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RESEARCH

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The effectiveness and safety of staged halo-pelvic traction combined with posterior spinal fusion in the treatment of severe rigid spine deformity: a prospective cohort study

Lijin Zhou[1*†], Honghao Yang[1†], Jianqiang Wang[1†], Yiqi Zhang[1], Yunsheng Wang[1] and Yong Hai[1*]

Abstract

Background Severe rigid spinal deformities present significant challenges in correction surgery due to complexity and associated comorbidities. To mitigate the surgical risks, preoperative halo-pelvic traction (HPT) have been employed. This study aims to evaluate the effectiveness and safety of staged HPT combined with posterior spinal fusion (PSF) in the treatment of severe rigid spine deformity.

Methods This is a prospective cohort study. From 2020 to 2022, 61 consecutive patients (mean age 26.2 years) with severe rigid spine deformity who underwent staged HPT combined with PSF with a minimum 24-month follow-up were recruited. Radiographic parameters, clinical information, pulmonary functions tests, and perioperative complications were recorded.

Results The mean preoperative coronal Cobb angle was 114.2° ± 38°, and the mean MK was 105.8° ± 34.7°. Following the HPT (mean duration 19.2 weeks), the mean coronal Cobb angle were corrected to 55.3° post-traction (50.6%) and 47.4° after PSF (58.3%); the mean MK angle were corrected to 52.6° post-traction (49.5%) and 38.1° after PSF (63.4%). The overall complication rate during HPT was 16.4%, while surgery-related complications were 18.0%, with no permanent neurological deficits observed.

Conclusion Staged HPT combine with PSF is effective and safe for patients with severe rigid spine deformities. HPT could mitigate the severity of spine deformity, minimize the need for invasive three-column osteotomies, and reduce the risk of complications for correction surgery.

Keywords Spinal deformity, Halo-pelvic traction, Posterior spinal fusion, Effectiveness, Safety

†Lijin Zhou, Honghao Yang and Jianqiang Wang contributed equally to this work.

*Correspondence:
Lijin Zhou
doctorzhoulijin@163.com
Yong Hai
yong.hai@ccmu.edu.cn
[1]Department of Orthopedic Surgery, Beijing Chao-Yang Hospital, Capital Medical University, GongTiNanLu 8#, Chaoyang District, Beijing 100020, China

Introduction

Severe rigid spine deformities present significant challenges in correction surgery due to their complexity and associated comorbidities. Patients often suffer from related conditions, including restrictive pulmonary diseases, cardiovascular complications, and malnutrition, which could lead to increased mortality rates. The leading causes of death in untreated spinal deformity patients are respiratory failure and cardiovascular disease, underscoring the critical need for effective treatment strategies [1, 2].

Correcting severe rigid spinal deformities is particularly challenging, especially when the Cobb angle exceeds 100° [3]. In aggressive one-stage surgical corrections, three-column osteotomies, including pedicle subtraction osteotomy (PSO) and vertebral column resection (VCR), are often required. However, these procedures carry significant risks, including massive blood loss, neurological deficits, and pulmonary complications, with complication rates reported to be between 18% and 74% for spinal deformity surgeries [4–6]. Patients with severe spinal deformities frequently endure prolonged operating time, which could result in serious postoperative issues.

To mitigate these risks, preoperative traction methods such as halo-femoral traction (HFT), halo-gravity traction (HGT), and halo-pelvic traction (HPT) have been employed [7–9]. While HGT has demonstrated the ability to provide gradual corrections, it may not achieve satisfactory results for patients with severe rigidity due to its poor strength and low efficiency [10]. HFT has been gradually discarded due to its requirement for prolonged bedrest and associated discomfort [3]. In contrast, HPT, introduced in the 1970s, provides powerful and continuous corrective forces that effectively manage severe rigid spinal deformities [11]. Short-term HPT is particularly advantageous, as it allows for significant curvature reduction while minimizing complications [9].

Despite the potential benefits of HPT, there is a lack of comprehensive studies reporting the clinical efficacy of preoperative HPT for severe rigid spinal deformities. This study aims to evaluate the effectiveness and safety of staged HPT combined with posterior spinal fusion (PSF) in the treatment of severe rigid spine deformity.

Materials and methods

Study design and ethics approval

This study was designed as a prospective cohort study to assess the effectiveness and safety of staged HPT combined with PSF for patients with severe rigid spine deformities. All patients were treated at our institution between June 2020 June and June 2022. Ethical approval was obtained from the institutional review board at Beijing Chao-Yang Hospital, and all participants provided informed consent prior to enrollment. The study adhered to the principles of the Declaration of Helsinki for human research ethics.

Inclusion and exclusion criteria

Patients eligible for inclusion were those diagnosed with severe rigid spine deformity, defined by a coronal Cobb angle and/or significant kyphosis greater than 90° with reduced flexibility (< 30%). Exclusion criteria included a history of active spinal infection, previous spine surgery and/or an inability to tolerate traction due to psychological or physical limitations.

Halo-pelvic traction and posterior spinal fusion protocol

All patients underwent a standardized halo-pelvic traction protocol. Under general anesthesia, the pelvic fixation component was installed by placing two pins bilaterally into the iliac crest and the posterior superior iliac spine, with subsequent connection to a circular pelvic ring. A standard halo was fixed to the skull with ten sharp-tipped pins, ensuring correct placement in safe zones around the skull. Four threaded rods connected the halo to the pelvic ring, providing the foundation for gradual traction. Traction was initiated at a rate of 1–2 mm/day in the first week and reduced to 0.5–1 mm/day in the following weeks based on patient tolerance. Traction was performed until the desired radiographic correction (correction rate of 50% for coronal curve or kyphosis) was achieved. Patients were closely monitored for neurological deterioration, pin-site infection, and mechanical complications. Daily neurological assessments and weekly radiographs were performed to evaluate the traction's effects and detect potential complications. Neurological symptoms were treated by immediately reducing the traction distance by 10 mm and simultaneously administered methylprednisolone as well as mannitol via intravenous infusion. Gradual resumption could be tried if symptoms resolved. Once adequate correction was achieved via HPT, PSF surgery was performed with the HPT device sustained. It should be noted that thoracoplasty could be performed simultaneously with the insertion of pelvic fixation component or fusion surgery. Somatosensory evoked potentials and motor evoked potentials were used to monitor spinal cord condition during whole operative process.

Radiographic evaluation

Radiographic evaluation was conducted using standing whole spine radiography. Key parameters including coronal Cobb angle, apical vertebral translation (AVT), C7 plumb line to center sacral vertical line (C7PL-CSVL), maximal kyphosis (MK), sagittal vertical axis (SVA), pelvic incidence (PI), pelvic tilt (PT), sacral slope (SS), and T1 pelvic angle (TPA) were recorded pre- and

Table 1 Demographic and surgical information

Parameter	
No. of patients	61
Age (year)	26.2 ± 9.5
Male: Female	23: 38
BMI (kg/m^2)	19.6 ± 3.4
Etiology, n (%)	
Idiopathic	19 (31.1%)
Congenital	38 (62.3%)
neuromuscular	4 (6.6.%)
Spinal cord malformation, n (%)	27 (44.3%)
Traction time (week)	19.2 ± 4.5
EBL (mL)	571.8 ± 310.6
ORT (min)	305.7 ± 66.3
Fusion level (n)	13.5 ± 1.7
LOS (day)	36.0 ± 16.6
Length of ICU stay (day)	1.6 ± 1.4
Osteotomy, n (%)	23 (37.7%)

BMI, body mass index; EBL, estimated blood loss; ORT, operating time; LOS, length of hospital stay

post-traction, post-PSF as well as at final follow-up after PSF surgery.

Clinical evaluation

Operating time (ORT), estimated blood loss (EBL), the length of hospital stay (LOS), the length of ICU stay were recorded. Complications during HPT (traction-related) and post-PSF (surgery-related) were also recorded. Scoliosis Research Society (SRS)-22 scale were used to assess health-related quality of life (HRQoL) pre-traction and at the last follow-up.

Statistical analysis

Descriptive statistics were used to summarize patient demographics, baseline characteristics, and surgical parameters. Continuous variables with a normal distribution are presented as the mean ± standard deviation; otherwise, the median and interquartile range are used. The counts and percentages are presented for categorical variables. Data were compared using paired t-test or Wilcoxon's rank-sum test, with a P-value < 0.05 considered statistically significant. Statistical analysis was performed using SPSS software (Version 25.1, IBM Corp., Armonk, NY, USA).

Results

Demographics and surgical information

A total of 61 patients with severe rigid spine deformity were enrolled in this study, with a mean age of 26.2 ± 9.5 years, including 23 males and 38 females (Table 1). The mean preoperative coronal Cobb angle was 114.2° ± 38°, and the mean MK was 105.8° ± 34.7°. All patients underwent HPT for a period ranging from 11 to 29 weeks, with an average traction period of 19.2 ± 4.5 weeks. The mean ORT for PSF was 305.7 ± 66.3 min, and the average estimated EBL was 571.3 ± 310.6 mL. The average LOS was 36.0 ± 16.6 days, and the mean length of ICU stay was 1.6 ± 1.4 days.

Radiological data

Significant radiographic improvements were observed following HPT and PSF (Table 2). The mean coronal Cobb angle improved to 55.3° ± 22.3° post-traction, representing a correction rate of 50.6% (P < 0.001). After PSF, the Cobb angle further improved to 47.4° ± 22.7°, achieving an overall correction of 58.3%. The mean MK improved to 52.6° ± 22.6° post-traction, representing a correction rate of 49.5% (P < 0.001). After PSF, the MK further improved to 38.1° ± 21.9°, achieving an overall correction of 63.4%. During the follow-up, the the correction effect of PSF maintained well.

SRS-22 score

HRQoL, as assessed by the SRS-22 scale, showed significant improvements at the last follow-up (Table 3). The overall SRS-22 score increased from 3.6 ± 0.2

Table 2 Radiographic parameters

Parameter	Pre-traction	Post-traction	P-value [a]	Post-PSF	P-value [b]	Final FU	P-value [c]
Cobb angle (°)	114.2 ± 38	55.3 ± 22.3	< 0.001	47.4 ± 22.7	< 0.001	47.1 ± 23.2	0.855
MK (°)	105.8 ± 34.7	52.6 ± 22.6	< 0.001	38.1 ± 21.9	< 0.001	38.5 ± 20.9	0.7
TK (°)	87.7 ± 31.5	52 ± 24.3	< 0.001	44.7 ± 22.6	0.003	44.6 ± 22.4	0.926
LL (°)	65.7 ± 22	46.8 ± 18.7	< 0.001	42.2 ± 15.5	0.033	42.1 ± 16	0.905
PT (°)	10.9 ± 7.6	10.1 ± 6.5	0.448	11 ± 6.3	0.267	12.8 ± 7.7	0.064
SS (°)	25.7 ± 9.2	23.7 ± 7.9	0.086	22.7 ± 8.8	0.222	21.8 ± 7.9	0.179
TPA (°)	7.7 ± 5.6	7.1 ± 5.7	0.544	9 ± 6.3	0.059	9.2 ± 4.6	0.688
C7PL-CSVL (mm)	26.9 ± 25.8	20.4 ± 23.3	0.053	26.5 ± 24.3	0.02	23.6 ± 19.2	0.143
SVA (mm)	16.9 ± 22.2	22.4 ± 37.6	0.233	23.7 ± 27	0.801	24.4 ± 22.4	0.79
AVT (mm)	89.3 ± 36.2	64.9 ± 29.9	< 0.001	44.7 ± 27.8	< 0.001	42.2 ± 24.9	0.087

a, Post-traction vs. Pre-traction; b, Post-PSF vs. Post-traction; c, Final FU vs. Post-PSF

PSF, posterior spinal fusion; FU, follow-up; MK, maximal kyphosis; TK, thoracic kyphosis; LL, lumbar lordosis; PT, pelvic tilt; SS, sacral slope; TPA, T1 pelvic angle; C7PL-CSVL, C7 plumb line to center sacral vertical line; SVA, sagittal vertical axis; AVT, apical vertebral translation

Table 3 Scoliosis research society-22 outcomes

Domain	Pre-traction	Post-traction	*P*-value
Functional activity	3.6 ± 0.4	3.9 ± 0.4	< 0.001
Pain	4.1 ± 0.3	4.2 ± 0.3	< 0.001
Self-image	2.8 ± 0.2	3.7 ± 0.2	< 0.001
Mental health	3.9 ± 0.3	4.3 ± 0.3	< 0.001
Overall	3.6 ± 0.2	4 ± 0.2	< 0.001

Table 4 Traction-related and surgery-related complications

Complications	*n* (%)
Traction-related complications	10 (16.4%)
Pin-site infection	3 (4.9%)
Atlantoaxial instability	2 (3.3%)
Instrumentation-related cutting	1 (1.6%)
Brachial plexus palsy	4 (6.6%)
Surgery-related complications	11 (18.0%)
Temporary neurological deficit	3 (4.9%)
Pulmonary infection	2 (3.3%)
Pleural effusion	3 (4.9%)
Dural tear	3 (4.9%)

preoperatively to 4.0 ± 0.2 at the last follow-up ($P < 0.001$). Improvements were particularly noted in the self-image and mental health domains, where the scores increased from 2.8 ± 0.3 to 3.7 ± 0.2 ($P < 0.001$) and 3.9 ± 0.3 to 4.3 ± 0.3 ($P < 0.001$). Functional activity domain also demonstrated positive changes, reflecting enhanced physical functioning and daily activity levels postoperatively.

Complications

Traction-related complications

Minor complications were observed during the HPT phase, with an incidence of 16.4% (Table 4). Pin-site infections occurred in 4.9% of patients and were managed successfully with local wound care and antibiotics. There were two cases of atlantoaxial instability and one case of instrumentation-related cutting. Temporary neurological symptoms, including mild lower limb weakness or paresthesia, were noted in 6.6% of patients and resolved after reducing the traction distance by 10 mm. No permanent neurological deficits occurred during traction, and no patients required early cessation of HPT due to severe complications.

Surgery-related complications

The incidence of surgery-related complications was 18.0% (Table 4). There were three cases (4.9%) of dural dear, two cases of pulmonary infection (3.3%%), and three cases of pleural effusion (4.9%). Intraoperative neurophysiological monitoring signal loss occurred in three cases (4.9%), who experienced transient motor weakness postoperatively. All patients ultimately made a full neurologic recovery within 12 weeks. There were no reports of permanent neurological deficits, implant-related failures, or other major complications during the follow-up period.

Discussion

The management of severe rigid spine deformities remains a significant challenge in orthopedic surgery, often complicated by the technical difficulties of corrective procedures, high risks of neurological complications, and associated risks of pulmonary dysfunction [12]. Since HPT was applied for spine deformities in 1971, it became the optimal treatment [11]. However, the utilization of HPT has gradually declined with the rise of internal fixation. Nevertheless, patients with rigid severe spine deformity suffer from combination of cardiopulmonary and digestive dysfunction, the relatively poor nutritional status. One-stage surgical correction may encounter long operation time, massive intraoperative blood loss, and even irreversible distraction spinal cord injury [13, 14]. Indeed, it is difficult to achieve a satisfactory curative effect after one-stage correction surgery and radical osteotomy, especially when the Cobb angle exceeds 100° [15]. This study demonstrated that staged HPT combined with PSF is an effective and safe approach to address these challenges.

HPT has emerged as an effective preoperative strategy for managing severe rigid spine deformities, particularly when compared to high-grade osteotomy. Posterior vertebra column resection (PVCR) has been widely recognized for its capacity to correct severe rigid spine deformities, with studies demonstrating correction rates ranging from 50 to 70% [16, 17]. Saif et al. noted that severe coronal and sagittal malalignments treated with PVCR could achieve approximately 60% correction, while Xie et al. reported a scoliosis correction rate of 59% in patients with curves exceeding 100° [18, 19]. The current study found that preoperative HPT, when combined with multi-level Ponte osteotomies and PSF, could yield an overall correction rate of 58.3% and 63.4% in the coronal and sagittal plane, respectively. This result is comparable to those reported for PVCR, suggesting that HPT serves as an effective adjunctive method that could potentially mitigate the need for high-grade osteotomies during subsequent surgeries. The findings underscore the value of HPT in improving surgical outcomes while avoiding the risks associated with more invasive procedures. A representative case was presented inn Fig. 1.

When treating severe spine deformities, HPT demonstrates superior safety compared to PVCR. A systematic review by Yang et al. reports an overall complication rate for PVCR as high as 32%, with neurological complications being the most prevalent, occurring in approximately 8% of cases [17]. Other studies indicate that the incidence of transient neurological deficits following VCR ranges from 2 to 13.8%, while the risk of permanent

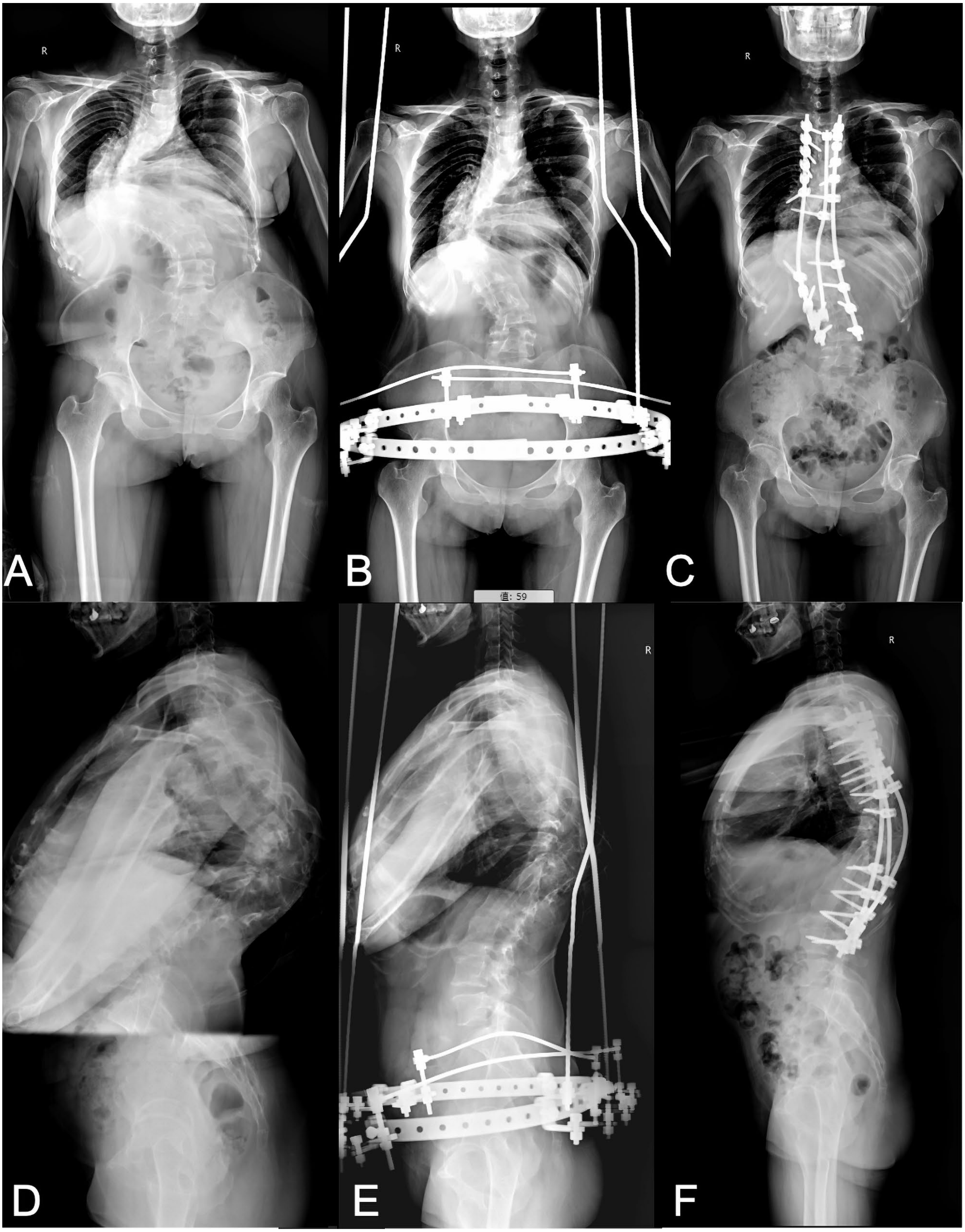

Fig. 1 A-E A 36-year female with severe rigid spinal deformity who underwent staged halo-pelvic traction (15 weeks) combined with posterior spinal fusion

neurological complications is estimated at 2–6% [20–23]. In the current study, staged HPT combined with PSF has shown a significantly lower incidence of neurological deficits (4.9%), with no cases of permanent neurological dysfunction. The advantage of HPT involves providing a gradual and powerful traction force, which effectively corrects spinal curves while minimizing the risk of severe complications associated with high-grade osteotomies.

The safety of HPT can be attributed to its short-term application and gradual force increment. By increasing traction incrementally while patients remain conscious, any neurological deficits could be detected and addressed immediately, with the maintain of spine stability. Additionally, the continuous gradual traction allows the spinal cord adequate time to adapt to pathological and physiological changes, unlike VCR which causes sudden alterations. Our study revealed that the HPT-related complication rate was 16.4% while four patients (6.6%) experienced temporary neurological deficits during the period of HPT; however, all the symptoms were resolved after reduction of traction distance or PSF surgery. Daily inspections of all connection points of the HPT device are performed to ensure device integrity, with prompt troubleshooting to prevent loosening prior to definitive PSF surgery. Therefore, there was no any loosening of device before the PSF surgery.

The most practical difficulty in PSF surgery with HPT device applied is that the pelvic ring may obstruct the insertion of pedicle screws in L5 and S1 vertebra. Therefore, the lowest instrumented vertebra could only be stopped at L4. For patients who have severe lumbar curve requiring instrumentation extended to L5 or lower, a two-staged PSF surgery have to be performed. Another concern is the comfort level of patients during sleeping with HPT device, which is closely related to their quality of life. To address sleep discomfort caused by the pelvic ring, a customized solution have been developed, which placed a thick sponge pad (larger than the patient's body dimensions) beneath the back and individually carving out a central cavity to accommodate the patient. This modification not only allows supine positioning during sleep but also prevents pressure ulcers caused by prolonged immobility. A series of standardized assessment tools and feedback metrics would also be designed in the future studies to enrich research outcomes and provide clinical guidance for institutions adopting HPT.

Despite the promising results, this study has limitations, including its single-arm design without a control group, which may affect the generalizability of the findings. Future studies could benefit from comparative studies, comparing HPT with halo-gravity traction or PVCR (direct surgical correction without HPT), to further elucidate the advantages of HPT. We would collaborate with multiple centers to expand follow-up durations and enrich outcome metrics, including different populations and settings. Beyond radiographic parameters and complications, future investigations will prioritize pulmonary function assessments, quality-of-life evaluations, and other patient-centered outcomes to comprehensively assess the therapeutic efficacy. Additionally, keep looking for any permanent residual effect on atlantoaxial instability stability is also important.

Conclusion

Staged HPT combined with PSF is effective and safe for patients with severe rigid spine deformities. HPT could mitigate the severity of spine deformity, minimize the need for invasive three-column osteotomies, and reduce the risk of complications for correction surgery. HPT was a valuable addition to the management protocols for enhancing surgical outcomes in severe rigid spine deformity.

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Author contributions
Lijin Zhou contributed to conceptualization; formal analysis; validation; visualization; roles/writing-original draft; Yong Hai contributed to conceptualization; methodology; Honghao Yang contributed to data curation; formal analysis; validation; visualization; roles/writing-original draft; Jianqiang Wang contributed to writing-review & editing. Yiqi Zhang contributed to data curation; Yunsheng Wang contributed to data curation.

Data availability
No datasets were generated or analysed during the current study.

Declarations

Ethics approval and consent to participate
This study was approved by the Institutional Review Board of Beijing Chaoyang Hospital, and informed consent was obtained from all patients.

Consent for publication
Consent for publication were obtained from patients.

Competing interests
The authors declare no competing interests.

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