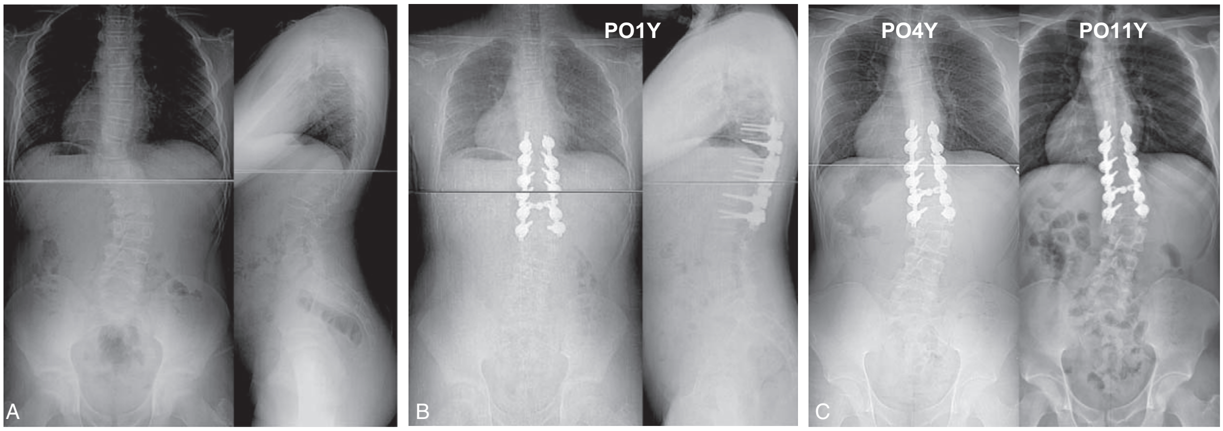

Figure 3. (**A**) A 13-year-old male who had congenital hemivertebra of T11 with 41° of left thoraco-lumbar main curve. (**B**) Postoperative 1-year follow-up radiographs showed that the main curve improved to 10°. (**C**) Four years and 10 years follow-up radiographs showed that distal lumbar curve somewhat progressed during follow-up period with treatment by brace.

not only pedicle and vertebral body (hemivertebra) but also discs above and below and obtains body-to-body contact.[16–20] PVCR could correct more deformity corrections especially kyphotic deformity through sufficient shortening of posterior column and achieve more bony union through bone-to-bone contract of vertebral body even if the coronal curves were not severe. Therefore, PVCR is a very powerful operative method and is reserved for severe spinal deformity.

Until now there have been no reports on surgical outcomes of PVCR and fusion with PSF by the age at the time of surgery in children under age 18 years for congenital scoliosis with a long-term follow-up (over 10 years). Therefore, we focused on the deformity correction before and after the age of 10 years but less than 18 years of age, and the long-term effects on the growing spine in the treatment of congenital scoliosis.

According to the results of our study, preoperative radiographic parameters of main curve were not statistically different in the two groups. However, comparison by the age at the time of surgery showed that preoperative values of the main curve were larger in Group 2 than in Group 1. This assumed that Group 2 surgery was performed for more rigid curves, that the deformity had extended, and that structural change had taken place in the adjacent segments during growth.[17] Both groups showed improvement of the main curve after surgery; however, there was a significantly better correction of main curve in Group 1 postoperatively and at last follow-up compared with Group 2. These results imply that Group 1 may result in more satisfactory radiologic outcomes for main curve corrections. Therefore, PVCR and fusion with PSF before age 10 years had significantly better deformity correction compared with the group treated after 10 years of age. Our main curve correction rates of 76.8% and 64.7% after surgery, 67.7% and 58.1% at last follow-up, respectively, were similar but a little better than these previous reports.[12,16,17,22,25,33–36] These results proved the long-term follow-up effects of PVCR in the treatment of congenital scoliosis. Surgical timing is an important factor and early surgery had significantly better deformity correction that may be closely related to the fusion level in the treatment of congenital scoliosis. Fusion level should be selected for deformity correction and preventing the curve progression as well as reducing the influence of adjacent vertebral growth but as short fusion as possible. It is sufficient to PVCR with mono-segmental or two level fixation in young children under 6 years of age, before structural changes occur at above and below. Otherwise, fusion of more than two or three levels above and below the PVCR is usually recommended in children of older age because short fusion with PVCR may cause adding-on deformity when the levels are fused with segmental pedicle screw fixation. However, there was a more loss of correction in Group 1 (9.1%) than in Group 2 (6.6%) at last follow-up compared with the postoperative values. This may be related to the high stress due to the vertebral growth in Group 1.

When considering the compensatory curve, there was a significant difference of compensatory cranial curve preoperatively and postoperatively. Compensatory cranial curve corrections have been reported at 30% to 78%.[11,12,33,35] In our study, corrections of compensatory cranial curve were as follows: in Group 1, 69.2% postoperatively and 51.6% at last follow-up and in Group 2, 52.6% postoperatively and 47.4% at last follow-up. There has been reported about 60% correction in the caudal compensatory curves.[11,12,16,17,33,35] This study showed that compensatory caudal curve corrections were: in Group 1, 79.4% after surgery was maintained at 65.4% and in Group 2, 64.3% after surgery was 57.3% at last follow-up. The effect of the timing of surgery on compensatory curves was significantly different postoperatively between the two groups showing a significant improvement of the compensatory curve in group 1. In both groups, the cranial compensatory curve was less corrected when compared with the caudal compensatory curve postoperatively and at last follow-up, respectively.

These results might be closely correlated with the ribs of the thoracic cage which may cause the difficulty in correction of the cranial compensatory curves.[16,17]

Anterior fusion across the resection gap was performed in all patients. The anterior column reconstruction was performed with autogenous cancellous bone graft in all patients and additional insertion of titanium mesh in four patients. After resection and deformity correction, the height of anterior interbody gap was measured. If the shortest height was less than 5 mm, autogenous cancellous chip bone was put into the anterior gap. If the height was more than 5 mm, a titanium and additional autogenous bone was put around the titanium mesh which was used to provide reliable anterior column reconstruction without excessive shortening. Titanium meshes also had the advantage of offering additional stability because they were strong enough to be punched in and serrated at both ends so that they could be sunk into the bone beds with compression. This could provide structural support for load transfer from above to below the resected vertebrae during the period before bony fusion is complete.[18–20]

Regarding the complications, there were 22 complications in 16 patients and the overall incidence of complications was 48.9%. The complication rate was much higher in Group 2 (53.8%) than in Group 1 (42.1%). One major concern of PVCR is the risk of neurologic complications. In this study, there were four cases of transient neurologic deficit (one case in Group 1 and three cases in Group 2) that were graded D according to American Spinal Injury Association (ASIA) impairment scale but none were permanent and recovered to grade E in all cases. This may be related to the fact that the spinal cord and nerve roots were under direct vision during the PVCR and direct injury could be avoided.

Crankshaft phenomenon results from the continued growth of the anterior column in the presence of a posterior tether that causes rotation of the fused segments. This mainly occurs in the immature patients below the age of 10 years who have open triradiate cartilages. In our study, there were no cases of crankshaft phenomenon in both groups. That was prevented by the biomechanical characteristics of the pedicle screws that served as a structural tie and resistance to the longitudinally directed forces through the three columns of the spinal vertebra.[12,13] Furthermore, there was no patient showing indentation of the dura due to the screws or any patients who showed symptoms of neurogenic claudication that would be suggestive of spinal stenosis. This result implies that transpedicular screws that cross the neurocentral synchondrosis have no major adverse effects because of the instrumentation, particularly, no spinal stenosis or neurologic deficit. The absence of iatrogenic spinal stenosis in our study may be attributable to the patients' age at the time of surgery being more than 2.4 years, when the spinal canal was nearly fully mature.[14–17] Chang *et al*[16] reported about continued growth in the instrumented levels and appositional growth at the periosteum and epiphysis of the vertebra body could be the cause of continued growth of vertebral body.

In this study, five of patients showed the adding-on phenomena with a progression of the curves that were three cases in Group 1 and two cases of Group 2. There was one case of main curve progression (Group 1) and four cases of compensatory curve progression (Group1: two cases *vs.* Group 2: two cases). The need for revision surgery for curve progression may be due to incomplete hemivertebra resection, improper fusion levels, or failure of anterior/posterior fusion. Main curve progression may be due to incomplete hemivertebra resection and/or improper fusion levels. The remnant of the hemivertebra remaining after surgery may cause deterioration of the main curve as well as the compensatory curves. On the other hand, patients with progression of compensatory curves had no increased curvature at PVCR levels that were fused with segmental PSF. This may be due to a short fusion that may induce increased curvature more than 20° above and below the fusion levels. It is important that the adjacent compensatory curve be corrected to less than 20°.

This study has some limitations. This is a retrospective study and does not contain clinical results. Cosmesis in congenital scoliosis plays an important role in patients' satisfaction of surgical outcomes. This study was evaluated only by radiographic parameters without any corresponding cosmetic parameters. Further trials are needed to establish a correlation between radiologic correction and clinical outcome (Scoliosis Research Society scores-24, Visual Analog Scale, Oswestry Disability Index). The second limitation of this study is that the number of patients was small and further study with a large number of cases will be needed to confirm our results.

In conclusion, PVCR is an effective procedure for the management of congenital scoliosis under age 18. PVCR and fusion with PSF for congenital scoliosis before the age of 10 years had significantly better deformity correction. Early surgical correction of a congenital hemivertebra in children under 10 years of age, before structural changes occur effectively achieves a more satisfactory correction with short fused segments compared to children older than 10 years but under 18 years of age.

Key Points

- This is the first long-term follow-up report after PVCR and fusion with PSF that pertain to the timing of surgery for congenital scoliosis in children under age 18 years.
- PVCR in congenital scoliosis is an effective procedure that may achieve rigid fixation, satisfactory deformity correction without an anterior surgical approach.
- PVCR and fusion with PSF for congenital scoliosis before the age of 10 years had significantly better deformity correction compared with the group

after the age of 10 years and did not cause crankshaft phenomenon.

Acknowledgments

The authors thank Dr. P William Haake for English-language editing and Jihyun Nam for statistical analysis of this paper.

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