Journal of the Pediatric Orthopaedic Society of North America 9 (2024) 100129

Contents lists available at ScienceDirect

Journal of the Pediatric Orthopaedic Society of North America

journal homepage: www.jposna.com

Current Concept Review

Pediatric Halo Use: Indications, Application, and Potential Complications

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A R T I C L E I N F O

Keywords:
Halo
Halo gravity traction
Pediatric halo
Pediatric scoliosis
Scoliosis
Pediatric cervical spine

A B S T R A C T

A halo has many applications for the treatment of pediatric spine pathology. It is most commonly used with gravity traction for the correction of severe thoracolumbar deformity over the course of several weeks before a staged fusion or growing implant placement. It is also used for preoperative optimization, secure positioning of small skulls for prone spine approach, cervical deformities such as basilar invagination, trauma treatment, or postoperative immobilization with a halo vest. Application of a halo is generally straightforward, but surgeons must be vigilant about complications and risks.

Key Concepts:

(1) Halo placement must be done with an understanding of safe corridors for pin placement and pin torque specific to a patient's bony anatomy, quality, and age.
(2) In severe thoracolumbar spinal deformity, halo-gravity traction (HGT) allows for elongation of the spine, correction of deformity, and chest elongation before the second-stage placement of implants.
(3) In the cervical spine; HGT can be used to reduce basilar invagination before occipitocervical fusion, C1-2 rotatory subluxation before C1-2 fusion. A halo vest orthosis can be a definitive treatment for atlanto-occipital dislocation without neurologic injury.
(4) Complications such as pin site infections and nerve palsies are frequent but most resolve quickly with appropriate management and vigilant monitoring.

Introduction

In pediatric spinal care, there are many uses for a halo, or a ring affixed to the skull percutaneously with pins. A halo can be used preoperatively in conjunction with traction to gradually improve severe deformity before surgery; intraoperatively to aid positioning; to apply traction for large spinal deformity correction; or it can be attached to a vest to immobilize or stabilize in the postoperative period. While the application can be straightforward, care must be taken to avoid common complications. Here, we offer a complete review of indications and authors' preferred approaches, here applications, and complications of halo use in pediatric spine patients.

Indications for halo use

Thoracolumbar deformity

Halos in the pediatric population are most commonly applied in conjunction with gravity traction for the treatment of severe thoracolumbar deformity. The first uses of halo-gravity traction by Dr. Pierre Stagnara in the 1960s were for the treatment of severe thoracolumbar spine deformity [1], which remains the most common application for halo-gravity traction (HGT) in pediatric patients. Halo-gravity traction is often the first step in a two-stage correction of spinal deformity and can be followed by cast or brace application, implantation of spinal growing rods, or definitive spinal fusion. Regardless of the clinical endpoint, the goals of treatment remain the same: safe, gradual correction of deformity, limiting the need for riskier acute correction maneuvers, reducing the risk of neurologic injury, and minimizing stress on the osseous anchors of the final construct. Inline axial traction relies on the viscoelastic nature of the pediatric spine, allowing for correction of the spine in the coronal, sagittal, and axial planes simultaneously, typically over a period of several weeks [2].

In the case of severe thoracolumbar deformity in short-stature patients, either young patients with early onset scoliosis (EOS) or skeletal dysplasia, increased spine height gained via traction allows for more options in selecting spinal implants. Traditional growing rods (TGR) can be customized to fit any shape/size of deformity; however, the advent of magnetically controlled growing rods (MCGR) has resulted in fewer surgeries, making them an attractive option for many patients. Despite these benefits, the magnetic rods are bulky with a straight magnetic actuator (minimum of 70 mm actuator + 20 mm adjacent segment) that

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https://doi.org/10.1016/j.jposna.2024.100129
Received 17 September 2024; Accepted 28 September 2024
Available online 11 October 2024

cannot be contoured. Deformity correction with HGT lengthens the spine and reduces kyphosis, making these larger implants more easily implanted and an option for short-stature patients (Fig. 1).

The clearest demonstration of the efficacy of HGT is the radiographic correction of spinal deformity, which has been reported as a 30%–35% correction of coronal plane deformity and a 25%–35% correction of sagittal deformity [4–6,9]. Coronal trunk shift improves up to 65% with HGT and an increase of T1-L5 trunk height of over 5 cm have been reported [2,5]. Multiple studies confirm that 66%–85% of the coronal curve correction occurs within the first 2 weeks of HGT, with diminishing returns each week after [2,6,10]. Rocos et al. found that in their series, 100% of coronal deformity correction was achieved by 4 weeks of HGT, with no further correction over another 2 weeks. While T1-L5 spine height did continue to improve until 6 weeks, as did the reduction of deformity angular ratio, the majority of correction was within the first month.

Uniplanar thoracolumbar kyphosis is less common than kyphoscoliosis but is an excellent scenario for correction utilizing HGT. Kyphotic spinal deformities tend to be stiff, are challenging to safely correct acutely, and increase the risk of implant failure/pullout. Careful preoperative assessment for spinal stenosis on history, examination, and MRI is imperative in these children to avoid iatrogenic injury. Not only does HGT safely correct kyphosis but correction can indirectly decompress the spinal canal, reducing the risk to these patients in the future.

The authors commonly consider anterior releases in those patients with severe kyphosis as the contracted anterior longitudinal ligament (ALL) limits the ability for HGT to elongate the spine [12] (Fig. 2). In cases where the deformity is so severe as to prevent the passage of thoracoscopic instruments to the apex of deformity, it is possible to begin with 2–3 weeks of HGT, followed by a return to the OR for anterior releases, and a further 2–3 weeks of HGT. This technique is reserved for only the most complex cases but has been effective in the authors' experience.

Patients with spinal deformity and poor pulmonary function testing (PFT) have been shown to trend toward increased postoperative complications [3]. The secondary benefits of HGT include improved respiratory function in patients with severe thoracolumbar deformity, which can decrease thoracic volume, stiffen the chest wall, and affect the function of the diaphragm [1]. By elongating the trunk and spine with HGT correction, it is hypothesized that chest wall motion becomes less restricted, along with greater diaphragmatic excursion, improving respiratory mechanics [1]. Over the course of HGT, the space available for the lungs has been shown to increase by 14.9% [4], with several studies demonstrating overall improvement in PFTs before the second stage procedure [5–7]. Bogunovic et al. found a 9% improvement in both forced vital capacity (FVC) and forced expiratory volume over 1 min (FEV1) following HGT, with improved pulmonary function in 19 out of 21 patients [6]. Recent meta-analysis of published HGT series similarly supports improved pulmonary function (forced vital capacity % predicted) over the course of traction, as well as increased body mass index (BMI) [7]. For medically fragile children, improved pulmonary function and nutritional status further optimize them for the second-stage spine procedure. Additionally, the initial halo application surgery can be paired with an anterior release or posterior anchor placement before the final correction.

Indications

Precise indications for HGT in thoracolumbar deformity have been debated in the literature, though it can be generalized that the technique is most appropriate when treating large rigid spine deformities. Patients include young children with early onset scoliosis, congenital malformations, skeletal dysplasias, and adolescents with large, stiff thoracolumbar deformities, frequently associated with syndromes and neuromuscular conditions. Recent expert opinion has been published with the consensus that HGT should be considered for thoracolumbar deformity measuring greater than 90° Cobb angle in either the coronal or sagittal planes [11]; however, HGT can also be considered for curves measuring 60°–90° in patients with respiratory compromise or malnutrition, and in short, acute deformity (high deformity angular ratio) or stiff kyphosis [1]. In these scenarios, final constructs often require overcontouring and place substantial stress on bony fixation points, making them prone to both immediate failure and gradual loss of fixation. Following correction with HGT, final constructs may be placed in situ, with very little additional stress exerted on the bone [5]. There are few contraindications to HGT due to its relative safety (Table 1). While often avoided, HGT in the setting of spinal stenosis can be attempted in some but with a high level of caution, surveillance, and slow weight increases.

Any child under consideration for HGT requires a thorough preoperative workup in addition to family education in preparation for admission. A complete history, neurologic examination, and MRI will help identify any potential contraindications as above. In cases with spinal stenosis and concern for spinal cord compression, a urodynamic

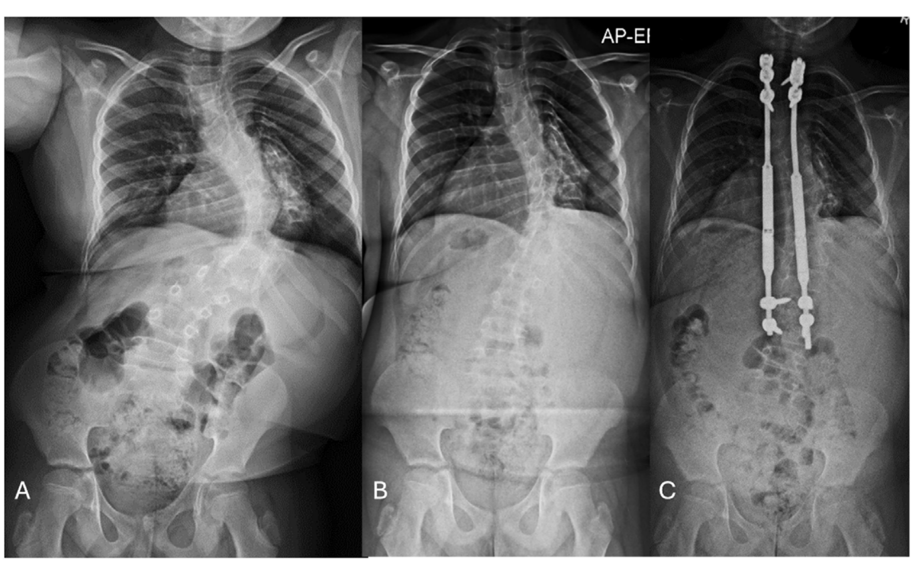

Figure 1. (A) Preoperative AP radiograph of an 11-year-old short-stature boy with idiopathic early onset scoliosis measuring 100°. (B) Reduction of scoliosis to 60° following 2 weeks of HGT at 50% body weight. (C) Final growing rod construct out of traction with correction to 35 degrees of scoliosis. HGT, halo-gravity traction.

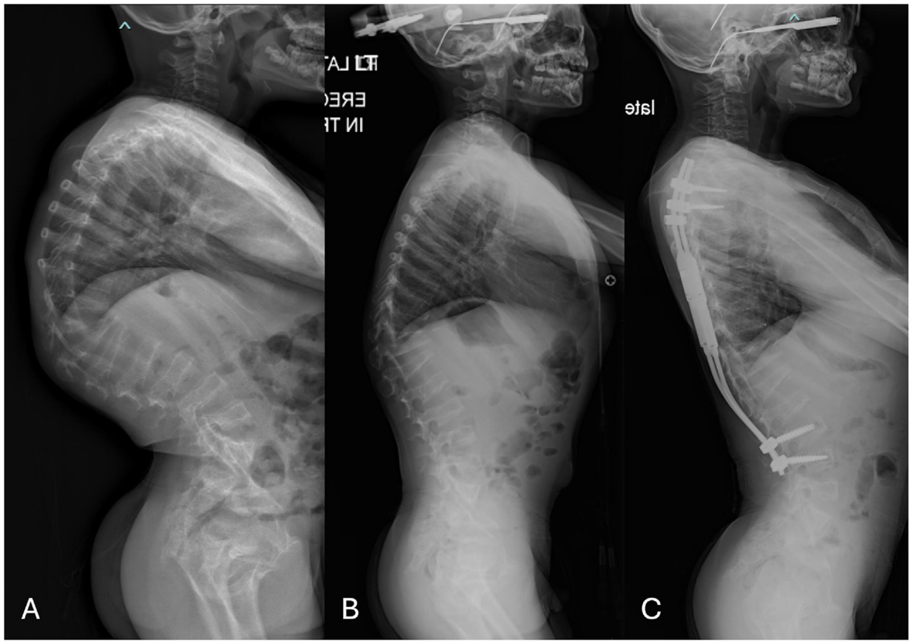

Figure 2. (A) Preoperative lateral radiograph of a 7-year-old boy with metatropic dysplasia and 110 degrees of thoracic kyphosis. (B) Improvement of thoracic kyphosis to 70° following apical anterior thoracoscopic releases and 4 weeks of HGT at 50% body weight. (C) Final growing rod construct out of traction with 35 degrees of thoracic kyphosis. HGT, halo-gravity traction.

Table 1
Common indications and contraindications for HGT.

Indications	**Contraindications**
Sagittal or coronal curve >90	<1 year of age, open fontanelles
Curve 60–90 with: - Short, sharp curve - Stiff kyphosis	Spinal dysraphism/tethered cord
Respiratory deficiency needing intensive pulmonary prehabilitation	Canal occupying lesions
Nutritional deficits needing intensive preoperative improvement	**Relative** - Stenosis with cord compression

HGT, halo-gravity traction.

study is useful to assess for early neurogenic bladder changes, which could preclude use of HGT. Preparation for surgery also includes medical optimization and clearance with the pediatric hospitalist service and relevant subspecialists (pulmonology, gastroenterology, etc). Our patients remain inpatient for the duration of HGT (outpatient care has been described [8]), with involvement of rehabilitation medicine and physical therapy throughout their admission. Preoperative evaluation helps plan for mobilization during HGT, as well as the ability to tailor the HGT equipment to each specific patient.

Cervical spine deformity

Intraoperative positioning

The most common application of a halo in the cervical spine is for intraoperative positioning to fix the head to an operating table for a prone posterior cervical spine approach. We use a halo for positioning for all patients under the age of 10, or those with a soft or brittle bone disease at any age. In patients older than 10 years of age with normal bone, we would instead use a Mayfield for stationary positioning or Gardner-Wells tongs if applying traction cranially. When applied, a halo is placed after induction and connected to the bed with lateral cervical fluoroscopy obtained to ensure appropriate alignment and/or reduction before proceeding to surgery. The authors prefer an open posterior ring halo when used for cervical spine surgery (Fig. 3).

After a cervical spine fusion surgery, the intraoperative halo can be connected to a halo vest orthosis to maintain stabilization postoperatively. This may provide additional support in patients whose spinal anatomy does not support robust spinal fixation. The halo-vest orthosis can also be

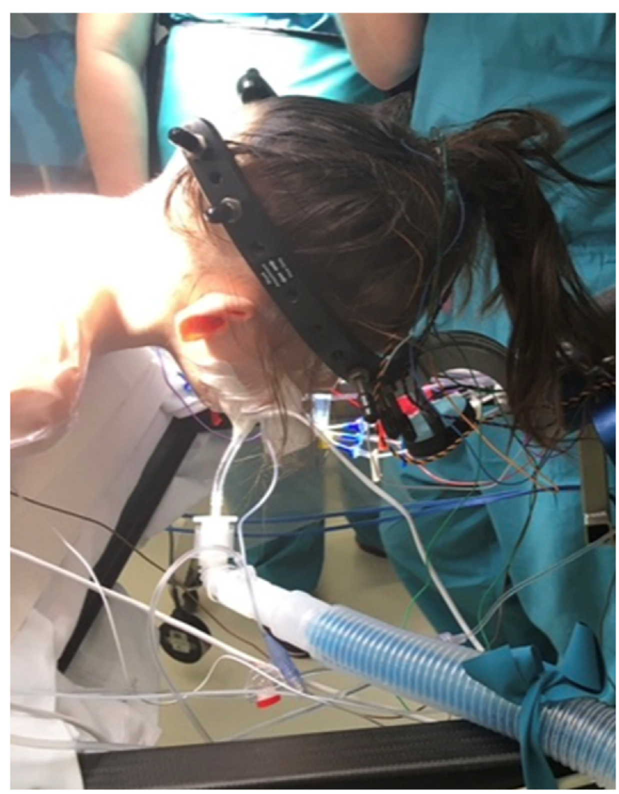

Figure 3. Patient positioned with a halo attached to the bed frame, with an open posterior ring for better access to the cervical surgery site.

used as a stand-alone stabilization treatment in certain traumatic injuries, as discussed below.

Basilar invagination

Basilar invagination (BI) can be seen in pediatric patients with soft bone disease such as osteogenesis imperfecta or in patients with congenital anomalies at the basal skull or occipital-cervical (OC) junction. Preoperative halo-gravity traction can be applied to help reduce the brainstem compression in BI ahead of a fusion surgery by slowly pulling the head cephalad away from the compressed brainstem. The halo ring is continued during surgery, where the same traction force can be continued until implant fixation. Alternatively, one can consider a halo vest for stepwise distraction by screw bolts attached to the rods [13–15]. With HGT, BI improved after traction by an average of 63%, or 4–5 mm as measured by McGregor's line, and the clival angle improved by 10°–20° [16]. Others have applied traction by progressive weight outside of a vest, either supine or with traditional halo-gravity traction systems [17,18]. Using traction until radiographic reduction, this technique obtained a similar reduction in 13–30 days. Notably, patients presenting with myelopathy all improved during traction.

The author's preferred technique for patients with BI is to use halo gravity traction, starting at 10% of body weight traction and adding 1 pound per day pending patient tolerance, with in-traction lateral cervical spine radiographs every 3–5 days, and to proceed to surgery once reduced or correction plateaued. In our experience, this is within 2–3 weeks. (Fig. 4).

Rotatory subluxation

C1-2 rotatory subluxation is common in pediatric patients with ligament laxity disorders such as trisomy 21 but can also occur from minor trauma or nearby infection. The patient may present with a fixed neck position and decreased range of motion, with or without neurologic injury. If presenting early, our preferred treatment is first antiinflammatories, muscle relaxants, and soft-collar outpatient treatment. Without swift resolution, we move to cervical traction, normally with halter gravity traction first but HGT can also be used. If a reduction is obtained within 3–5 days, the reduction can be held with halo vest orthosis for several weeks to allow the ligaments to stiffen in the corrected position (Fig. 5). We place the halo and fix it to the vest in an overcorrected position. If the subluxation does not reduce with traction, or if the reduction is lost while in the halo vest, we proceed with a C1-2 posterior spinal fusion.

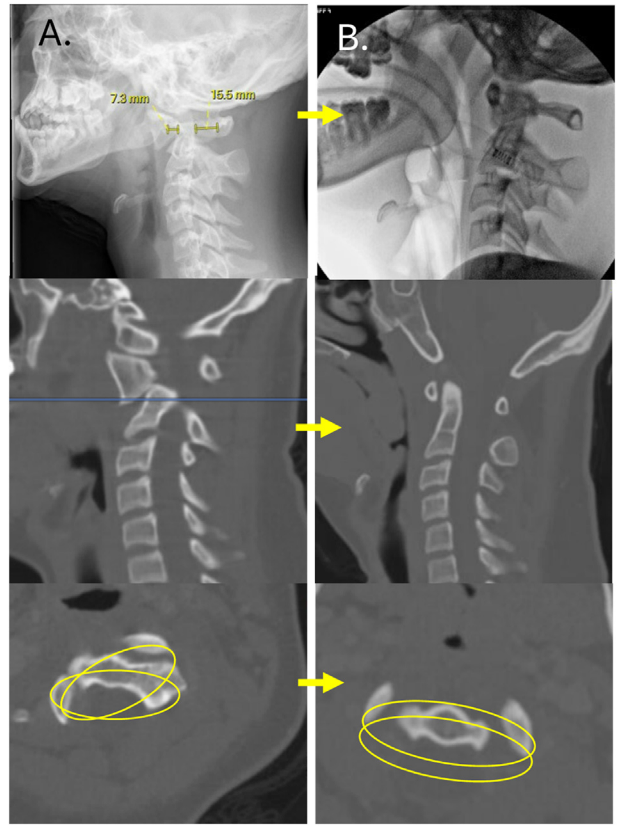

Figure 5. (A) presenting lateral cervical radiograph and CT showing C1-2 subluxation. The patient was treated with inpatient halter traction, which reduced after 5 days. Because of the duration for reduction, the next step was fixation in the halo vest in a reduced position. Overlapping axial plane ovals represent the axial alignment of C1 (seen as the small segments of lateral masses anteriorly and posteriorly in its rotated position) and C2 (more visible, square to the alignment of the CT gantry). (B) Intraoperative upright lateral in halo-vest in a reduced position, confirmed on CT, and represented again with the overlapping ovals now both square to the CT alignment and to one another (with the dens centrally and the C1 lateral masses in their appropriate relationship medially and laterally to the dens). CT, computed tomography.

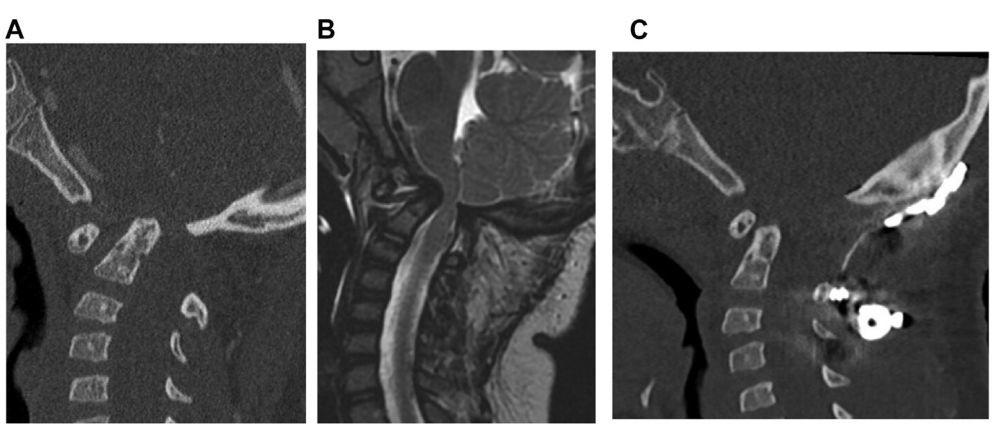

Figure 4. A 4-year-old female with craniosynostosis and developmental delay, status-post Chiari decompression, presented with BI and cervical stenosis from regrowth of her basal skull. She was treated in halo gravity traction for two weeks with reduction achieved, followed by occiput to C3 posterior spinal fusion with iliac crest bone grafting and occipital decompression. Reduction from the traction is evident from preoperative CT to initial postoperative CT. BI and spinal stenosis preoperatively on CT (A), and MRI (B) Postoperative CT with BI reduction, occipital decompression, and O–C3 PSF (C). BI, Basilar invagination; CT, computed tomography; MRI, magnetic resonance imaging.

Cervical spine trauma and stabilization

In young pediatric patients, the upper cervical spine or cranio-cervical junction is more at risk of a traumatic injury [19]. The large size of the head compared with the torso, and generalized laxity of the ligamentous structures increase the risk of injury [20]. The treatment goal is to restore cervical stability while limiting risk to the neural elements and minimizing loss of range of motion. Halo/vest stabilization is commonly used for the upper cervical spine because it allows for more rigid fixation and the ability to perform closed reductions when compared with a cervical collar. It also allows for the maintenance of motion when compared with cervical fusion. This is especially critical when considering nearly 50% of motion is from the upper cervical spine.

Atlanto-occipital dislocation

The most concerning injury of the upper cervical spine is atlanto-occipital dislocation (AOD) or cranio-cervical dissociation [21]. It is frequently the result of a high-energy event such as a motor vehicle collision in which distraction forces are applied across the craniocervical junction [22]. It can be associated with either an upper cervical spinal cord or brain stem injury. Secondary to the high risk of mortality associated with AOD, surgical stabilization is widely considered the treatment of choice. Recent data have suggested that halo stabilization is a viable option in young pediatric patients, with one small study reporting good outcomes in eight patients with AOD who were treated with only halo stabilization [23].

The use of a halo for treating pediatric AODs is becoming more common in pediatric facilities and is the authors' primary treatment method in nonneurologic injury patients. When placing the halo, it is important to perform the procedure under fluoroscopic imaging. Compression across the injury site is the primary reduction maneuver. This ensures that the injury remains reduced in the upright position and that the spinal cord does not experience any distractive forces. It is also important to instruct caregivers to avoid lifting or carrying the patient by either the halo or vest. This will minimize any delayed distraction across the injury. Frequent upright X-rays are needed to confirm the maintenance of reduction. The author will perform a CT at 3 months to document healing; while frequently thought to be a purely ligamentous injury, it is not uncommon to see bone healing across the tentorial membrane.

Odontoid and C1 fractures

Odontoid fractures in patients under the age of six can occur at the synchondrosis at the base of the odontoid, resulting in a Salter-Harris I fracture [24]. In patients with a closed physis, the fracture can occur throughout the odontoid. Treatment is typically directed by the amount of displacement and stability of the reduction. Collar immobilization can be used in patients with stable and minimally displaced fractures. In patients who require a reduction, the author's preference is to use halo vest immobilization. If there is a small loss of reduction, a repeated adjustment or reduction can be performed. If the fracture is unstable or an adequate reduction cannot be obtained, then a C1–C2 posterior fusion is typically performed.

Less common injuries of the upper cervical spine include C1 burst fractures (Jefferson fracture) and C2 hangman fracture [25]. These injuries are more commonly seen in older patients and frequently follow an adult pattern or injury mechanism. Stable, minimally displaced fractures can be treated with a collar, but any attempts at reduction are typically treated with more rigid immobilization, such as halo vest orthosis. Unstable fractures should be treated with surgical fusion. In the case of a C1 burst fracture, fusion across the C1–C2 is performed. C2 hangman fracture can be treated with a C2–C3 anterior fusion. Any concern for fixation construct can be backed up by halo vest.

Subaxial fractures

Subaxial cervical spine injuries are more typically found in older pediatric patients or patients near skeletal maturity. The spectrum of injury is quite broad from either posterior element fractures to three-column fracture dislocations [26]. Many of the injury types in older pediatric patients follow the treatment algorithm reported in adult literature. When treated nonsurgically, the majority of these injuries are placed into a collar or a Minerva for injuries near the cervical-thoracic junction. The use of a halo vest for subaxial spine injury is less commonly used the more caudal along the spine as the fixation to the skull is less necessary. The tolerance and risks for halo/vest fixation become more challenging as the patient becomes older [27,28]. The one situation in which the author has used halo vest fixation successfully is when attempting to restore lordosis in multilevel compression/flexion injuries. In these cases, the patient has multilevel anterior body height loss resulting in significant global kyphosis. Surgical treatment would require extensive multilevel fusion. To avoid this, accentuated translation of the head posteriorly can correct the kyphosis. This is difficult to do in a collar or Minerva, and the additional force can create pressure areas around the chin and jaw line. The halo vest option also provides the ability to build an additional padded support connecting horizontally across the posterior bars, which can gently push from the posterior at the mid-cervical region and create some additional lordosis.

Halo ring application

Safe and optimal placement of a halo ring in a pediatric patient balances biomechanical and anatomic considerations. To maximize the stiffness of the halo ring and decrease slippage or failure at the pin-bone interface, several rules must be considered [29,30]. First, the ring must be positioned ideally at or below the maximal width (equator) of the skull. Second, the distance from the ring to the skull should be within 1 cm at all pin sites whenever possible to decrease the lever arm torque onto the pin-bone interface when force is applied to the halo ring. Pins should also be placed as perpendicularly as possible to the bone at each site [31].

The skull is thickest directly posterior, directly anterior, followed by posterolateral and anterolateral, then direct lateral. Directly anterior pins are avoided due to the location of the frontal sinus and supraorbital nerve, and routine directly posterior pins are generally less utilized as the patient would be resting on the pin when supine. The thinnest portion of the skull is directly lateral along the temporal fossa region. This leaves the anterolateral and posterolateral aspects of the skull the optimal sites for halo pin placement. It is important to recognize that the thickness of the skull in the ideal anterolateral and posterolateral pin positions can be < 3 mm for most pediatric patients under age 4, gradually increasing to >4 mm in adolescence (age >13) [33].

Anterolateral-based pins are placed in a safe zone medially at the midpoint of the eye and laterally to the palpably softer temporalis muscle where the temporal artery runs. They should be approximately 1 cm above the lateral margin of the eyebrow to avoid injury to the supraorbital and supratrochlear nerves (Fig. 6). Direct laterally based pins are generally avoided because of risks to the temporal muscle, which can cause discomfort with chewing. In addition, if there is a chance of connecting the halo to a vest, the two most lateral pin sites on the halo ring

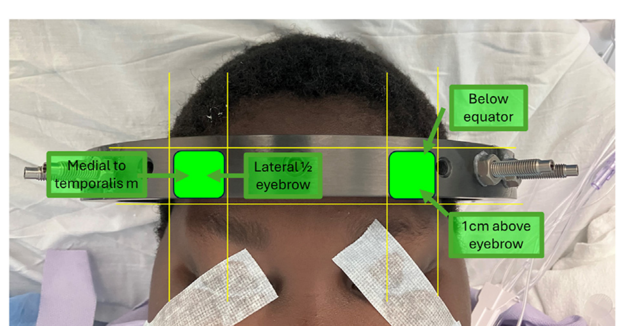

Figure 6. Demonstration of safe zone and explanation of its boarders for anterior pins.

will be needed for this connection. Posterolateral-based pins are generally safe, without major neurovascular structures at risk. The ear can serve as a reference to the avoidance of the temporal fossa when placing the posterolateral pins. Posterolateral pins are placed posterior and 1 cm above the pinna of the ear. An example of optimal pin and halo ring placement in a pediatric patient is in Fig. 7.

A consensus amongst pediatric spinal deformity surgeons is that at least 6 pins should be placed in children, with consideration of >8 pins in patients under 6 years old [11]. The torque of the pins should aim to match the quality of the bone and thickness of the skull by age [32]. In adults, generally, pins are set to 6–8 in-lb of torque without high risk of skull penetration and provide optimal pin-bone interface mechanics. In children, the bone is softer and thinner. McIntosh et al. suggested a general rule of setting the torque to 1 in-lb per child, with a maximum of 8 in-lb (for example, a 2-year-old would have pins torqued to 2 in-lbs) [33]. However, many children undergoing halo placement in our practices often have abnormal bone anatomy or abnormal metabolism resulting in osteopenia or osteomalacia. For these patients and those under five years of age, it is our preferred technique to apply finger-tightened torque for better tactile feedback in the thinnest of skulls and verify at least 1.5 in-lbs with the torque driver. Care is taken to slowly increase torque on each pin thereafter, especially if the halo will be used for traction, but we often stop short of the 1in-lb per year recommendation in these children. A head CT can be considered before pin placement to confirm suture closure in very young children and skull thickness in those with abnormal osseous anatomy, including from prior skull surgery.

The step-by-step consideration of halo ring placement is as follows (**Video link**):

1) Materials needed: Halo ring, minimum 6 pins (the shortest that will fit the head-halo ring length), and an equivalent number of locking nuts, a torque-limiting wrench for the pins, hex and allen wrenches for the locking nut, head support board, povidone-iodine solution, or bacitracin ointment, local anesthetic of choice, and corresponding needle/syringe.

Figure 7. Young patient with poor bone, with closed-ring halo with 10-pins applied to spread out force.

2) Preplacement sizing
   a. Halo ring size. The halo ring should allow for clearance of the skull to approximately 1 cm circumferentially along the equator. In very young patients in which >8 pins are needed, ensure that the halo ring has adequate hole sites and does not need a modification to drill in additional holes [34]. A closed ring halo offers the most rigidity and hole options, though a posterior open ring may be easier to apply and improve access for occipitocervical surgical exposure.
   b. Halo vest. If a halo vest is required, perform a fit trial with an orthotist before halo application, which can allow vest modifications or construction of a custom vest if needed for smaller, especially kyphotic or younger patients.
3) Anesthesia: Although halo rings can be placed awake, we prefer general anesthesia in children. Local anesthesia can be infiltrated around each pin site before or after application.
4) Positioning: The patient is positioned supine on the table. A head support board can be placed under the shoulders and head such that the patient's head rests above the edge of the bed. This facilitates working around the posterior aspect of the head, especially with a closed ring. A minimum of two people are needed to optimize ring and pin placement, generally one to hold the ring stable and the other to place pins. In cases of cervical instability or trauma, a third assistant is needed to maintain the head position.
5) Ring placement and temporary positioning: The appropriately sized templated ring is placed along the head, at or just below the equator, with <1 cm space from the head to the ring circumferentially. The ring should be slightly above the pinna of the ears to avoid skin contact. Once the appropriate placement is held, temporary position pin blocks can be placed directly anterior and lateral through the halo ring to loosely hold the position of the ring on the head. Care must be taken not to cross-thread the soft carbon fiber holes with these pins, rendering them useless for attachment to a surgical bed or vest.
6) Pin placement: Pin sites are prepped. Ideally, pins are placed perpendicular to the skull when possible. Hair removal is not necessary. Pins are provisionally placed along the anterolateral and posterolateral skulls bilaterally. We start with 4 pins, placed equidistant from each other until each is touching the skin. Then, we tighten the pins two at a time diagonally to each other. We finger-tighten all four screws, tighten them to the appropriate torque, then more hands are freed to add 2–6 more pins around the ring depending on the patient's skull thickness and bone quality. Care must also be taken to avoid other medical devices, including ventriculoperitoneal shunt tubing.
7) Pin torque: A torque-limiting driver is set at the appropriate torque as above. Locking nuts are placed and tightened with a hex wrench while using an Allen wrench to hold the pin still as a counter-torque and prevent driving the pin in further while tightening the bolt.

Halo-gravity traction application

If using a halo for HGT, placing the initial traction and weight can be done after the patient awakes from anesthesia, which allows for an awake neurologic examination. Alternatively, traction can start while under anesthesia and be monitored via intraoperative neuromonitoring. The cervical spine should be maintained in neutral alignment while the inline traction is applied, which may require a bolster under the mattress or under the patient's shoulders and neck. A reference for new centers on how to modify a bed, walker, and wheelchair for an HGT program is available through JPOSNA [35]. Traction set-up is often specific to an institution with many viable options and is not repeated within this paper. Initial traction weight in bed ranges from 5 to 10 lbs, 2 lbs greater in the wheelchair, and 2 lbs further in the walker. While there is variability in goal traction weight, most surgeons agree that the goal weight is approximately 50% body weight in a wheelchair [11], reached over 2 weeks by adding 1–3 lbs of weight, 1–2 times daily, though the actual weight advancement protocol varies by center. Clinically, the goal has been met when the patient becomes "antigravity" in wheelchair and walker traction and can suspend themselves. We normally stay at 10% body weight in bed. The addition of weight is followed by a detailed neurologic examination 30 min later, with the removal of weights with any neurologic change. We expect 12–16 h per day of out-of-bed activities; some may prefer sleeping upright in the wheelchair, which provides more effective traction for longer duration. Weekly cervical and spine radiographs are obtained in traction to monitor progress and to assess cervical spine stability. We routinely plan for 4 weeks of HGT (shorter for cervical deformities), with extension to 6 weeks for particularly stiff or large thoracolumbar deformities. Traction is typically maintained as an inpatient for the duration of treatment, though home traction has been described in appropriate situations in patients with less concern for neurologic risk and with reliable families [8].

Complications

While halo rings can be placed and maintained safely, risks exist. Screw placement itself may cause complications: placement of anterior pins above the medial third of the eyebrow can injure the supraorbital nerve; placement of anterior pins lateral to the edge of the eyebrow can enter the temporal muscle causing irritation with jaw movement or injure the temporal artery. Low placement of posterolateral pins can enter the mastoid air cells. Pins that are tightened beyond appropriate for age or skull thickness can result in fracture, as can a fall or trauma while wearing a halo (Fig. 8 A + B). The authors' practice is to obtain a CT of the skull of any patient whose pins appear to have moved, often easier to tell by pins that have moved away from the skull and skin to signify that the opposite pins may have penetrated through the skull. Pins that have penetrated are removed under sedation, and the ring is re-tightened with other pin sites used as available. Evidence of cerebrospinal fluid (CSF) leak from a penetrated pin site is treated with a stitch at the skin site and repeat CT scans the next day to detect the presence of intracranial bleeding. Care must also be taken to avoid other medical devices, including ventriculoperitoneal shunt tubing.

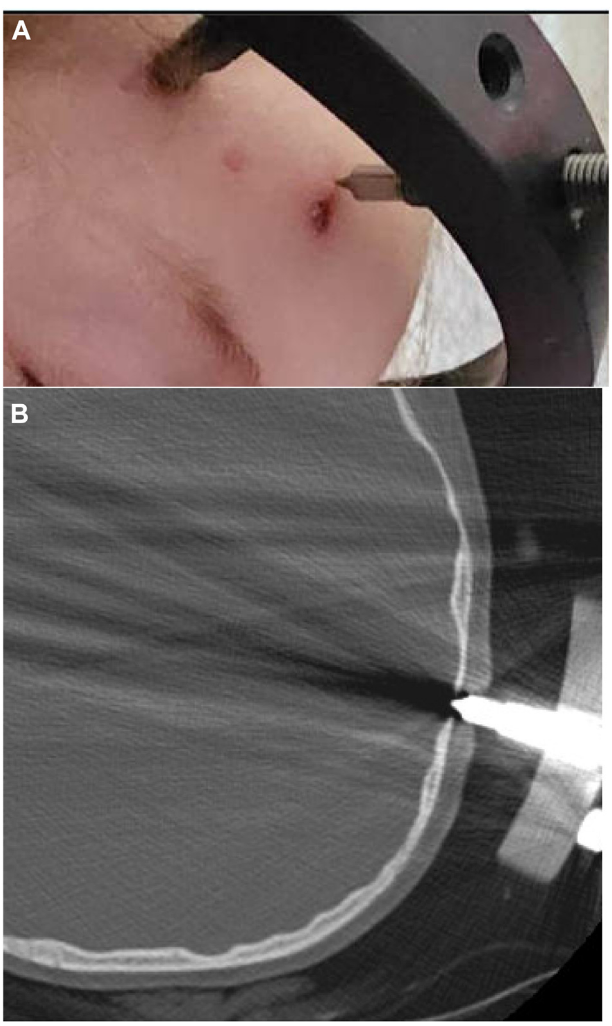

Figure 8. (A) Family sent a photo of a child in a halo vest who had fallen off a bed while jumping on it. A screw appeared to come loose and to have backed out. (B) A CT scan was obtained to evaluate the pins that demonstrated potential penetration of one screw opposite the backed-out screw. CT, computed tomography.

The longer-term use of a halo in the setting of preoperative traction or postoperative halo vest leads to further risks. The most common complication is a pin site infection or loosening, occurring in up to 33% [9,10,18,36–42]. Our standard pin site care is twice daily saline cleansing, increased to dilute hydrogen peroxide for 1–3 days if redness or minor drainage occurs. We add oral antibiotics if pin irritation persists past, and pin removal with or without replacement is performed if that treatment fails (Fig. 9). The revision rate for the halo during the duration of traction is reported up to 8% and has some association with length traction or falls [9,39,41].

While a patient is in HGT, cranial nerve palsies occur up to 10%, a sixth cranial nerve (CN) palsy is suspected with new-onset strabismus, but several others have also been observed, including tongue deviation, altered swallowing, and voice change [43–45]. More extensive cord injury and brachial plexus palsies have also been reported [18,46,47]. Providers should regularly examine for signs of CN palsies, weakness, or numbness in any extremity, and signs of myelopathy, including increased

Figure 9. Early pin site infection with crusting from drainage at pin sites. At this stage, the authors would start treatment with dilute hydrogen peroxide skin cleaning.

reflexes from baseline, altered balance, or bowel or bladder changes. When encountered, our practice is to remove weight until several pounds less than when the neurologic change first occurred and wait for resolution. If there is no improvement in the first 12 h or if there is a more severe deficit, all weight is removed.

Although preoperative HGT aims to reduce the operative risk at the next-stage spine fusion, some studies show an increased risk of neurologic complication in surgery for those who had long preoperative HGT [48] which can lead to reduced bone mineral density [49]. There have also been reports of middle- and long-term complications after HGT is completed. At five-year follow-up of patients placed into HGT before a thoracolumbar surgery, one study found a 53% rate of cervical spine degenerative changes, avascular necrosis, spontaneous fusion, and loss of range of motion; this was much higher in those over 15 years old [50]. At least one report also highlights the risk of instability and resultant deformity of the cervical spine after HGT in those with connective tissue disease [45].

Conclusion

Halo rings have many applications in pediatric spine treatment, and all treating surgeons should have good familiarity with safe application and use. They should be considered when facing the most challenging deformities, challenging patient pathophysiology, and when maximal postoperative stability is needed. While complications occur frequently, most are minor and will be resolved with troubleshooting techniques. Still, vigilance should be taken while patients are in a halo.

Consent for publication

The authors declare that informed patient consent was not provided for the following reason: This does not qualify as needing informed consent. Images are non-identifiable. No patient PHI included.

Author contributions

Jennifer M. Bauer: Conceptualization, Methodology, Project administration, Resources, Writing – original draft, Writing – review & editing. **Scott Yang:** Conceptualization, Writing – original draft, Writing – review & editing. **Burt Yaszay:** Conceptualization, Writing – original draft, Writing – review & editing. **W.G. Stuart Mackenzie:** Conceptualization, Writing – original draft, Writing – review & editing.

Funding

None.

Declaration of competing interests

The authors declare the following financial interests/personal relationships which may be considered as potential competing interests: Jennifer M. Bauer, MD MS reports a relationship with Orthopediatrics that includes: consulting or advisory. Jennifer M. Bauer, MD MS reports a relationship with DePuy Synthes Spine Inc that includes: consulting or advisory. Jennifer M. Bauer, MD MS reports a relationship with Proprio Inc that includes: consulting or advisory. W.G. Stuart Mackenzie, MD reports a relationship with DePuy Synthes Spine Inc that includes: consulting or advisory. Jennifer M. Bauer, MD MS reports a relationship with Globus Medical Inc that includes: consulting or advisory. Burt Yaszay reports a relationship with Stryker Spine that includes: consulting or advisory. Burt Yaszay reports a relationship with DePuy Synthes Spine Inc that includes: consulting or advisory. Burt Yaszay reports a relationship with Pacira BioSciences Inc that includes: consulting or advisory. Burt Yaszay reports a relationship with Medtronic that includes: consulting or advisory. Burt Yaszay reports a relationship with Biogen that includes: consulting or advisory. Burt Yaszay reports a relationship with Nuvasive that includes: consulting or advisory. Burt Yaszay reports a relationship with Bioventus LLC that includes: consulting or advisory. -Burt Yaszay, royalties - Stryker, Nuvasive, Orthopediatrics, Globus -Jennifer Bauer - editor for JPOSNA If there are other authors, they declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.jposna.2024.100129.

View the video(s) on POSNAcademy here: http://www.kaltura.com/tiny/2tlwc

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