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COMPARATIVE RESULTS IN HEMIVERTEBRECTOMY AND FUSION SURGERY BELOW AND ABOVE 10 YEARS OF AGE

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ABSTRACT

Objective: The aim of this study was to present and compare preoperative and postoperative radiologic results and health-related quality of life scores (HRQoL) in patients below and above 10 years who underwent hemivertebrectomy.

Materials and Methods: We reviewed 22 patients who underwent posterior hemivertebra resection and fusion for congenital or kyphoscoliosis at a single center. The mean follow-up period was 24.5 months. Patients were equally divided into G1 (below 10 y/o) who underwent short-level fixation (SLF) and G2 (above 10 y/o) who underwent SLF or long-level fixation (LLF). Radiological evaluations were performed, and HRQoL questionnaires were examined.

Results: G2 exhibited longer fusion (7.2 vs. 2.5), longer surgery (401.3 vs. 218.2 minute), higher blood loss (818.8 vs. 263.6 mL), and higher blood transfusion (5 vs. 1 unit) compared with G1 ($p<0.05$). Preoperative Cobb angles were higher in G2 than in G1, and both groups experienced decreased Cobb angles in the early and late postoperative periods ($p<0.05$). Other examinations included the thoracic kyphosis angle, lumbar lordosis angle, coronal balance, sagittal balance, shoulder balance, and pelvic obliquity, but no significant differences were observed between the groups ($p>0.05$). In G1, patients' postoperative general health status improved, child and parent satisfaction increased, and activities of daily living increased, but their emotional state worsened ($p<0.05$). In G2, postoperative pain, physical function, self-image, mental health, and satisfaction with treatment management increased ($p<0.05$).

Conclusion: Hemivertebrectomy is a successful surgical treatment for improving radiological and HRQoL scores both below and above 10 years. We recommend SLF for physiological growth and less fusion in children aged 10 years, but psychological support is crucial to prevent emotional deterioration. LLF offers advantageous radiological results in children aged >10 years but may lead to painful HRQoL scores.

Keywords: Congenital scoliosis, congenital kyphoscoliosis, posterior hemivertebrectomy, limited fusion, posterior spinal fusion, health-related quality of life, HRQoL

INTRODUCTION

The primary etiology of congenital scoliosis is believed to be a developmental defect in the paraxial mesoderm[1]. It is associated with a higher incidence of intraspinal, cardiac, renal, and gastrointestinal anomalies compared to the general population[2]. Anomalies in rib number commonly accompany this condition, and Goldenhar syndrome may also be associated with this condition[3,4]. Hemivertebra (HV) is a congenital spine defect, leading to progressive scoliosis and coronal or sagittal imbalance if left untreated. HV is classified into fully segmented, semi-segmented, and unsegmented types. The prognosis of HV-related deformities depends on factors like HV type, defect location, number of defective vertebrae, and the patient's growth potential[5]. Conservative treatment for congenital scoliosis has limited effectiveness, with 75% of curves being progressive and only 5-10% responding to casting or custom-made bracing[6]. Early surgical intervention is often necessary to prevent deformity progression[7]. Surgical treatment options include preventing future deformity, gradual correction, and acute correction[8]. The aim of this study was to present and compare preoperative and postoperative radiologic results and health-related quality of life scores (HRQoL) in patients below and above 10 years of age who underwent hemivertebrectomy.

MATERIALS AND METHODS

Study Design

We reviewed 22 pediatric patients (n=22) who underwent posterior HV resection and spinal fusion for congenital scoliosis or kyphoscoliosis at Başakşehir Çam and Sakura City Hospital between 2021 and 2023 retrospectively. The mean follow-up period was 24.5 months (range 12.1 to 36.9 months). Informed consent was obtained from each patient. Patients were divided

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into two groups: those below 10 years old and those above 10 years old, with 6 females and 5 males in each group (n=11 per group). The mean age was 10.6±4.6 years (range 4.0 to 18.0), the mean coronal main Cobb angle was 49.8°±20.5° (range 21° to 85°), and the mean thoracic kyphosis angle was 46.4°±19.8° (range 5° to 80°). Kyphoscoliosis was present in 2 patients in Group 1 (G1) and 6 patients in Group 2 (G2). The mean age in G1 was 6.5±1.9 years, and the main Cobb angle was 45.5°±22.2°, while in G2, the mean age was 14.6±2.0 years, and the main Cobb angle was 54.1°±18.8°. In G1, 5 patients had type 1 and 6 had type 3 congenital defects, while in G2, 4 had type 1 and 7 had type 3 congenital defects according to the McMaster classification[9].

The inclusion criteria were as follows: age below 18, surgery required for congenital spinal deformity related to HV (failure of conservative treatment and observed increase in curve >5° over 6 months), no previous deformity surgery, regular follow-up. The exclusion criteria were as follows: age above 18, pure congenital kyphosis, no increased curve with conservative treatment, previous deformity surgery, and no regular follow-up. Radiologic coronal and sagittal parameters were compared preoperatively, early postoperatively (early term), and at final follow-up (late term) within and between groups. Additionally, changes in HRQoL scores were analyzed within groups preoperatively and at the final follow-up. The study adhered to ethical standards and received approval from the Başakşehir Çam and Sakura City Hospital Clinical Research Ethics Committee (approval number: KAEK/25.10.2023-533, date: 06.11.2023).

Radiological Examinations

Standard radiographs (posteroanterior and lateral views of the whole spine, including the pelvis) were obtained at preoperative, early, and late terms. Measurements included coronal main Cobb angle, thoracic kyphosis angle (T2-T12), lumbar lordosis angle (L1-S1), coronal balance (C7-CSVL/cm), sagittal balance (C7-S1/cm), shoulder balance (coracoid height difference/cm), and pelvic obliquity (horizontal pelvic angle). Measurements were made on calibrated radiographic images by an independent spine surgeon twice at a one-month interval, with excellent intraobserver reliability (intraclass correlation coefficient=0.986-0.996). Preoperative computed tomography and magnetic resonance imaging were performed to detect possible spinal pathologies such as diastematomyelia, spinal cord anomalies, tethered cord, spinal dysraphism, syrinx, and Arnold-Chiari malformation. Cardiologic and genitourinary evaluations were also performed under detailed ultrasound examination by consultant physicians preoperatively.

Surgical Procedure

HV removal involved a one-stage posterior approach with a midline skin incision. Posterior elements of HV were removed, and the spinal cord and surrounding nerve roots were identified. HV was excised by placing a concave rod, preserving the spinal cord, and removing the upper and lower cartilaginous discs. A convex rod was placed, and the gap was closed with compression. If a large HV was removed, an anterior titanium mesh cage packed with an autograft was used to prevent spinal cord compression and increase fusion. A ponte osteotomy was used for excising the lamina, posterior ligaments, and facet joints. A third rod with supra- and infralaminar hooks was used when necessary in patients with short-level fixation. Intraoperative neuromonitoring was used in all patients to avoid neurological injuries. Autologous bone grafts obtained from HV and facet joints were used for fusion. In G1, one patient underwent surgery for two HVs located in the thoracic and lumbar regions. In addition to hemivertebrectomy, three patients in G2 had a Ponte osteotomy. Two patients in G2 with large osteotomy gaps following HV excision were filled with mesh cages. Short-level fixation was performed in all patients in G1 and in six patients in G2, with long-level fixation in five patients in G2 (Figure 1). Patients in G1 wore a custom-made brace following a postoperative trunk cast, and patients in G2 wore a custom-made brace for six months.

HRQoL Questionnaires

Parents or caregivers completed the Early Onset Scoliosis Questionnaires (EOSQ-24) for those younger than 10 years old and the Scoliosis Research Society Patient Outcome Questionnaires (SRS-22) for those older than 10 years old

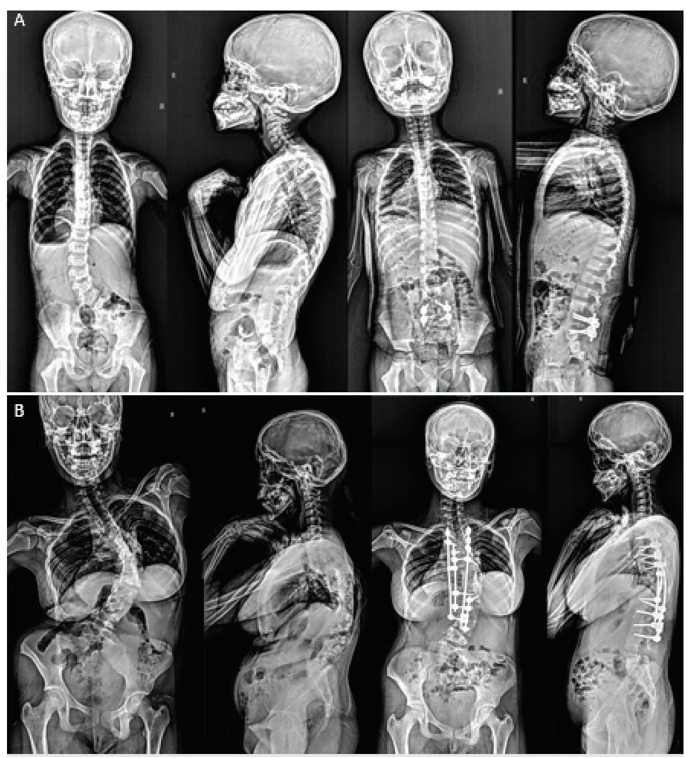

Figure 1. A) Excision and short level fixation of the hemivertebra at the lumbosacral level of the patient with type 1 defect belonging to the Group 1, B) Excision and long level fixation of the hemivertebra at the thoracolumbar level of the patient with type 3 defect belonging to the Group 2

preoperatively and at final follow-up. The SRS-22 questionnaire consists of 22 items, each scored on a scale of 1 to 5, divided into five domains. A high total SRS-22 score indicates better HRQoL. The EOSQ-24 questionnaire consists of 24 items, each scored on a scale of 1 to 5, divided into several domains. A high total EOSQ-24 score indicates better HRQoL and less burden on caregivers.

Statistical Methods

Descriptive statistics included mean, standard deviation, median, minimum, and maximum values. The Kolmogorov-Smirnov test was used to examine the distribution of variables. Quantitative data were compared using Mann-Whitney U tests and independent sample t-tests. For repeated measurements, the Wilcoxon test and paired sample t-test were employed. Qualitative data were compared using a chi-square test. Statistical analyses were performed using SPSS 26.0.

RESULTS

Comparisons of preoperative intraspinal pathologies between the G1 and G2 groups were as follows: Arnold-Chiari malformation: 2 cases in G1 vs. 1 case in G2; tethered cord: 2 cases in G1 vs. none in G2; diastematomyelia: 1 case in G1 vs. none in G2; intraspinal lipoma: 1 case in both groups; and syrinx: 5 cases in G1 vs. 2 cases in G2. Comparisons of previous spinal surgeries performed in the G1 and G2 groups were as follows: myelomeningocele surgery: 1 case in both G1 and G2; tethered cord surgery: 2 cases in G1 vs. none in G2; and intraspinal lipoma surgery: 1 case in G1 vs. none in G2.

Additional system anomalies between the G1 and G2 groups were as follows: cardiovascular anomalies: 1 case in G1 vs. 2 cases in G2; genitourinary anomalies: 3 cases in G1 vs. none in G2; musculoskeletal anomalies: 3 cases in both groups; rib number anomalies: 7 cases in G1 vs. 6 cases in G2; and Goldenhar syndrome: none in G1 vs. 1 case in G2.

Radiologic coronal and sagittal curve measurements are presented in Table 1, and coronal and sagittal balance measurements are presented in Table 2. Patient and surgical data are presented below (G1 vs. G2, respectively):

- Mean age at surgery: 6.5±2.0 years vs. 14.8±2.3 years,
- Mean fusion level: 2.5 0.8 (minimum 2-maximum 4) vs. 7.2±4.6 (minimum 2-maximum 13),
- Mean surgical time: 218.2±56.2 minutes vs. 401.3±159.4 minutes,
- Intraoperative blood loss: 263.6±257.9 mL vs. 818.8±575.7 mL,
- Blood transfusion volume: 1 unit vs. 5 units

These differences were higher in G2 than G1 ($p<0.05$). There were no significant differences in gender distribution, body mass index values, or follow-up times ($p>0.05$).

Curve Measurements

Preoperative Cobb angles were higher in G2 than G1 (p=0.049). No significant difference was found between early and late Cobb angles in both groups (p=0.803 and 0.408, respectively). Cobb angles showed a significant decrease in early and late terms in both groups ($p<0.05$), but the late change in the Cobb angle decrease was higher in G2 than G1 (p=0.039).

There was no significant difference in terms of preoperative, early, and late kyphosis angles in both groups (p=0.090, 0.933, and 0.900, respectively). In G1, early and late changes in kyphosis angles were not significant (p=0.574 and 0.482, respectively). In G2, there was a significant early decrease in kyphosis angle (p=0.036), while the late change was not significant (p=0.091).

There was no significant difference in preoperative, early, and late lordosis angles between G1 and G2 (p=0.507, 0.618, and 0.868, respectively). In G1, early and late changes in lordosis angles were not significant (p=0.472 and 0.621, respectively), whereas in G2, lordosis angles decreased in early and late terms (p=0.018).

Table 1. Radiologic coronal and sagittal curve measurements

	Group 1		Group 2		
	Mean ± SD	Median	Mean ± SD	Median	p-value
Coronal main Cobb angle					
Preoperative period	45.5±22.2	43.0	54.1±18.8	57.0	0.049 ᵐ
Early postoperative period	23.9±22.2	20.5	22.3±13.8	21	0.803 ᵐ
Final follow-up	30.7±24.6	29.0	23.9±13.8	25.5	0.408 ᵐ
Thoracic kyphosis angle (T2-T12)					
Preoperative period	40.2±20.9	40.0	54.6±16.6	53.0	0.090 ᵐ
Early postoperative period	36.5±11.0	35.0	36.5±7.9	36.0	0.933 ᵐ
Final follow-up	42.5±13.4	45.0	42.1±16.3	40.0	0.900 ᵐ
Lumbar lordosis angle (L1-S1)					
Preoperative period	49.5±21.1	50.0	55.4±14.1	56.0	0.507 ᵐ
Early postoperative period	46.8±16.5	50.0	43.4±10.1	41.5	0.618 ᵐ
Final follow-up	50.0±17.5	45.0	48.4±15.1	51.5	0.868 ᵐ

ᵐMann-Whitney U test , SD: Standard deviation

Balance Measurements

Preoperative, early, and late coronal and sagittal balances did not show a significant change within or between groups (p>0.05). Late sagittal balance change was higher in G1 than G2 (p=0.025).

There was no significant difference between the groups in preoperative, early, and late shoulder balance (p=0.741, 0.301, and 0.709, respectively). Early shoulder balance change in G2 was higher than in G1 (p=0.042).

There was no significant difference in preoperative, early, and late pelvic obliquity between and within groups (p=0.137, 0.363, and 0.246, respectively). Leg length inequality and hip contracture were not found on physical examination in both groups.

HRQoL Outcomes

In G1, the following changes were observed:

•Patients' general health status, child and parent satisfaction, and activity of daily living increased (p<0.05)

•There were no substantial changes in postoperative pain or discomfort, pulmonary function, transfer capacity, physical function, fatigue or energy level, parental impact, or financial impact (p>0.05)

•The postoperative emotional state decreased (p<0.05)

In G2, the following changes were observed:

•Postoperative pain, physical function, self-image, mental health, and satisfaction with treatment management increased (p<0.05)

Table 3 provides a detailed comparison of the HRQoL outcomes.

Complications

A proximal adding-on phenomenon was observed in 1 patient in G1, and a superficial surgical site infection developed in 1 patient in G2. No postoperative neurological complications were observed in either group.

DISCUSSION

We observed emotional deterioration in children below 10 years old who underwent hemivertebrectomy and fusion surgery. Emotional states; including anxiety, stress, and disappointment, were assessed according to the questionnaire. Our findings highlight the critical need for perioperative psychological support for these young patients. We also noted that older children might experience higher pain scores due to the complexity of their surgical procedures or inadequate postoperative pain management. Despite these challenges, all other HRQoL scores improved positively in both age groups. Although there was no significant difference between the two groups in terms of postoperative radiological scores, intra-group changes in G2 were higher than G1.

Literature shows varying HRQoL outcomes. For instance, a clinical study with a minimum follow-up of 2 years reported that hemivertebrectomy with short-level fusion resulted in high scoliosis correction rates and increased back pain but improved function[10]. Another study with a 1-year follow-up of patients with congenital scoliosis found that initial postoperative scores for function and pain decreased in the surgical fusion group, but function, image, and satisfaction scores eventually increased[11]. Normal growth of unaffected spine sections is possible if the

Table 2. Radiologic coronal and sagittal balance measurements

	Group 1		Group 2		
	Mean ± SD	Median	Mean ± SD	Median	p-value
Coronal balance (C7-CSVL/cm)					
Preoperative period	1.3±1.3	1.0	0.9±1.0	0.6	0.341 m
Early postoperative period	1.6±1.0	1.5	1.7±1.5	1.3	0.901 m
Final follow-up	1.1±0.9	0.8	1.2±1.1	1.1	0.589 m
Sagittal balance (C7-S1/cm)					
Preoperative period	5.2±3.5	5.5	3.4±2.4	4.2	0.224 t
Early postoperative period	3.1±2.5	2.5	4.6±3.0	4.2	0.285 t
Final follow-up	2.5±2.1	1.8	2.8±2.1	2.2	0.790 t
Shoulder balance (coracoid height difference / cm)					
Preoperative period	1.4±1.2	1.2	1.8±1.4	1.2	0.741 m
Early postoperative period	1.1±1.2	0.9	1.6±1.1	1.4	0.301 m
Final follow-up	1.2±1.3	0.6	1.0±0.7	0.9	0.709 m
Pelvic obliquity (horizontal pelvic angle°)					
Preoperative period	5.2±4.6	4.0	2.9±2.8	2.3	0.137 m
Early postoperative period	3.5±3.4	1.8	3.6±5.3	1.5	0.363
Final follow-up	2.5±1.0	2.2	3.3±4.8	1.6	0.246 m

mMann-Whitney U test, tIndependent samples t-test, SD: Standard deviation

Table 3. EOSQ-24 questionnaire results for Group 1 and SRS-22 questionnaire results for Group 2

	Preop		Postop		
EOSQ-24	**Mean ± SD**	**Median**	**Mean ± SD**	**Median**	**p-value**
General health	34.7±23.2	37.5	63.9±18.2	75.0	0.017 ^{w}
Pain/discomfort	70.8±35.9	87.5	83.3±25.8	100.0	0.461 ^{w}
Pulmonary function	70.8±38.5	100.0	94.4±11.0	100.0	0.109 ^{w}
Transfer	58.3±39.5	75.0	66.7±35.4	75.0	0.655 ^{w}
Physical function	65.0±34.7	75.0	87.2±9.3	90.0	0.078 ^{w}
Daily living	57.5±23.7	50.0	75.6±18.4	75.0	0.042 ^{w}
Fatigue/energy level	61.7±33.4	62.5	75.0±25.0	62.5	0.141 ^{w}
Emotion	62.5±24.2	62.5	40.3±16.3	37.5	0.021 ^{p}
Parental impact	53.9±25.0	55.0	57.8±18.0	65.0	0.624 ^{p}
Financial impact	72.2±19.5	75.0	75.0±35.4	100.0	0.783 ^{w}
Child and parent satisfaction	33.3±28.0	25.0	80.6±11.0	75.0	0.017 ^{w}
	Preop		**Postop**		
SRS-22	**Mean ± SD**	**Median**	**Mean ± SD**	**Median**	**p-value**
Pain	2.5±1.0	2.4	3.7±0.8	3.7	0.005 ^{p}
Function	3.3±1.0	3.2	4.0±0.9	3.9	0.022 ^{p}
Self image	2.3±0.5	2.3	3.9±0.6	3.7	0.001 ^{p}
Mental health	2.4±0.7	2.3	3.5±0.7	3.4	0.006 ^{p}
Satisfaction/dissatisfaction with treatment management	2.0±0.8	2.0	4.4±0.7	4.8	0.000 ^{p}

^{p}Paired samples t-test, ^{w}Wilcoxon test, SD: Standard deviation, SRS-22: Scoliosis Research Society Patient Outcome Questionnaires, EOSQ-24: Early Onset Scoliosis Questionnaires

local deformity is corrected with a short fusion segment. Ruf and Harms[12] noted that older children occasionally required longer fusion segments following HV excision[12]. Delayed treatment of advanced deformities necessitates long fusion segments, which are difficult to correct and pose a high risk for neurological injury[13]. Dimeglio et al.[14] reported that puberty peaks between ages 11 and 13 for females and 13 and 15 for males, with significant growth acceleration during the first two years. G2 had a higher mean age at surgery and a higher preoperative Cobb angle compared to G1. G2 also had longer fusion levels and more complex surgeries, resulting in higher surgical time, intraoperative blood loss, and blood transfusion volume than G1. The crankshaft phenomenon was not observed in our series, consistent with Kesling et al.[15] findings in congenital scoliosis patients.

Xu et al.[16] demonstrated that hemivertebrectomy and short-level fixation effectively reduce coronal segmental and main Cobb angles. Our results showed a significant early and late reduction in main Cobb angles in both groups, with a more substantial late reduction in G2, likely due to higher preoperative Cobb angles and longer fusion level surgeries.

Bao et al.[17] observed a significant correction in the following parameters: segmental kyphosis, total major curve, caudal compensatory curves, and segmental scoliosis, from the preoperative to the final follow-up. But the effects of these surgical procedures on the main thoracic kyphosis angle are also controversial. Although Bixby et al.[18] and Wang et al.[19] have shown that hemivertebrectomy and short-level fixation caused an increase in the thoracic kyphosis angle, Oksanen et al.[10] have demonstrated that hemivertebrectomy and short-level fixation did not change the thoracic kyphosis angle at the final follow-up. Our study found no significant changes in kyphosis angles in G1 at any term, but a significant early decrease in G2, likely due to higher preoperative kyphosis angles and additional corrective osteotomies.

Oksanen et al.[10] and Wang et al.[19] reported that hemivertebrectomy and short-level fixation did not change the lumbar lordosis angle at final follow-up, which our findings in G1 support. In G2, early and late lordosis angles decreased, parallel to the early thoracic kyphosis change. The study has shown a significant correlation between lumbar lordosis and thoracic kyphosis reduction after posterior corrective surgery[20].

A trunk decompensation from the C7 plumb line of more than 20 mm was considered a coronal imbalance of the spine, and a distance of more than 40 mm between the upper posterior sacral vertical line and the C7 plumb line was considered a sagittal imbalance[21]. Studies have shown that HV excision in the lumbosacral region improves coronal and sagittal balance, while thoracolumbar excision has a limited contribution[10,22-24].

In our study, the excised HVs were located in 3 thoracic, 5 thoracolumbar, 3 lumbar, and 1 lumbosacral in G1, and 3 thoracic, 6 thoracolumbar, and 2 lumbar in G2. Coronal and sagittal balance improvements were not different between groups at preoperative, early, and late terms. However, late sagittal balance change was higher in G1, likely due to a higher preoperative sagittal imbalance.

Shoulder balance is crucial for evaluating scoliosis surgery results and cosmetic effects. While the studies with hemivertebrectomy and short-level fixation reported improvements in shoulder balance at final follow-up, the results are not significant[12,18]. Shoulder balance did not differ between groups or at any term in G1, but showed a higher early shoulder balance change in G2, indicating the success of longer fusion levels in achieving shoulder balance.

Pelvic obliquity results from various factors, including leg length inequality, hip contractures, and structural scoliosis[25]. In children who are ambulatory and their caretakers, remaining pelvic obliquity at the conclusion of surgical therapy is associated with worse HRQoL scores. These findings imply that for patients with early-onset scoliosis undergoing surgery, pelvic obliquity correction should continue to be the major objective of care[26]. In our study, no leg length discrepancy or hip contractures were found, and pelvic obliquity was attributed to scoliosis. Pelvic obliquity did not differ between or within groups at any term.

In a series of 27 patients younger than 5 years of age who underwent HV excision and posterior spinal fusion, most of the patients developed spinal instability, and their scoliosis worsened at the last follow-up. Early age at surgery, preoperative scoliosis severity, HV location, lack of arthrodesis technique, and adding-on phenomenon may play a role in it[27]. A 6-year-old patient in G1 who required revision surgery with magnetically controlled growing rods due to a progressive proximal adding-on phenomenon and truncal shift. This patient was the youngest in our study, having undergone the first deformity surgery at age 4.

The limitations of the study include the fact that it does not have a large sample size due to its single-center design.

CONCLUSION

Hemivertebrectomy is a successful surgical treatment for improving radiological and HRQoL scores in children, both below and above 10 years old. Postoperative decreases in the Cobb angle were higher in G2 compared to G1. For children below 10 years old, short-level fixation is recommended for physiological growth and less fusion, along with necessary psychological support to prevent emotional deterioration. Long-level fixation provides advantageous radiological results but may lead to painful HRQoL scores.

Ethics

Ethics Committee Approval: The study adhered to ethical standards and received approval from the Başakşehir Çam and Sakura City Hospital Clinical Research Ethics Committee (approval number: KAEK/25.10.2023-533, date: 06.11.2023).

Informed Consent: Informed consent was obtained from each patient.

Authorship Contributions

Concept: Y.Ö., M.B.B., Design: Y.Ö., M.B.B., Data Collection or Processing: Y.Ö., A.V.Ö., Analysis or Interpretation: K.A., M.B.B., Literature Search: Y.Ö., A.V.Ö., Writing: Y.Ö., M.B.B.

Conflict of Interest: The authors have no conflicts of interest to declare.

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