Liang et al. Journal of Orthopaedic Surgery and Research (2024) 19:652
https://doi.org/10.1186/s13018-024-04985-5

Journal of Orthopaedic Surgery and Research

RESEARCH ARTICLE

Open Access

The impact of halo-pelvic traction on sagittal kyphosis in the treatment of severe scoliosis and kyphoscoliosis

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Abstract

Background Halo-pelvic traction (HPT) is acknowledged for enhancing pulmonary function and reducing neurological complications in severe and rigid scoliosis and kyphoscoliosis. While its role in improving coronal balance is established, its impact on sagittal kyphosis remains under-researched. This study aims to assess HPT's effects on sagittal alignment in these conditions.

Methods A retrospective review of 37 patients with severe and rigid scoliosis or kyphoscoliosis was conducted to evaluate HPT's efficacy. The analysis focused on the impact of HPT on coronal and sagittal parameters, pulmonary function tests (PFTs) and complications. Radiographic assessments included main cobb angle in coronal, sagittal major kyphosis.

Results HPT was applied for an average of 2.9 months, significantly reducing the primary coronal curve from 127.7°±30.3° to 74.9°±28.3° ($P<0.05$), achieving a 41.3% correction rate. Sagittal kyphosis correction was more pronounced, with angles decreasing from 80.4°±26.4° to 41.3°±24.4° ($P<0.05$), resulting in a 48.6% correction rate. Pulmonary function tests showed improvements in forced vital capacity (FVC) (from 1.32 ± 0.91 to 1.55 ± 0.83) and forced expiratory volume in 1 s (FEV1) (from 1.03 ± 0.76 to 1.28 ± 0.72), with percentage predicted values also increasing (FVC%: 40.4%±24.3–51.4%±23.1%; FEV1%: 37.8%±25.2–48.1%±22.7%; all $P<0.05$).

Conclusion HPT effectively reduces spinal deformity severity and improves pulmonary function in patients with severe and rigid scoliosis and kyphoscoliosis. Sagittal kyphosis correction was notably greater than coronal scoliosis correction. The correlation between PFT improvements and coronal curve adjustments suggests that correcting the coronal Cobb angle is pivotal for pulmonary function enhancement.

Keywords Halo-pelvic traction, Kyphoscoliosis, Pulmonary function, Forced vital capacity, Spine deformities

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Introduction

Severe spine deformities were commonly defined as a Cobb angle larger than 90 and flexibility of less than 30%. There was no unified diagnostic standard, with the cause often being a congenital deformity, Pott's deformity, and ankylosing spondylitis [1–4]. The management of severe deformity remains a major challenge, which includes severe kyphoscoliosis and pulmonary dysfunction. Due to the aggressive procedure of the correction, the nerves were easily damaged by traction. To improve pulmonary function and evaluate the tolerance of the nerves, the HPT was used in the treatment of severe deformity.

The HPT was first used in the treatment of Pott's deformity in the 1960s. The HPT consists of a head ring, a pelvic ring, and retractable connecting rods. It has been reported as an effective method, which could gradually lengthen the height of the thoracic spine and rib cage and enlarge the volume of the lungs. Meanwhile, the patients could move freely and perform the exercise of the pulmonary function [5, 6]. Therefore, the pulmonary function could be improved during HPT. Moreover, evaluating the adaption of spinal cord traction during HPT could provide surgical strategies for surgeons. Previous studies have proved that HPT can reduce the severity of scoliosis [7].

There was little study focused on the improvement of sagittal kyphosis. Therefore, the purpose of this study was to evaluate the impact of HPT on sagittal kyphosis in the treatment of severe and rigid scoliosis and kyphoscoliosis.

Methods

From January 2018 to January 2021, patients with severe and rigid scoliosis and kyphoscoliosis treated with HPT in our hospital were retrospectively enrolled. Inclusion criteria were as follows: (1) age less than 18 years, (2) the kyphosis or scoliosis was rigid (the change of Cobb angle in bending or lateral radiograph less than 30%), (3) main coronal Cobb angle more than 90 in scoliosis or Cobb angle more than 70 in kyphosis, (4) duration of HPT more than 1.5 months. Patients who underwent revision surgery after other surgical procedures failed to treat scoliosis, or were diagnosed with Pott's and ankylosing spondylitis (AS) were excluded.

The HPT device (Beijing Fule Technology Development Co., Ltd., certificate number: 20162040214) consisted of a head ring, a pelvic ring, and connecting rods. All patients underwent general anesthesia. The patient was in the lateral position. Two k-wires (Beijing Fule Technology Development Co., Ltd., 4.0*373 mm) were inserted into the pelvic through the inner and outer table of the ilium bilaterally. The same procedure was performed on the other side. The procedure for the installation of head pins involved drilling at the points located at one-third the distance from the outer edge of the bilateral supraorbital margins and 1.5 cm posterior and superior to the auricle. Following the placement of the halo ring, pins were tightened into the skull with a hex wrench, with a minimum of three pins per side, ranging from six to eight pins in total, to distribute the stress evenly. The pins were tightened alternately in a diagonal pattern from front to back. The torque of the pins is determined by the hardness of the patient's skull to ensure that the screw tips engage with the outer table of the bone, avoiding both penetration of the inner table and any cutting of the outer table during traction. Traction was performed after the installment. The frame was elongated at a rate of 0.5 cm per day. The function of the upper/lower extremity was observed every day, especially after each increase in traction length. If any complication occurred, such as upper-extremity numbness, the traction length was reduced to the previous length. During HPT, patients blow balloons and climb stairs with the help of others every day to improve pulmonary function. In view of the poor nutritional status of most patients, we do our best to improve the nutritional status of patients during traction. Imaging data of patients treated with HPT before surgery were showed in Figs. 1 and 2.

The measurements were obtained by review of inpatient medical records and questionnaires. The primary outcomes of this study were the Cobb angle, kyphosis angle, and pulmonary function, while the secondary outcomes were a change of height and the complications of HPT.

Standing anteroposterior and lateral radiographs were performed preoperatively, postoperatively, and once a month during HPT. The Coronal thoracic or lumbar/thoracolumbar Cobb angle was measured between the maximally tilted upper and lower end vertebrae by using the standard Cobb's method [8].

The sagittal major kyphosis angle was the angle between the upper endplate of the vertebra one cephalad to the apical vertebrate and the lower endplate of the vertebra one caudal to the apical vertebrate. In addition, Magnetic resonance imaging is used to observe the morphology of the spinal cord to determine whether there is compression of the nervous system. Determine whether the spine has formed bony connections and evaluate its flexibility in different spatial slices and three-dimensional reconstructed images of CT.

The efficacy of pulmonary function was evaluated at both pre-traction and the final traction, which mainly contained FVC, FVC%, FEV1and FEV1%. In addition, the vital capacity/weight ratio (VCWR) (ml/kg) as another measurement reflecting the pulmonary function was also calculated. In males, the VCWR of more than 75 ml/kg was excellent, 64 ~ 69 ml/kg, 54 ~ 56 ml/kg, and lower than 43 ml/kg were respectively regarded as good,

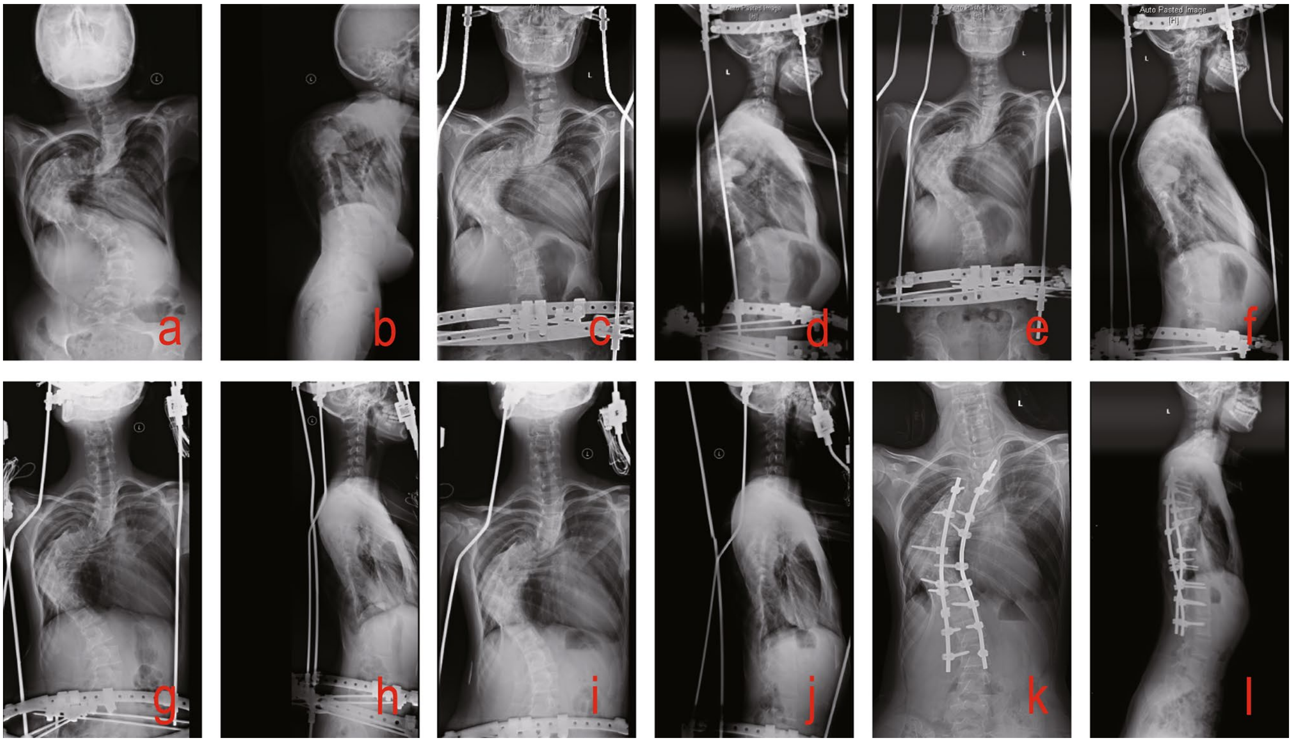

Fig. 1 female,14 years, congenial scoliosis and kyphosis **(a, b)**, Pre-traction: coronal: 122° **(c)**, sagittal:106° **(d)**; One month traction: coronal: 106° **(e)**, sagittal: 90° **(f)**; Two months traction: coronal: 102° **(g)**, sagittal: 81° **(h)**; Three months traction: coronal: 90° **(i)**, sagittal: 53° **(j)**; Four months traction: coronal: 85° **(k)**, sagittal: 46° **(l)**

fair, and poor. In female, the excellent-good-fair-poor of VCWR was respectively corresponded to 70 ~ 74 ml/kg, 57 ~ 63 ml/kg, 44 ~ 53 ml/kg and < 43 ml/kg [9].

Data were expressed as mean ± standard deviations for measurement variables. Pre-traction and post-traction differences were performed using paired t-test. The comparisons of categorical variables between pre-HPT and post-HPT were used by the Mann-Whitney test. Pearson's correlation was also performed to analyze the relationship between the changes in pulmonary function and radiographic parameters. All analyses were carried out by using the SPSS (Statistics for Windows, Version 17.0. Chicago: SPSS Inc.) and the statistical significance was set at $P < 0.05$.

Results

A total of 37 cases, with a gender distribution of 17 males to 20 females, were enrolled in the study. The mean age of the participants was 14.5 ± 7.5 years. The etiology of the spinal deformities included congenital deformity in 16 patients, idiopathic in 14, Marfan syndrome in one, and neurofibromatosis in six. The duration of HPT was 2.9 ± 1.4 months, with the majority (70.3%) lasting within three months. The average height at baseline was 143.3 ± 18.1 cm, with a mean increase of 9.5 ± 5.6 cm ($p < 0.001$). The mean body weight was 39.1 ± 11.8 kg, ranging from 19.0 to 57.0 kg, and the change in weight was 3.2 ± 2.6 kg (range: -1.5 to 6.8 kg; $P < 0.001$) at the conclusion of HPT (Tables 1 and 2).

The primary coronal curve of scoliosis, which averaged 127.7 ± 30.3°, was reduced to 74.9 ± 28.3° following HPT ($P < 0.05$), achieving a correction rate of 41.3%. In the sagittal plane, the major kyphosis, initially averaging 80.4 ± 26.4°, was corrected to 41.3 ± 24.4° ($P < 0.05$), with a correction rate of 48.6%. Notably, significant correction of the deformity occurred within the initial eight weeks, with the major coronal curve of scoliosis improving by 35.5% (from 127.7 ± 30.3° to 82.3 ± 27.6°) and the major kyphosis by 42.3% (from 80.4 ± 26.4° to 46.4 ± 21.7°).

Pulmonary function, as measured by FVC and FEV1, showed improvements from 1.32 ± 0.91 to 1.55 ± 0.83 and from 1.03 ± 0.76 to 1.28 ± 0.72, respectively, after HPT ($P < 0.05$). Similarly, the percentage predicted values for FVC and FEV1 (FVC% and FEV1%) improved from 40.4 ± 24.3 to 51.4 ± 23.1 and from 37.8 ± 25.2 to 48.1 ± 22.7, respectively, after HPT ($P < 0.05$) (Tables 2 and 3).

Pearson's correlation analysis revealed that improvements in FVC, FVC%, FEV1, and FEV1% were significantly correlated with changes in the Cobb angle (all $P < 0.05$). In contrast, improvements in FVC%, FEV1, and FEV1% were not significantly correlated with changes in the sagittal kyphosis angle (all $P > 0.05$). Only the improvement in FVC showed a significant correlation

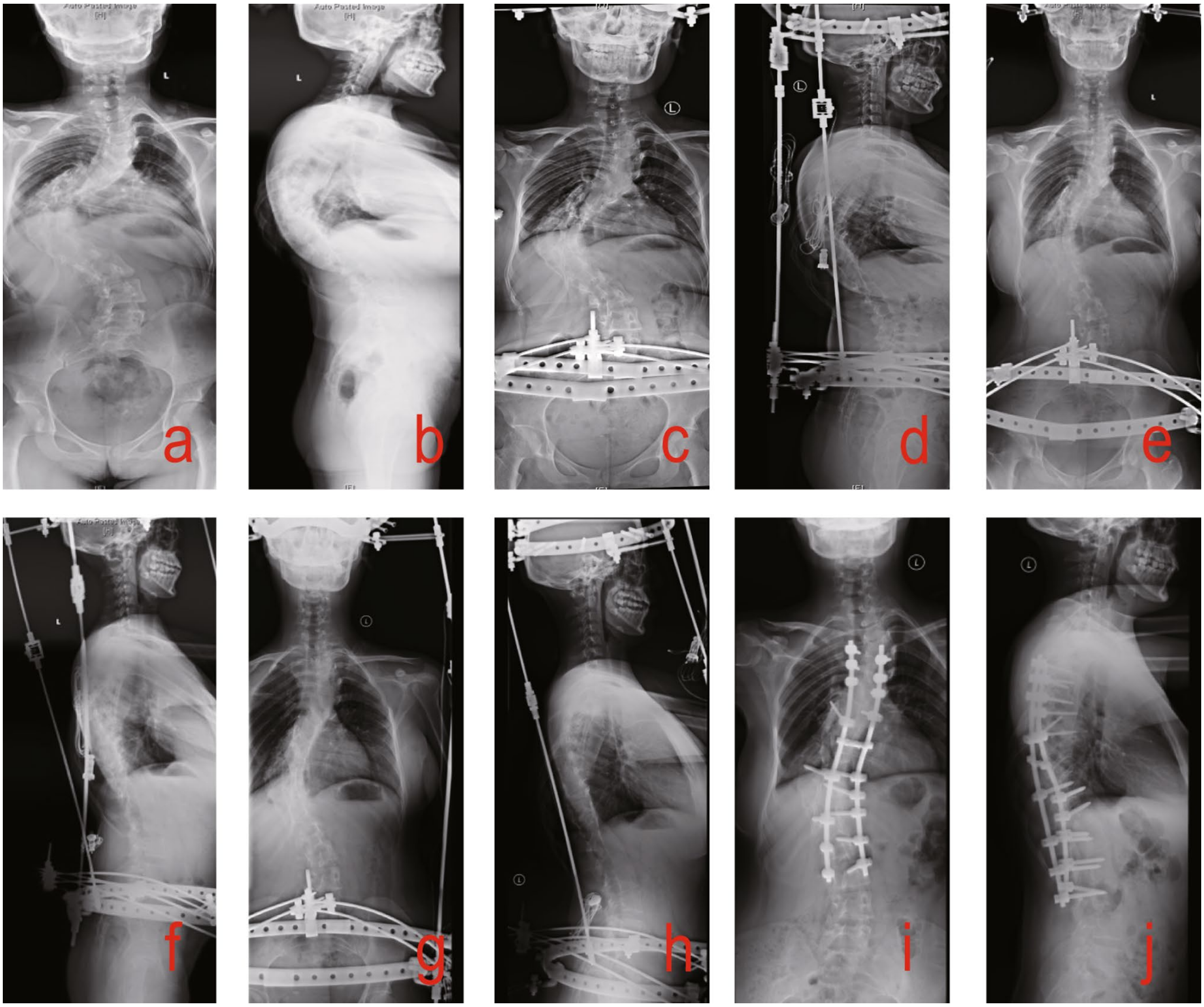

Fig. 2 female, 22 years, diagnosis as idiopathic scoliosis earlier **(a, b)**; Pre-traction: coronal: 110° **(c)**, sagittal: 85° **(d)**; One month traction: coronal: 92° **(e)**, sagittal: 68° **(f)**; Two months traction: coronal: 70° **(g)**, sagittal: 57° **(h)**; Three months traction: coronal: 62° **(i)**, sagittal: 52° **(j)**

with changes in the sagittal kyphosis angle ($P<0.05$) (Table 4).

At baseline, the vital capacity to total lung capacity ratio (VC/TLC) was categorized as excellent in 2 cases, good in 4, fair in 7, and poor in 24. Following HPT, there was an improvement in VC/TLC distribution to 4-5-14-14 cases, respectively ($P<0.05$) (Table 5).

No permanent neurological complications were observed during the course of HPT. Three patients experienced pin site infection, which resolved with antibiotic treatment. Additionally, one patient developed blepharoptosis that resolved upon the removal of the HPT during the final corrective surgery. It is noteworthy that one patient reported numbness in the left lower extremity, which improved after the traction length was adjusted to the previous setting.

Discussion

The prevalence of severe spine deformities is increasing, presenting a significant challenge for spine surgeons [10, 11]. Severe scoliosis and kyphosis compress the thoracic region, which can result in respiratory impairment. Additionally, the severe deformity can stretch the cord, potentially affecting its function. Correcting the severe and rigid alignment is a challenging task for spine surgeons. These factors increase the risk of neurologic injury, morbidity, and mortality [12]. To reduce the incidence of complications, Halo-traction is used to treat patients with severe and rigid scoliosis and kyphoscoliosis [13, 14]. During traction, the deformity of the patients is greatly improved in both the coronal and sagittal planes. In our study, the mean coronal curve scoliosis was 127.7±30.3° and was reduced to 74.9±28.3° after HPT. The correction rate was 41.3%. The mean

Table 1 The demographics of severe scoliosis and kyphosis with HPT

Parameters	Statistics
Male (%)	17 (45.9)
Age (y)	14.5 ± 7.5
Weight (kg)	39.1 ± 11.8
Δ Weight (kg)	3.2 ± 2.6
Traction time (m)	2.9 ± 1.4
Diagnosis	
Congenital deformity	20
Idiopathic deformity	14
Marfan syndrome	1
Neurofibromatosis	2
Apical vertebrae of scoliosis	
> T8 (T8/9)	13
T9 (T9/10)	8
< T10 (T10/11)	5
Kyphotic peak	
> T8 (T8/9)	5
T9 (T9/10)	3
< T10 (T10/11)	3

Δ: the change of variable

Table 2 Radiographic parameters of the patients with rigid scoliosis ($n = 37$)

	Pre-traction	Post-traction	P
Height	143.3 ± 18.1	152.7 ± 20.3	$P < 0.05$
Coronal cobb angle	127.7 ± 30.3	74.9 ± 28.3	$P < 0.05$
Sagittal kyphosis angle	80.4 ± 26.4	41.3 ± 24.4	$P < 0.05$

Table 3 Comparison of PFT results before and after HPT ($n = 37$)

	Pre-traction	Post-traction	P
FVC(L)	1.32 ± 0.91	1.55 ± 0.83	$P < 0.05$
FVC%	40.4 ± 24.3	51.4 ± 23.1	$P < 0.05$
FEV1 (L)	1.03 ± 0.76	1.28 ± 0.72	$P < 0.05$
FEV1%	37.8 ± 25.2	48.1 ± 22.7	$P < 0.05$

Table 4 Pearson's coefficients between radiographic parameters and PFT results after traction ($n = 37$)

	Δ Coronal cobb angle		Δ Sagittal kyphosis angle	
	r	P	r	P
FVC(L)	0.35	0.03	0.69	0.02
FVC%	0.46	0.04	0.54	0.09
FEV1 (L)	0.34	0.03	0.57	0.04
FEV1%	0.37	0.04	0.50	0.12

Δ: the change of variable

Table 5 The distribution of grade of VCWR before and after HPT

	Pre-traction	Post-traction	P
Excellent (*n*)	2	4	0.04
Good (*n*)	4	5	
Fair (*n*)	7	14	
Poor (*n*)	24	14	

sagittal major kyphosis was 80.4±26.4° and was reduced to 41.3±24.4° after HPT ($P<0.05$). The correction rate was 48.6%. The correction of deformity was similar to that observed in the study by Qi [15]. It is evident that the sagittal kyphosis was significantly improved, even to a normal state, following traction. In other words, the HPT was found to be an effective method for correcting the sagittal deformity, with a greater impact than the correction of the coronal plane. During the traction period, the axial traction applied to the sagittal plane was found to be more effective than that applied to the coronal plane. This provides a convenient framework for the second stage of correction surgery. Furthermore, in our study, the first two months of treatment resulted in 90% correction of deformities. Initially, the spine itself has a certain degree of flexibility. With the progression of traction, it is challenging to retract the stiff spinal deformity. Therefore, two months of traction was necessary for the patient to improve the deformity. Prolonged traction was of little significance to the improvement of deformity. Conversely, prolonged traction would result in increased patient discomfort and an elevated risk of complications. It was therefore imperative that the patients' pulmonary function and nutrition be optimized as soon as possible, as this would facilitate their ability to end traction and perform the deformity correction surgery with greater speed and ease. All patients who underwent HPT treatment were subsequently subjected to definitive fixation and fusion surgery using pedicle screws and titanium rods after achieving satisfactory results from the traction.

It is possible that the Halo-traction could correct the deformity to some extent and recover the effective volume of the thoracic cavity, which could effectively improve the pulmonary function with respiratory function exercise [10]. Furthermore, the Halo-traction could evaluate the tendency of the nerve during the traction in case injury to the nerve occurs during the correction of the deformity [16]. The Halo traction technique encompasses Halo-gravity, Halo-femur and HPT techniques. The pulmonary function was found to have been significantly enhanced in the course of this study [17, 18]. The FVC was observed to increase from 1.32±0.91 to 1.55±0.83 following the implementation of the HPT technique ($P<0.05$). The FEV1 was improved from 1.03±0.76 to 1.28±0.72 after HPT ($P<0.05$). The FVC% was improved from 40.4±24.3 to 51.4±23.1 after HPT ($P<0.05$). The FEV1% was enhanced from 37.8±25.2 to 48.1±22.7 following HPT ($P<0.05$). Furthermore, the VCWR exhibited a notable improvement following HPT ($P<0.05$). The improvement in thoracic volume is likely to be the main reason for this.

At present, Halo-gravity traction is the most commonly used in clinical settings, and its safety and efficacy have been well-documented. However, it should be noted that the strength of the Halo-gravity traction is limited and that its controllability is insufficient. These limitations require further study. The HPT has gained increasing popularity among surgeons due to its advantages. Firstly, the HPT could provide a persistent and powerful traction, which would release the contracture tissue and improve the stiffness of the spine. Secondly, the HPT was performed in a gradual manner, which was beneficial in enabling a safe evaluation of the nerve's tendency. Furthermore, the HPT was a convenient procedure for patients. The patients were able to move freely and perform pulmonary function exercises, which allowed for the greatest possible evaluation of their tolerance of the operation [19–22].

Both coronal correction and sagittal improvement have the potential to alter the thoracic volume. However, it is the effective cavity ventilation that represents the more significant factor in improving pulmonary function. Pearson's correlation demonstrated a statistically significant correlation between the improvement in FVC, FVC%, FEV1 and FEV1% and the change in Cobb angle (all $P<0.05$). Conversely, the improvement of the FVC%, FEV1 and FEV1% was negatively correlated to the change of sagittal kyphosis angle (all $P>0.05$). The improvement of the FVC was the only variable correlated to the change of sagittal kyphosis angle ($P<0.05$). For patients with severe and rigid scoliosis and kyphoscoliosis, pulmonary function is often impaired, with some cases commonly complicated by type II respiratory failure, which can result in inability to operate or significant risk of anesthesia [23]. In a study by Weinstein, it was found that clinically relevant pulmonary impairment was commonly observed in patients with curves exceeding 100° [24]. Furthermore, there was a significant correlation between pulmonary function and curve severity. Consequently, the primary objective was to enhance pulmonary function, which represented the most crucial aspect of the HPT. Payo [25] indicated that restrictive lung dysfunction is associated with decreased lung volume, and that this could be improved by enlarging the thoracic cavity and increasing the contraction ability of respiratory muscles through exercise. A simple increase in thoracic volume may not necessarily improve pulmonary function, given the existence of non-functional alveoli. For patients with severe and rigid scoliosis and kyphoscoliosis, the thoracic kyphosis contributes to an increase in the vertical diameter of the thoracic cavity. Correction of the kyphosis may result in a reduction in the longitudinal diameter and an increase in the transverse diameter, although this is unlikely to result in a significant increase in the thoracic volume. Correction of the scoliosis may result in an increase in the transverse diameter of the compressed thorax. Furthermore, the correction of the scoliosis may result in a reduction of the invalid cavity on the opposite side of the chest. Consequently, the correction of coronal scoliosis may be of significant benefit in improving pulmonary function.

Three patients exhibited symptoms of a pin site infection, which were successfully treated with antibiotics. The prolonged retention of a K-wire in the pelvis may result in the inflammation of surrounding soft tissue. Prophylactic antibiotics can effectively control infections caused by exposed nail tracts. During the entire orthopedic process, one patient developed ptosis, which improved after the HPT was removed. It is our contention that this protracted stretching of the nerve is distinct from acute nerve injury. Similarly, patients who experienced limb numbness also experienced improvement in their symptoms following the adjustment of the traction frame. The common occurrence of nerve damage in HPT necessitates the careful observation of the patient's neurological condition throughout the orthopaedic process. In the event of such an occurrence, it is imperative that the traction length be adjusted without delay.

It should be noted that this study is subject to certain limitations. Firstly, halo-gravity has been employed in numerous other hospitals and has been demonstrated to be an efficacious treatment for severe and rigid forms of scoliosis and kyphoscoliosis. This study did not compare the HPT with halo-gravity. Secondly, this study is a small sample, retrospective study. Due to the limited number of cases, further studies with a larger sample size are required to facilitate further discussion. Additionally, the study only analysed and researched biomechanical parameters and lung function indicators, with relevant laboratory test results excluded. Nevertheless, the results of this study also demonstrate that both sagittal and coronal corrections are significantly correlated with the patient's lung function. In the context of preoperative preparation, it is of paramount importance to be fully cognizant of the interrelationship between biomechanical enhancement and the correlation between patient quality of life and the implementation of efficacious intervention strategies.

Conclusion

The HPT was an efficacious method to diminish the severity of the deformity and enhance pulmonary function in the treatment of severe and rigid scoliosis and kyphoscoliosis patients. The sagittal kyphosis was corrected to a greater extent than the coronal scoliosis. While there was a correlation between the improvement in the PFT and the change in the coronal scoliosis, it can be concluded that the correction of the coronal Cobb angle plays the most important role in the improvement of pulmonary function.

Author contributions

Yan Liang, Zhenqi Zhu and Chong Zhao contributed equally to this work. YL and ZZ and CZ carried out the molecular genetic studies, participated in the sequence alignment and drafted the manuscript, SX and CG participated in the design of the study and performed the statistical analysis. DZ and HL conceived of the study and participated in its design and coordination and helped to draft the manuscript. All authors read and approved the final manuscript.

Funding

This work was supported by the found of Peking University People's Hospital (RDY2021-09), and the fund of National Orthopedics and Sports Rehabilitation Clinical Research Center, cultivation project "Application and promotion of pressure sensor assisted craniopelvic spinal traction device"(2021-NCRC-CXJJ-PY-38) .

Data availability

No datasets were generated or analysed during the current study.

Declarations

Ethics approval and consent to participate

This retrospective study was approved by the Institutional Review Board (IRB) of Peking University People's hospital and Chengdu Third People's Hospital. All patients involved in the study consent to participate in the study. And the written consent has been obtained from all the patients.

Consent for publication

All individual person's data consent to publish.

Competing interests

The authors declare that they have no competing interests.

Received: 18 May 2024 / Accepted: 6 August 2024
Published online: 15 October 2024

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