The Use of Halo Gravity Traction in Severe, Stiff Scoliosis

Brett Rocos, MD, FRCS, Luke Reda, MD, MSc,* David E. Lebel, MD, PhD,* Michael K. Dodds, FRCS,† and Reinhard Zeller, MD, MSc, FRCSC**

Purpose: The correction of severe, stiff scoliosis in children is challenging. One method used to reduce the risk is preoperative halo gravity traction (HGT). In this study, the authors sought to define the efficiency and safety of HGT and characterize the chronology of the correction seen.

Method: A consecutive group of pediatric patients with severe spinal deformities was treated with HGT before definitive correction. A standard protocol with the daily addition of weight to 50% of body weight at 3 weeks was used. Traction remained in place until signs of impending neurological complication or 6 weeks, whichever was sooner.

Results: Twenty-four patients were included with a mean age of 11.8 years. The mean coronal deformity was 123 degrees, with a T1-L5 height of 234 mm. The mean duration of traction was 42 days with a mean improvement in height of 72 mm with 82% occurring over the first 3 weeks. Hundred percent of the angular and 98% of T1-L5 height correction was reached by 6 weeks. One patient showed early signs of a cranial nerve palsy prompting early surgery and 8 patients showed pin loosening, 1 of which required revision of their halo. One patient underwent a slower progression of traction because of transitory urinary disturbance. Following fusion, angular correction of the major curve was 49%.

Conclusion: HGT is a safe treatment for severe, stiff scoliosis because it can respond to early signs of impending neurological impairment. The first 3 weeks of treatment, reaching 50% of body weight as a traction force accounts for 80% of correction, with the remaining 20% in the following 2 weeks. At least 4 weeks of traction is recommended when following this protocol.

Key Words: traction, spine deformity, correction, pediatric deformity

(*J Pediatr Orthop* 2021;41:338–343)

From the *Department of Orthopaedic Surgery, Hospital for Sick Children, Toronto, ON, Canada; and †Department of Trauma and Orthopaedic Surgery, Mater Misericordiae University Hospital and Children's University Hospital, Rotunda, Dublin, Ireland.

No funding was received for this work.

B.R.: data collection, analysis, and manuscript preparation. L.R. and M.K.D.: data collection and analysis. D.E.L. and R.Z.: study conception and manuscript preparation.

The authors declare no conflicts of interest.

Reprints: Brett Rocos, MD, FRCS, Department of Orthopaedic Surgery, Hospital for Sick Children, 555 University Avenue, Toronto, ON, Canada M5G 1XB. E-mail: brett.rocos@sickkids.ca.

DOI: 10.1097/BPO.0000000000001830

The treatment of severe, stiff scoliosis in children is challenging with surgical correction having the potential to cause neurological injury either directly or through stretching or compromising the vascular supply to the cord.[1,2] Avoiding these catastrophic complications is critical to prevent dysfunction and long-term disability.

Surgeons can choose from a selection of strategies to tackle these deformities, including osteotomy, which is associated with a significant risk of neurological complications, and preoperative halo gravity traction (HGT).[3–5] First proposed by Dubousset as an adjunct to Stagnara's elongation cast, HGT is hypothesized to take advantage of Hooke's law and viscoelasticity of the pediatric spine through gradual application of weight through a halo with the patient's body weight acting as countertraction.[6–8] This gradual correction of the deformity over a period of weeks allows the bony and neurological elements of the spine to accommodate to their new shape through stress relaxation, thus preventing the adverse neurological effects seen in acute correction.

Since its introduction, several authors have sought to establish the optimal duration of traction and the complications associated with its use.[9,10] These are important to understand because of the potential for neurological injury, the length of inpatient stay, and the expense inherent with the use of HGT. In this retrospective cohort study, we sought to identify the optimal duration of HGT in pediatric patients treated for severe, stiff scoliosis treated at a single unit by multiple surgeons over 14 years, and to describe the pitfalls and complications associated with its use.

METHODS

Local research ethics board approval was granted. The study was deemed exempt from informed consent. A consecutive group of patients treated with HGT before posterior spinal fusion and segmental spinal instrumentation at a single center by multiple surgeons for severe, stiff scoliosis was identified from departmental records. The inclusion criteria were (i) patients diagnosed with a coronal angular deformity exceeding 100 degrees or with a high risk for neurological injury because of a high deformity angular ratio (the angular deformity at each motion segment, DAR) or scarred spinal cord, (ii) undergoing definitive posterior instrumented fusion surgery before age of 18 years, and (iii) treated with at least 14 days of HGT before definitive surgical correction.

The clinical records and pretreatment radiographs were assessed to define the demographics, diagnoses, comorbidities, and characteristics of the underlying deformity. The immediate and delayed complications of halo placement were recorded from surgical reports and inpatient records. Complications, adverse events, symptoms, or returns to the operating room during traction were recorded.

Each radiograph acquired prior, during, and after traction was arranged chronologically and categorized by week of treatment to calculate the weekly changes in the deformity. Angles were measured using the Cobb technique. The DAR, a measure of curve magnitude per level of deformity, was calculated before traction being applied and at each subsequent week until definitive fusion by dividing the angle of coronal deformity by the number of levels involved in the curve.[11,12] The improvement in DAR each week was expressed as a percentage of the improvement achieved by the traction treatment immediately before fusion. The change in T1-L5 height was calculated as the difference between the T1-L5 before traction and the T1-L5 height during each 7-day period expressed as a percentage of the T1-L5 height seen immediately before fusion. L5 was selected as the distal extent of this measurement because of the clarity of its inferior endplate in every case. The final correction achieved by definitive fusion was then described and compared with the deformity at presentation.

Traction Protocol

Under general anesthesia, the patient was positioned supine and sized for the appropriate halo orthosis. Following the manufacturer's instructions for pin location, placement, and torque, 6 to 8 pins were placed to fix the halo to the cranium. A bail was then fixed to the halo in such a way as to prevent flexion or extension of the neck. A 2.2 kg traction mass was then applied to the bail before transfer to the recovery area. Once the patient was returned to the inpatient area, 0.9 kg of weight was added to the bail daily with the patient's body weight working as countertraction until 50% of body weight was reached or clinical signs or symptoms of impending neurological dysfunction were identified. The upper limit for traction was 23.6 kg regardless of patient weight. The traction force remained in place day and night and was released only for personal hygiene. Patients ambulated in a traction wheelchair for the duration of treatment (Fig. 1). Anteroposterior and lateral full-length sitting spine radiographs were taken at intervals during treatment as determined by the treating surgeon. The halo was removed concurrently with the definitive fusion surgery. Patients remained under inpatient care for the duration of HGT until discharge after definitive fusion.

Data were recorded and analyzed using STATA V.14.0 (StataCorp, College Station, TX). Demographics were described using assessment of central tendency and spread. A paired *t* test was used to analyze the radiographic changes. Categorical data were described using the free text.

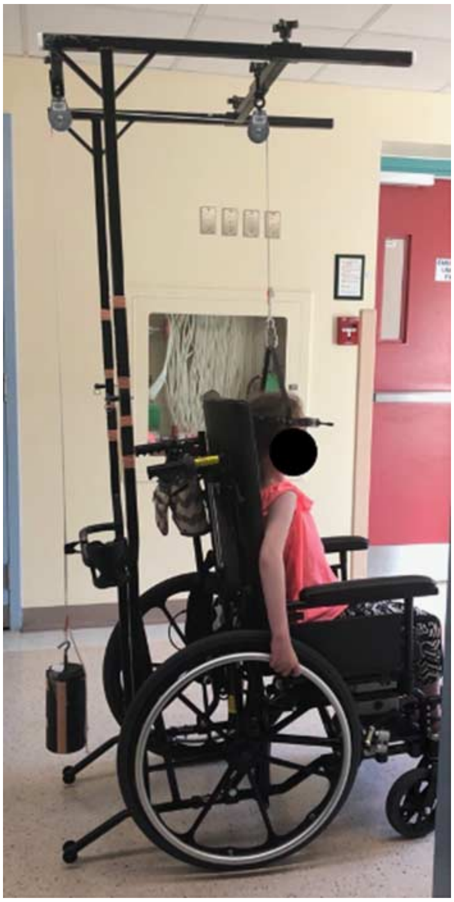

FIGURE 1. The halo gravity traction apparatus is used during mobilization in a custom wheelchair. full color online

RESULTS

Twenty-four eligible patients were included in the analysis. The mean age at the application of the halo was 11.8 years (range, 6.1 to 16.6 y), and median body weight was 26.9 kg (interquartile range, 21.0 to 45.1 kg). The underlying diagnosis was syndromic scoliosis in 9, neuromuscular scoliosis in 4, congenital scoliosis in 3, idiopathic in 7, and post paralysis in 1.

The major curve was thoracic in 20 patients with a mean coronal deformity of 123 degrees (range, 87 to 175 degrees) and mean T1-T12 sagittal deformity of 47 degrees (range, 3 to 126 degrees). The median DAR for the major deformity in this subgroup was 17 degrees (range, 10 to 25 degrees). Eleven patients showed an apical vertebra of either T9 or T10. The mean T1-L5 height in this group was 234 mm (range, 150 to 347 mm).

Two patients showed proximal thoracic major curves. These measured 82 and 99 degrees with a DAR of 5 in both cases. Two further patients showed a thoracolumbar primary curve of 76 and 147 degrees with a DAR of 6 and 9. Those with a proximal thoracic curve showed T1-L5 heights of 263 and 290 mm, and those with a thoracolumbar curve T1-L5 heights of 224 and 162 mm, respectively.

TABLE 1. The Percentage Improvements in Both T1-L5 Height, Coronal Angular Deformity, and DAR as a Percentage of the Final Measurements by Week of Traction Treatment

Week of Traction Treatment	Mean Improvement in T1-L5 Height, % (95% CI)	Mean Improvement of Major Curve, % (95% CI)	Mean Improvement on DAR of the Major Curve, % (95% CI)
1	54.8% (42.5-67.0)	37.5 (13.7-61.4)	38.3% (20.9%-55.8%)
2	71.7% (55.4-88.1)	85.4 (51.1-100)	66.7% (45.5%-87.9%)
3	82.1% (66.9-97.3)	95.8 (58.3-100)	71.5% (54.2%-88.7%)
4	92.6% (82.0-103.1)	100 (49.0-100)	77.9% (48.6%-100%)
5	98.4% (91.3-105.5)	100 (79.7-100)	97.7% (90.8%-100%)
6	98.3% (94.6-102.0)	100 (82.7-100)	98.9% (96.5%-100%)

CI indicates confidence interval; DAR, deformity angular ratio.

The median duration of traction was 42 days (interquartile range, 39 to 47). The shortest duration was 18 days because of the development of an XII cranial nerve palsy. The longest duration was 63 days. A single patient reported 1 incidence of neck pain that prompted pausing the addition of weight for 24 hours before continuing with the protocol.

The mean overall improvement in T1-L5 height was 68.3 mm (range, 12 to 117 mm). The mean improvement in T1-L5 length was 55% (95% CI, 43-67) in week 1, 72% (95% CI, 55-88) in week 2, 82% (95% CI, 67-97) in week 3, 93% (95% CI, 82-103) in week 4, 98% (95% CI, 91-106) in week 5, and 98% (95% CI, 95-102) in week 6 (Table 1). The coronal deformity improved by 37.5% (13.7-61.4) by week 1, 85.4% (51.1-100) by week 2, 95.8% (58.3-100) by week 3, and 100% by week 4.

One patient remained in traction until week 7 and saw an improvement of their DAR increase from 90% to 100% and their T1-L5 distance from 78% to 100% over the seventh week. Another was in traction until 8 weeks, seeing an improvement in DAR from 93% at 6 weeks to 94% at 7 weeks and 100% at 8 weeks, accompanied by a 5% increase in the T1-L5 length over the same period.

One patient refused the fusion procedure after traction. Two patients showed early signs of hypoglossal palsy that prompted earlier fusion in one. Both patients showed complete recovery after fusion. One patient had transient urinary dysfunction that resolved on 48 hours of pausing the progression of traction. Eight patients showed signs of pin site infection that necessitated local treatment. One patient returned to the operating room for the replacement of loose pins.

During the fusion procedure, 6 patients showed a loss of motor evoked potentials (MEPs). One patient showed a return to <10%, 1 to within 75%, and 1 to 50% of baseline signal amplitude. The remaining 3 returned to 100% of baseline values. In each case, the intraoperative mean arterial blood pressure was raised in response to the reduction in potentials, and in 4 cases, the intraoperative traction was released. Two patients had the release of the corrective instrumentation as part of the management of the complication. In both cases, less contoured rods were then fitted with no recurrence of signal loss. A single patient (with a 50% reduction in MEPs) showed a reduction in ankle dorsiflexion strength to MRC grade 4/5 after surgery, which had resolved by first follow-up at 6 weeks. This group showed a mean DAR of 18 degrees at presentation, which was no different to that of the remainder of the cohort ($P=0.39$). The group showed equivalent flexibility at week 1 ($P=0.11$) and no difference in the rate of improvement in the deformity to those patients who did not show neuromonitoring changes during the definitive correction ($P=0.30$).

After fusion, the mean thoracic curve coronal deformity in patients in whom this was the major curve was 61 degrees (range, 34 to 109 degrees), representing a mean improvement of 60 degrees (95% CI, 51-69 degrees; $P<0.01$). In patients with a proximal thoracic major curve, the mean post-fusion coronal deformity was 63 degrees (range, 51 to 75) representing an improvement of 28 degrees (−17 to 72 degrees; $P=0.08$). In those with a major thoracolumbar curve, the postoperative coronal deformity was 71 degrees (range, 50 to 92) representing an improvement of 41 degrees (−142 to 224; $P=0.2$). When these values are pooled, the correction of the major curve after fusion surgery was 49.1% (40.6 to 57.6). The DAR for the major curve, regardless of location, improved by a mean of 8 degrees (95% CI, 7-10; $P<0.01$) after fusion.

DISCUSSION

Our analysis shows that HGT effectively addresses the risk of neurological injury encountered when correcting severe, stiff spinal deformity in pediatric patients (Figs. 2, 3). The majority of the correction occurs over the first 3 weeks, where the application of force corresponds linearly with the increase in T1-L5 length and change in DAR. With our protocol, the traction force remains constant from the third week onward, yet the correction continues to improve, which we hypothesize represents the 3 element model viscoelastic effect described by Panjabi and White.[13] Neurological deficits can be seen with rapid application of corrective force, regardless of how it is applied, through stretching of neural structures or through compromise of the anterior spinal circulation. HGT allows the treating surgeon to reduce or remove the corrective force in response to neurological signs and symptoms, bringing an element of safety to correction not found in other strategies.

The 60% angular correction observed in main thoracic curves in our series exceeds that found in previously published cohorts. In a recent series, Hwang et al[10]

Copyright © 2021 Wolters Kluwer Health, Inc. All rights reserved.

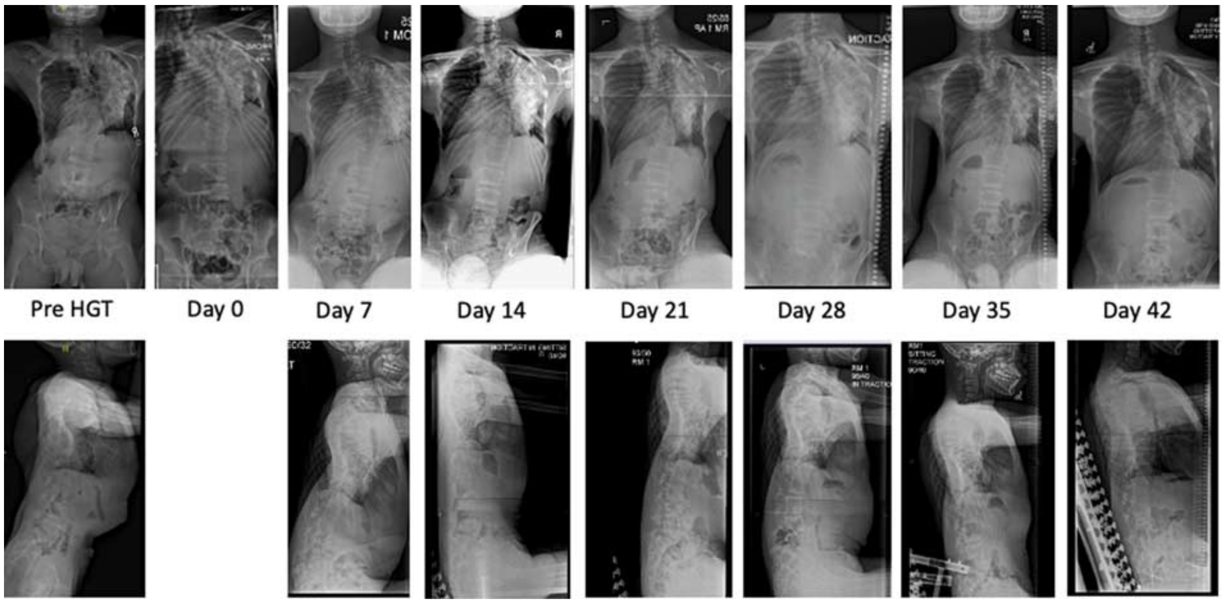

FIGURE 2. The radiologic improvements seen in a 12-year-old male patient with Larsen syndrome treated with 6 weeks of HGT. HGT indicates halo gravity traction. full color online

retrospectively reviewed 59 patients with varied etiology and a maximal deformity of 97 degrees showing that 32% of correction was achieved by 3 weeks. Rinella et al[14] conducted an analysis of 33 patients treated with HGT for severe scoliosis, though in this study, the traction force was reduced by up to 75% overnight. Patients were treated with traction for between 2 and 12 weeks with a 46% improvement in angular coronal deformity and a low rate of complication. Sink showed the effectiveness of HGT in 19 patients, only 6 of whom had not undergone any previous anterior release or spine surgery, by demonstrating a mean improvement of 35% in the angular coronal deformity.[15] In contrast to these positive findings, Sponseller et al[16] carried out a multicentre retrospective investigation comparing the treatment of idiopathic curves exceeding 90 degrees with and without preoperative traction and showed that although the technique is safe, HGT did not lead to a significantly improved overall correction either immediately postoperatively or at 2 years.

HGT has been shown to create similar corrections to 3 column osteotomy by Wang et al[9] who carried out an investigation of 62 patients treated with halopelvic traction, osteotomy, and instrumented fusion for rigid scoliosis exceeding 120 degrees. The group showed a 50% correction after 6 weeks of traction, a 65% correction when vertebral column resection (VCR) was used in addition, and 64% without VCR. However, osteotomy carries with it an inherent risk to neurological structures in severe pediatric deformity. Boachie-Adjei et al[5] showed a 5% incidence of neurological injury when correcting pediatric spinal deformities but noted that osteotomy and vertebral resections were brought an odds ratio of 1.7 for postoperative neurological complications. The same author later found a 9% rate of new neurological deficit in 286 pediatric patients treated for deformities exceeding 100 degrees or treated with VCR using the international FOX database.[17]

We suggest that the majority of the adverse incidents observed within our cohort should be considered pitfalls rather than complications because their management does not require any change to the treatment plan, except in one case where a return to the operating room for replacement of halo pins was needed. The literature shows a higher rate of adverse incidents. Although brachial plexus injury, cranial osteomyelitis, deep brain abscess, and avascular necrosis of the odontoid peg have been rarely reported after HGT, pin loosening and infection are commonly reported at a rate of between 0% and 30%.[2,14,15,18,19] Watanabe showed a single incident of pin site infection and no incidents of neurological deficit in a series of 21 patients treated with traction.[20] Wang et al[9] showed an incidence of 2 of 62 of infected halo pins, 3 of 62 incidence of infected pelvic pins, and 1 case of cranial neurapraxia in their series, and Hwang et al[10] found a 10 of 59 incidence of complications, all pin site related, including a single skull fracture.

Our data confirm that cranial and peripheral neurological injury is seldom observed with the slow and progressive application of HGT, and during definitive fusion, only 25% of our patients showed changes in MEP, none of which showed any postoperative neurological deficits despite the severity and stiffness of the curves.[2] Only rare cases of paraplegia, hypoglossal nerve palsy, and transient lower limb sensory deficits have been documented with the use of traction.[21–24] Wilkens et al showed a 9% incidence of cranial nerve palsy, Sponseller et al[16] a single incident of transient leg paresis in 30 patients, and Koller no incidences of neurological complication in their retrospective series of 45 similar patients.[25,26]

Copyright © 2021 Wolters Kluwer Health, Inc. All rights reserved.

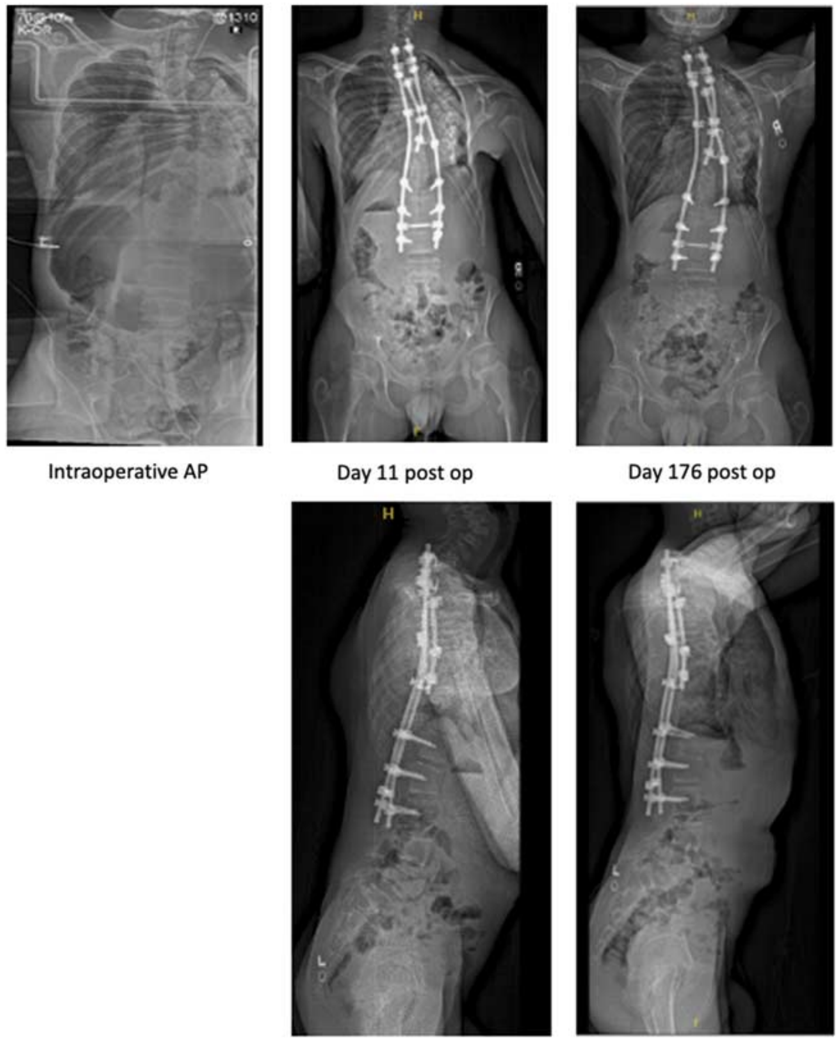

FIGURE 3. The postoperative radiographs of the case seen in Figure 2. AP indicates anteroposterior. full color online

The duration of preoperative traction has been debated for 45 years. In 1975, Letts et al[27] published a series of 10 patients with a mean coronal deformity of 81 degrees treated with halo femoral traction before definitive fusion. The group added 1.8 kg/d to a maximum of 18 kg showing that close to 41% of the correction was achieved within the first week. The team identified a higher rate of pin loosening and pain, leading the Pediatric Orthopaedic Society of North America to recommend a maximum duration of traction of 15 days for these patients. A similar finding was documented by Clark and colleagues who demonstrated that the maximum correction was achieved at between 10 and 12 days with halopelvic traction. More recently, Watanabe et al[20] examined a cohort of 6 patients with curves exceeding 100 degrees treated with HGT without anterior release, showing a 92% improvement in angular deformity within the first 3 weeks.[28] Our data show that 71% of the correction occurs in the 2 weeks of treatment, and 81% in the first 3 weeks. This is followed by 19% over the subsequent 3 weeks where no additional weight is added. It may be that Hooke's law is being followed initially, where the correction is proportional to the force applied, whereas stress relaxation occurs in the subsequent 3 weeks, suggesting that viscoelasticity of the spine is a characteristic that may be being taken advantage of in deformity correction.[28,29] This, combined with the viscoelasticity of the spinal cord itself, explains why the gradual correction of deformity with consistent force does not lead to the same incidence of neurological complication as an acute correction.[30] These data suggest a recommendation for 4 weeks of HGT to achieve 100% of the coronal angular and 93% of the thoracic height correction. Continuing to 5 weeks brings only a small improvement in thoracic height, which should be considered on an individual basis, as should the use of traction for longer periods if it is being tolerated and correction is observed to continue through serial radiographs.

These data support the use of HGT in managing severe, stiff scoliosis, show that it is safe and effective, and suggest a viscoelastic characteristic of the pediatric spine.

Copyright © 2021 Wolters Kluwer Health, Inc. All rights reserved.

The study is limited by the inconsistent timing of radiographs in some cases, which limits the ability to calculate the precise chronology of the correction of the deformity with a greater resolution. The cohort is heterogenous in the etiology of the deformity, which may influence the patients' vulnerability to pitfalls and complications of traction. Further challenges were encountered in taking measurements from the radiographs because of the severe nature of the deformities in some cases. Finally, it may be that the ideal duration of traction is case-dependent and traction duration beyond 4 weeks yields as yet unrecognized benefits; however, this must be balanced with the practicalities of long inpatient stay.

CONCLUSION

HGT is an effective technique to address the neurological risks inherent in managing severe, stiff spinal deformities in pediatric patients. The first 3 weeks of treatment, reaching 50% of body weight as a traction force accounts for 80% of correction, with the remaining 20% in the following 2 weeks. At least 4 weeks of traction is recommended when following this protocol; however, the duration of traction should be decided on a case-by-case basis.

REFERENCES

1. Koptan W, El Miligui Y. Three-staged correction of severe rigid idiopathic scoliosis using limited halo-gravity traction. *Eur Spine J*. 2012;21:1091–1098.
2. Yang C, Wang H, Zheng Z, et al. Halo-gravity traction in the treatment of severe spinal deformity: a systematic review and meta-analysis. *Eur Spine J*. 2017;26:1810–1816.
3. Bianco K, Norton R, Schwab F, et al. Complications and intercenter variability of three-column osteotomies for spinal deformity surgery: a retrospective review of 423 patients. *Neurosurg Focus*. 2014;36:E18.
4. Diab M, Smith AR, Kuklo TR. Spinal Deformity Study G. Neural complications in the surgical treatment of adolescent idiopathic scoliosis. *Spine (Phila Pa 1976)*. 2007;32:2759–2763.
5. 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;2:340–349.
6. Stagnara P. Cranial traction using the "Halo" of Rancho Los Amigos. *Rev Chir Orthop Reparatrice Appar Mot*. 1971;57:287–300.
7. Perry J. The halo in spinal abnormalities: practical factors and avoidance of complications. *Orthop Clin North Am*. 1972;3:69–80.
8. Stagnara P, Fleury D, Fauchet R, et al. Major scoliosis, over 100 degrees, in adults. 183 surgically treated cases. *Rev Chir Orthop Reparatrice Appar Mot*. 1975;61:101–122.
9. Wang Y, Li C, Liu L, et al. Presurgical short-term halo-pelvic traction for severe rigid scoliosis (Cobb angle > 120 degrees): a 2-year follow-up review of 62 patients. *Spine (Phila Pa 1976)*. 2020;46:E95–E104.
10. Hwang CJ, Kim DG, Lee CS, et al. Preoperative halo traction for severe scoliosis. *Spine (Phila Pa 1976)*. 2020;45:E1158–E1165.
11. Lenke LG, Boachie-Adjei O, Sucato DJ. The deformity angular ratio accurately predicts risk of intraoperative spinal cord monitoring alerts during surgery for severe pediatric spinal deformity. SRS 49th Annual Meeting, Anchorage, AK; 2014.
12. Lewis ND, Keshen SG, Lenke LG, et al. The deformity angular ratio: does it correlate with high-risk cases for potential spinal cord monitoring alerts in pediatric 3-column thoracic spinal deformity corrective surgery? *Spine (Phila Pa 1976)*. 2015;40:E879–E885.
13. White AA, Panjabi MM. *Clinical Biomechanics of the Spine*, 2nd ed. Philadelphia, PA: Lippincott; 1990.
14. Rinella A, Lenke LG, Whitaker C, et al. Perioperative halo-gravity traction in the treatment of severe scoliosis and kyphosis. *Spine (Phila Pa 1976)*. 2005;30:475–482.
15. 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;21:519–524.
16. Sponseller PD, Takenaga RK, Newton P, et al. The use of traction in the treatment of severe spinal deformity. *Spine (Phila Pa 1976)*. 2008;33:2305–2309.
17. Boachie-Adjei O, Duah HO, Yankey KP, et al. New neurologic deficit and recovery rates in the treatment of complex pediatric spine deformities exceeding 100 degrees or treated by vertebral column resection (VCR). *Spine Deform*. 2020;9:427–433.
18. Qian BP, Qiu Y, Wang B. Brachial plexus palsy associated with halo traction before posterior correction in severe scoliosis. *Stud Health Technol Inform*. 2006;123:538–542.
19. Garfin SR, Botte MJ, Nickel VL. Complications in the use of the halo fixation device. *J Bone Joint Surg Am*. 1987;69:954.
20. 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;15:720–730.
21. Ginsburg GM, Bassett GS. Hypoglossal nerve injury caused by halo-suspension traction. A case report. *Spine (Phila Pa 1976)*. 1998;23:1490–1493.
22. 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;24:667–673.
23. Ransford AO, Manning CW. Complications of halo-pelvic distraction for scoliosis. *J Bone Joint Surg Br*. 1975;57:131–137.
24. MacEwen GD, Bunnell WP, Sriram K. Acute neurological complications in the treatment of scoliosis. A report of the Scoliosis Research Society. *J Bone Joint Surg Am*. 1975;57:404–408.
25. Koller H, Zenner J, Gajic V, et al. The impact of halo-gravity traction on curve rigidity and pulmonary function in the treatment of severe and rigid scoliosis and kyphoscoliosis: a clinical study and narrative review of the literature. *Eur Spine J*. 2012;21:514–529.
26. Wilkins C, MacEwen GD. Cranial nerve injury from halo traction. *Clin Orthop Relat Res*. 1977;126:106–110.
27. Letts RM, Palakar G, Bobecko WP. Preoperative skeletal traction in scoliosis. *J Bone Joint Surg Am*. 1975;57:616–619.
28. Clark JA, Hsu LC, Yau AC. Viscoelastic behaviour of deformed spines under correction with halo pelvic distraction. *Clin Orthop Relat Res*. 1975;110:90–111.
29. Senkoylu A, Cetinkaya M. Correction manoeuvres in the surgical treatment of spinal deformities. *EFORT Open Rev*. 2017;2:135–140.
30. Bilston LE, Thibault LE. The mechanical properties of the human cervical spinal cord in vitro. *Ann Biomed Eng*. 1995;24:67–74.