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Original Research

Preoperative Halo-Gravity Traction for Severe Pediatric Spinal Deformity: Can it Replace a Vertebral Column Resection?

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Abstract

Background: While vertebral column resections (VCRs) are an effective means for correcting severe spine deformities, these complex procedures are associated with high rates of complications. We hypothesized that preoperative halo-gravity traction (HGT) followed by spinal fusion without VCRs can produce equivalent outcomes with less risk than a VCR in complex pediatric spinal deformity.

Methods: This was a retrospective review of prospectively collected data of pediatric patients who underwent spinal fusion for severe spinal deformity. Patients treated with either 1) preoperative HGT without VCRs or 2) VCRs without preoperative HGT were included. Patients with congenital etiology and those with prior surgery were excluded. Comparisons were made between cohorts with respect to preoperative, intraoperative, and postoperative (2 years) demographic, radiographic, and health-related quality of life (HRQoL) variables. The rate of revision surgery and any treatment complications were also compared.

Results: We identified 49 patients (mean age 16+2.9 years; 54% males) who underwent VCR (17/49; 35%) or preoperative HGT (32/49; 65%) for severe spinal deformities. Those in the HGT cohort had more severe deformity at baseline based on radiographic variables, including maximum Cobb angle, maximum kyphosis, major coronal Cobb angle, and apical vertebral translation. They also had greater residual deformities at 2 years postoperatively, though percent correction of the major deformity magnitude (p=0.28), major (p=0.54) and minor (p=0.91) coronal curve, and apical vertebral translation (p=0.66) was similar to the VCR cohort. Operative time (p=.18), estimated blood loss (0.37), hospitalization length (0.52), and ICU stay (0.12) were similar between cohorts, though patients who underwent VCR had higher rates of total complications (47% vs. 3%; p<0.01). There were no significant differences between cohorts with respect to percent change in HRQoL outcomes from baseline to 2 years postoperatively.

Conclusion: Our study suggests that in patients without congenital deformities undergoing primary deformity correction, preoperative HGT followed by spinal fusion produces radiographic outcomes that are similar to VCRs with fewer perioperative complications. Thus, preoperative HGT for severe pediatric deformities may lessen the need to perform higher risk VCRs.

Level of Evidence: Level III

Key Concepts

- This study aimed to determine the impact that preoperative halo-gravity traction (HGT) followed by a spinal fusion without vertebral column resection (VCR) has on patients with complex pediatric spinal deformities.
- Compared to patients treated with VCR, patients in the HGT cohort experienced similar deformity correction, fewer total perioperative complications, and similar improvements in HRQoL scores 2 years postoperatively.
- VCR may increase the risk of perioperative complications relative to management of severe deformities with HGT.

Introduction

While the surgical correction of any pediatric spine deformity presents inherent difficulties and risks,[1-3] patients with severe deformities (often defined as a Cobb angle of >100 degrees) are particularly challenging from an operative standpoint.[4,5] To obtain adequate deformity correction, these patients generally require more extensive surgical procedures, ultimately heightening the risk of increased intraoperative blood loss, neurologic complications, and other perioperative medical complications.[5-8]

While there are numerous surgical options for the management of severe deformities, 2 commonly employed techniques include the use of preoperative halo-gravity traction (HGT) and/or intraoperative vertebral column resections (VCRs), both of which have demonstrated efficacy in the surgical correction of severe deformities.[9-17] The benefits of HGT include gradual deformity correction over time (which permits the avoidance of acute corrective maneuvers and the accompanying high risk for neurologic compromise or failure at instrumentation anchor sites), the ability to continuously monitor patients for neurologic complications since they are awake, and the ability to quickly adjust the force if necessary.[12-15,17,18] While VCRs have demonstrated a strong ability to correct severe deformities and improve pulmonary function, these complex procedures are associated with an alarmingly high rate of complications, including up to a 59% rate of overall complications and a 27% rate of intraoperative neurologic events.[7,8,19-24] As a result, there has been a recent resurgence in the interest in using preoperative HGT as alternative means of achieving optimal surgical correction.

Ultimately, however, treatment algorithms for complex pediatric spinal deformity are subject to surgeon preference and institutional bias, which is due in large part to a lack of clinical data directly comparing the outcomes of different techniques. The aim of the present study was to compare the radiographic outcomes, complication rates, and long-term health-related quality of life (HRQoL) scores in patients who 1) underwent preoperative HGT followed by spinal fusion without VCRs and 2) underwent VCRs without the use of preoperative HGT.

Materials and Methods

A retrospective review of a large multicenter, prospectively collected database was performed to identify eligible patients with severe spinal deformities who underwent surgical intervention from 2011 through 2016. Those who underwent operative treatment for a severe spinal deformity (which was defined as a major coronal or sagittal deformity of greater than 100 degrees) or those who underwent vertebral column resection (VCRs) were included in the study per the inclusion criteria of the multicenter study group. Patients were excluded if they had less than 2 years of follow-up, did not undergo preoperative HGT or a VCR, underwent both preoperative HGT and a VCR, had a congenital etiology of their spinal deformity, or had prior spinal surgery.

Patient demographics and deformity characteristics, radiographic measures, and HRQoL scores were collected preoperatively and at each postoperative visit. HRQoL was evaluated using the validated Scoliosis Research Society 22 (SRS-22) questionnaire.[25] Intraoperative data, hospitalization length, and time in the intensive care unit (ICU) were also recorded. Any peri- or postoperative complications up to the most recent follow-up were documented and categorized according to type or system involved. Complications were stratified according to the Clavien-Dindo classification system. Intraoperative neuromonitoring changes were not considered to be a complication if there was no postoperative neurologic deficit observed.

Several radiographic measures were reviewed, including major and minor curve magnitude (Cobb method), coronal deformity angular ratio (c-DAR), maximum kyphosis (Cobb method), sagittal deformity angular ratio (s-DAR), coronal balance, apical vertebral translation (AVT) to the C7 plumb line (C7PL), AVT to the central sacral vertical line (CSVL), sagittal balance, T1 and LIV (last instrumented vertebra) tilt (angle between a horizontal line and a line parallel to the horizontal axis of T1 or LIV), LIV translation (LIV to CSVL), thoracic spine height, pelvic obliquity, angulation of the disc inferior to the LIV, and trunk shift.

To answer our study questions, we divided the patients who met the inclusion and exclusion criteria for the study into two cohorts: 1) those who underwent preoperative HGT without intraoperative VCRs (HGT cohort) and 2) those who underwent VCRs intraoperatively without the use of preoperative HGT (VCR cohort). Statistical comparisons were made between the cohorts with respect to preoperative patient and radiographic variables, intra- and postoperative data including complications, and 2 year absolute and percent change in the radiographic and HRQoL measures. In addition, we evaluated the degree of radiographic improvement within each cohort by comparing the preoperative and postoperative (2 years) radiographic measures separately for the HGT and VCR cohorts. A separate subgroup analysis was performed which excluded patients with neuromuscular conditions or tuberculosis as the deformity etiology, as these were disproportionately represented in each cohort.

Statistical Analysis

All statistical analyses were performed using Statistical Package for the Social Sciences (SPSS, Inc., Chicago, IL; Version 23.0.0.0). Standard descriptive summaries were used to summarize patient characteristics and radiographic data. Univariate analyses for comparison between the cohorts were performed using the

Chi-squared or Fischer's exact test for categorical data and independent samples t-tests or Mann-Whitney U tests for continuous variables, depending on the normality of distribution.

Results

We identified 49 patients who met the inclusion and exclusion criteria for the study (Figure 1). Seventeen (35%) underwent VCRs without the use of preoperative HGT, while 32 (65%) underwent preoperative HGT without VCRs. Patients in the HGT cohort underwent traction for an average of 91 + 40 days with a mean final weight of 39 + 10 pounds. Prior to HGT treatment, the mean coronal curve was 122 + 24, maximum kyphosis was 118 + 38, and the maximum deformity magnitude was 134 + 22. After HGT (but before definitive surgical correction), the mean coronal curve was 90 + 21, kyphosis was 95 + 27, and maximum deformity magnitude was 105 + 20. The demographics and baseline deformity characteristics for all patients included in the study are shown in Table 1.

Comparison of Pre- and Intraoperative Factors

There were numerous statistically significant differences between the HGT and VCR cohorts with respect to baseline characteristics (Table 2). Patients in the HGT cohort most commonly had idiopathic (75%),

Table 1. Demographics and Deformity Characteristics All Patients (n=49) in the Study

Variable	Value
Age	16.2 + 2.9 years
Sex	54% Male
BMI	19.4 + 3.6
Risser stage	3.5 + 1.7
Etiology	Idiopathic: 33 (67%) Tuberculosis: 7 (14%) Syndromic: 5 (10%) Neuromuscular 4 (8%)
Major Deformity	KS: 31 (63%) Scoliosis: 7 (14%) Kyphosis: 11 (22%)
Maximum Deformity Magnitude	125 + 23°
Treatment Cohort	HGT: 32 (65%) VCR: 17 (35%)
Traction Time (HGT)	91 + 40 days
Final Traction Weight (HGT)	39 + 10 pounds
Traction to Body Weight % (HGT)	44 + 6%

HGT = Halo-gravity traction (preoperative).
VCR = vertebral column resection.
KS = kyphoscoliosis (major curve > 50 deg. AND max kyphosis > 75 deg.).

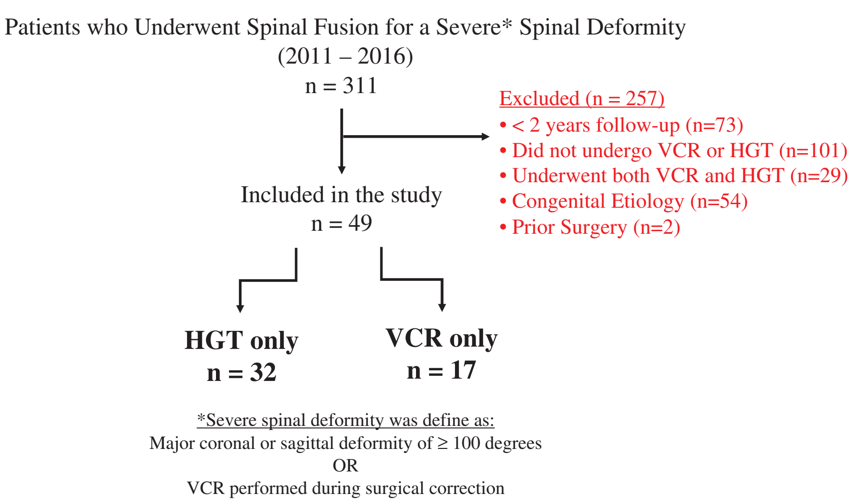

***Figure 1.** Inclusion/exclusion diagram for patients in the present study.*

Table 2. Comparison of Baseline Demographics and Preoperative Spinal Deformity in the HGT vs. VCR Cohorts

Variable	HGT N = 32	VCR N = 17	P-value
Age (years)	16.5 (14.2 – 18.9)	16 (12.8 – 18.6)	0.329
Sex	50% Female	35% Female	0.378
BMI	18.6 (17.2 – 19.7)	20.6 (17.7 – 23.2)	**0.029**
Risser stage	4 (2.3 – 5)	4.5 (2.3 – 5)	0.441
Etiology	Idiopathic: 24 (75%) Tuberculosis: 1 (3%) Syndromic: 3 (9%) Neuromuscular 4 (13%)	Idiopathic: 9 (53%) Tuberculosis: 6 (35%) Syndromic: 2 (12%) Neuromuscular 0 (0%)	**0.010**
Major Deformity	Scoliosis: 5 (16%) Kyphosis: 1 (3%) KS: 26 (81%)	Scoliosis: 2 (12%) Kyphosis: 10 (59%) KS: 12 (29%)	**<0.001**
Maximum Deformity Magnitude (°)	133 (115 – 150)	113 (101 – 123)	**0.002**
Kyphosis (°)	128 (96 – 148)	102 (83 – 115)	**0.022**
Sagittal DAR	16.3 (13.4 – 21.3)	16 (13.2 – 22.7)	0.779
Major Coronal Curve (°)	122 (107 – 133)	23 (15 – 113.5)	**<0.001**
Major c-DAR	15 (13.2 – 19.5)	4.6 (2 – 15)	**<0.001**
Coronal Balance (cm)	2.9 (0.9 – 3.8)	1.1 (0.7 – 1.8)	0.063
AVT to C7PL (cm)	8.9 (7.6 – 9.5)	2.6 (1 – 6.9)	**0.001**
AVT to CSVL (cm)	10.6 (9 – 12.5)	2.5 (1.6 – 8.6)	**0.002**
T1 tilt (°)	11 (5 – 26)	4.5 (3.3 – 7.8)	**0.004**
LIV tilt (°)	18.5 (12.8 – 26.3)	12 (2.3 – 35)	0.244
LIV to CSVL (cm)	1.8 (1.2 – 2.8)	1 (0.4 – 1.9)	0.088
Disc Angulation Below LIV (°)	10 (2.8 – 15)	3 (1 – 10)	0.144
T1 – T12 Spine Height (cm)	14.4 (12.2 – 17.9)	16.7 (13.1 – 20.4)	0.129
Pelvic Obliquity (°)	3 (0 – 6)	2 (0.5 – 4)	0.280
Trunk Shift (cm)	3.7 (2.3 – 5.4)	0.5 (0 – 3.4)	**0.004**
Sagittal Balance (cm)	2.7 (1.6 – 4.1)	3.5 (2.3 – 5)	0.283

All values are expressed as medians and interquartile ranges.
KS = kyphoscoliosis (major curve > 50 deg. AND max kyphosis > 75 deg.).
c-DAR = coronal deformity angular ratio.
Bolded variables represent statistically significant differences between the cohorts.

neuromuscular (13%), and syndromic (9%) scoliosis, while idiopathic (53%), tubercular (35%), and syndromic (12%) scoliosis were most common in VCR cohort. In addition, 81% of patients in the HGT cohort had kyphoscoliosis (major coronal curve > 50 degrees AND max kyphosis > 75 degrees) compared to only 29% in the VCR cohort (59% kyphosis only; 12% scoliosis only). With respect to other preoperative variables, patients in the HGT cohort had a lower preoperative BMI and greater maximum deformity magnitude, major coronal curve magnitude and c-DAR, maximum kyphosis, AVT to C7PL and CSVL, T1 tilt, LIV tilt, and trunk shift.

With respect to intraoperative variables, there were no statistically significant differences between the cohorts with respect to total EBL (median 1500 cc in HGT cohort vs. 1200 in VCR; p=0.370), EBL as a percentage of blood volume (51 vs. 45%; p=0.482), or operative time (329 vs. 336 mins; p=0.175). In the HGT cohort, 27/32 (84%) patients underwent Smith-Peterson (SPO) osteotomies compared to 2/17 (12%) in the VCR cohort (p<0.001). Thoracoplasty was performed in 24/32 (75%) patients in the HGT cohort and 9/17 (53%) in the VCR cohort (p=0.200) and included a median of 5 levels in the HGT cohort versus 3.5 in the VCR cohort (p=0.148). There were a greater number of levels fused in the HGT cohort compared to the VCR cohort (median 13 vs. 11; p=0.001).

Postoperatively, there were no differences between the groups with respect to length of hospitalization (8 vs. 7 days; p=0.515) or length of ICU stay (1 vs. 1 day; p=0.115).

Two-Year Radiographic Outcomes Within Each Cohort
From the preoperative period to 2 years postoperatively, patients in both the HGT and VCR cohorts experienced statistically significant improvements in major deformity magnitude, AVT to C7PL, and AVT to CSVL (Table 3). Patients in the HGT cohort experienced significant improvements in major and minor coronal curve magnitude and c-DAR in addition to thoracic spine height, while these variables were not significantly different at 2 years in the VCR cohort. Coronal and sagittal balance were not significantly different at 2 years in either cohort.

Comparison of 2-Year Radiographic Outcomes
At 2 years postoperatively, patients in the HGT cohort had significantly greater maximum deformity magnitude, major coronal curve magnitude and c-DAR, AVT to C7PL, AVT to CSVL, and T1 tilt. (Table 4).

Table 3. Comparison of Pre- and Postoperative (2 Years) Radiographic Variables Within Each Cohort

	HGT (n=32)			VCR (n=17)		
Variable	Pre-Op	2 Years	P-value	Pre-Op	2 Years	P-value
Maximum Deformity Magnitude (°)	133 (115 – 150)	77 (69 – 85)	**<0.001**	113 (101 – 123)	49 (44 – 68)	**<0.001**
Major Curve (°)	122 (107 – 133)	70 (53 – 75)	**<0.001**	23 (15 – 114)	19 (8 – 52)	0.073
Major c-DAR	15 (13 – 20)	9 (6 – 10)	**<0.001**	5 (2 – 15)	4 (1 – 6)	0.053
Minor Coronal Curve (°)	69 (52 – 87)	42 (26 – 55)	**<0.001**	18 (4 – 74)	15 (1 – 32)	0.290
Minor c-DAR	11 (8 – 15)	7 (4 – 9)	**<0.001**	6 (2 – 13)	4 (2 – 6)	0.153
Coronal Balance (cm)	2.9 (0.9 – 3.8)	1.6 (0.7 – 3.3)	0.154	1.1 (0.7 – 1.8)	1.1 (0.5 – 2)	0.922
AVT to C7PL (cm)	8.9 (7.6 – 9.5)	6.7 (4.3 – 7.7)	**<0.001**	2.6 (1 – 6.9)	0.8 (0.3 – 1.3)	**0.007**
AVT to CSVL (cm)	10.6 (9 – 12.5)	5.6 (4.2 – 7.7)	**<0.001**	2.5 (1.6 – 8.6)	0.7 (0.5 – 1.1)	**<0.001**
T1 – T12 Spine Height (cm)	14.4 (12.2 – 17.9)	20.8 (17.9 – 22.8)	**<0.001**	16.7 (13.1 – 20.4)	20.6 (17.4 – 29.7)	0.069
Sagittal Balance (cm)	2.7 (1.6 – 4.1)	2.3 (1.2 – 4.9)	0.697	3.5 (2.3 – 5)	2.9 (0.6 – 5.6)	0.655

All values are expressed as medians and interquartile ranges.
DAR = deformity angular ratio.
Bolded variables represent statistically significant differences between the cohorts.

Table 4. Comparison of 2-Year Radiographic Outcomes in the HGT vs. VCR Cohorts

Variable	HGT (n=32)	VCR (n=17)	P-value
Maximum Deformity Magnitude (°)	77 (69 – 85)	49 (44 – 68)	**0.001**
Major Coronal Curve (°)	70 (53 – 75)	19 (8 – 52)	**<0.001**
Major c-DAR	8.8 (6.2 – 10.3)	3.8 (0.9 – 6.2)	**<0.001**
Coronal Balance (cm)	1.6 (0.7 – 3.3)	1.1 (0.5 – 2)	0.275
AVT to C7PL (cm)	6.7 (4.3 – 7.7)	0.8 (0.3 – 1.3)	**<0.001**
AVT to CSVL (cm)	5.6 (4.2 – 7.7)	0.7 (0.5 – 1.1)	**<0.001**
T1 tilt (°)	10 (5 – 23)	4 (1 – 5)	**0.001**
LIV tilt (°)	10.5 (5 – 15.5)	4 (1 – 17)	0.130
LIV to CSVL (cm)	1.3 (0.5 – 1.9)	0.7 (0.2 – 1.5)	0.247
Disc Angulation Below LIV (°)	3 (1.5 – 5)	2 (1 – 4)	0.143
T1 – T12 Spine Height (cm)	20.8 (17.9 – 22.8)	20.6 (17.4 – 29.7)	0.613
Sagittal Balance (cm)	2.3 (1.2 – 4.9)	2.9 (0.6 – 5.6)	0.760

All values are expressed as medians and interquartile ranges.
Bolded variables represent statistically significant differences between the cohorts.

Despite more severe deformities in the HGT cohort at 2 years in terms of absolute radiographic values, there were no significant differences between the groups with respect to percent change in major deformity magnitude, kyphosis, major or minor coronal curve magnitude, or AVT to C7, CSVL, or thoracic spine height (Figure 2).

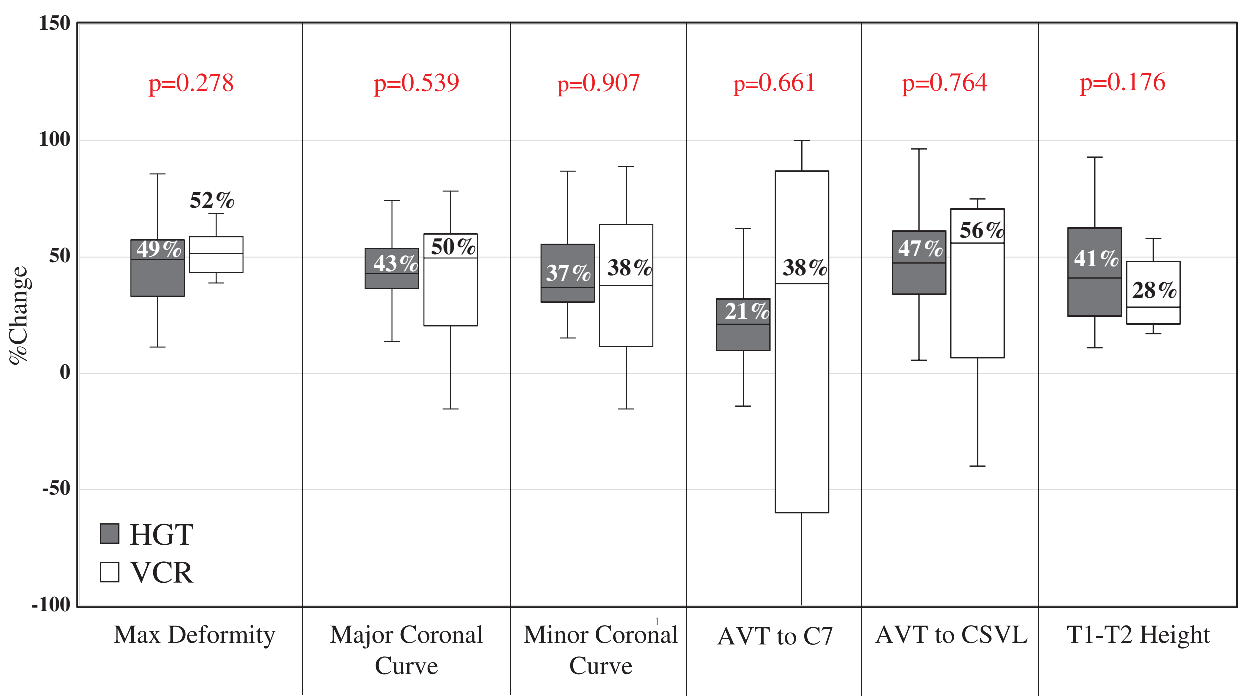

Figure 2. *Comparison of percent change in several radiographic variables from baseline to 2 years postoperatively in the HGT vs. VCR cohorts.*

Table 5. List of the Intra- and Postoperative Complications and Their Associated Clavien-Dindo Grade, Reported for All Patients in the Study

Type	Complication
Neurologic (n=5)	2 Neuromonitoring Alert with PO deficits • 1 transient upper extremity motor deficit (HGT) **[Grade I]** • 1 persistent bilateral lower extremity paralysis secondary to hematoma, requiring re-operative for evacuation (VCR) **[Grade IIIB]** 1 Screw Malposition Causing Lower Extremity Deficit Requiring Re-operation for Screw Removal (HGT) **[Grade IIIB]** 1 Postoperative CSF Leak Requiring Re-operation for Dural Repair (VCR) **[Grade IIIB]** 1 Intraoperative CSF Leak Requiring Suture Repair **[Grade I]**
Pulmonary (n=3)	2 Pleural Effusions Requiring a Chest Tube (VCR) **[Grade IIIA]** 1 Prolonged Intubation Secondary to Acute Respiratory Failure (VCR) **[Grade IVA]**
Gastrointestinal (n=1)	1 Superior Mesenteric Artery Syndrome Requiring Nasojejunal Tube Feeds (VCR) **[Grade IIIA]**

PO = postoperative.
Bolded variables represent statistically significant differences between the cohorts.

Complications

A list of all complications by Clavien-Dindo grade is provided in Table 5.[26,27] A total of 10 complications occurred in 10 patients in the study. Eight of 17 (47%) patients in the VCR cohort experienced a complication compared to 2/35 (6%) in the HGT cohort (p=0.001).

Health-Related Quality of Life

In a comparison of SRS-22 scores from baseline to 2 years postoperatively, there were no statistically significant differences with respect to percent change between the HGT and VCR cohorts (Table 6).

Subgroup Analysis

A separate subgroup analysis was performed comparing the baseline data and treatment outcomes of patients with idiopathic and syndromic deformities only, excluding those with neuromuscular or tubercular etiologies. Since neuromuscular and tuberculosis patients disproportionately comprised each cohort, the rationale for this analysis was to evaluate the validity of our findings with more similar cohorts in terms of deformity etiology.

This analysis included 27 patients who underwent HGT and 11 who underwent VCRs. With respect to etiology,

Table 6. Percent Change in SRS-22 Scores From the Preoperative Period to 2 years Postoperatively in the HGT vs. VCR Cohorts

SRS-22 Domain	HGT	VCR	P-value
General Function	22 (1 – 46)	35 (14 – 50)	0.221
Pain	0 (-16 – 19)	6 (0 – 25)	0.198
Self-Image	78 (47 – 141)	75 (35 – 150)	0.731
Mental Health	17 (2 – 46)	19 (5 – 50)	0.858
Satisfaction	100 (42 – 283)	29 (17 – 67)	0.069
Total	27 (13 – 50)	39 (18 – 55)	0.491

All values are expressed as median percent change with interquartile ranges.

the cohorts were similar (89% idiopathic/11% syndromic in HGT cohort, 82% idiopathic/18% syndromic in VCR cohort; p=0.615). Similar to the results from the entire study cohort, the HGT cohort had greater baseline maximum deformity magnitude (135 vs. 113; p=0.006), coronal curve magnitude (123 vs. 110; p=0.008), and maximum kyphosis (128 vs. 102; p=0.027). With respect to percent change in these parameters 2 years postoperatively, there was no significant difference in the improvement of maximum deformity (49% vs. 57%; p=0.170) or coronal curve (43% vs. 57%; p=0.115).

Discussion

In the age of advanced modern surgical procedures and techniques, the use of spinal traction—one of the oldest modalities of treatment for spinal deformities[28-31]—has undergone a resurgence as a commonly utilized adjunct in the surgical treatment of severe deformities. This, in large part, is due to the host of reported complications associated with complex vertebral column resections (VCRs).[32]

Several previous investigations have demonstrated the benefits of preoperative HGT for severe deformities. In a study comparing the outcomes of patients who underwent surgical treatment with or without the use of HGT, Sponseller et al. reported similar radiographic outcomes despite a significantly lower rate of VCRs in the traction group.[14] However, only 7/23 patients in the control group (no HGT) underwent VCRs, limiting their ability to directly compare the differences between HGT and VCRs, specifically. Nemani et al. studied 24 patients who underwent HGT prior to definitive spinal fusion and showed a 31% improvement in the major curve after HGT, with a 56% correction postoperatively.[12] Iyer et al. reported that in 96 patients, preoperative HGT lowers the risk of surgical complications, largely by decreasing curve magnitude and reducing the need for VCRs. Collectively, these data surrounding the use of HGT suggests that it may reduce the need for VCRs intraoperatively. However, these studies have been limited by either 1) the lack of a control or comparison group,[9,11-13,15-17] 2) the presence of a comparison group which is heterogenous with respect to the use of VCR,[14] or 3) a lack of long-term radiographic or HRQoL outcomes.[11,16] Due to these limitations, whether the preoperative use of HGT can effectively replace the need for VCRs and their host of complications is unclear.

In our comparative analysis of radiographic outcomes, complications, and postoperative HRQoL scores in pediatric patients with severe spinal deformities treated with either preoperative HGT without VCRs or VCRs without preoperative HGT, we found that despite having more severe baseline deformities, patients in the HGT cohort experienced a similar degree of deformity correction, fewer total perioperative complications, and similar improvements in HRQoL scores at 2 years postoperatively. Of note, patients who underwent HGT without VCR underwent more pedicle subtraction or Smith-Peterson osteotomies, had a higher rate of thoracoplasty, and included a greater number of levels in the definitive fusion. Additionally, the significant differences between the HGT and VCR cohorts with respect to several baseline features (e.g., major deformity, etiology, and deformity severity) suggest that there are particular characteristics surgeons use to decide which procedure to perform. In the present study, those who underwent HGT more often had kyphoscoliosis, an idiopathic etiology, and more severe spinal deformities, suggesting that these features may be associated with the decision to perform HGT over VCR.

While these baseline differences were informative, major discrepancies between the cohorts ultimately threaten the validity of our results. Specifically, one of the most significant baseline differences between the cohorts was in disease etiology: 35% of patients in the VCR cohort had deformities from tuberculosis (compared to 3% in the HGT cohort) while 13% of the HGT cohort was comprised of neuromuscular curves (compared to 0% in the VCR cohort). Thus, we performed a subgroup analysis looking at baseline radiographic parameters and 2-year outcomes with tubercular and neuromuscular etiologies excluded and ultimately found results reflective of the entire cohort analysis (i.e., patients in the HGT cohort had more severe baseline deformities but experienced a similar degree of deformity correction), bolstering the validity of the broader analysis.

The rate of complications associated with VCRs reported here is consistent with previous investigations. Lenke et al., in a multicenter analysis of 147 consecutive pediatric patients who underwent VCRs, reported a 59% complication rate with a 27% rate of intraoperative neurologic events.[7] Papadopoulos et al. studied 45 patients who underwent VCRs and reported a 22% rate of intraoperative monitoring changes, with one patient who progressed to complete spinal cord injury.[33] In a recent systematic review, which analyzed the outcomes of VCRs in adult and pediatric patients, Yang et al. concluded that although VCRs are a powerful means for achieving deformity correction, they carry significant risks.[19] The overall complication rate was 32%, the most common of which were neurologic complications or revisions. In the present study, we found a total complication rate of 47% in pediatric patients who underwent VCRs with an 18% rate of intra- or postoperative neurologic complications. The overall complication rate in patients who underwent preoperative HGT without VCRs was 3%, despite more severe baseline deformities in this group. Ultimately, these findings support the notion that the performance of VCRs may heighten the risk of perioperative complications.

There are several limitations to the present study. First, the retrospective nature of the analysis limits our ability to establish a causal relationship between HGT or VCRs and the outcomes reported. Second, as with any multicenter study, there is inherent variability in surgical technique, decision-making, traction protocol, and the reporting of complications by institution and surgeon. Relatedly, any retrospective analysis of a multicenter database is limited by the possibility for selection bias and an inability to determine surgeon rationale for a specific treatment strategy. Nonetheless, we believe the strengths of the multicenter data include greater generalizability of our results and the relatively large sample size considering the rare nature of severe deformities, which would be difficult to accomplish in a single-center investigation. Third, the cohorts were significantly different with respect to disease etiology and additional baseline factors including BMI, deformity type, and deformity severity, all which raise concern for selection bias. However, to best correct for these differences, we calculated percent improvement in radiographic and HRQoL variables as the primary 2-year outcomes of interest.

Despite its limitations, this large retrospective study is the first to directly compare the radiographic outcomes, complications, and postoperative HRQoL scores in patients who underwent preoperative halo-gravity traction (without the use of vertebral column resections) or vertebral column resections (without the use of halo-gravity traction). Ultimately, the results of our study suggest that, in patients without congenital deformities undergoing primary deformity correction, preoperative HGT followed by spinal fusion produces radiographic outcomes that are similar to VCRs with the benefit of fewer complications. Thus, preoperative HGT for severe pediatric deformities may reduce the need to perform a VCR.

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References

1. Patil CG, Santarelli J, Lad SP, et al. Inpatient complications, mortality, and discharge disposition after surgical correction of idiopathic scoliosis: a national perspective. *Spine J.* 2008;8(6):904-910.
2. Carreon LY, Puno RM, Lenke LG, et al. Non-neurologic complications following surgery for adolescent idiopathic scoliosis. *J Bone Joint Surg Am.* 2007;89(11):2427-2432.

3. Diab M, Smith AR, Kuklo TR, et al. Neural complications in the surgical treatment of adolescent idiopathic scoliosis. *Spine (Phila Pa 1976)*. 2007;32(24):2759-2763.
4. Neal KM, Siegall E. Strategies for surgical management of large, stiff spinal deformities in children. *J Am Acad Orthop Surg*. 2017;25(4):e70-e78.
5. Boachie-Adjei O, Yagi M, Nemani VM, et al. Incidence and risk factors for major surgical complications in patients with complex spinal deformity: a report from an SRS GOP site. *Spine Deform.* 2015;3(1):57-64.
6. Boachie-Adjei O, Yagi M, Sacramento-Dominguez C, et al. Surgical risk stratification based on preoperative risk factors in severe pediatric spinal deformity surgery. *Spine Deform.* 2014;2(5):340-349.
7. Lenke LG, Newton PO, Sucato DJ, et al. Complications after 147 consecutive vertebral column resections for severe pediatric spinal deformity: a multicenter analysis. *Spine (Phila Pa 1976)*. 2013;38(2):119-132.
8. Wang Y, Xie J, Zhao Z, et al. Perioperative major non-neurological complications in 105 patients undergoing posterior vertebral column resection procedures for severe rigid deformities. *Spine (Phila Pa 1976)*. 2015;40(16):1289-1296.
9. Watanabe K, Lenke LG, Bridwell KH, et al. Efficacy of perioperative halo-gravity traction for treatment of severe scoliosis (>/=100 degrees). *J Orthop Sci.* 2010;15(6):720-730.
10. Mehlman CT, Al-Sayyad MJ, Crawford AH. Effectiveness of spinal release and halo-femoral traction in the management of severe spinal deformity. *J Pediatr Orthop.* 2004;24(6):667-673.
11. Park DK, Braaksma B, Hammerberg KW, et al. The efficacy of preoperative halo-gravity traction in pediatric spinal deformity the effect of traction duration. *J Spinal Disord Tech.* 2013;26(3):146-154.
12. Nemani VM, Kim HJ, Bjerke-Kroll BT, et al. Preoperative halo-gravity traction for severe spinal deformities at an SRS-GOP site in West Africa: protocols, complications, and results. *Spine (Phila Pa 1976)*. 2015;40(3):153-161.
13. Sink EL, Karol LA, Sanders J, et al. Efficacy of perioperative halo-gravity traction in the treatment of severe scoliosis in children. *J Pediatr Orthop.* 2001;21(4):519-524.
14. Sponseller PD, Takenaga RK, Newton P, et al. The use of traction in the treatment of severe spinal deformity. *Spine (Phila Pa 1976)*. 2008;33(21):2305-2309.
15. Rinella A, Lenke L, Whitaker C, et al. Perioperative halo-gravity traction in the treatment of severe scoliosis and kyphosis. *Spine (Phila Pa 1976)*. 2005;30(4):475-482.
16. Bogunovic L, Lenke LG, Bridwell KH, et al. Preoperative halo-gravity traction for severe pediatric spinal deformity: complications, radiographic correction and changes in pulmonary function. *Spine Deform.* 2013;1(1):33-39.
17. Iyer S, Boachie-Adjei O, Duah HO, et al. Halo gravity traction can mitigate preoperative risk factors and early surgical complications in complex spine deformity. *Spine (Phila Pa 1976)*. 2019;44(9):629-636.
18. Garabekyan T, Hosseinzadeh P, Iwinski HJ, et al. The results of preoperative halo-gravity traction in children with severe spinal deformity. *J Pediatr Orthop B*. 2014;23(1):1-5.
19. Yang C, Zheng Z, Liu H, et al. Posterior vertebral column resection in spinal deformity: a systematic review. *Eur Spine J.* 2016;25(8):2368-2375.
20. Bumpass DB, Lenke LG, Bridwell KH, et al. Pulmonary function improvement after vertebral column resection for severe spinal deformity. *Spine (Phila Pa 1976)*. 2014;39(7):587-595.
21. Suk SI, Chung ER, Kim JH, et al. Posterior vertebral column resection for severe rigid scoliosis. *Spine (Phila Pa 1976)*. 2005;30(14):1682-1687.
22. Wang XB, Lenke LG, Thuet E, et al. Deformity angular ratio describes the severity of spinal deformity and predicts the risk of neurologic deficit in posterior vertebral column resection surgery. *Spine (Phila Pa 1976)*. 2016;41(18):1447-1455.
23. Chang DG, Yang JH, Lee JH, et al. Pediatric posterior vertebral column resection (PVCR): before and after ten years of age: greater than 10-year follow-up. *Spine (Phila Pa 1976)*. 2016;41(21):E1271-E1278.
24. Chang DG, Yang JH, Lee JH, et al. Congenital scoliosis treated with posterior vertebral column resection in patients younger than 18 years: longer than 10-year follow-up. *J Neurosurg Spine.* 2016;25(2):225-233.
25. Haher TR, Gorup JM, Shin TM, et al. Results of the Scoliosis Research Society instrument for evaluation of surgical outcome in adolescent idiopathic scoliosis. A multicenter study of 244 patients. *Spine (Phila Pa 1976)*. 1999;24(14):1435-1440.
26. Clavien PA, Sanabria JR, Strasberg SM. Proposed classification of complications of surgery with examples of utility in cholecystectomy. *Surgery.* 1992;111(5):518-526.
27. Dindo D, Demartines N, Clavien PA. Classification of surgical complications: a new proposal with evaluation in a cohort of 6336 patients and results of a survey. *Ann Surg.* 2004;240(2):205-213.
28. Stagnara P. Cranial traction using the '"Halo"' of Rancho Los Amigos. *Rev Chir Orthop Reparatrice Appar Mot.* 1971;4(57):287-300.
29. Dewald RL, Ray RD. Skeletal traction for the treatment of severe scoliosis. The University of Illinois halo-hoop apparatus. *J Bone Joint Surg Am.* 1970;52(2):233-238.
30. Letts RM, Palakar G, Bobecko WP. Preoperative skeletal traction in scoliosis. *J Bone Joint Surg Am.* 1975;57(5):616-619.
31. O'Brien JP, Yau AC, Hodgson AR. Halo pelvic traction: a technic for severe spinal deformities. *Clin Orthop Relat Res.* 1973(93):179-190.
32. D'Astous JL, Sanders JO. Casting and traction treatment methods for scoliosis. *Orthop Clin North Am.* 2007;38(4):477-484, v.
33. Papadopoulos EC, Boachie-Adjei O, Hess WF, et al. Early outcomes and complications of posterior vertebral column resection. *Spine J.* 2015;15(5):983-991.