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Research Article

Effectiveness and Safety of Preoperative Halo Gravity Traction-Assisted Posterior Spinal Fusion Surgery for Severe and Rigid Scoliosis: A Comparative Matched-Cohort Study

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Background. Severe and rigid scoliosis poses significant challenges in surgical correction, and innovative approaches are continually sought to enhance effectiveness and ensure patient safety. Halo-gravity traction (HGT) continues to be a vital tool in managing severe spinal conditions, offering a nonsurgical or preoperative approach to address spinal deformities. However, the correction effect that HGT can achieve for severe and rigid spinal deformity is currently unclear and the impact of HGT on the selection of spinal osteotomy grade was still unknown. *Methods*. A retrospective matched-cohort study was conducted and a total of 74 patients from January 2018 to December 2021 in our institution were finally enrolled in this study, including 27 patients in the HGT group and 47 patients in the non-HGT group based on whether patients receive HGT or not. Comprehensive assessments including radiographic outcomes, surgical parameters, and clinical complications were collect and analyzed before and after correction surgery. *Results*. Of the patients included in the HGT group, 21 had thoracic curvature and 6 had thoracolumbar/lumbar curvature, compared with 38 and 9 in the non-HGT group, respectively ($P = 0.66$). There was no significant difference in the etiologies of scoliosis between two groups (15/7/3/2 vs. 25/16/4/2, $P = 0.85$). The main curve in HGT and non-HGT groups were corrected from an average of 113.69°–51.25° and 111.94°–63.79° ($P < 0.01$). For the HGT group, the mean correction rate of focal kyphosis (FK) was 45.43%, which was significantly higher than those in the non-HGT group (33.98%, $P < 0.05$). There were no statistically significant differences in preoperative parameters of sagittal vertical axis (SVA) ($P = 0.13$) or thoracic kyphosis (TK) ($P = 0.07$) between the two groups. Postoperatively, the HGT group showed significantly lower values in SVA ($P = 0.001$) and TK ($P = 0.001$) compared to the non-HGT group. However, there was no significant difference in the imaging parameters coronal vertical axis (CVA) and apical vertebral translation (AVT) between the two groups ($P > 0.05$). In the preoperative surgical planning phase before HGT treatment, 26 patients were initially considered candidates for 3-column osteotomy (3CO), while one patient was evaluated as suitable for posterior column osteotomy (PCO). Following HGT treatment, the assessment changed with 11 patients identified as candidates for 3CO and 16 patients deemed suitable for PCO. The application proportion of 3CO was significantly higher in the non-HGT group than in the HGT group ($P < 0.05$). The mean blood loss of the non-HGT group was significantly greater than that of the HGT group (666.67 ± 486.55 ml vs. 1024.47 ± 718.46 ml, $P < 0.05$), but the surgical time showed no difference between the two groups (297.33 ± 66.89 mins vs. 299.15 ± 56.73 mins, $P = 0.90$). The incidence of complications in the HGT group was 7.4%, which was significantly lower than that of the non-HGT group ($P < 0.05$). *Conclusion*. This study showed that the use of HGT, as a feasible and safe strategy, has superior efficacy and safety for treating severe and rigid scoliosis and can reduce the level of osteotomy used during surgery to some extent.

1. Introduction

Severe and rigid spinal deformity, marked by a visibly curved spine exceeding 90 degrees, entails a consequential twisting or rotation of the vertebrae [1, 2]. In addition, severe scoliosis may lead to respiratory and nutrition problems, further emphasizing the multifaceted challenges associated with this condition [2, 3]. Although often combined with highly invasive procedure of spinal osteotomy techniques, correction surgery for such spinal deformities carries inherent risks [4]. Potential complications include nerve injury, infections, massive blood loss, nonfusion, and internal fixation-related issues [5]. Therefore, surgeons are pursuing other techniques to improve such conditions to reduce the use of spinal osteotomies and thus minimize the surgical risks.

HGT is a therapeutic technique extensively utilized in the management of spinal deformities, particularly in conditions such as severe scoliosis or kyphosis. This approach involves the application of a halo device secured to the patient's skull, connected to a system of pulleys and weights [6]. The primary objectives of HGT include gradually realigning and straightening the spine, effectively reducing curvature. This method is often employed as a preparatory measure before surgical interventions, allowing for a gradual correction of spinal deformities, which has been demonstrated in some previous studies [7–12]. Furthermore, enhancing cardiopulmonary function assists surgeons in assessing spinal cord tolerance and the probability of spinal cord nerve injury during traction, thereby attenuating postoperative complications associated with the spinal cord and nerves [12–14].

Previous studies have suggested that HGT may have a certain role in optimizing the osteotomy procedure in the final correction surgery [11, 13]. However, to the best of our knowledge, detailed description and high-level evidence for such an effect that HGT can be achieve severe and rigid spinal deformity are still lacking. Hence, this investigation of HGT technology not only centers on appraising its efficacy and safety for severe spinal conditions, encompassing corrective effects and perioperative complications, but also delves into the influence of preoperative HGT on the determination of osteotomy grade during corrective surgery.

2. Materials and Methods

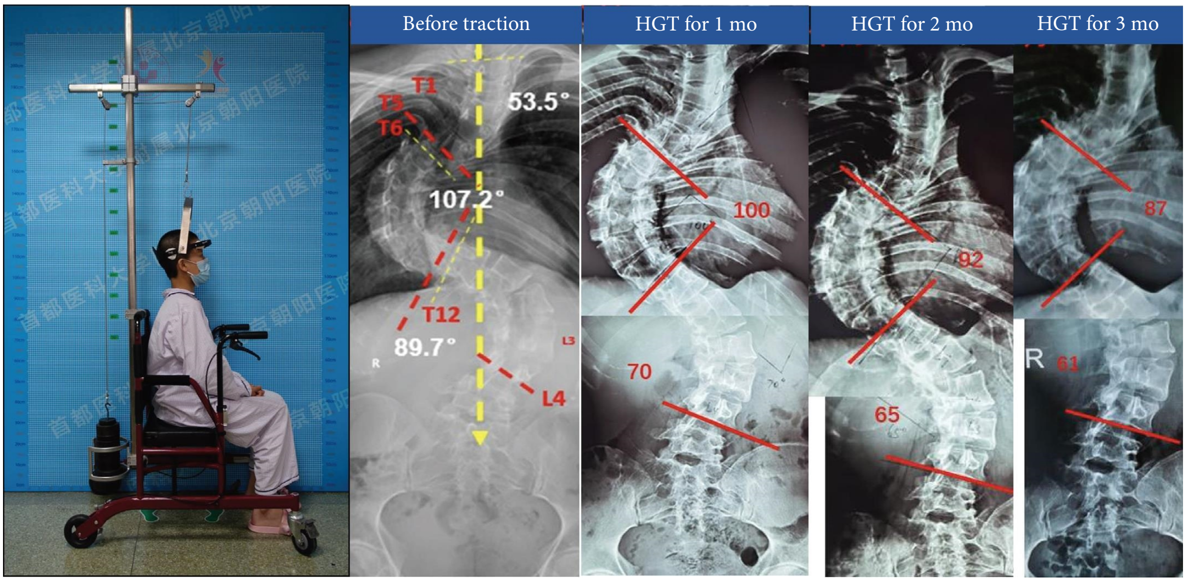
2.1. Patients Selection. This investigation was conducted as a retrospective cohort study with matched participants, receiving approval from the Institutional Review Board. Consent was explicitly provided by all individuals involved. The study encompassed a systematic review of consecutive cases, selecting patients with significant spinal abnormalities who were subjected to corrective spinal surgery within our facility from January 2018 to December 2021. Eligibility for inclusion required (1) a pronounced spinal deformity characterized by a Cobb angle surpassing 80°; (2) a primary curve flexibility of less than 25%, as determined through bending radiographs; and (3) a minimum of 24 months' follow-up after surgery. Conversely, the exclusion criteria were as follows: (1) any patient with a prior history of spinal surgeries; (2) cases with incomplete radiological, surgical, or clinical records; (3) individuals unable to undergo surgical anesthesia or complete the procedure; and (4) procedures not involving spinal fusion, such as the insertion of growth rods.

Participants were stratified into two cohorts depending on their receipt of HGT therapy as follows: those undergoing HGT constituted the HGT cohort, while individuals without HGT treatment were classified into the non-HGT cohort. An initial retrospective examination of 153 patients was conducted, from which 96 qualified based on the inclusion criteria and were thus incorporated into the analysis. Pairing of patients receiving HGT treatment with those in the non-HGT group was executed at a ratio of 1 : 2, matching based on several preoperative parameters including main curve (MC) magnitude, MC flexibility, sagittal vertical axis (SVA), coronal vertical axis (CVA), apical vertebral translation (AVT), lumbar lordosis (LL), and thoracic kyphosis (TK). Ultimately, 74 patients were selected for inclusion in the study, comprising 27 in the HGT cohort and 47 in the non-HGT cohort. The mean follow-up duration for all participants was 32.32 ± 4.98 months.

2.2. Traction Approach and the Surgical Procedure. All the HGT patients began wheelchair suspension traction 3–5 days later, adjusting to the traction setup. Starting with a 1.5 kg force, the traction weight was increased weekly by 3–5 kg, considering each patient's health conditions and tolerance. The target traction force reached 40%–50% of the patient's weight. Traction, lasting a minimum of 12–15 hours daily, was conducted in bed, a wheelchair, or a standing device. To avoid upward movement during sleep, the weight was reduced by 50–75% [15].

During the traction phase, rigorous daily routines were maintained for pin site sterilization and monitoring of neurological functions, which encompassed assessments of cranial nerves, muscular strength, and sensory perception in limbs. In the event of neurological complications, the intensity of traction was either reduced or temporarily suspended until the patient exhibited symptom resolution. The continuation of traction was contingent upon the rate of curvature correction, as determined through monthly radiographic evaluations, with additional consideration given to the patient's pulmonary and nutritional status (Figure 1). Criteria for the cessation of halo-gravity traction (HGT) included (1) attainment of sufficient spinal deformity correction that either met the prerequisites for subsequent corrective surgery or exhibited no further improvement; (2) emergence of neurological or other adverse events during traction, especially when conservative management failed to provide relief; and (3) the patient's incapacity to endure the traction process any longer.

All corrective surgical procedures were conducted by a singular surgeon, adhering to a consistent methodological approach. The surgical strategy involved the exclusive use of a pedicle screw construct, with all corrections being executed through a posterior approach, as meticulously outlined in the preoperative surgical plan. Osteotomy techniques,



(a) (b) (c) (d) (e)

Figure 1: Gravity traction diagram. (a) This patient with severe spinal deformity was treated with gravity traction on a modified wheelchair. (b) The full-spine X-ray examination showed a main curve of 107.2° before traction. (c) After 1 month of HGT treatment, the main curve improved to 100° and the compensatory curve improved to 70°. (d) After 2 months of HGT treatment, the main curve improved to 92° and the compensatory curve improved to 65°. (e) After 3 months of HGT treatment, the main curve improved to 87° and the compensatory curve improved to 61°.

specifically spinal posterior column osteotomy (PCO) and vertebral column resection (VCR), were employed, tailored to the distinct characteristics of each curve. These procedures were carried out in accordance with methodologies delineated in prior research [16, 17]. (Figure 2).

3. Data Collection and Evaluation

Clinical and radiographic data were systematically gathered at the following three pivotal junctures: prior to the initiation of traction, following the completion of traction, and subsequent to the surgical intervention. Concurrently, patients were mandated to adhere to a structured follow-up regimen as dictated by our center's protocols. This regimen necessitated that patients participate in comprehensive, in-person follow-up sessions at the surgeon's clinic, extending to a minimum duration of 24 months before the surgical procedure.

3.1. Radiographic Evaluation. Full length X-ray examination of the spine was performed for all patients. For the purpose of radiographic analysis, the picture archiving and communication system (PACS) was employed. This facilitated the measurement of key radiographic parameters, including the Cobb angle of the main curve (MC), thoracic kyphosis (TK), lumbar lordosis (LL), sagittal vertical axis (SVA), coronal vertical axis (CVA), apical vertebral translation (AVT), and flexibility of the curve (FK). These measurements were meticulously taken from both preoperative and postoperative imaging, allowing for a comprehensive assessment of surgical outcomes.

3.2. Clinical Evaluation. The study's demographic and clinical information was collected and processed anonymously by two blinded researchers. Clinical data were meticulously collected from patient records at the following three critical points: prior to surgery, immediately after surgery, and at the final follow-up visit. This data compilation encompassed demographic details such as age, sex, and body mass index (BMI), along with specific surgical metrics. The surgical details recorded included the volume of operative blood loss, the number of vertebral segments fused, the quantity of screws implanted, and the total duration of the surgical procedure. This comprehensive dataset enabled a robust analysis of patient outcomes and surgical efficacy.

Perioperative and follow-up complications as well as revision surgery were recorded and analyzed including neurological complications, pulmonary complications, and skin infections (surgical site infections and chronic sinus issues). Besides, complications occurred during HGT were also recorded in the HGT group.

3.3. Evaluation of Osteotomy. To better document the role of HGT in reducing the grade of osteotomy, two independent surgeons with extensive osteotomy experience separately conducted preoperative osteotomy planning for HGT patients before and after traction. The osteotomy grade of surgical plan was collected and compared before and after HGT. In cases of dispute, a third senior surgeon was consulted for further evaluation. All HGT patients were categorized into the following two situations: one undergoing PCO and the other receiving 3CO, which included both PSO and VCR techniques [18].

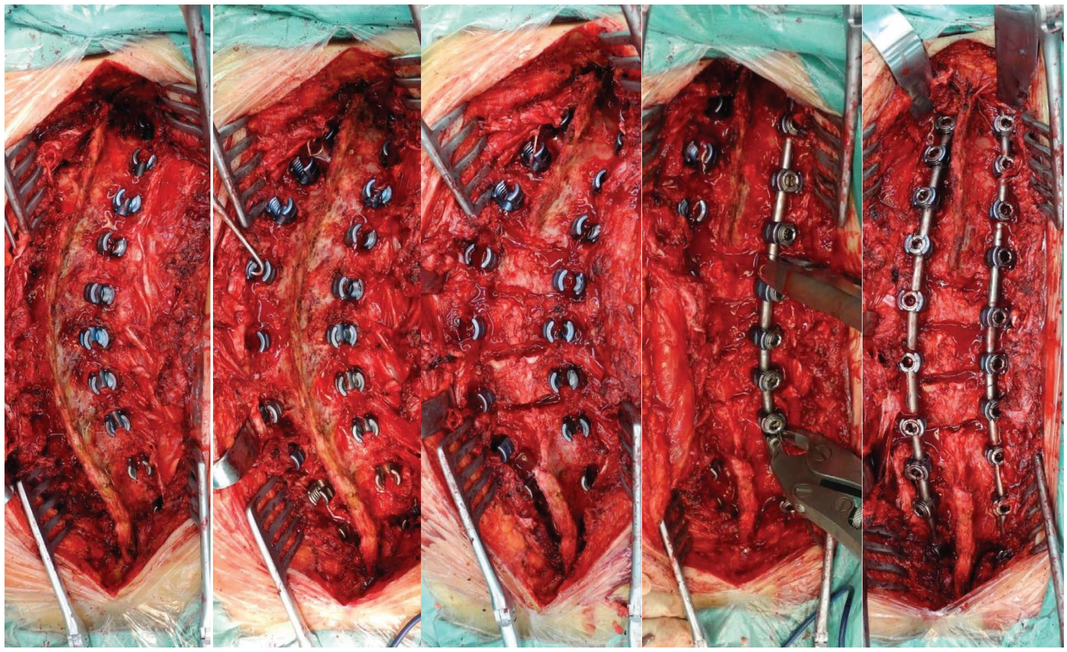


Figure 2: Surgical image of a patient undergoing correction with PCO technology. (a) Insert pedicle screws on the concave side of the curve. (b) Pedicle screws were implanted on the convex side of the curve. (c) Perform multilevel PCO osteotomy in the main curve area. (d) Implant a prebend rod on the concave side and use the derotation technique for correction. (e) Implant another rod on the convex side and further correct deformity through the compression, distraction, and derotation technique.

3.4. Statistical Analysis. Statistical analyses were executed employing SPSS Statistics version 20.0 (IBM, Armonk, New York). The correction rates for major thoracic (MT) curvature and flexibility of the curve (FK) were quantified as percentages. Continuous variables were described using mean values and standard deviations (SDs) and were analyzed using independent *t*-tests and the Mann–Whitney *U* test for distributions not assuming normality. For categorical data, analysis was performed utilizing the χ^2 test and Fisher's exact probability test when appropriate. Graphical depictions of the data were generated with GraphPad Prism 8.0 software (GraphPad software, LLC). A *P* value of less than 0.05 was considered statistically significant.

4. Results

Among the 74 patients, there were 19 male and 55 female, with an average age of 23.57 ± 9.32 (range: 9–56) years and a mean body mass index of 20.08 ± 3.99 (range: 15.34–32.34). In the HGT group, the mean duration of HGT treatment in patients with HGT was 4.41 ± 2.22 weeks. There were 27 patients of the HGT group which were composed of 8 male and 19 female, with a mean age of 17.4 ± 6.6 years. A total of 47 patients of the non-HGT group consist of 11 male and 36 female, with a mean age of 27.1 ± 8.8. Details of the demographic and baseline characteristics of the patients in two groups are listed in Table 1. Of the patients included in the HGT group, 21 had thoracic curvature and 6 had thoracolumbar/lumbar curvature, compared with 38 and 9 in the nonHGT group, respectively ($P = 0.66$). There was no significant difference in etiologies of scoliosis (idiopathic scoliosis/congenital scoliosis/neuromuscular scoliosis/syndromic scoliosis) between the two groups (15/7/3/2 vs. 25/16/4/2, $P = 0.85$.) We found no statistically significant differences between the preoperative image parameters of two groups in terms of gender, Cobb angle of MC, flexibility of MC, CVA, AVT, LL, TK, and SVA ($P > 0.05$).

4.1. Radiographic Outcome. For the HGT group, the Cobb angle of the main curve was corrected from 113.68° to 88.71° via HGT treatment after an average duration of 132.22 ± 66.70 days ($P < 0.05$), with an average correction rate of 21.97% in the HGT group. After surgery, the mean correction rate of MC was 53.80%, while the correction rate of FK was 45.43% (Figure 3). While in the non-HGT group, the mean MC correction rate was 43.76% and the FK correction rate was 33.98%, which was significantly lower than those in the non-HGT group (Table 2, $P < 0.05$) (Figure 4).

There were no statistically significant differences in preoperative parameters of MC ($P = 0.79$), SVA ($P = 0.13$), or TK ($P = 0.07$) between the HGT and non-HGT groups. However, postoperatively, the HGT group showed significantly lower values in MC ($P = 0.02$), SVA ($P = 0.001$), and TK ($P = 0.001$) compared to the non-HGT group (Table 2). Meanwhile, FK in the HGT group was significantly greater than that in the non-HGT group ($P = 0.001$), and there was no statistically significant difference in FK between two groups after undergoing correction surgery after HGT ($P = 0.37$). Changes in AVT ($P = 0.83$), CVA ($P = 0.10$), and LL ($P = 0.98$) from preoperative to postoperative stages did not differ significantly between the HGT and non-HGT groups.

Table 1: Summary of demographic parameters and baseline parameters.

Variables	HGT group $N = 27$	Non-HGT group $N = 47$	P value
Sex (male/female)	8/19	11/36	0.56
Levels of deformities (T/TL-L)	21/6	38/9	0.66
Type of scoliosis (CS/IS/NMS/SS)	15/7/3/2	25/16/4/2	0.85
Major curve	113.69 ± 26.30	111.94 ± 26.52	0.79
Flexibility	13.09 ± 9.24	13.02 ± 10.74	0.98
CVA	27.41 ± 16.78	22.56 ± 33.40	0.46
AVT	82.40 ± 34.50	73.77 ± 28.32	0.49
LL	61.75 ± 28.30	67.12 ± 17.84	0.32
TK	91.72 ± 41.64	77.75 ± 23.89	0.07
SVA	37.43 ± 25.23	28.56 ± 23.61	0.13

HGT: halo-gravity traction; CVA: coronal vertical axis; AVT: apical vertebral translation; LL: lumbar lordosis; TK: thoracic kyphosis; SVA: sagittal vertical axis; IS: idiopathic scoliosis; CS: congenital scoliosis; NMS: neuromuscular scoliosis; SS: syndromic scoliosis; T: thoracic curve; L: lumbar curve; TL: thoraciclumbar curve.

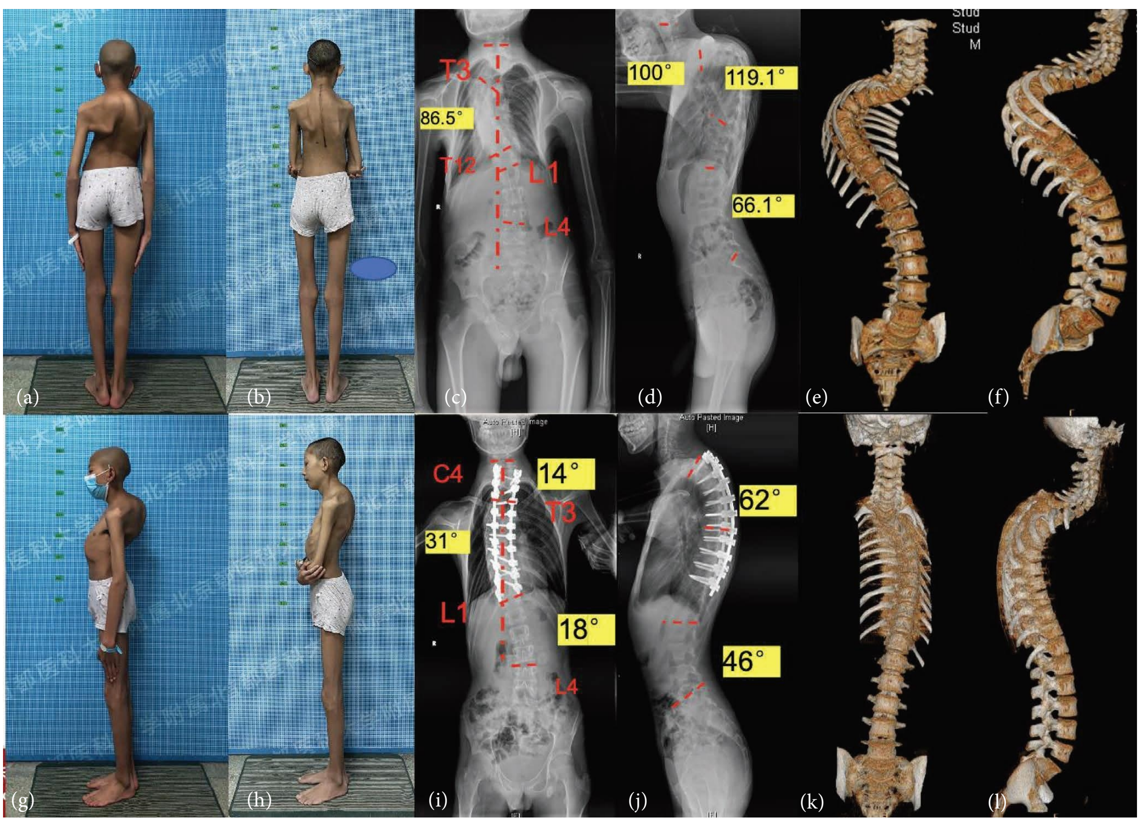


Figure 3: Imaging of a typical case in the HGT group: (a) Preoperative full-body photograph of the patient (coronal view). (b)Postoperative full-body photograph of the patient (coronal view). (c) Preoperative full-length spine radiographs (anteroposterior and lateral views). (d) Preoperative full-length spine radiographs (sagittal view). (e) Preoperative spinal CT with 3D reconstruction. (coronal view). (f) Preoperative spinal CT with 3D reconstruction. (sagittal view). (g) Preoperative full-body photograph of the patient (sagittal view). (h) Postoperative full-body photograph of the patient (sagittal view). (i) Postoperative full-length spine radiographs (anteroposterior and lateral views). (j) Postoperative full-length spine radiographs (sagittal view). (k) Postoperative spinal CT with 3D reconstruction. (coronal view). (l) Postoperative spinal CT with 3D reconstruction. (sagittal view). The patient underwent the posterior column osteotomy surgery.

4.2. HGT Reduced the Grade of Osteotomy. In the preoperative surgical planning phase before HGT treatment, 26 patients were initially considered candidates for 3CO, while one patient was evaluated as suitable for PCO. Following HGT treatment, the assessment changed, with 11 patients identified as candidates for 3CO and 16 patients deemed suitable for PCO. This shift highlights a significant increase in the proportion of patients recommended for PCO after HGT compared to before treatment ($P \leq 0.001$) (Figure 5). During surgery, the numbers changed further, with five patients ultimately undergoing 3CO and 22 patients deemed suitable for PCO. This demonstrates a notable increase in the proportion of patients recommended for PCO during the actual corrective surgery compared to the pre-HGT phase ($P \leq 0.001$) (Figure 5). In addition, 27 patients in the non-HGT group received PCO, while 20 received the 3CO technique. The application

Table 2: Comparison of the surgical outcomes between the correction after HGT and non-HGT.

Variable	HGT group $N = 27$		Non-HGT group $N = 47$		P value
	Mean	SD	Mean	SD	
Correction rate of MC (%)	53.80	18.11	43.76	12.38	**0.01***
Correction rate of FK (%)	45.43	18.29	33.98	20.51	**0.02***
COBB angle of MC					
Preoperation	113.69	26.30	111.94	26.52	0.79
Postoperation	51.25	18.94	63.79	23.75	**0.02***
△Prepost	62.43	26.20	48.14	15.62	**<0.001***
COBB angle of KF					
Preoperation	107.26	37.16	74.54	38.74	**<0.001***
Postoperation	54.96	20.25	49.28	28.94	0.37
△Prepost	52.30	27.56	25.26	17.56	**<0.001***
SVA					
Preoperation	37.43	25.24	28.56	23.61	0.13
Postoperation	17.21	12.70	29.16	20.36	**0.01***
△Prepost	−20.21	26.65	−0.02	27.51	**<0.001***
TK					
Preoperation	91.72	41.65	77.75	23.89	0.07
Postoperation	14.43	8.83	44.85	19.14	**<0.001***
△Prepost	77.30	43.23	32.90	15.83	**<0.001***
AVT					
Preoperation	82.40	34.50	73.77	28.32	0.25
Postoperation	55.96	22.78	48.59	33.41	0.31
△Prepost	26.44	28.24	25.18	23.58	0.83
CVA					
Preoperation	27.41	16.78	22.56	33.40	0.49
Postoperation	19.53	11.41	26.46	19.16	0.09
△Prepost	7.88	18.01	−3.90	33.90	0.10
LL					
Preoperation	61.76	28.30	67.12	17.84	0.32
Postoperation	49.35	18.74	52.60	16.41	0.44
△Prepost	12.41	27.01	12.54	16.62	0.98

BMI: body mass index, HGT: halo-gravity traction; MC: main curve; FK: focal kyphosis; CVA: coronal vertical axis; AVT: apical vertebral translation; LL: lumbar lordosis; TK: thoracic kyphosis; SVA: sagittal vertical axis; *means $P < 0.05$. Esignificance of bold values represents a statistically significant difference.

proportion of 3CO was significantly higher in the non-HGT group than in the HGT group ($P < 0.05$) (Figure 5).

4.3. Complications of the Operation and the Traction. The complications were observed in 16 patients, resulting in an overall perioperative complication rate of 21.62%. These complications were categorized as follows: neurological complications in seven cases, pulmonary complications in five cases, and skin infections in four cases. Furthermore, seven patients required reoperation due to various reasons, including dissatisfaction with the extent of correction achieved, the need for debridement, and adjustments to the surgical instrumentation.

Two patients experienced complications (1 patient in HGT and 1 patient in the operation), resulting in a complication rate of 7.4%. In contrast, the non-HGT group had 14 patients experiencing complications, leading to a complication rate of 29.79%. As shown in Table 3, the incidence of complications in the non-HGT group was significantly higher than that in the HGT group ($P = 0.04$). Furthermore, the HGT group exhibited a significantly lower incidence of neurological complications compared to the non-HGT group ($P = 0.04$). However, the incidence of pulmonary ($P = 0.40$) and incision complications ($P = 0.54$) did not reach statistical significance. In addition, none of the patients in the HGT group required revision surgery, whereas seven cases (14.89%) in the non-HGT group underwent revision surgery for various reasons, indicating a significant difference between the two groups ($P = 0.03$).

Throughout the traction phase, a singular patient experienced complication. In the third week of undergoing traction, this individual reported radiative pain extending into the upper limbs. Halting the traction temporarily alleviated these symptoms, yet they did not fully dissipate. Postoperative observation revealed that the symptoms persisted in the affected forearm, albeit they began to gradually diminish and showed significant improvement two months following the surgical intervention.

4.4. Clinical Outcome. The mean operative blood loss for the HGT group was significantly less than the non-HGT group (666.67 ± 486.55 ml vs. 1024.47 ± 718.46 ml, $P = 0.02$). There was no significant difference in the average number of screws used between the two groups (19.07 vs. 18.47) ($P = 0.34$). The operative time was similar between the HGT group and the non-HGT group (297.33 ± 66.89 mins vs. 299.15 ± 56.73 mins, $P = 0.90$).

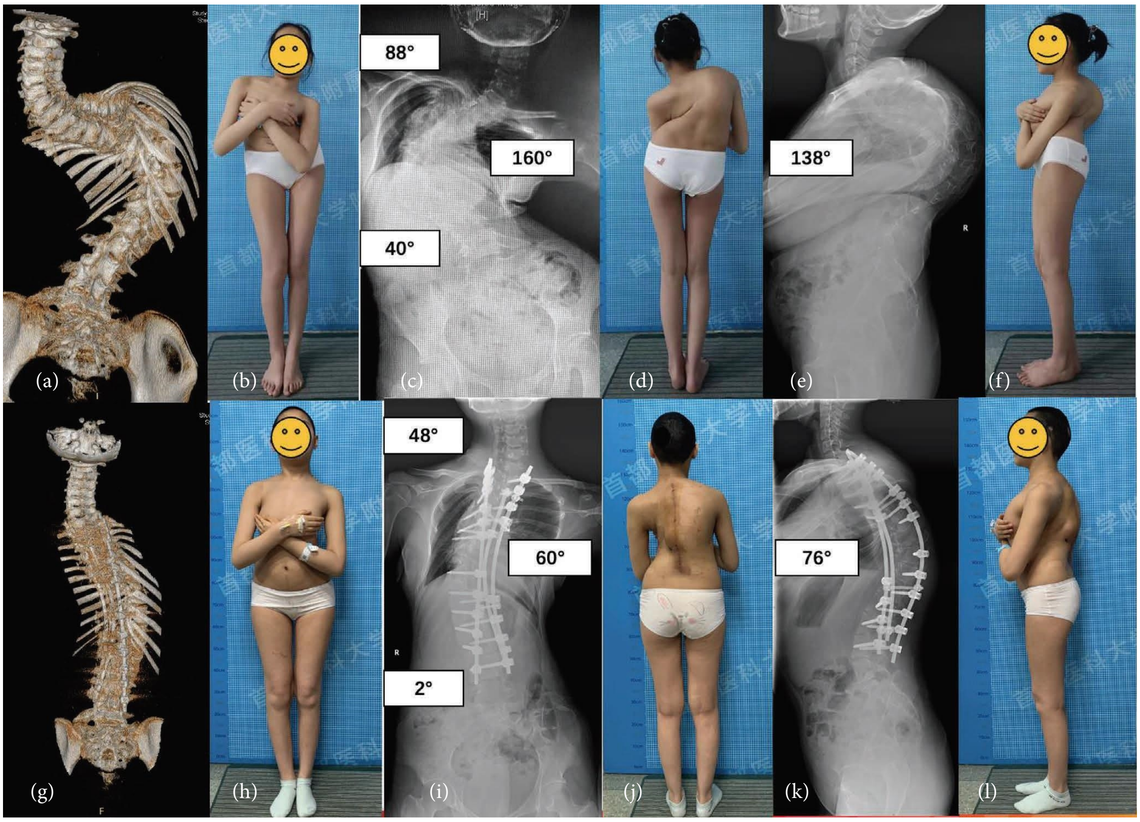


Figure 4: Imaging of a typical case in the non-HGT group: (a) Preoperative spinal CT with 3D reconstruction. (b) Preoperative full-body photograph of the patient (coronal view). (c) Preoperative full-length spine radiographs (anteroposterior and lateral views). (d) preoperative full-body photograph of the patient (coronal view). (e) Preoperative full-length spine radiographs (sagittal view). (f) Preoperative full-body photograph of the patient (sagittal view). (g) Postoperative spinal CT with 3D reconstruction. (h) Postoperative full-body photograph of the patient (coronal view). (i) Postoperative full-length spine radiographs (anteroposterior and lateral views). (j) Postoperative full-body photograph of the patient (coronal view). (k) Postoperative full-length spine radiographs (sagittal view). (l) Postoperative full-body photograph of the patient (sagittal view). The patient underwent the posterior column osteotomy surgery.

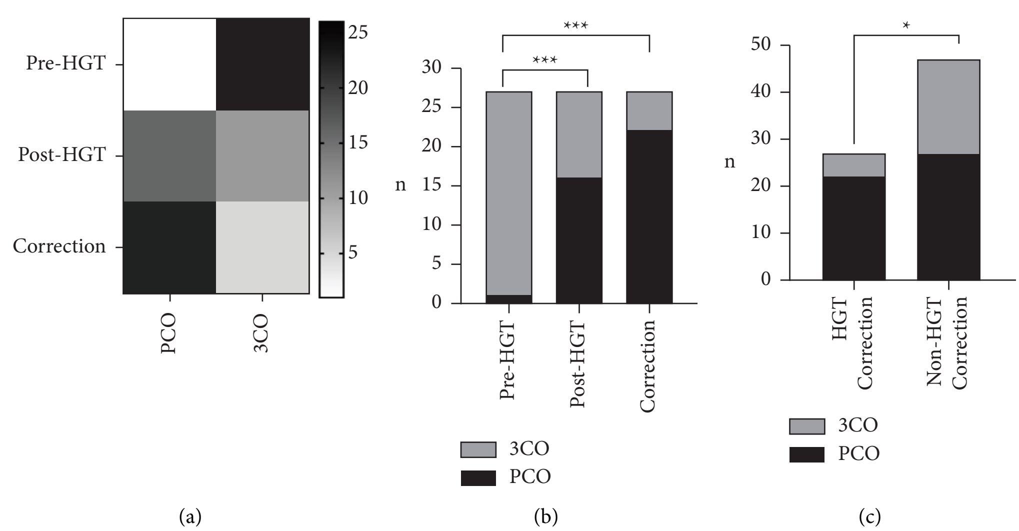


Figure 5: Comparison of preoperative osteotomy planning grades before and after halo-gravity traction (HGT) and comparison of actual osteotomy grades performed in surgeries between the HGT group and the non-HGT group. (a) Proportional comparison heatmap of patient numbers between pre-HGT, post-HGT, and correction operation in the HGT group. (b) Histogram depicting the proportion of different osteotomy grades between pre-HGT, post-HGT, and correction operation in the HGT group. (c) Histogram depicting the proportion of different osteotomy grades between correction operations in the HGT group and the non-HGT group. *stands for p value <0.05, *** stands for p value <0.001.

Table 3: Comparison of the occurrence of complications between the correction after HGT and non-HGT.

Variable	HGT group $N=27$	Non-HGT group $N=47$	P value[#]
General complication (n, %)	2 (7.40)	14 (29.79)	**0.04**[*]
Neurological complication (n, %)	0 (0)	7 (14.89)	**0.04**[*]
Pulmonary complications (n, %)	1 (3.70)	4 (8.51)	0.40
Skin infection (n, %)	1 (3.70)	3 (6.38)	0.54
Surgical site infections (n, %)	1 (3.70)	2 (4.26)	0.71
Chronic sinus (n, %)	0 (0)	1 (2.13)	0.64
Revised operation (n, %)	0 (0)	7 (14.89)	**0.03**[*]
Dissatisfaction with the correction (n, %)	0 (0)	2 (4.26)	0.41
Debridement (n, %)	0 (0)	2 (4.26)	0.41
Instrument adjustment (n, %)	0 (0)	3 (6.38)	0.26

[*]Means $P < 0.05$. [#]Fisher's precision probability test. Esignificance of bold values represents a statistically significant difference.

5. Discussion

Severe rigid spinal deformity has always been a challenge for spine surgeons, and spinal osteotomy is often necessary. However, direct correction and spinal osteotomy are likely to lead to various complications, especially neurological deficit [3, 4, 19]. With the advancement of clinical experience and technology in the treatment of severe spinal deformity, posterior spinal fusion combined with osteotomy has become a common surgical strategy in recent years, but risks still cannot be effectively avoided [4, 17, 20, 21]. To address severe spinal deformities, HGT, as described by Stagnara [22] continues to be a vital tool in managing such conditions, offering a nonsurgical or preoperative approach. Several studies have concluded that could correct the spinal deformity and improve pulmonary function effectively by loosening soft tissues, distract spine curve, and increase the flexibility of the spine [9–11, 14, 23]. In two systematic reviews and meta-analysis on the correction effects of HGT, this partial correction effects and lung function improvement have been confirmed, but the proportion of high-level literature evidence included in these studies is still low [13, 14]. At the same time, when analyzing various literatures, only Sponseller et al. [11] mentioned their observation on the application grade of intraoperative spinal osteotomy and found that HGT had a certain optimization effect on the application of osteotomy grade but not in detail. Therefore, we conducted this matched-cohort study to provide high-level evidence on the efficacy and safety of HGT in the treatment of severe and rigid scoliosis and to validate the role of HGT in the optimization of osteotomy procedure by comparing the application grade of osteotomy procedure between the two groups.

In this comparative study, HGT technology was used to administer traction therapy to 27 patients with severe rigid spinal deformity and followed by the posterior correction surgery. In addition, we incorporated a comparative group which included 47 patients who had previously undergone direct posterior correction surgery. There was no significant difference in preoperative imaging parameters such as MC, flexibility, AVT, CVA, TK, LL, and SVA between the two groups of patients with spinal deformity. Although there is a certain age difference between the two groups, the relatively youthful HGT group may be superior to the non-HGT group in terms of spinal rigidity and deformity. However, the similarity of imaging parameter features between the two groups ensures comparability of study cohorts.

6. Correction Outcome of HGT

In line with prior research, patients undergoing HGT exhibit a reduced likelihood of prolonged rest duration compared to other traction methods. HGT utilizes the patient's weight as a counterforce, contributing to effective traction while allowing mobility with the use of a wheelchair or mobile traction frame. This approach minimizes the risk of osteoporosis and other complications associated with traction [24, 25]. While existing studies generally concur on the corrective impact of HGT on spinal deformities, the extent of its effectiveness varies. Sink and Watanabe et al. reported an improvement of approximately 30° in the Cobb angle following preoperative traction [23, 26]. However, the study of Koller et al. showed that the average angle of the main curve in patients with HGT decreased by only 16° [9]. In this study, after an average of 132.22 ± 66.70 days of HGT, the Cobb angle of the main curve was corrected from 113.68° to 88.71° ($P < 0.05$), with an average correction rate of 21.97% in the HGT group. This difference may be attributed to variations in patients' deformity severity, flexibility, and bone maturity. In addition, differences in the selected traction period and weight might contribute to this observed variability.

However, it is still controversial whether HGT has a corrective effect in the final fusion surgery for severe scoliosis. Sponseller et al. [11] pointed out in their comparative study that HGT did not have a positive effect on the corrective effect of the final fusion surgery. Koller et al. [9] proposed that without spinal release surgery, HGT would not significantly improve the main curve of final surgery. In contrast, Koptan and ElMiligui [10] observed a more significant improvement in correction rate of the main curve in the HGT group in their comparative study. In this study, the average Cobb angle of the main curve in the HGT group improved from 113.69° to 51.25° after surgery and the overall correction rate of the main curve was 53.80%, which was better than that in the non-HGT group ($P < 0.05$). However, there was no significant difference in the imaging parameters CVA and AVT between the two groups. In view of this phenomenon, we supposed that in this study, we performed multilevel posterior column osteotomy(MPCO) in patients who did not undergo 3CO, which increased the flexibility of the spine during the operation to a certain extent, and reach the same conclusions of Koptan et al. and Koller et al. [9, 10]. In sponseller et al's study, the significant reduction in the proportion of 3CO in the traction group resulted in a similar correction outcome compared to that in the nontraction group with a high proportion of 3CO. The authors did not perform intraoperative or preoperative release and thus reached this conclusion.

There were notable differences in the improvement of sagittal alignment between the two groups, with the HGT group exhibiting superior improvements in FK, TK, and SVA compared to the non-HGT group. Although the local kyphosis of the non-HGT group was significantly higher than that of the HGT group before surgery (107.26° vs. 74.54°), there was no significant difference in FK between the two groups after surgery. This result also indicates that the HGT group has better improvement in kyphosis, which is also confirmed by the comparison of correction rate of FK between the two groups. After a certain period of traction, improved degree and flexibility of spinal deformity made correction surgery easier to implement, resulting in better correction outcome in the HGT group. At the same time, by gradually increasing the traction weight before surgery, it can cultivate the tolerance of the spinal cord to potential injury, reducing the difficulty of surgery and the incidence of intraoperative neurological complications [27–29].

6.1. Decrease of the Osteotomy Grade. Though advances in surgical techniques continually contribute to improving outcomes and mitigating the risks, 3-column osteotomy in severe deformities still remains a complex and challenging procedure [21]. As previously mentioned, patients with severe and rigid spinal deformities have a great demand for high-grade osteotomy, and the prevalence is gradually elevated [4, 17, 20, 21]. HGT improves the degree of deformity and spinal flexibility by longitudinal traction of the main curve and the upper and lower compensatory curved segments, thereby providing an opportunity for severe spinal deformities to be corrected through lower-grade osteotomy surgery. In this study, senior surgeons considered that most patients in the HGT group required 3CO technology based on preoperative imaging data. However, as traction imaging data emerged and intraoperative considerations, the proportion of using PCO technology gradually increased. During correction surgery, this prior deformity improvement allows most patients to achieve good correction using low-grade osteotomy procedures, substantially diminishing the need for high-level osteotomy surgeries and reducing the incidence of complications. These outcomes were found to be similar to those of other literature report [11]. It should be noted that the main curve may not be improved by HGT for extensive congenital fusion or fused ribs, but the upper and lower compensatory curved segments can still be improved to some extent.

According to previous studies, the combination of corrective surgery and VCR requires relatively longer surgery time (266–577 minutes) and significant blood loss (691–2810 ml) compared to surgery without VCR [17, 20]. However, patients receiving MPCO technology had significantly reduced surgery time and blood loss [16, 21, 30]. In this study, the average surgery time in the HGT group was 297.33 ± 66.89 minutes, and the blood loss was 666.67 ± 486.55 ml. The average blood loss in the non-HGT group significantly increased (1024.47 ± 718.46, $P < 0.05$), while the surgery time was similar ($P > 0.05$). The average number of screws in the HGT group was similar to the non-HGT group ($P > 0.05$). This result may be also due to the relatively higher proportion of patients receiving MPCO technology in the HGT group.

6.2. Perioperative Complications. Surgeons must carefully plan and execute the operation to achieve the desired correction while minimizing complications. Complications arising from traction, while typically not severe, were not uncommon [13]. Thus, the complication rate during HGT traction was 3.2% in our study. A critical aspect of prevention lies in the gradual application of traction weight. The protocol typically starts with a low weight, incrementally increasing based on patient tolerance and continuous neurophysiological feedback. This cautious approach allows for the identification of adverse neurological responses at subclinical levels, facilitating prompt adjustment of traction forces [14, 15]. Despite preventative measures, should neurological deficits arise, a predefined emergency protocol is activated. This involves the immediate cessation of traction, reassessment of the patient's neurological status, and potentially the removal of the halo device. Previous studies indicated that the overall complication rate in patients undergoing 3CO treatment is approximately 34–40%, while the incidence of neurological complications is about 11–17% [17, 20]. However, the application of low-grade PCO has significantly reduced the complication rate [21, 30]. In this group of patients, there were 2 complications in the HGT group (2/27, 7.40%), while there were 14 complications in the non-HGT group (14/47, 29.79%), showing significant differences ($P < 0.05$). The HGT group mainly had incision complications and pulmonary complications, which were all addressed through conservative treatment. In the non-HGT group, in addition to general complications, 7 neurological complications occurred, and 7 patients underwent revision surgery due to infection, internal fixation issues, and correction effects. Therefore, we conclude that the HGT procedure for severe and rigid scoliosis patients is much safer than in patients without traction.

6.3. Limitations. There are still some limitations in our study. The relatively small sample size may have reduced the statistical significance to some extent, but all surgeries in this study were performed by the same surgeon, and the imaging and clinical outcomes between two groups were comparable, fully demonstrating the effectiveness of this procedure. We will expand the sample size and attempt to evaluate the differences in the efficacy of HGT treatment for different types of severe spinal deformities in future work. At the same time, more work will focus on identifying the factors that affect the correction outcome of HGT. The primary outcome and secondary outcome of this study were not pulmonary function test, nutrition, and expenditure incurred. In order to ensure the rigor of clinical registration, we did not include them in the registration of this study, so we will not add any more in this study.

7. Conclusion

This study showed that the use of HGT, as a feasible and safe strategy, has superior efficacy and safety for treating severe and rigid scoliosis and can reduce the level of osteotomy used during surgery to some extent.

Data Availability

The data used to support the findings of this study are available from the corresponding author upon reasonable request.

Ethical Approval

This study has been approved by the Ethics Committee of Beijing Chaoyang Hospital (2022-division-521). Patient interests and identifiable images were adequately protected by the Ethics Committee. All methods were performed in accordance with the relevant guidelines and regulations.

Consent

Informed consent to publish was obtained from the participants for publication of the images.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

Authors' Contributions

Yangpu Zhang, Bo Han, and Jianqiang Wang contributed equally to this paper and should be considered as cofirst authors. Y.Z and B.H wrote the main manuscript text and made a contribution to the analysis of data; J.W and Y.Z prepared the Figures and Tables; Y.L. guided the research design; #Y.H and L.Z. guided the research design and revised the manuscript critically. All the authors have reviewed and approved the final manuscript.

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