Effects of one-stage posterior hemivertebrectomy for hemivertebral imbalance on spinal imbalance and shoulder balance: A retrospective study

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Abstract

Background

One-stage posterior hemivertebrectomy is widely used for the treatment of hemivertebral-induced scoliosis. However, reports on posterior hemivertebrectomy evaluating hemivertebral-induced spinal imbalance and shoulder balance remain scarce. This study aimed to retrospectively analyze the effects of one-stage posterior hemivertebrectomy on spinal imbalance and shoulder balance.

Methods

Clinical data of 49 patients with scoliosis caused by congenitally imbalanced hemivertebra who underwent posterior hemivertebrectomy between January 2018 and March 2021 were evaluated. Radiographic parameters included sagittal Cobb angle, total main Cobb angle, coronal balance, T1 tilt angle, clavicle angle (CA), shoulder lengthdifference (RSH), T1–S1 length, sagittal kyphosis, thoracic kyphosis, lumbar lordosis, sagittal vertical alignment, L1 pelvic incidence angle, sacral inclination angle, and pelvic incidence angle. After descriptive analysis, the demographic and radiological data were compared.

Results

The preoperative RSH, CA, and T1 tilt angles of the shoulder imbalance group were significantly different from those of the shoulder balance group ($P < 0.001$). After surgical treatment, shoulder imbalance was significantly improved at the last follow-up than before surgery ($P < 0.05$). At the last follow-up, a significant difference in the T1 tilt angle was observed between the shoulder imbalance group and shoulder balance group ($P < 0.05$); however, no significant differences in the RSH and CA were observed between the two groups. Surgical treatment may significantly improve shoulder imbalance caused by imbalanced hemivertebral. Additionally, thoracic and lumbar hemivertebrectomy had a greater impact on shoulder balance, and lumbar hemivertebrectomy was more likely to cause coronal and sagittal imbalances.

Conclusion

In patients with congenital scoliosis caused by imbalanced hemivertebra, posterior hemivertebrectomy combined with short-segment pedicle screw fixation can provide good correction of scoliotic curve, coronal and sagittal plane imbalances, and shoulder imbalance. No serious complications were observed.

1. Background

Scoliosis (CS) is a three-dimensional spinal deformity generally accompanied by rotation of the vertebral bodies, which can cause a rib or lumbar process [1, 2]. On plain anteroposterior X-ray imaging, CS is diagnosed when the Cobb angle is > 10° [3]. CS is generally classified into three types, namely congenital, syndromic, and idiopathic. Hemivertebra (HV) formed by abnormal vertebral body development is an important cause of congenital CS [4, 5]. HV produces a wedge-shaped deformity in both the sagittal and coronal planes, which adversely affects spinal growth and development. HV-induced changes in some curves in the thoracic, thoracolumbar, and lumbar spine have been reported to be gradual, developing at a rate of approximately 2°–3.5° annually in children [6, 7].

Spinal balance is defined as the interaction between the forces acting on the spine and trunk muscles to maintain a stable upright posture [8]. HV causes abnormal spinal alignment, causing an imbalance in the upper body posture [9, 10]. Therefore, the body needs to utilize more energy expenditure and muscle load to maintain an upright posture, which can lead to increased muscle demand, pain, fatigue, and related disabilities [11].

Therefore, early surgical treatment is necessary to correct the spinal imbalance caused by HV. At present, surgical methods related to HV include in situ spinal fusion, Smith–Peterson osteotomy, HV resection, and spinal resection, and even anterior complementary fusion [6, 12, 13]. Royle first described HV resection for the treatment of patients with CS in 1928 [5]. HV resection has been widely used for the treatment of patients with HV-induced CS; however, reports of surgical management to evaluate HV-induced spinal imbalance and shoulder balance remain scarce. This study aimed to evaluate the impact of HV resection on spinal imbalance and shoulder balance using the corresponding parameters in the coronal and sagittal planes on anterior and lateral radiographs.

2. Methods

2.1 Case collection

The inclusion criteria were as follows: (1) diagnosis of congenital CS with single HV deformity; (2) with HV in the thoracic or lumbar spine; (3) one-stage posterior HV resection and bilateral pedicle screw fixation; (4) fixed segment of ≤ 6 vertebral bodies; and (5) follow-up time of ≥ 12 months. The exclusion criteria were as follows: (1) anterior HV resection or combined anterior and posterior HV resection; (2) treatment with the growing rod technique; (3) structural CS or kyphosis in other parts of the spine; (4) underwent previous spinal orthopedic surgery; (5) incomplete clinical and imaging data; and (6) follow-up time of < 12 months. The surgical indications for HV resection in this study were a Cobb angle or sagittal kyphosis angle of ≥ 25° with deformity progression of > 5° within 6 months or failure of conservative treatment. This study was approved by the ethics committee, and informed consent was obtained from all the patients and their families.

2.2 Data collection

All the surgical procedures were performed by the corresponding author. The clinical data of 64 patients with congenital HV CS who underwent surgical treatment at our hospital between January 2018 and March 2021 were retrospectively analyzed. In total, 49 patients with HVCS were enrolled in the study, including 21 men and 28 women. Of the cases, 18 were thoracic (T1–T9) HV, 23 were thoracolumbar (T10–L2) HV, and 8 cases were segmented (L3–L5) HV. Patient details, including sex, age at surgery, body mass index (BMI), resected hemivertebrae and their location, associated abnormalities, surgical data, and follow-up time, were recorded (Table 1). Before surgery, all patients developed trunk imbalance, which had a serious impact on the patient's quality of life and was the main reason for seeking treatment. None of the patients experienced nerve damage, radicular pain, motor weakness, abnormal reflexes, or pulmonary insufficiency.

Table 1
Demographic, anatomical, and operative data.

case	gender	year	BMI	Resection of HV location	Hemivertebra side	Segmentation	Combined deformities	blood loss (ml)	operation time (min)	Follow-up time (month)
1	M	14	18.87	T 6–7	RIGHT	Semi-segmented		150	260	16
2	M	14	17.6	T 6–7	RIGHT	Semi-segmented	T9 butterfly vertebra	296	285	12
3	F	15	16.02	T 6	RIGHT	Full-segmented		100	170	14
4	F	11	13.88	T 5–6	LEFT	Semi-segmented	Right T3 HV	100	185	28
5	M	9	20.41	T 8–9	RIGHT	Semi-segmented	10 ribs on the left	300	135	13
6	M	26	22.03	T 6–6	RIGHT	Semi-segmented		400	165	25
7	F	6	14.95	T 7–8	RIGHT	Semi-segmented		200	235	20
8	M	17	17.3	T 3–4	RIGHT	Semi-segmented		500	300	14
9	F	20	17.63	T 3–4	RIGHT	Semi-segmented		300	220	12
10	F	17	17.63	T 3–4	RIGHT	Semi-segmented		250	220	14
11	M	13	17.78	T 9	LEFT	Full-segmented		200	170	14
12	F	12	15.31	T 8–9	RIGHT	Semi-segmented	T7 butterfly vertebra	350	310	24
13	F	12	19.23	T 5–6	RIGHT	Semi-segmented		350	270	16
14	M	13	14.57	T 5–6	LEFT	Semi-segmented		150	140	14
15	M	9	13.89	T 8–9	LEFT	Semi-segmented		175	260	19
16	M	15	17.78	T 8–9	RIGHT	Semi-segmented		200	150	13
17	F	15	21.36	T 9–10	RIGHT	Semi-segmented		200	150	12
18	F	12	20.12	T 6–7	RIGHT	Semi-segmented		500	340	15
19	M	7	21.52	L1-2	LEFT	Semi-segmented		50	90	32
20	M	11	18.05	T 11 L	LEFT	Full-segmented		400	220	36
21	F	15	17.12	T 11–12	RIGHT	Semi-segmented	T12 butterfly vertebra	350	320	14
22	F	23	16.4	T 2	RIGHT	Full-segmented		300	280	12
23	F	12	13.26	T 11	LEFT	Full-segmented		40	140	21
24	F	24	17.58	L 1	LEFT	Full-segmented		300	160	18
25	F	18	21.78	L 2–3	RIGHT	Full-segmented		320	250	34
26	M	9	12.45	T 10–11	LEFT	Semi-segmented		200	160	27
27	F	17	17.28	L 2	LEFT	Full-segmented	Partial fusion on the right side of L2-3	250	220	18

case	gender	year	BMI	Resection of HV location	Hemiver-tebra side	Segmentation	Combined deformities	blood loss (ml)	operation time (min)	Follow-up time (month)
28	F				RIGHT	Full-segmented				
		20	20.81	T 11				400	310	25
29	M	13	18.67	L1-2	RIGHT	Semi-segmented	L5 butterfly vertebra	200	145	24
30	F	7	17.7	T 10–11	LEFT	Semi-segmented		50	140	22
31	F	16	19.22	L 2	LEFT	Full-segmented		400	230	19
32	F	26	18.37	T10	LEFT	Full-segmented	L2 butterfly vertebra	450	290	24
33	F	21	18.75	L 2	LEFT	Full-segmented		400	270	16
34	M	12	23.49	L 10	LEFT	Full-segmented		200	140	18
35	M	19	19.05	L 2–3	LEFT	Semi-segmented		300	270	23
36	M	14	22.22	T 12-L 1	LEFT	Semi-segmented		300	260	16
37	M	8	13.02	T 11–12	LEFT	Semi-segmented		100	130	12
38	M	14	17.48	T 11–12	RIGHT	Semi-segmented		200	150	15
39	F	7	13.61	L2-3	LEFT	Semi-segmented		50	160	18
40	F	10	17.56	L2-3	RIGHT	Semi-segmented		400	175	13
41	F	15	18.73	L1	LEFT	Full-segmented	Partial fusion of the right vertebral body L1-3	300	200	16
42	F	15	17.78	L3-4	RIGHT	Semi-segmented	T11 butterfly vertebra	250	240	30
43	M	10	13.32	L2-3	RIGHT	Semi-segmented		50	190	15
44	F	9	13.19	L2-3	RIGHT	Semi-segmented		200	140	28
45	F	15	25.39	L4	RIGHT	Full-segmented		300	300	33
46	F	14	17.15	L5	RIGHT	Full-segmented		500	320	24
47	F	8	16.45	L4	RIGHT	Full-segmented		50	100	18
48	M	10	15.38	L3-4	LEFT	Semi-segmented	L4 butterfly vertebra	200	130	13
49	M	16	19.43	L3-4	LEFT	Semi-segmented		200	190	12
average value		13.98 ± 4.88	17.73 ± 2.90					253.69 ± 127.76	209.9 ± 67.14	19.20 ± 6.63

Deformities were assessed using standard whole-spine plain radiographs and further confirmed and assessed using whole-spine 3D computed tomography reconstruction. Magnetic resonance imaging was used to rule out intraspinal abnormalities.

2.3 Specific imaging metrics

Full-spine standing posteroanterior and lateral radiographs were examined preoperatively, at 1 month postoperatively, and at the final follow-up to assess deformity correction, spinal balance, and growth. The sagittal Cobb angle, total main Cobb angle, coronal balance (CB), T1 tilt angle, clavicle angle (CA), shoulder lengthdifference (RSH), and T1–S1 length were measured in the coronal plane. Sagittal kyphosis (SK), thoracic kyphosis (TK), lumbar lordosis (LL), sagittal vertical alignment (SVA), L1 pelvic incidence angle (L1PA), sacral inclination angle (SS), and pelvic incidence angle (PI) were measured in the sagittal plane.

The coronal imaging parameters were as follows. The sagittal Cobb angle was defined as the angle between the upper endplate of the adjacent cephalic vertebral body and the adjacent lower endplate of the caudal vertebral body on the frontal radiograph of the entire spine. This reflects the degree of deformity of CS caused by HV. The total main Cobb angle was defined as the maximum CS angle between the two most inclined vertebrae of the main curve. The CB was defined as the horizontal distance from the C7 plumb line (C7PL) to the center sacral vertical line. The T1 tilt angle was the angle formed by the upper endplate of the T1 vertebral body and the horizontal line. The CA was defined as the angle formed by the line connecting the highest point of the right or left clavicle and the clavicle horizontal reference line. The RSH was defined as the lengthdifference between the left and right soft tissue shadows precisely above the acromioclavicular joint on the standing posterior anterior radiograph, where a difference of > 10 mm reflects imbalance. The T1–S1 length was defined as the distance from the midpoint of the upper endplate of T1 to the midpoint of the upper endplate of S1 on the frontal radiograph of the entire spine.

Meanwhile, the sagittal imaging parameters were as follows. The SK was defined as the angle between the upper endplate of the adjacent cephalic vertebral body and the adjacent lower endplate of the caudal vertebral body on the lateral radiograph of the spine. The TK was defined as the angle between the tangent to the upper endplate of the T5 vertebral body and the tangent to the lower endplate of the T12 vertebral body on the lateral radiograph of the whole spine. The LL was defined as the angle between the tangent to the upper endplate of the L1 vertebral body and the tangent to the upper endplate of S1 on the lateral radiograph of the entire spine. The SVA was the vertical distance from the C7PL to the posterior edge of the S1 upper endplate on the lateral full spine radiograph. The L1PA was the line connecting the midpoint of the S1 upper endplate and the center of the femoral head, and the midpoint of the L1 endplate and the center of the femoral head connected to the center. The SS was the angle between the parallel and horizontal lines of the upper endplate of S1. The PI was a vertical line drawn perpendicular to the endplate through the midpoint of the upper endplate of S1. A line connecting the midpoint and the center of the femoral head, and then the angle between the two lines were drawn (Fig. 1).

2.4 Statistical analysis

All statistical analyses were performed using the IBM SPSS Statistics version 20 (IBM Corp., Armonk, NY, USA). The Shapiro–Wilk test was used to evaluate the data distribution. A one-way analysis of variance was performed to compare the quantitative data of the two groups of patients with a normal distribution. Non-normally distributed quantitative data were compared between the two groups using the nonparametric multiple independent samples test. Statistical significance was set at $P < 0.05$.

3 Results

3.1 Demographics

In total, 21 male and 28 female patients were included in the study. The mean surgical age was 13.98 ± 4.88 years (range, 6–26 years), the mean BMI was 17.73 ± 2.90 kg/m^2 (range, 12.45–25.39 kg/m^2), and the mean follow-up time was 19.20 ± 6.63 months (range, 12.00–36.00 months). Additionally, the mean operation time was 209.9 ± 67.14 min (range, 90–340 min), and the mean blood loss was 253.69 ± 127.76 ml (range, 40–500 ml) (see Table 1). Of the patients, 11 had other deformities.

3.2 Surgical correction results

In the coronal correction results, the mean sagittal Cobb angle was 38.7° (31.85°–46.05°) preoperatively, 16.4° (13.7°–18.15°) postoperatively, and 14.3° (12.73°–18.38°) at the last follow-up, with correction rates of 55.95% (48.98–65.75%) and 60.61% (53.71–70.29%). The mean total main Cobb angle was 47.5° (38.7°–57.7°) preoperatively, 18.9° (16.7°–21.75°) postoperatively, and 17.55° (14.25°–21.15°) at the last follow-up, with respective correction rates of 60.69% (53.47–65.40%) and 64.08% (57.97–71.76%). The mean CB was 21.43 mm (14.82–29.74 mm) preoperatively, 13.57 mm (10.26–18.14 mm) postoperatively, and 10.53 mm (7.05–15.24 mm) at the last follow-up, with average correction rates of 29.74% (13.83–56.41%) and 45.53% (31.12–65.30%) (Fig. 2). In addition, the postoperative and last follow-up (T1 tilt angle, CA, and RSH) and preoperative imaging parameters were significantly different ($P < 0.05$) (Table 2).

Table 2
Radiographic data on the coronal and sagittal planes and spinal lengths.

	Preoperative	Postoperative	Last follow-up	Preoperative vs Postoperative		Preoperative vs Last follow-up	
				Correction rate %	P value	Correction rate %	P value
Coronal plane							
Sagittal Cobb	38.7(31.85, 46.05)	16.4 (13.7, 18.15)	14.3(12.73,18.38)	55.95(48.98, 65.75)	< 0.001***	60.61(53.71, 70.29)	< 0.001***
total main Cobb	47.5(38.7, 57.7)	18.9(16.7, 21.75)	17.55(14.25, 21.15)	60.69 (53.47, 65.40)	< 0.001***	64.08(57.97, 71.76)	< 0.001***
CB	21.43(14.82, 29.74)	13.57(10.26, 18.14)	10.53(7.05, 15.24)	29.74(13.83, 56.41)	< 0.001***	45.53(31.12, 65.30)	< 0.001***
T1 tilt angle	6.5(3.05, 9.8)	3.6(1.95, 6.35)	2.3(1.23, 4.7)	42.86(15.76, 56.93)	< 0.001***	58.46(34.13, 72.57)	< 0.001***
CA	2.5(1.3, 4.1)	1.9(0.85, 3.35)	1.3(0.83, 2.1)	34.35(-20.39, 52.19)	< 0.001***	52.38(6.67, 84.20)	< 0.001***
RSH	8.7(4.75, 16.3)	7.2(2.6, 12.9)	4.95(2.4, 8.6)	35.13(-20.55, 62.15)	0.007**	51.93(4.92, 83.22)	< 0.001***
Sagittal plane							
SK	25.0(19.2, 33.3)	11.5(8.7, 15.15)	12.1(8.55, 14.7)	51.84(38.34, 65.08)	< 0.001***	56.80(42.98, 63.70)	< 0.001***
TK	35.9(31.15, 44.25)	35.9(32.7, 38.3)	37.75(34.53, 39.55)	-	0.077	-	0.541
LL	50.8(43.75, 58.7)	45.8(40.95, 52.75)	48.35(43.6, 53.5)	8.23(0.53, 18.83)	0.001***	5.51(-7.09, 19.51)	0.011*
SVA	37.27(28.27, 57.03)	22.0(13.14, 26.49)	18.79(11.46, 23.13)	49.30(22.19, 69.13)	< 0.001***	59.53(37.10, 69.67)	< 0.001***
LPA	8.3(5.4, 12.15)	8.3(5.7, 11.9)	8.0(5.9, 9.7)	-	0.689	-	0.618
SS	34.7(28.6, 38.0)	34.0(30.15, 37.8)	33.95(26.73, 36.63)	-	0.330	-	0.430
PI	44.7(35.65, 51.75)	42.5(38.15, 48.5)	45.3(39.15, 50.4)	-	0.271	-	0.397
radiographic spine length							
T1-S1 length	343.44(305.47, 371.9)	365.32(320.1, 392.12)	368.53(339.84, 398.11)	4.52(2.08, 8.23)	< 0.001***	7.43(3.70, 9.63)	< 0.001***

***P < 0.001, **P < 0.01, and *P < 0.05 indicate significant differences.

Regarding sagittal plane correction results, the mean SK was 25.0° (19.2°–33.3°) preoperatively, 11.5° (8.7°–15.15°) postoperatively, and 12.1° (8.55°–14.7°) at the last follow-up, with correction rates of 51.84% (38.34–65.08%) and 56.80% (42.98–63.70%). The mean LL was 50.8° (43.75°–58.7°) preoperatively, 45.8° (40.95°–52.75°) postoperatively, and 48.35° (43.6°–53.5°) at the last follow-up, with average correction rates of 8.23% (0.53–18.83%) and 5.51% (–7.09–19.51%), respectively. The mean SVA was 37.27 mm (28.27–57.03 mm) preoperatively, 22.0 mm (13.14–26.49 mm) postoperatively, and 18.79 mm (11.46–23.13 mm) at the last follow-up, with average correction rates of 49.30% (22.19–69.13%) and 59.53% (37.10–69.67%). No significant differences in the mean TK, L1PA, SS, and PI were observed between the preoperative values and those of the postoperative and last follow-up results (Table 2).

Further analysis revealed that some radiographic parameters preoperatively were significantly correlated. A positive correlation between the sagittal Cobb angle and total main Cobb angle ($r = 0.511$, $P < 0.01$) was identified. The T1 tilt angle was positively correlated with CA ($r = 0.506$, $P < 0.01$) and RSH ($r = 0.587$, $P < 0.01$), and CA was positively correlated with RSH ($r = 0.973$, $P < 0.01$). SK was positively correlated with LL ($r = 0.399$, $P < 0.01$), and TK ($r = 0.374$, $P < 0.01$). LL was positively correlated with TK ($r = 0.637$, $P < 0.01$), SS ($r = 0.524$, $P < 0.01$) and PI ($r = 0.356$ $P < 0.05$). SVA was negatively correlated with SS ($r = -0.363$, $P < 0.05$). Additionally, PI was positively correlated with SS ($r = 0.508$, $P < 0.01$) (Table 3).

Table 3
Spearman correlation analysis results of the preoperative imaging parameters of patients.

	Sagittal cobb	Total main Cobb	CB	T1 tilt angle	CA	RSH	SK	TK	LL	SVA	LPA	SS	PI	T1-S1 length
Sagittal cobb	1.000													
Total main Cobb	0.511**	1.000												
CB	0.043	0.258	1.000											
T1 tilt angle	-0.104	0.126	0.160	1.000										
CA	0.086	0.087	0.047	0.506**	1.000									
RSH	0.065	0.098	0.102	0.587**	0.973**	1.000								
SK	0.138	0.028	0.168	-0.029	-0.130	-0.105	1.000							
TK	0.228	0.245	-0.096	-0.128	-0.152	-0.187	0.399**	1.000						
LL	0.249	0.018	-0.068	-0.335*	-0.268	-0.335*	0.374**	0.637**	1.000					
SVA	0.038	0.107	0.124	-0.183	-0.176	-0.201	-0.047	0.017	-0.085	1.000				
L1PA	-0.254	-0.198	0.180	0.127	0.132	0.111	-0.055	-0.180	0.106	-0.207	1.000			
SS	0.062	− .007	0.046	0.052	-0.038	-0.026	0.192	0.217	0.524**	-0.363*	0.116	1.000		
PI	0.155	0.162	0.155	0.219	0.317	0.321	-0.028	0.096	0.356*	-0.221	0.267	0.508**	1.000	
T1-S1 length	-0.030	0.009	0.117	0.047	-0.200	-0.090	0.217	-0.119	-0.323**	0.034	-0.234	-0.230	-0.321*	1.000

**P < 0.01 and *P < 0.05 indicate significant differences.

3.3 T1–S1 length

The mean T1–S1 length of the patients was 343.44 mm (305.47–371.9 mm) preoperatively, 365.32 mm (320.1–392.12 mm) postoperatively, and 368.53 mm (339.84–398.11 mm) at the last follow-up, with average correction rates of 4.52% (2.08–8.23%) and 7.43% (3.70–9.63%), indicating a significant difference ($P < 0.001$) (Table 2). Additionally, the Spearman correlation analysis results demonstrated that the T1–S1 length was negatively correlated with LL ($r = -0.323$, $P < 0.01$) and PI ($r = -0.321$, $P < 0.01$), had no significant correlation with the other parameters (Table 3).

3.4 Shoulder balance

The RSH, CA, and T1 tilt angles are currently among the main indicators for evaluating shoulder balance [14, 15]. According to Table 2, the differences in the imaging parameters T1 tilt angle, CA, and RSH preoperatively, postoperatively, and at the last follow-up were significant. However, RSH indicated the lengthdifference between the left and right soft tissue shadows immediately above the acromioclavicular joint on the anterior radiograph after standing. The difference was > 10 mm, indicating shoulder imbalance. However, the overall analysis cannot accurately reflect the correction of the shoulder balance. Therefore, according to whether the RSH was > 10 mm as the criterion for assessing shoulder balance, we divided the patients into two groups: the bilateral shoulder balance and bilateral shoulder imbalance groups (Table 4).

Table 4
Comparison of imaging parameters of shoulder balance between the two groups of patients.

		Shoulder balance group (22 cases)		Shoulder imbalance group (27 cases)		P value
Preoperative						
RSH (mm)		16.6 (14.275, 23)		5.7(2.6, 7.1)		< 0.001***
CA (°)		4.3(3.55, 6.325)		1.4(0.8, 2.1)		< 0.001***
T1 tilt angle °		9.0(6.25, 23.775)		3.4(1.8, 7.2)		< 0.001***
Postoperative						
RSH (mm)		8.8(7.05, 15.45)		2.9(2.4, 11.0)		0.002**
CA (°)		2.8(1.9, 3.925)		1.0(0.7, 2.5)		0.001**
T1 tilt angle (°)		4.75(2.325, 15.23)		3.0(1.6, 4.2)		0.009**
Last follow-up						
RSH (mm)		5.85(3.925, 8.725)		4.3(0, 7.8)		0.139
CA (°)		1.45(1.0, 2.15)		1.2(0, 2.1)		0.125
T1 tilt angle (°)		3.15(1.375, 8.225)		2.0(1.0, 3.4)		0.045*
		Correction rate %	P value	Correction rate %	P value	
RSH	Preoperative vs Postoperative	50.0(4.90, 62.15)	< 0.001***	-	0.840	
	Preoperative vs Last follow-up	65.44(47.97, 80.85)	< 0.001***	-	0.374	
CA	Preoperative vs Postoperative	44.44(5.08, 56.23)	0.002**	-	0.936	
	Preoperative vs Last follow-up	62.50(40.80, 81.03)	< 0.001***	-	0.381	
T1 tilt angle	Preoperative vs Postoperative	45.82(25.84, 62.02)	< 0.001***	30.67(8.33, 54.50)	0.007**	
	Preoperative vs Last follow-up	69.66(49.26, 74.71)	< 0.001***	49.06(21.25, 64.58)	< 0.001***	

***P < 0.001, **P < 0.01, and *P < 0.05 indicate significant differences.

The preoperative RSH in the shoulder imbalance group was 16.6 mm (14.275–23 mm), which was significantly higher than that in the shoulder balance group, which was 5.7 mm (2.6–7.1 mm) (P < 0.001). Similarly, the preoperative CA and T1 tilt angle in the shoulder imbalance group were significantly higher than those in the shoulder balance group (P < 0.001). At 1 month postoperatively, significant differences in the RSH, CA, and T1 tilt angles were also observed between the two groups (P < 0.05). However, at the last follow-up, a significant difference only in the T1 tilt angle was observed (P < 0.05), whereas no significant differences in RSH and CA were observed between the two groups (P > 0.05) (Table 4).

Moreover, after surgical treatment of the patients with shoulder imbalance, the mean RSH was 16.6 mm (14.275–23 mm) preoperatively, 8.8 mm (7.05–15.45 mm) postoperatively, and 5.85 mm (3.925–8.725 mm) at the last follow-up, with average correction rates of 50.0% (4.90–62.15%) and 65.44% (47.97–80.85%). The mean CA was 4.3° (3.55°–6.325°) preoperatively, 2.8° (1.9°–3.925°) postoperatively, and 1.45° (1.0°–2.15°) at the last follow-up, with average correction rates of 44.44% (5.08–56.23%) and 62.50% (40.80–81.03%). The mean T1 tilt angle was 9.0° (6.25°–23.775°) preoperatively, 4.75° (2.325°–15.23°) postoperatively, and 3.15° (1.375°–8.225°) at the final follow-up, with average correction rates of 45.82% (25.84–62.02%) and 69.66% (49.26–74.71%). In the shoulder balance group, only the preoperative T1 tilt angle was compared with the postoperative and last follow-up values, and the difference was significant (P < 0.01). However, no significant differences in RSH and CA were observed between the preoperative values and the postoperative and last follow-up values of the two groups (P > 0.05) (Table 4).

Preoperative imaging parameters of shoulder balance were significantly correlated in patients with bilateral shoulder imbalances. Among them, RSH was positively correlated with CA (r = 0.951, P < 0.01) but was not significantly correlated with T1 tilt angle (Table 5). In addition, the RSH change in the shoulder imbalance group was positively correlated with the CA change (r = 0.978, P < 0.01) but was not significantly correlated with the T1 tilt angle change (Table 6).

Table 5
Spearman correlation analysis results of the imaging parameters in the patients with preoperative shoulder imbalance.

	RSH	CA	T1 tilt angle
RSH	1.000		
CA	0.951**	1.000	
T1 tilt angle	0.127	0.146	1.000
**P < 0.01 indicates a significant difference.			

Table 6
Spearman correlation analysis results of changes in the imaging parameters in patients with shoulder imbalance.

	RSH	CA	T1 tilt angle
RSH	1.000		
CA	0.978**	1.000	
T1 tilt angle	-0.018	0.027	1.000
**P < 0.01 indicates a significant difference.			

3.5 Location of HV

Differences in the HV location may have different effects on the spine. The patients were divided into three groups based on the location of the HV as follows: 18 cases of thoracic HV (T1–T9), 23 cases of thoracolumbar HV (T10–L2), and eight cases of lumbar HV (L3–L5). After statistical analysis, the thoracic HV [T1 tilt angle of 9.70° (4.78°–23.78°), CA of 2.95° (1.50°–4.88°), and RSH of 13.05 mm (7.10–17.45 mm)] was significantly higher than the thoracolumbar HV [T1 tilt angle of 3.4° (1.7°–7.5°), CA of 1.7° (0.8°–3.5°), and RSH of 7.1 mm (2.6–15.0 mm)]. The significant difference indicates imbalance of the thoracic HV on the shoulder. Moreover, a significant difference was observed between the thoracic T1 tilt angle of 9.70° (4.78°–23.78°) and the lumbar T1 tilt angle of 4.95° (2.55°–6.25°). In addition, the lumbar SK 13.80° (10.73°–22.73°) was significantly smaller than the thoracic SK 30.55° (23.68°–39.65°) and the thoracolumbar SK 13.80° (10.73°–22.73°), and the difference was statistically significant (see Table 7).

Table 7
Preoperative radiographic data of the HV locations.

	Thoracic HV	Thoracolumbar HV	Lumbar HV	Thoracic HV vs Thoracolumbar HV	Thoracolumbar HV vs Lumbar HV	Thoracic HV vs Lumbar HV
				P value	P value	P value
Coronal plane						
sagittalCobb	38.05(30.1, 51.5)	39.80(32.60, 46.0)	39.35(34.67, 41.88)	0.906	0.735	0.718
total Main Cobb	46.55(38.05, 46.55)	48.80(38.70, 58.40)	48.4(39.63, 56.7)	0.773	1.000	0.697
CB	18.43(15.48, 24.74)	21.73(14.66, 34.0)	21.97(13.86, 24.18)	0.386	0.619	0.824
T1 tilt angle	9.70(4.78, 23.78)	3.4(1.7, 7.5)	4.95(2.55, 6.25)	< 0.001***	0.557	0.012*
CA	2.95(1.50, 4.88)	1.7(0.8, 3.5)	3.85(1.20, 6.20)	0.031*	0.161	0.868
RSH	13.05(7.10, 17.45)	7.1(2.6, 15.0)	15.05(4.48, 19.55)	0.034*	0.223	0.956
Sagittal plane						
SK	30.55(23.68, 39.65)	24.20(21.30, 32.60)	13.80(10.73, 22.73)	0.141	0.025*	0.001**
TK	38.55(34.65, 51.25)	34.60(29.40, 44.90)	33.4(27.87, 36.65)	0.193	0.366	0.026*
LL	52.75(44.33, 63.28)	52.5(46.6, 58.7)	43.55(36.7, 54.7)	0.969	0.090	0.096
SVA	36.26(17.16, 54.57)	36.65(28.45, 61.67)	45.71(28.93, 61.84)	0.227	0.786	0.267
LPA	8.3(5.65, 12.95)	8.5(4.9, 10.5)	9.0(4.35, 11.4)	0.636	0.769	0.657
SS	35.10(29.55, 40.70)	35.8(26.1, 38.8)	32.65(25.63, 34.25)	0.618	0.176	0.085
PI	45.35(38.87, 56.97)	42.9(34.3, 48.1)	45.05(31.08, 52.07)	0.115	0.769	0.345
radiographic spine length						
T1-S1 length	355.95(308.98, 374.59)	346.24(307.2, 366.79)	314.8(269.99, 378.19)	0.834	0.321	0.374
***P < 0.001, **P < 0.01, *P < 0.05 indicate significant differences.						

4. Discussion

The reported incidence of congenital CS is approximately 1 in 1,000 and is one of the most common congenital spinal diseases [16]. HV is the most common type of vertebral dysplasia, accounting for approximately 46% of CS cases[17]. According to the relationship between the HV and the upper and lower vertebral bodies, HV-induced CS can be divided into three types: wedge-shaped vertebrae, fully segmented HV, and partially segmented HV [18]. HV often causes spinal growth imbalance and can also lead to rapid curve progression, trunk imbalance, and shoulder imbalance; thus, early surgical intervention is crucial [17, 19, 20]. Posterior HV excision combined with short-segment pedicle screw fixation can maintain the normal development of the spine and thorax as much as possible and correct spinal deformity. Currently, it is the most common surgical method for correcting CS caused by HV [13, 14, 21].

Our results demonstrated that the correction rates of the sagittal Cobb angle and total main Cobb angle at the last follow-up were 60.61% (53.71–70.29%) and 64.08 (57.97–71.76%), respectively, which were similar to the previously reported results of HV resection [17, 22, 23]. In addition, compared with preoperative, the correction rates of the SK angle at the last follow-up 56.80% (42.98–63.70%). What's more, the Spearman correlation analysis indicated that the SK was positively correlated with LL($r = 0.399$, $P < 0.01$) and TK ($r = 0.374$, $P < 0.01$). In terms of T1–S1 length, the patients' mean preoperative T1–S1 length improved by 7.43 mm (3.70–9.63 mm) compared with that at the last follow-up. Moreover, the Spearman correlation analysis indicated that the T1–S1 length was negatively correlated with LL ($r = -0.323$, $P < 0.01$) and PI ($r = -0.321$, $P < 0.01$). However, some studies have reported that postoperatively, patients may experience curve re-progression during follow-up, which may be related to multiple factors, including multiple deformed vertebral bodies, improper manipulation, shorter fusion levels, and incomplete HV resection [6, 24]. In our study, the scoliotic curves of four patients were significantly improved postoperatively, although their values significantly increased at the last follow-up compared with those postoperatively. Therefore, we provided bracing as an adjuvant therapy to delay curve progression, and good therapeutic results were obtained.

Coronal and sagittal imbalances are also major problems in patients with HV. Bao et al. [14] performed posterior HV resection in 27 patients with a thoracolumbar spine. The coronal plane increased from 8.45 mm preoperatively to 3.78 mm at the final follow-up; the sagittal balance improved from 16.98 mm preoperatively to 8.71 mm at the final follow-up. Zhuang et al. [25] have reported that after one-stage posterior HV resection in 14 patients with congenital

HV, postoperative coronal and sagittal parameters improved by 63% and 58%, respectively, compared with preoperative values and remained stable during the follow-up. Similarly, Li et al. [26] have also reported that posterior resection of the HV could significantly improve balance in the coronal and sagittal planes. In our study, the CB was 21.43 mm (14.82–29.74 mm) preoperatively, 13.57 mm (10.26–18.14 mm) postoperatively, and 10.53 mm (7.05–15.24 mm) at the last follow-up, and the differences were significant. Likewise, preoperative SVA improved by 49.30% (22.19–69.13%) and 59.53% (37.10–69.67%) compared with the postoperative and last follow-up SVA values. In addition, the correlation analysis of the preoperative imaging parameters indicated that SVA was negatively correlated with SS ($r = -0.363$, $P < 0.05$). Therefore, for imbalances in the coronal and sagittal planes of the spine caused by HV, posterior HV excision combined with short-segment internal fixation can significantly improve trunk balance.

Shoulder imbalance caused by HV should also be considered. Bao et al. [14] have reported improved RSH from 3.36 mm preoperatively to 1.65 mm at the final follow-up in 27 patients with HV. Chen et al. [15] conducted a study on 18 patients with cervicothoracic HV and reported that in terms of shoulder balance, both the T1 tilt angle and CA were significantly improved, with correction rates of 55 ± 22% and 47 ± 32%, respectively. The abovementioned reports were based on an overall analysis of imaging parameters related to shoulder balance in patients. In our study, we divided the patients into the bilateral shoulder balance group and bilateral shoulder imbalance group according to whether the RSH was > 10 mm as the criterion for assessing shoulder balance. Our results revealed significant differences in the RSH, CA, and T1 tilt angles between the two groups preoperatively ($P < 0.05$). After posterior HV resection for patients with shoulder imbalance, the preoperative means (RSH, CA, and T1 tilt angle) were significantly different from the postoperative and last follow-up values ($P < 0.01$). Additionally, at the last follow-up, the T1 tilt angle of the shoulder imbalance group was significant compared with that of the shoulder balance group ($P < 0.05$), while the difference between RSH and CA was not significant ($P > 0.05$), which indicated that posterior HV resection can significantly improve shoulder balance. Kuklo et al. [27] have suggested preoperative CA as the best predictor of postoperative shoulder imbalance. In this study, preoperative RSH was positively correlated with CA in patients with shoulder imbalance, and the RSH changes were positively correlated with CA changes. Meanwhile, T1 tilt does not represent the preoperative shoulder tilt direction, and the T1 tilt angle and postoperative RSH having no significant correlation has become a more recognized point of view in the academic community. Our results are consistent with those of previous studies [28, 29].

Here, we explored the effect of HV position on spinal imbalance and shoulder balance for the first time. Our results revealed that the effect of the thoracic HV on shoulder balance-related imaging parameters (T1 tilt angle and CA) was significantly greater than that of the thoracolumbar HV. The RSH is an important indicator of shoulder balance. RSH values at the thoracic HV of 13.05 mm (7.10–17.45 mm) and lumbar HV of 15.05 mm (4.48–19.55 mm) were significantly higher than a thoracolumbar HV of 7.1 mm (2.6–15.0 mm), which indicated that the thoracic HV and lumbar HV had a greater impact on shoulder balance. Such results may be due to the thoracolumbar HV being located in the middle of the spine, and the body needs to maintain shoulder balance during growth. Changes in the position of the vertebral bodies in some thoracic and lumbar segments partially compensate for the shoulder imbalance caused by a thoracolumbar HV. We also observed that the thoracic CB of 18.43 mm (15.48–24.74 mm) was significantly smaller than the thoracolumbar of 21.73 mm (14.66–34.0 mm) and the lumbar of 21.97 mm (13.86–24.18 mm), although the changes were not significant ($P > 0.05$). This may be due to the small sample size; however, based on the statistical results, HV below the thoracolumbar segment may have a greater impact on CB. Similarly, the lumbar SVA of 45.71 mm (28.93–61.84 mm) was significantly larger than the thoracic of 36.26 mm (17.16–54.57 mm) and thoracolumbar of 36.65 mm (28.45–61.67 mm). The lumbar HV may have a greater impact on the SVA, although the changes were not evident. Therefore, expanding the sample size further is necessary to improve the reliability of the study. In addition, the SK of the lumbar vertebrae was significantly smaller than that of the thoracic vertebrae and thoracolumbar vertebrae, possibly because the cross-sectional area of the lumbar vertebrae was larger, which was not easily displaced, and the lower end was more stable in connection with the pelvis.

Previous studies have reported that complications such as bleeding, infection, and recurrence of deformity may occur after HV resection [30, 31]. Additionally, studies have suggested that posterior HV resection may increase neurological complications [32, 33]. The corrections obtained in all our patients remained stable during the postoperative period, and no patient experienced bleeding, infection, deformity recurrence, or neurological complications during the follow-up. Nevertheless, this study had some limitations. First, this retrospective study had a relatively small number of cases. A larger sample size is needed in order to improve the reliability of the study and validity of the data. Second, although the mean follow-up time was relatively long (interim follow-up), the final surgical impact requires further long-term follow-up. Last, we did not report relevant assessments of quality of life in this study, and further research is needed to focus on indicators of patient quality of life, spinal mobility, and pain in the future.

5. Conclusion

In patients with congenital CS caused by an imbalance in the HV, posterior hemivertebrectomy combined with short-segment pedicle screw fixation can provide good correction of the scoliotic curve, coronal and sagittal plane imbalances, and shoulder imbalance. Moreover, the impact of the thoracic and lumbar HV on shoulder balance was greater than that of the thoracolumbar HV, and the lumbar HV was more likely to cause coronal and sagittal imbalances.

Abbreviations

HV, hemivertebrae; CS, scoliosis; CB, coronal balance; CA, clavicle angle; C7PL, C7 plumb line; RSH, shoulder lengthdifference; SK, sagittal kyphosis; TK, thoracic kyphosis; LL, lumbar lordosis; SVA, sagittal vertical alignment; L1PA, L1 pelvic incidence angle; SS, sacral inclination angle; PI, pelvic incidence angle; BMI, body mass index

Declarations

Ethics approval and consent to participate

This study was approved by the ethics committee, and informed consent was obtained from all the patients and their families.

Competing interests

The authors declare that there are no conflicts of interest.

Availability of data and materials

The data sets used and analysed during the current study are available from the corresponding author on reasonable request.

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Authors' contributions

Hai-Wei.Chen, Shuan-Hu.Lei, and Guang-Zhi.Zhang contributed equally to this work and is listed as a co-first author. Hai-Wei.Chen, Shuan-Hu.Lei, and Guang-Zhi.Zhang: Conceptualization, Validation, Visualization, Writing - original draft, Writing - review & editing. Cang-Yu.Zhang: Conceptualization, Validation. Zhang-Bin.Luo, Lei.Li, and Da-Xue.Zhu: Data curation, Formal analysis. Feng-Guang Yang: Project administration, Resources. Xue-Wen Kang: Conceptualization, Validation, Visualization, Writing - original draft, Writing - review & editing.

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Figures

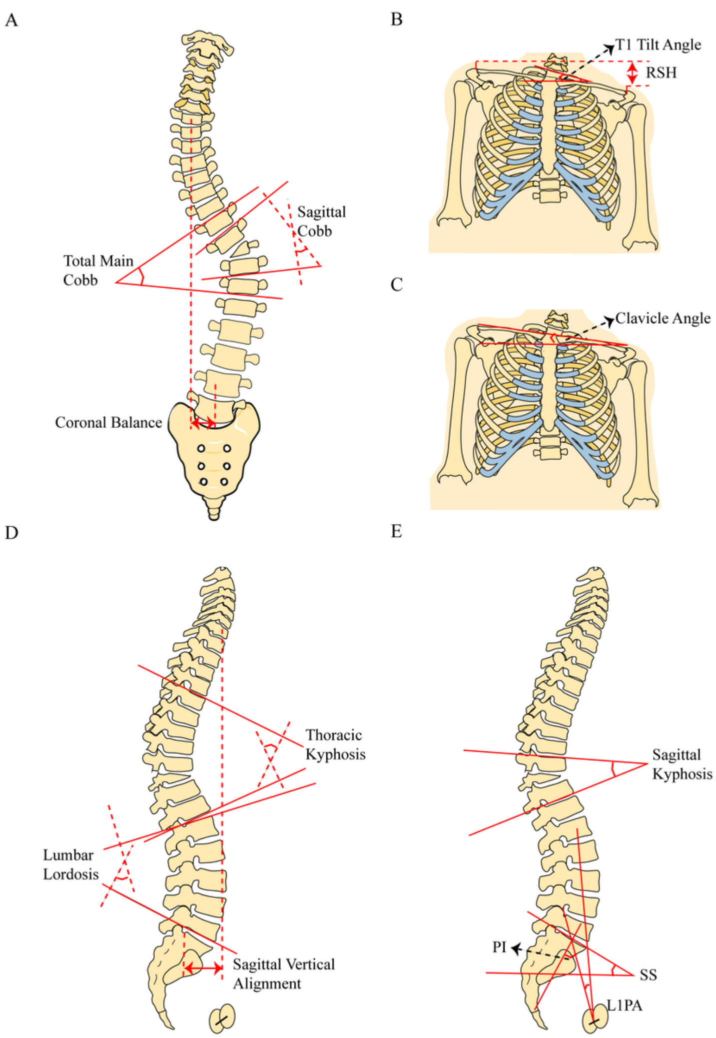

Figure 1

Schematic diagram of specific imaging metrics. A, Sagittal Cobb, total main Cobb, and coronal balance; B-C, T1 tilt angle; shoulder lengthdifference; clavicle angle; D-E, thoracic kyphosis and lumbar lordosis; Sagittal kyphosis, L1 pelvic incidence angle, sacral inclination angle, and pelvic incidence angle.

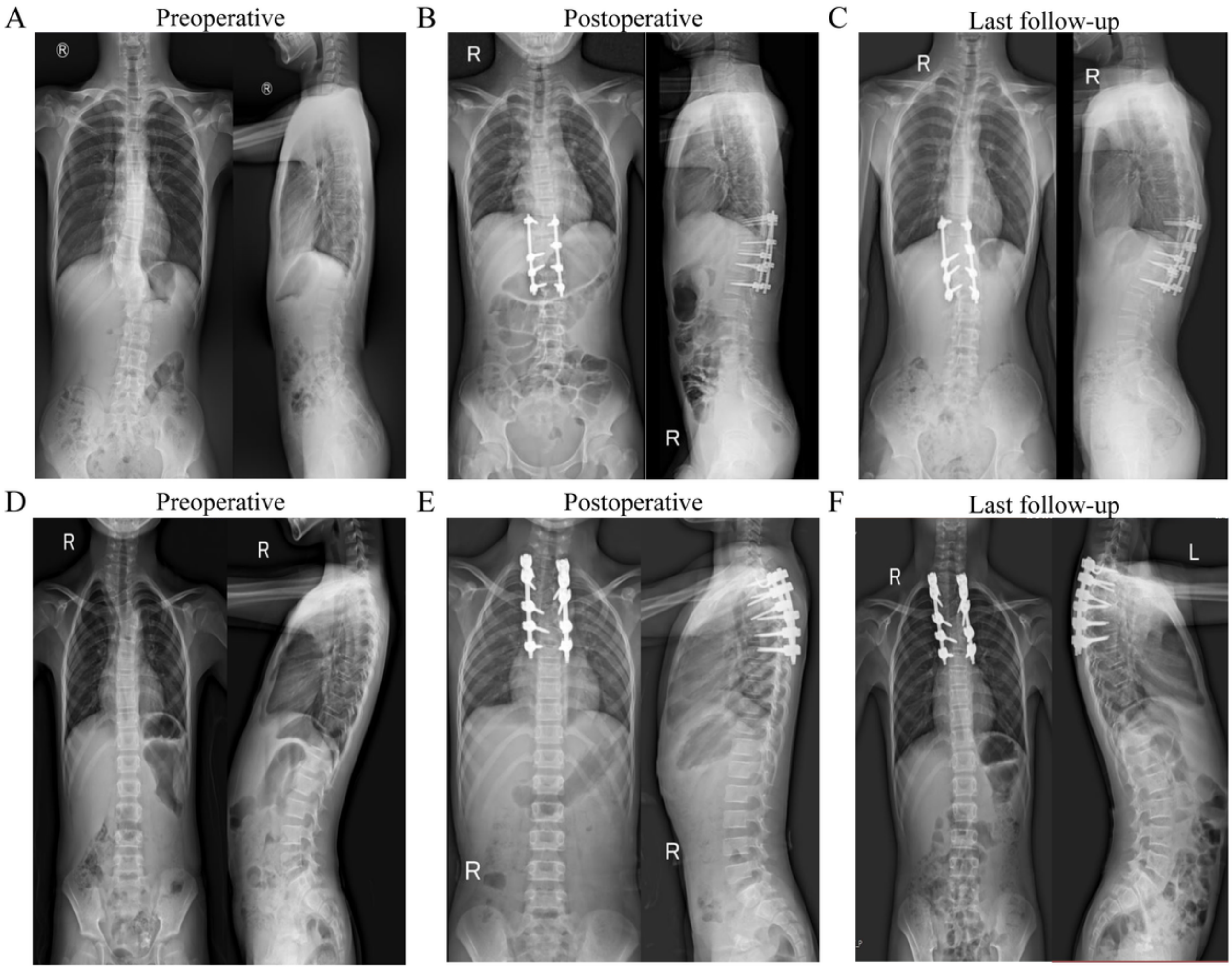

Figure 2

X-rays of the two patients with congenital scoliosis. A–C, 14-year-old male patient with hemivertebrae located between the right thoracic vertebrae 11–12. X-rays were recorded preoperatively, postoperatively, and at the last follow-up; D–F, 11-year-old female patient with a hemivertebral body located between the 5 and 6 vertebral bodies of the left thoracic body. X-rays were recorded preoperatively, postoperatively, and at the last follow-up.