CLINICAL ARTICLE

Individualized Study of Posterior Hemivertebra Excision and Short-Segment Pedicle Screw Fixation for the Treatment of Congenital Scoliosis

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Objectives: To compare the surgical effect of children with symmetrical screw fixation and asymmetric screw fixation during posterior hemivertebra excision and short-segment pedicle screw fixation for the treatment of congenital scoliosis (CS).

Methods: A total of 30 children with CS who underwent posterior hemivertebra excision and short-segment bilateral pedicle screw fixation in our hospital from 2012 to 2018 were retrospectively included and were divided into two groups: symmetric fixation group (n = 18) and asymmetric fixation group (n = 12). The total main curve, segmental main curve, cranial compensatory curve, caudal compensatory curve, coronal balance, and apical vertebra translation were measured in the coronal plane. The segmental kyphosis, thoracic kyphosis, lumbar lordosis, and sagittal balance were measured in the sagittal plane.

Results: Of the 30 children, 28 hemivertebrae were resected. Twenty-two children had one hemivertebra, three had two hemivertebrae, and five were rib deformities. The average operation time was 268 min (180–420 min). The average blood loss was 291 mL (150–550 mL). The average follow-up was 21.1 months (12–47 months). For symmetric fixation group and there were significant differences among postoperative and follow-up parameters including the total main curve, segmental main curve, cranial compensatory curve, caudal compensatory curve, apical vertebra translation and segmental kyphosis compared with those of preoperative parameters ($P < 0.05$). The postoperative coronal balance was significantly lower than preoperative coronal balance ($P < 0.05$). The follow-up thoracic kyphosis was significantly higher than preoperative and postoperative thoracic kyphosis ($P < 0.05$). For asymmetric fixation group, the postoperative and follow-up parameters including the total main curve, segmental main curve, cranial compensatory curve, caudal compensatory curve, apical vertebra translation, and segmental kyphosis had statistical differences compared with those of preoperative parameters ($P < 0.05$). The postoperative sagittal balance was significantly higher than preoperative postoperative ($P < 0.05$). There were no significant differences in the postoperative and follow-up correction rate and correction loss between the two groups ($P > 0.05$). There were three complications in 30 children in our study, including two cases who had poor wound healing, and the wound healed smoothly after half a month of sterile dressing change. Postoperative curve progression occurred in one case after T_{12} and L_3 hemivertebra resection and thoracic hemivertebra resection was planned again.

Conclusion: For pedicles which were difficult for screw fixation, adjacent segments can be chosen for screw fixation and it is safe and effective for vertebral pedicles ≤3 without internal fixation.

Key words: Asymmetric fixation; Congenital scoliosis; Hemivertebra; Short segment; Spinal fusion

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Introduction

Hemivertebra produced by the complete failure of unilateral formation is the most common cause of congenital scoliosis (CS)[1]. The natural history of CS has been well-documented. The deterioration rate and ultimate severity of this spinal deformity due to hemivertebra depend on patient age, vertebral anomaly size and type, and location at which it occurs[2]. Hemivertebra can be divided into three types including fully segmented, semi-segmented, or unsegmented varieties. The most rapidly developing type of malformation is a fully segmented hemivertebra with a bone bridge, followed by two unilateral hemivertebrae and a single hemivertebra. Non-occluded hemivertebrae have growth potential, and the resulting scoliosis is usually more severe and more difficult to be corrected by non-surgical treatments, which requires surgical correction[3, 4]. Hemivertebra should be treated at the earliest patient age before the deformity extends and structural differentiation takes place in the adjacent segments[5]. Early surgery in young children prevents the development of several local deformities and secondary structural curves, thus allowing normal growth in the unaffected parts of the spine.

Various surgical treatment modalities that have been described are *in situ* posterior spinal fusion, combined anterior and posterior *in situ* spinal fusion, convex hemiepiphysiodesis[6] and hemivertebra excision[7]. However, hemivertebra excision is the only perpetually corrective therapy[8]. Since the publication of the first hemivertebra resection case by Royle in 1928, it has been proven to be reliable and effective in correcting deformities by several studies[9, 10]. In recent years, the application of posterior hemivertebra excision in children with early-onset CS has proven to be a safe and effective surgical method[11–13]. After the hemivertebra is removed, an internal fixation system with a laminar hook or a pedicle screw is used to stabilize the osteotomy. The orthopaedic brace should be worn for protection for 3–6 months after the operation to guard against postoperative complications such as broken screws, broken rods, and fractures in the internal fixation site.

At present, the most commonly used internal fixation method in posterior hemivertebra excision is a double-rod transpedicular internal fixation system. Strong and effective internal fixation is performed on both sides of the vertebra to ensure the safety and stability of orthopaedics. In order to reduce the influence on the growth and development of children's spines, the fixed segment should be as short as possible, usually only one or two vertebrae adjacent to the resected hemivertebra are fixed[14]. However, in clinical practice, screw fixation is extremely difficult since one or both of the vertebral pedicles are often deformed or absent and asymmetric fixation occurs[15]. In this study, we aim to compare: (i) the preoperative, postoperative and follow-up X-ray parameters in the coronal plane and sagittal plane; (ii) postoperative and follow-up correction rate; and (iii) postoperative and follow-up correction loss of children of symmetrical screw fixation with asymmetric screw fixation during posterior hemivertebra excision and short-segment pedicle screw fixation for the treatment of CS.

Patients and Methods

Patient

A total of 30 children with CS who underwent posterior hemivertebra excision/osteotomy and short-segment bilateral pedicle screw fixation in our hospital from 2012 to 2018 were retrospectively included. The study was approved by the medical ethics committee of our hospital, and signed informed consent was obtained from the children's guardians.

Inclusion criteria were patients: (i) with CS, single or multiple hemivertebra deformities, or osteoporosis; (ii) who underwent one-stage posterior hemivertebra excision osteotomy and short-segment bilateral pedicle screw fixation; and (iii) with a follow-up period of 12 months. Exclusion criteria were: (i) patients with previous spinal surgery history; (ii) combined with high scapularis.

Thirty children were divided into two groups: symmetric fixation group (n = 18) and asymmetric fixation group (n = 12).

Surgical Technique

All children underwent posterior hemivertebra excision/osteotomy and short-segment bilateral pedicle screw fixation (Fig. 1)[8, 16]. Spinal nerve monitoring was performed during the operation. After successful general anesthesia, the child was placed in the prone position. Subperiosteal dissection was performed carefully to expose the posterior spinal elements at the affected and adjacent levels, including the articular process, facet joint, and lamina. Fluoroscopy was performed to identify the vertebrae and adjacent pedicles. If no obvious deformity was found in the pedicle, symmetric fixation was performed (symmetrical fixation group); if the pedicle was deformity or absent, adjacent segments can be chosen for screw fixation instead (asymmetric fixed group).

Needle positioning was used to locate hemivertebra/bridge deformity and adjacent vertebral body pedicle. The cortical bone at the point of entry was drilled. After needle positioning with a 1.5 mm Kirschner wire, C-arm fluoroscopy was performed again to confirm the correct insertion point. The hole was marked with a 1.5 cm reamer and a pedicle screw with a diameter of 3.5–5.5 mm and a length of 35–45 mm was inserted to the normal upper and lower vertebrae. The posterior pedicle and superior and inferior nerve roots of the posterior hemivertebra were subsequently exposed, and the vertebral bodies and intervertebral discs were exposed. The posterior structures of the hemivertebra were removed, including the lamina, articular process, transverse process, and part of the pedicle. Exfoliate along the vertebral arch base to protect the nerve root and blood vessels, exfoliate outwards to expose the lateral side of the vertebral body as much as possible, and exfoliate inwards to protect the spinal cord until the complete vertebral body is exposed.

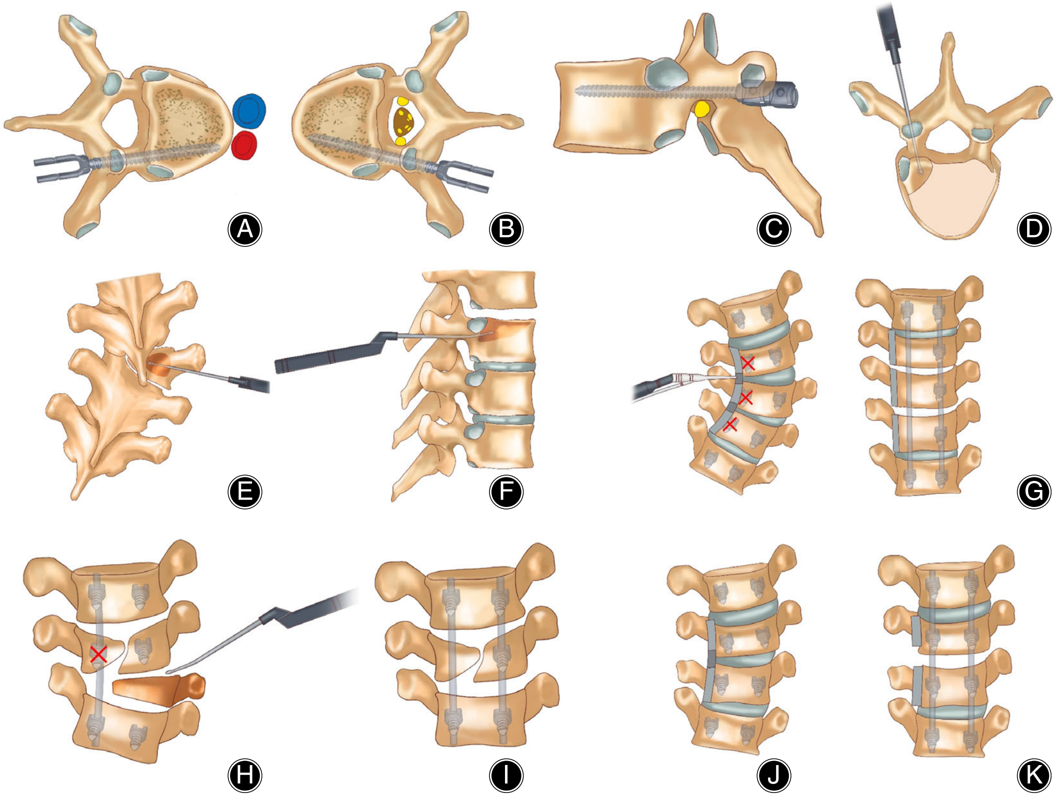

Fig. 1 Surgical diagrams. (A, B and C) After fully exposed, the screw were inserted after positioning. Do not insert screws beyond the anterior cortex to cause vascular damage. (D, E and F) The cancellous bone of the vertebral body was completely hollowing out and the endplate and intervertebral disc were removed. (G) For children with bone bridges, the bone bridges and the tethering effect were removed. For malformed pedicles that are not suitable for screw placement, no screws are placed. (H and I) The hemivertebra body was excised, and no screws are placed for pedicles that are not suitable for screw placement. Before the hemivertebra was removed, the rod can be placed on the opposite side to maintain stability. (J and K) After evaluation, the pedicles that can be normally placed.

The rib head and proximal part of the surplus rib on the convex side were exposed and resected, during which the pleura was protected carefully.

For children with a bone bridge, a bone bridge resection should be performed. For children with unilateral laminar fusion, part of the lamina needs to be removed. A pre-contoured rod was applied on the concave side to stabilize the spine before removing the vertebral body. The upper and lower discs, including the cartilage endplate, were completely removed from the bleeding bone. The anterior vessels were carefully handled to avoid injury during the entire procedure. Grade 2–3 osteotomy was performed in older children with lateral segment stiffness. A pre-contoured rod was applied on the convex side. Gradual compression was performed while leaving the concave rod unlocked until the gap was closed. The orthosis was kept for 6 months.

X-Ray Parameters Assessment

The following X-ray parameters were measured, which were all reported in previous studies[5, 17, 18]. The total main curve, segmental main curve, cranial compensatory curve, caudal compensatory curve, coronal balance, and apical vertebra translation were measured in the coronal plane. The segmental kyphosis, thoracic kyphosis, lumbar lordosis, and sagittal balance were measured in the sagittal plane. Whole-spine standing posteroanterior and lateral X-rays obtained preoperatively, postoperatively, and at the last follow-up were reviewed to assess deformity correction.

Main and Compensatory Curves

The magnitude of curve in both main and compensatory curves was measured by the Cobb method using the end vertebrae that was determined on the preoperative standing radiographs[19].

Coronal Balance

Coronal balance was measured by the deviation of C_7 plumb line from center sacral vertical line. It was considered significant when the deviation exceeded 20 mm. Coronal balance were measured on standing radiographs.

Segmental Kyphosis
Segmental angles of kyphosis/lordosis were measured from the upper endplate of above the hemivertebra to the lower endplate below the hemivertebra.

Thoracic Kyphosis
Thoracic kyphosis was measured from the upper endplate of the T_5 to the lower endplate of T_{12}.

Lumbar Lordosis
Lumbar lordosis was measured from the upper plate of the T_{12} to the upper endplate of the sacrum.

Sagittal Balance
Sagittal balance was measured as the distance from the C_7 plumb line to a perpendicular line drawn from the posterosuperior corner of the sacrum and designated positive (+) when the C_7 plumb line was anterior to the posterosuperior corner of the sacrum and negative (−) when the C_7 plumb line was posterior to the posterosuperior corner of the sacrum. A deviation greater than 20 mm was considered decompensation.

Correction Rate
Postoperative correction rate of each X-ray parameter = (preoperative − postoperative)/preoperative × 100%. The follow-up correction rate of each X-ray parameter (preoperative − follow-up)/preoperative × 100%. Correction loss = follow-up − postoperative.

Statistical Analysis
Statistical analysis was performed using SPSS 21.0 software. Values are presented as mean ± standard deviation (SD). One-way ANOVA was used for the comparison of X-ray parameters in each group. For the comparison of X-ray parameters between two groups, normally distributed data were compared by two independent samples *t*-test and variables of skewed distribution were compared by Wilcoxon rank sum test. A P value of less than 0.05 was considered statistically significant.

Results

General Results and Follow-Up
All surgeries were performed by the same surgeon. Of the 30 children, 28 hemivertebrae were resected. Twenty-two children had one hemivertebra, three had two hemivertebrae, and five had rib deformities. The average operation time was 268 minutes (180–420 min). The average blood loss was 291 mL (150–550 mL). The average follow-up was 21.1 months (12–47 months). The basic information of all children were shown in Table 1. As shown in Table 2, there were no significant differences in the basic information including age, gender, preoperative Cobb angle, location of the deformity, follow-up time, and image classification between the two groups ($P > 0.05$). It is accepted that in congenital scoliosis a worsening of the Cobb angle of at least 10° is sufficiently significant to be termed an aggravation[20]. Three cases were shown in Figs 2, 3, and 4.

Main and Compensatory Curves
For symmetric fixation group, the postoperative total main curve (6.3° ± 3.3°), segmental main curve (8.8° ± 5.7°), cranial compensatory curve (7.0° ± 7.6°), and caudal compensatory curve (7.1° ± 4.2°°) were significantly lower than preoperative parameters (22.8° ± 6.8°, 30.6° ± 7.8°, 13.7°± 10.2° and 14.5° ± 7.0°, respectively) ($P < 0.05$). Similarly, the follow-up parameters including the total main curve (10.7° ± 5.5°), segmental main curve (10.7° ± 7.1°), cranial compensatory curve (7.7° ± 7.4°), and caudal compensatory curve (7.4° ± 3.2°) had significant differences compared with preoperative parameters (22.8° ± 6.8°, 30.6° ± 7.8°, 13.7° ± 10.2° and 14.5° ± 7.0°, respectively) ($P < 0.05$). The follow-up total main curve (10.7° ± 5.5°) was significantly higher than postoperative total main curve (6.3° ± 3.3°) ($P < 0.05$).

For asymmetric fixation group, the postoperative total main curve (8.4° ± 6.8°), segmental main curve (15.5° ± 9.1°), cranial compensatory curve (4.0°± 4.3°), and caudal compensatory curve (5.9° ± 3.9°) had significant differences compared with preoperative parameters (24.9° ± 7.9°, 30.5° ± 10.1°, 15.2° ± 17.1° and 10.9° ± 4.5°, respectively) ($P < 0.05$). The follow-up parameters including the total main curve (11.1° ± 7.5°), segmental main curve (18.6° ± 9.7°), cranial compensatory curve (4.8° ± 4.9°), and caudal compensatory curve (6.9° ± 4.1°) had significant differences compared with preoperative parameters (24.9° ± 7.9°, 30.5° ± 10.1°, 15.2° ± 17.1° and 10.9° ± 4.5°, respectively) ($P < 0.05$) (Table 3).

Coronal Balance
For symmetric fixation group, the postoperative coronal balance (8.3 ± 7.4) was significantly lower than preoperative parameter (15.7 ± 12.5) ($P < 0.05$). For asymmetric fixation group, there were no significant differences in the preoperative, postoperative, and follow-up coronal balance (Table 3).

Segmental Kyphosis
For symmetric fixation group, the postoperative segmental kyphosis (3.8° ± 11.7°) and follow-up segmental kyphosis (5.3° ± 12.1°) were significantly lower than preoperative parameter (19.0° ± 16.6°) ($P < 0.05$). For asymmetric fixation group, the postoperative segmental kyphosis (5.7° ± 4.1°) and follow-up segmental kyphosis (6.5° ± 6.9°) were significantly lower than preoperative parameter (23.1° ± 10.5°) ($P < 0.05$) (Table 3).

Thoracic Kyphosis
The follow up thoracic kyphosis (27.3° ± 7.3°) was significantly higher than preoperative (21.2° ± 7.5°) and postoperative thoracic kyphosis (20.8° ± 7.7°) in symmetric fixation group ($P < 0.05$) (Table 3).

TABLE 1 Basic information

Case no.	Gender	Age (Years)	Follow-up (Months)	Associated anomalies	Complications	Hemivertebra	Fixed segment	Number of unscrewed pedicles	Operating time (min)	Bleeding volume (mL)
1	Male	3	47	Low spinal cord; Myelocyst		T3, T5	4	0	320	200
2	Female	6	26	Lumbosacral spina bifida; Low spinal cord; Diastematomyelia	Poor wound healing	L5	3	0	180	200
3	Male	6	12	Tethered spinal cord; Diastematomyelia; Syringomyelia		L5	3	0	400	500
4	Male	4	14			L2	4	0	240	300
5	Female	7	16	Rib deformity; Bifid sacrum; Sacral canal cyst		T10	5	0	420	500
6	Male	10	12	Rib deformity		T5 rib vertebral deformity	5	0	320	400
7	Female	4	14	Bifid sacrum		L4	2	0	300	250
8	Male	2	36	Malrotation of the left kidney		L2	4	0	180	200
9	Female	7	20	Lumbosacral spina bifida		T11	4	0	180	180
10	Female	10	12			L5	4	0	420	500
11	Female	1.5	36	Bifid sacrum		L1	3	0	180	200
12	Male	2.5	12	Lumbosacral spina bifida		L2	2	0	300	400
13	Male	4	12			T12	4	0	180	200
14	Male	9	16	Bifid sacrum	Poor wound healing	L4	2	0	300	400
15	Male	3	14	Bifid sacrum		L4	4	0	180	150
16	Male	3.5	24			T9	2	0	180	200
17	Female	5	12			T10	2	0	240	300
18	Male	2	12	Multiple vertebral deformity	Postoperative curve progression	T12, L3	4	0	320	300
19	Male	9	41	Diastematomyelia		T9 hemivertebra, T9-T10 bonebridge	4	1	240	300
20	Female	3	34	Lumbosacral spina bifida		T9	3	1	300	300
21	Female	3	33	Lumbosacral spina bifida; Diastematomyelia; Low spinal cord		L5	5	1	180	150
22	Male	5.5	16	Low spinal cord; Diastematomyelia; Terminal filament lipoma		T5-7 rib vertebral deformity, bonebridge	6	3	300	300
23	Female	2.5	16	Lumbosacral spina bifida		T10	4	2	300	200
24	Male	3	18			T5、T7	4	1	320	550
25	Female	3	12	Anal stenosis		L5	3	1	180	200
26	Male	4	35			L2	3	1	240	300
27	Male	9	42	Bifid sacrum; Diastematomyelia		T10, T11 vrtebral fusion	7	3	420	300
28	Male	2	12	Ventricular septal defect		T6	4	1	240	250
29	Female	3	12			L1	4	1	180	350
30	Male	2	14	Diastematomyelia; Tethered lower spinal cord; Terminal filament fatty deposits		T6-8 rib vertebral deformity, bonebridge	5	3	300	150

TABLE 2 Baseline information

Indicators (*n*, %)	Symmetric fixation group (*n* = 12)	Asymmetric fixation group (*n* = 18)	χ^2	*P* value
Age (years)			0.156	0.693
≤5	9 (75.0)	11 (61.1)		
>5	3 (25.0)	7 (38.9)		
Gender			0.000	1.000
Male	7	11		
Female	5	7		
Preoperative Cobb angle (°, Severity)			1.220	0.748
10–20	2 (16.7)	2 (11.1)		
20–30	5 (41.7)	7 (38.9)		
30–40	2 (16.7)	6 (33.3)		
>40	3 (25.0)	3 (16.7)		
Location of the deformity			1.391	0.238
Upper thoracic vertebrae	0 (0.0)	2 (11.1)		
Main thoracic vertebrae	6 (50.0)	1 (5.6)		
Thoracolumbar vertebrae	4 (33.3)	9 (50.0)		
Lumbar and lumbosacral vertebrae	2 (16.7)	6 (33.3)		
Follow-up time (months)			1.38	0.502
≤12	3 (25.0)	7 (38.9)		
12–24	4 (33.3)	7 (38.9)		
>24	5 (41.7)	4 (22.2)		
Image classification			4.052	0.256
Partially segmented upper vertebra	3 (25.0)	6 (33.3)		
Fully segmented upper vertebra	4 (33.3)	9 (50.0)		
2 or more hemivertebra	1 (8.3)	2 (11.1)		
Bone bridge	4 (33.3)	1 (5.6)		

Lumbar Lordosis

No significant differences were observed in the postoperative and follow-up lumbar lordosis in the two groups (Table 3).

Sagittal Balance

For asymmetric fixation group, the postoperative sagittal balance (17.5 ± 18.6) was significantly higher than preoperative sagittal balance (−0.1 ± 19.0) ($P < 0.05$) (Table 3).

Correction Rate

There were no significant differences in the postoperative and follow-up correction rate and correction loss between the two groups (Table 4).

Complications

There were three complications in 30 children in our study, including two cases who had poor wound healing, and the wound healed smoothly after half a month of sterile dressing change. Postoperative curve progression occurred in one case after T_{12} and L_3 hemivertebra resection and thoracic hemivertebra resection was planned again.

Univariate Analysis

Age, gender, follow-up time, and location of the deformity were included in the univariate analysis and age, gender, follow-up time, and location of the deformity were not predictors for the functional outcomes ($P > 0.05$).

Discussion

In this study, we compared the surgical effect and follow-up orthopaedic maintenance of children with symmetrical screw fixation and asymmetric screw fixation. There was no loss of correction at follow-up for children undergoing asymmetric internal fixation. Therefore, for pedicles which were difficult for screw fixation, adjacent segments can be chosen for screw fixation instead. In addition, it is safe and effective for vertebral pedicles ≤3 without internal fixation.

A comparative study conducted by Chang *et al.* showed that, compared with patients who received treatment after the age of 6 years old, patients who received treatment before the age of 6 years old had significantly better results in correcting deformity and had no negative impact on the growth of vertebral body or spinal canal[5]. Up to now, there has been no agreement on the appropriate time for surgery, but most opinions suggest early surgery after 1 year of age[21]. Therefore, the early diagnosis and surgical treatment of early-onset CS is very important. The children in this study were 1.5–10 years old, with an average of 4.6 ± 2.6 years, and all were considered as having early treatment.

Early correction of early-onset scoliosis in young children is very important and requires internal fixation with small damage, firm fixation, and small impact on growth[22]. Pedicle screws are a very effective orthopaedic method, which is more suitable than other instrument systems for transmitting corrective force to the vertebral body of young children's spines[22]. After posterior hemivertebra resection, the short segment is fixed internally with a screw rod system through the pedicle, pressurized on the convex side, and

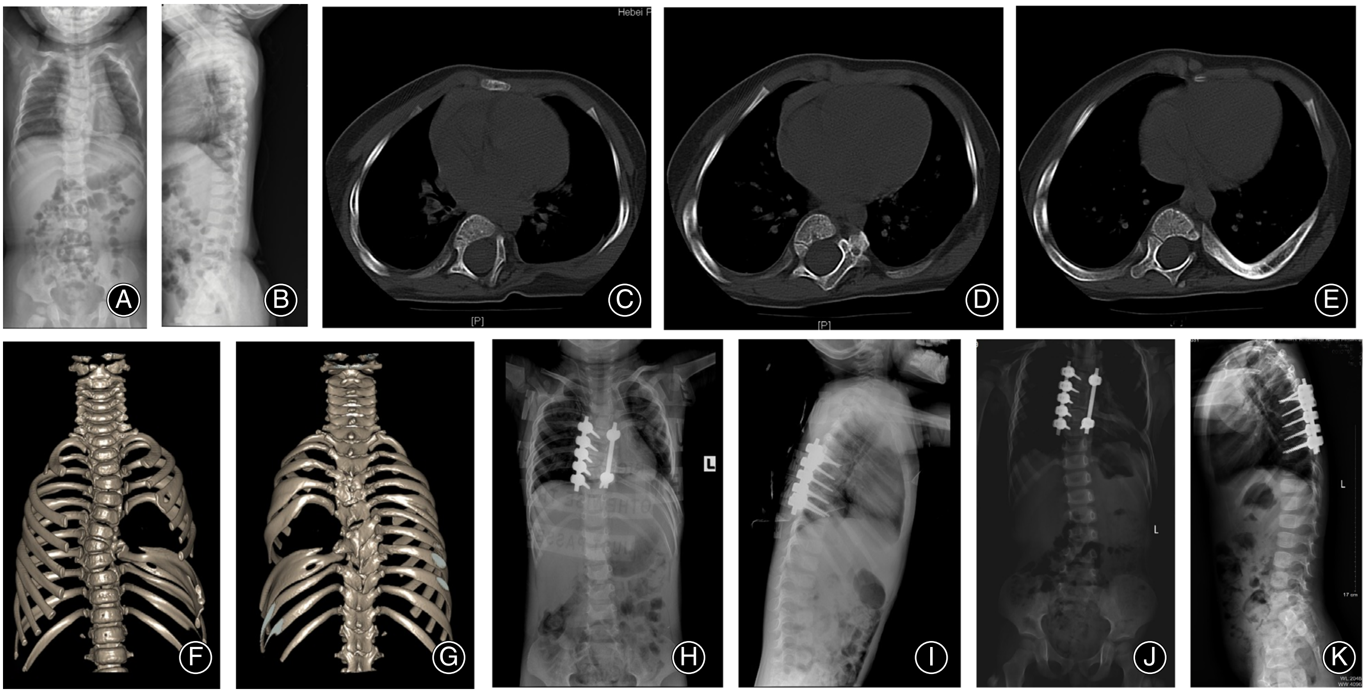

Fig. 2 A 2-year-old male patient who underwent posterior hemivertebra excision and short-segment bilateral pedicle screw fixation for the treatment of CS. The patient was followed up for 14 months. (A, B) Preoperative positive and lateral X-rays of the entire spine showed vertebral deformities in T_{6-8} and multiple costal vertebrae deformities; (C, D and E) CT showed deformity and absence of the pedicle; (F, G) CT three-dimensional reconstruction showed left lamina fusion of T_6 and T_7. T_{6-8} shares the same internal rib. The surgery requires removal of T_5, T_6, T_7, and T_8 lamina to relieve the unilateral tethering effect of the bone bridge on the spine. During the operation, T_6, T_7, and T_8 were found to have deformed left lamina and zygapophysial joint. Combined with the preoperative imaging assessment, it was considered that the risk of screw fixation was high. Asymmetric internal fixation was then performed and the bilateral pedicles of T_5 and T_9 and the right side of T_6, T_7, and T_8 were implanted with seven pedicle screws. Postoperative deformity correction was satisfactory. The segmental Cobb angle decreased from 27.1° before surgery to 20.1° after surgery, and 18.6° at the last follow-up. (H, I) Postoperative positive and lateral X-rays of the entire spine. (J, K) The positive and lateral X-rays of the entire spine at 14 months of follow-up.

stretched on the concave side to completely correct the deformity and close the open space left by the hemivertebra resection. It is very important to ensure the growth potential of children, therefore the fixed segment should be as short as possible, and any fusion beyond the deformed part should be avoided as much as possible[23].

Postoperative and Follow-Up X-Ray Parameters in the Coronal Plane and Sagittal Plane

At present, posterior hemivertebra excision and short-segment bilateral pedicle screw fixation has become a common method for treating congenital hemivertebra. However, in clinical practice, one or both vertebral pedicles of some vertebrae are often deformed or absent and the risk of screw fixation is extremely high. Therefore, asymmetric fixation often occurs. As shown in Fig. 2, the child had multiple costal vertebrae deformities, vertebral deformities in T_{6-8}, and left lamina fusion in T_6 and T_7. T_{6-8} shares the same internal rib, the left pedicle of T_8 was absent and the laminae was small. This child has multiple spinal deformities that cause severe scoliosis. The surgery requires removal of T_5, T_6, T_7, and T_8 lamina to relieve the unilateral tethering effect of the bone bridge on the spine. During the operation, T_6, T_7, and T_8 were found to have deformed left lamina and zygapophysial joint. Combined with the preoperative imaging assessment, it was considered that the risk of screw fixation was high. Asymmetric internal fixation was then performed and the bilateral pedicles of T_5 and T_9 and the right side of T_6, T_7, and T_8 were implanted with seven pedicle screws. Postoperative deformity correction was satisfactory. The segmental Cobb angle decreased from 27.1° before surgery to 20.1° after surgery, and 18.6° at the last follow-up. In addition, the pedicle of the deformed vertebra of the child with hemivertebra deformities may also be deformed or absent, and screw fixation is extremely difficult. As shown in Fig. 3, there was a hemivertebra on the right side between T_{12} and L_1. The hemivertebra lamina was fused with the L_1 lamina. T_{12} was a bisected vertebra, the left side was small, the pedicle is poorly developed, and the risk of screw fixation was high. Seven pedicle screws were implanted at the

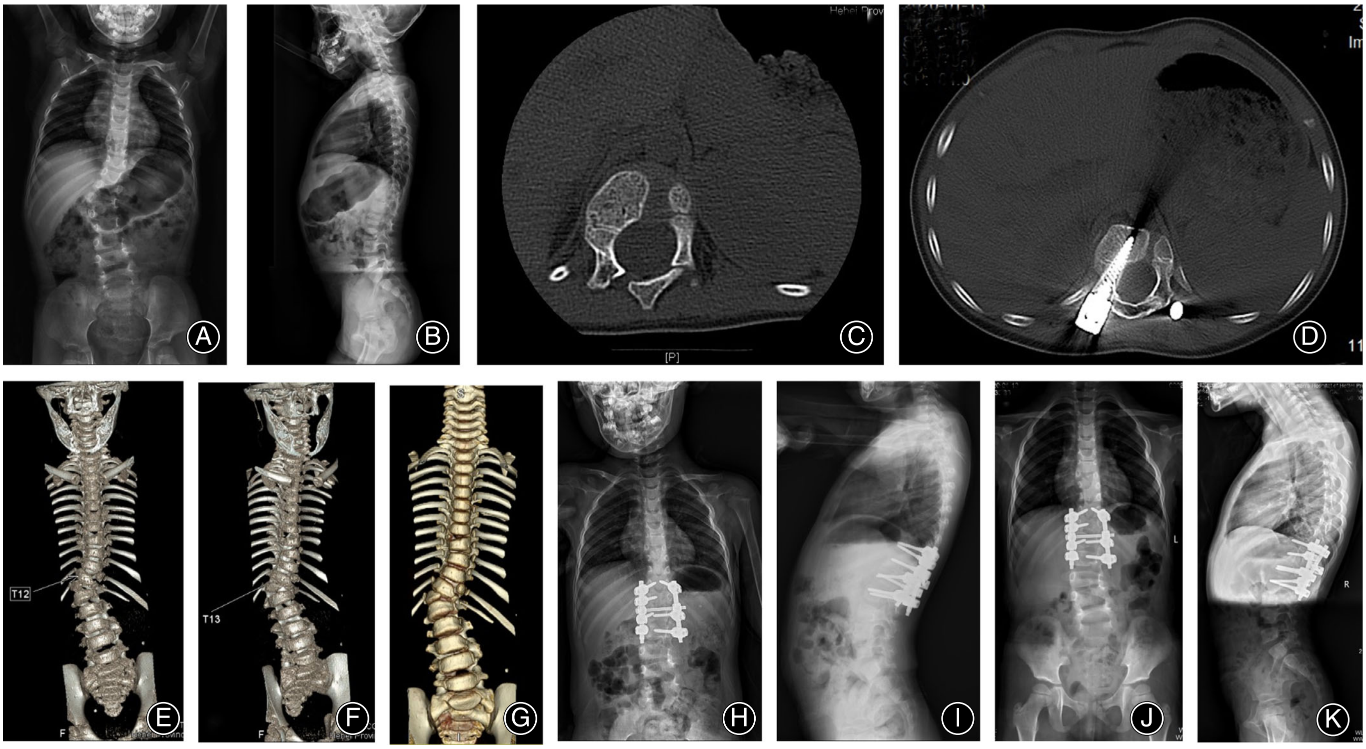

Fig. 3 A 3-year-old female patient who underwent posterior hemivertebra excision and short-segment bilateral pedicle screw fixation for the treatment of CS. The patient was followed up for 12 months. (A, B) Preoperative positive and lateral X-rays of the entire spine showed hemivertebra on the right side between T_{12} and L_1; (C and D) Preoperative and postoperative CT showed T_{12} was a bisected vertebra, the left side was small, the pedicle is poorly developed, and the risk of screw fixation was high; (E, F and G) CT three-dimensional reconstruction showed the bisected T_{12} vertebra and the T_{13} hemivertebra. Seven pedicle screws were implanted at the bilateral pedicles of T_{11}, L_1, L_2 bilateral and the right side of pedicles, respectively. Postoperative deformity correction was satisfactory. The segmental Cobb angle decreased from 22.1° before surgery to 9.6° after surgery, and 6.1° at the last follow-up. (H, I) Postoperative positive and lateral X-rays of the entire spine. (J, K) The positive and lateral X-rays of the entire spine at 12 months of follow-up.

bilateral pedicles of T_{11}, L_1, L_2 bilateral and the right side of pedicles, respectively. Postoperative deformity correction was satisfactory. The segmental Cobb angle decreased from 22.1° before surgery to 9.6° after surgery, and 6.1° at the last follow-up. The postoperative and follow-up X-ray parameters including the total main curve, segmental main curve, cranial compensatory curve, caudal compensatory curve, apical vertebra translation, and segmental kyphosis improved compared with those of preoperative parameters in two groups, indicating that both symmetric and asymmetric internal fixation can significantly improve CS.

Postoperative and Follow-Up Correction Rate and Correction Loss

There were no significant differences in the X-ray parameters, postoperative and follow-up correction rate and correction loss between the two groups, indicating the postoperative maintenance of the surgical effect of asymmetric internal fixation was the same as that of the symmetrical fixation group. No postoperative complications including internal fixation failure and screw breakage occurred in all children. The study of Li *et al.* indicated that pedicle screws can be replaced with laminar hooks for pedicles which were difficult for screw fixation[15]. According to our results, it is safe and effective for vertebral pedicles ≤3 without internal fixation.

Zhang *et al.*[24] reported that in 56 patients with an average follow-up of 32.9 months, 10.8% had complications, including delayed wound healing, screw rod breakage, and new deformities. Similarly, there were three complications in 30 children in our study, including two cases who had poor wound healing, and the wound healed smoothly after half a month of sterile dressing change. Due to the malformation of the remaining vertebrae of the thoracic spine, postoperative curve progression of the main curve and compensatory curve Cobb angle occurred after surgery and thoracic hemivertebrectomy was then performed. We speculated that the causes of complications may include the limitations of the operation itself, improper posterior fusion, or incomplete hemivertebrectomy. Therefore, computed tomography (CT)

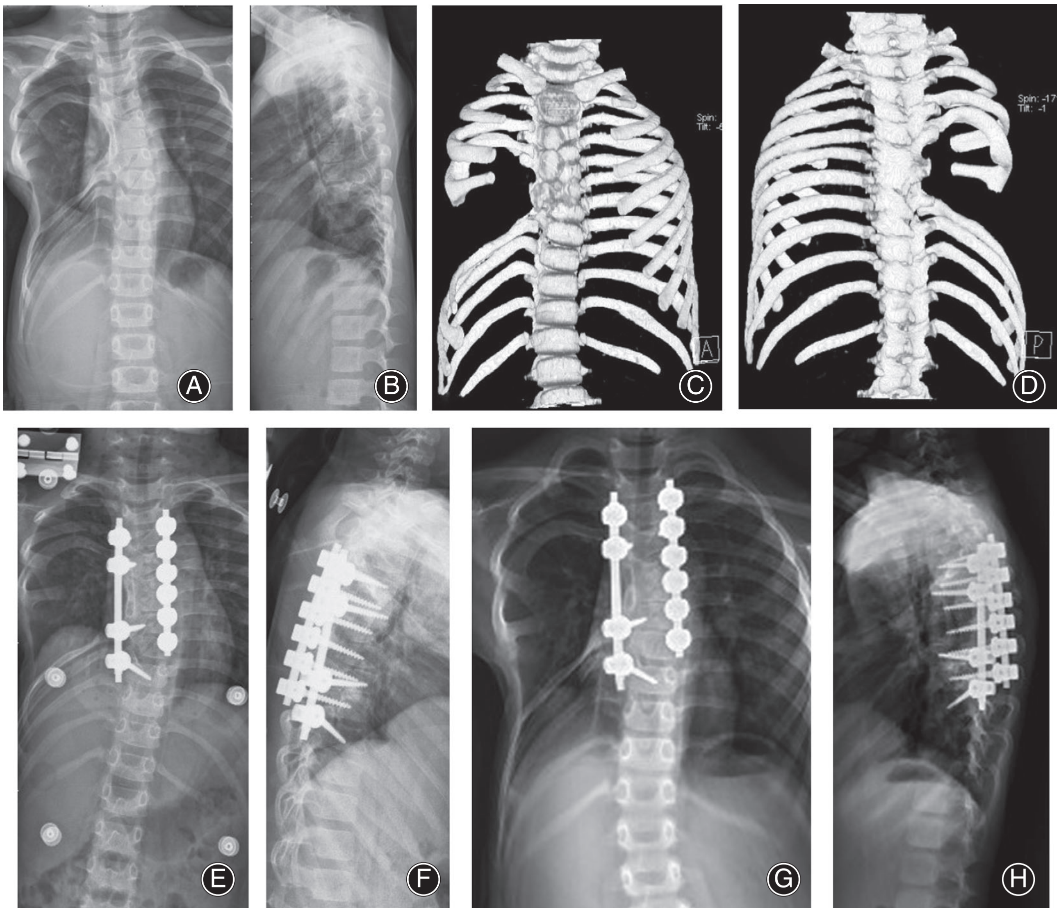

Fig. 4 A 5.5-year-old male patient who underwent posterior hemivertebra excision and short-segment bilateral pedicle screw fixation for the treatment of CS. The paravertebral muscles was exposed to separate T_3–T_9 spinous process, lamina, articular process joint and costal transverse process joint. Ten pedicle screws were implanted in T_3, T_4 and T_8 bilateral pedicles, T_5, T_6, and T_7 left pedicles and T_9 right pedicles. The bone bridge was removed during the operation to relieve its tethering effect. The patient was followed up for 16 months. (A, B) Preoperative positive and lateral X-rays of the entire spine showed vertebral deformities in $T_{5–7}$; (C and D) CT three-dimensional reconstruction. (E, F) Postoperative positive and lateral X-rays of the entire spine. (G, H) The positive and lateral X-rays of the entire spine at 16 months of follow-up.

TABLE 3 Preoperative, postoperative and follow-up X-ray parameters in the coronal plane and sagittal plane

	Symmetric fixation group (n = 12)			Asymmetric fixation group (n = 18)		
	Preoperative	Postoperative	Last follow-up	Preoperative	Postoperative	Last follow-up
Coronal plane						
Total main curve (°)	22.8 ± 6.8	6.3 ± 3.3*	10.7 ± 5.5*†	24.9 ± 7.9	8.4 ± 6.8*	11.1 ± 7.5*
Segmental main curve (°)	30.6 ± 7.8	8.8 ± 5.7*	10.7 ± 7.1*	30.5 ± 10.1	15.5 ± 9.1*	18.6 ± 9.7*
Cranial compensatory curve (°)	13.7 ± 10.2	7.0 ± 7.6*	7.7 ± 7.4*	15.2 ± 17.1	4.0 ± 4.3*	4.8 ± 4.9*
Caudal compensatory curve (°)	14.5 ± 7.0	7.1 ± 4.2*	7.4 ± 3.2*	10.9 ± 4.5	5.9 ± 3.9*	6.9 ± 4.1*
Coronal balance (mm)	15.7 ± 12.5	8.3 ± 7.4*	11.1 ± 5.8	13.0 ± 8.5	15.6 ± 11.0	14.0 ± 9.4
Apical vertebra translation (mm)	19.1 ± 9.4	5.8 ± 5.3*	8.3 ± 6.3*	14.8 ± 8.2	5.1 ± 3.7*	6.7 ± 6.0*
Sagittal plane						
Segmental kyphosis (°)	19.0 ± 16.6	3.8 ± 11.7*	5.3 ± 12.1*	23.1 ± 10.5	5.7 ± 4.1*	6.5 ± 6.9*
Sagittal balance (mm)	3.0 ± 19.0	9.0 ± 22.5	–0.1 ± 19.0	–7.8 ± 27.6	17.5 ± 18.6*	4.7 ± 13.4
Thoracic kyphosis (°)	21.2 ± 7.5	20.8 ± 7.7	27.3 ± 7.3*†	24.7 ± 13.9	19.0 ± 4.0	25.8 ± 7.6
Lumbar lordosis (°)	30.2 ± 12.8	26.6 ± 9.5	31.7 ± 13.9	24.8 ± 15.7	16.6 ± 11.7	26.8 ± 8.7

* Compared with preoperative data in the group, $P < 0.05$;; † Compared with postoperative data in the group, $P < 0.05$.

TABLE 4 The postoperative and follow-up correction rate and correction loss between the two groups

	Symmetric fixation group (n = 12)			Asymmetric fixation group (n = 18)		
	Postoperative correction rate (%)	Follow-up correction rate (%)	Correction loss (°/mm)	Postoperative correction rate (%)	Follow-up correction rate (%)	Correction loss (°/mm)
Total main curve	70.5 ± 16.0	41.3 ± 60.2	4.4 ± 4.9	69.6 ± 20.0	55.2 ± 27.1	2.7 ± 5.8
Segmental main curve	71.4 ± 18.5	65.3 ± 21.8	1.9 ± 6.8	50.9 ± 22.3	40.5 ± 26.0	3.1 ± 4.4
Cranial compensatory curve	43.9 ± 59.8	34.3 ± 51.2	0.7 ± 4.5	64.7 ± 38.3	47.8 ± 63.1	0.8 ± 3.9
Caudal compensatory curve	52.3 ± 31.0	31.3 ± 68.5	0.3 ± 4.7	43.3 ± 40.8	36.3 ± 39.4	0.9 ± 4.8
Segmental kyphosis	105.4 ± 102.8	103.4 ± 99.3	1.5 ± 4.3	67.5 ± 31.7	64.9 ± 40.3	0.8 ± 5.6
Apical vertebra translation	70.8 ± 18.0	57.4 ± 21.9	2.5 ± 2.6	62.3 ± 23.7	58.9 ± 18.2	1.5 ± 4.0

scan and three-dimensional reconstruction of the spine parallel to the pedicle should be performed preoperatively to evaluate the pedicle's morphology and help select the appropriate instruments and surgical methods. During the operation, for pedicles which were difficult for screw fixation, adjacent segments can be chosen for screw fixation instead. The hemivertebra should be removed as cleanly as possible to prevent recurrence.

There were some limitations in this study. One of the limitation was the small samples and the short follow-up. Large randomized RCTs remain to be studied in the future. Another limitation of this study was that it did not include related assessments of quality of life. Further studies focusing on indicators of children's quality of life, spinal mobility, and pain are needed in the future.

In conclusion, during posterior hemivertebra excision and short-segment bilateral pedicle screw fixation for the treatment of CS, for pedicles which were difficult for screw fixation, adjacent segments can be chosen for screw fixation instead. It is safe and effective for vertebral pedicles ≤3 without internal fixation. There was no loss of correction at follow-up for children undergoing asymmetric internal fixation.

Author Contributions

The authors acknowledge (i) that all authors listed meet the authorship criteria according to the latest guidelines of the International Committee of Medical Journal Editors and (ii) that all authors are in agreement with the manuscript.

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