Pediatric Cervical Spine Instrumentation

from the Cervical Spine Interest Group of the Pediatric Spine Study Group (PSSG)

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Abstract: Pediatric cervical spine fixation can be challenging to place as it must accommodate small and often abnormal anatomy. However, multiple safe options exist, and the purpose of this review is to highlight their use for pediatric orthopaedic surgeons. Halo-vest orthosis is a useful adjuvant technique to modern rigid implants. Occipital plates, C1 lateral mass screws, multiple C2 trajectories, and subaxial lateral mass screws all have proven efficacy in young children. Anterior approach for decompression and anterior column support is possible, with creative implant and graft solutions in the smallest children. While complications are reported, modern rigid implants can be used safely in pediatric spine with careful preoperative anatomic understanding and planning.

Key Concepts:

- The pediatric cervical spine presents uniquely challenging surgical anatomy, especially in the setting of instability, deformity, and pathology that indicate need for fusion.
- Several safe options exist for occipitocervical fixation in children.
- Preoperative 3D anatomic understanding is critical for success.

Introduction

As modern spinal instrumentation has evolved, so too has its use in the pediatric cervical spine. In children, surgical indications commonly involve anomalous anatomy inherent to the congenital, genetic, or syndromic diagnoses that cause the presenting cervical issue. Even in those without these abnormalities, such as traumatic injuries, the markedly smaller anatomy, decreased bony surface area, and weaker bone purchase in younger children can make instrumenting and fusing the pediatric cervical spine a challenge.

Early instrumentation techniques relied on sublaminar wiring and structural bone graft,[1,2] and halo immobilization; these remain a viable option. However, when anatomy allows, rigid internal fixation should be used to increase biomechanical stabilization,[3] improving the rate of fusion up to 16%, and decreasing complication rates by as much as 39%.[4,5] Multiple safe instrumentation options for rigid internal fixation exist at each occipitocervical level for most pediatric patients. Here we aim to review the important anatomy for the pediatric cervical

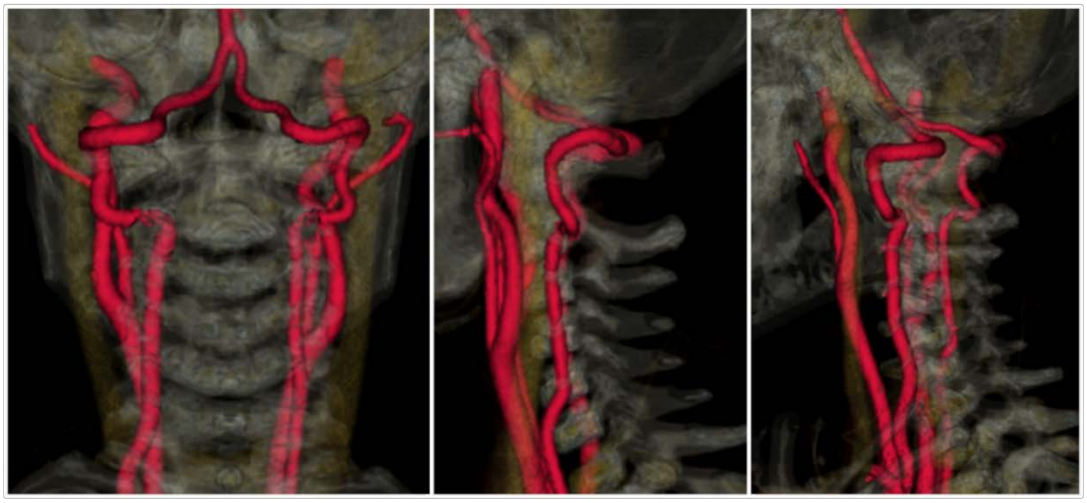

***Figure 1**. Posterior coronal, sagittal, and oblique cervical spine CT angiogram (CTA) images in a 6 year old showing a normal path of the vertebral artery.*

spine, current instrumentation options and techniques, including occipital, C1, C2, subaxial, and anterior fixation. We aim to balance the benefits of these techniques with a discussion on possible complications and how to avoid them.

Anatomy

There are important anatomic considerations when planning surgical instrumentation. Understanding a patient's vertebral artery anatomy is critical to safe fixation. The most common vertebral artery path is entry into the lateral foramen at C6, ascension along a straight vertical path through each foramen through C1, medial travel along the superior edge of the C1 posterior ring before turning proximally to ascend into the foramen magnum to become the basilar artery (Figure 1). The vertebral artery sits anterior to the exiting spinal nerve roots. Anomalous vertebral artery paths can make screw corridors that are already small in pediatric patients no longer safely possible. A common variant is foraminal entry at a level other than C6, most commonly C5, and a medial positioned foramen within the vertebral body which could preclude anterior fixation. The course at C2 is most important to understand, as a high-riding vertebral artery curvature at C2 foramen exit, found in 12-15% of normal children and up to 50% of those with instability,[6-8] can obscure a C2 pedicle or C1-2 transarticular screw path (Figure 2). Other anomalous vertebral artery anatomy, including a persistent first segmental artery, fenestration, or redundant

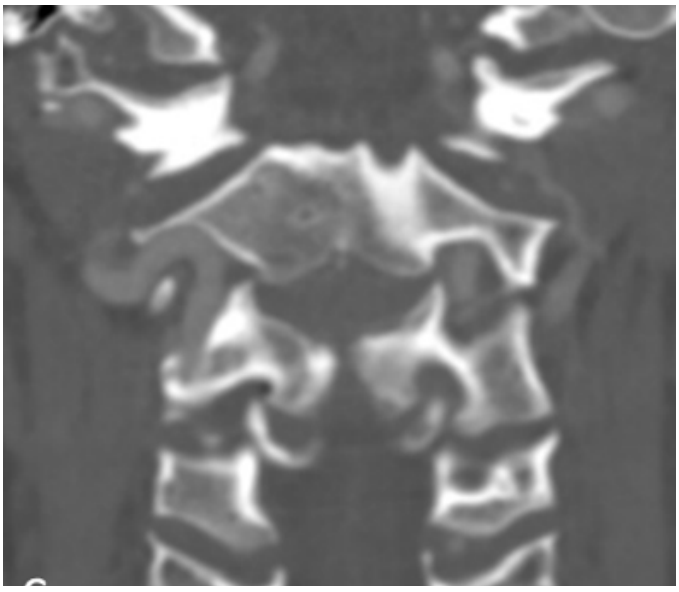

***Figure 2.** Coronal CTA demonstrating right side high-tracking vertebral artery at C2, this anatomic variant will limit the safe placement of a transarticular C1-2 screw and pedicle screw.*

loops, are similarly found at a higher rate in those with bony abnormalities such as occipitalized C1, os odontoideum, and basilar invagination.[9-11]

In addition to safe vertebral artery position, bony anatomy will ultimately determine where to place rigid instrumentation. In the past, there was concern that instrumenting the pediatric cervical spine may stunt the growth of the canal, but studies demonstrate that by 5 years of age, over 75% of adult pedicle dimensions are achieved, with continued pedicle width growth occurring

laterally and increased pedicle axis length occurring from the contribution of the growing vertebral body.[12-14] Despite smaller-sized and thinner bones, up to 95% of those as young as 2 years of age have bony anatomy feasible for screw, rod, and plate fixation from occiput to C7.[12,14-16] Even so, severe congenital bony abnormalities can be individually unique and not match any of the prior studies' feasibility findings. Three-dimensional imaging will allow a surgeon to understand these vascular and bony differences and proceed to safely place rigid internal fixation.

Instrumentation

Halo Placement

The use of a halo crown and vest in children with cervical spine disorders remains an important tool even in the face of modern screw-rod constructs.[17-19] The anatomical size of the patient, the strength of the bone, the compliance of the patient, and the risk of implant failure are all factors in consideration of halo use. Preoperative halo-gravity for deformity correction has been described in multiple series, including for cervical spine disorders in children.[20] Halo use is associated with a moderate complication rate; however, most of these complications are related to pin tract infections which are easily treated with oral antibiotics. More serious complications include loss of pin fixation requiring revision in the operating room as well as neurologic complications during traction which almost always resolve with alteration in weight.[20-21]

Paramount to success of halo use is proper application of the halo crown. The pediatric skull has varied stages of ossification and moderate variability in osteology requiring careful thought processes and planning with respect to pin application.[22] Variation in pin strength is related to the type of pin used, the thickness of the skull, torque applied during application, as well as the angle of pin insertion.[23-24] Correct placement of a halo ring is performed by sizing the ring, placing the ring in an appropriate position, as well as applying the correct number of pins at an appropriate torque and location. In general, we prefer rings that have an open back as these allow for ease of access to the occiput during surgery (Figure 3). Elevating the head above the shoulders with a pad directly above the occiput will allow the halo ring to be centered in the front-back direction, while the crown should be 1cm above the pinna of the ear. Anteriorly, the ring needs to be 1cm above the eyebrow with the eyelids closed during application. The optimal anterior pin placement remains 1cm above the brow in the outer two-thirds region above the orbit. Optimally, posterior pins should be placed 180 degrees opposite of the anterior pins.

Figure 3. *Clinical photo during halo application demonstrating a centered ring with an open back. Note the patient's head slightly elevated on towels as well as temporary noninvasive pins to keep ring centered during pin insertion (Copyright Children's Orthopedic Surgery Foundation Boston).*

As a general rule, CT scanning of the skull is needed in children less than two years of age to assess suture lines as well as any children with skull defects or palpable abnormal anatomy. In the pediatric population, special attention should be made to children with ventriculoperitoneal shunts in order to avoid pin penetration into the

shunt. The number of pins placed vary by age but in general should be 8 to 10 pins at finger tightness in children less than age 4, six to eight pins in children less than age 8 at 4-6 in-lbs. torque, and 4-6 pins in children older than age 8 at 6-8 in-lbs. torque. Rings may be centered and then held in place by temporary noninvasive pins. Placement of the first four pins can be done to optimize fixation, taking care to apply the anterior-lateral pins perpendicular to the skull which increases strength. Application of torque to the pins depends on the age of the patient. In younger children less than age 4 making a small incision after local anesthetic will allow the pin to engage the bone interface directly, and these should be placed to hand-tightness (Figure 4). The torque wrenches may be used in older children with the torque limiting function applied depending on the age of the patient per the guidelines above. Vest application is done in a manner taking care to size the vest accordingly in order to avoid large vests which become less stable or smaller vests that can cause skin irritation, breathing difficulty, or gastrointestinal dysfunction.

Figure 4*. Clinical photo during pin placement. In younger children, making a small skin incision helps engagement to be at bone pin-interface rather than including the skin. Note the pin being placed directly at a right angle to the skull which optimizes strength (Copyright Children's Orthopedic Surgery Foundation Boston).*

Occipital Fixation

Although the anatomy and thickness of the occiput have historically been a concern with modern occipital fixation in pediatric patients, the external occipital protuberance (EOP) is an ideal external landmark on the skull as it presents the thickest area of the occipital bone[25-26] The midline keel inferior to the EOP has been demonstrated to have adequate thickness for screw fixation in patients as young as 2 years of age.[27] Patients as young as 15-18 months have been reported to have safe occipital screw fixation,[28-29] but CT scan prior to surgery should assess the thickness and location of the keel and evaluate for any congenital anomalies.[30] Bicortical screw placement between the superior and inferior nuchal lines is superior to unicortical placement from a biomechanical standpoint even though the majority of pullout strength is from the outer table,[31] although this carries potential complications including durotomy, cerebrospinal fluid (CSF) leakage, dural venous sinus injury, and intracranial hemorrhage.[32] Bleeding and/or CSF leakage, if not extensive, can be potentially ameliorated with screw placement or bone wax to occlude the hole.[31,32] Placement of screws above the EOP is strongly discouraged as there is a confluence of large venous sinuses in this region, and inadvertent penetration could cause severe hemorrhage that is difficult to control.[31]

The authors typically prefer to utilize modern screw and plate techniques for OC fusion rather than wiring, which has been shown to provide more rigid fixation with lower complications and excellent fusion rates (90-99.5%) even in those under 5 years of age, often obviating the need for postoperative halo immobilization.[5,33-35] To place an occipital plate, patients are generally placed in either a halo or Mayfield tongs to maintain the skull in a neutral position during surgery. Confirmation of head position and neutral alignment with visual inspection and confirmation with biplanar fluoroscopy is critical for proper alignment to avoid excessive head flexion/extension and head rotation.[36] As described by Cohen et al.,[31] the incision is performed starting just above the EOP with full-thickness flaps to allow for adequate soft tissue coverage over the plate at the conclusion of the procedure. Plate choice should be determined based on maximizing the number of screws placed in the midline. The surgeon should have a goal of at least two midline screws placed, with one to two additional screws placed if skull size permits. Occasional contouring of the plate and burring of skull ridges may be required to minimize implant prominence. With the plate placed just below

the EOP, a pilot hole is created with a high-speed burr. This is followed by a hand or power drill, typically with a stop drill guide to avoid over-penetration (Figure 5). Drilling is performed to 6mm initially and then in 2mm increments. The hole is carefully probed after each stoppage point to assess for penetration of the inner table. Each hole should be tapped as the occipital screws cannot be self-tapping screws, the former screws have a blunt tip to minimize the risk of dural injury. Screw lengths typically range from 6 to 10mm.

It is strongly recommended to properly contour the rods to allow for minimal tension when placed into the occipital plate to minimize the chance for failure of the small occipital plate set screw.[31,36] Pre-contoured or articulated rods are available as well which can help avoid notching and possible early rod failure. The authors will then typically place autograft (rib or iliac crest) extending from the C2 spinous process to the decorticated portion of the exposed occiput caudal to the plate.[31] The use and type of cervical immobilization following OC fusions are based on bone quality, screw purchase, patient behavioral compliance factors, and surgeon preference.

When the osseous structures are too small and/or congenitally malformed to accommodate screw fixation, alternative means of fixation are possible. Wire-loop constructs can be passed through burr holes 2cm above the foramen magnum and 2cm lateral to midline and then through the foramen magnum or through an additional burr hole on either side.[37] In rare cases with no ability to achieve standard occipital fixation, occipital condylar screws may be used.[36]

Atlanto-Axial (C1 and C2) Fixation

Strategies for surgical fixation in the pediatric atlantoaxial region may require using different screw trajectory pathways on either side or even a unilateral construct. Multiple backup plans, even including halo placement, should be ready if planned screw locations fail or fixation is inadequate. In certain circumstances, a unilateral construct may be required. In a patient with highly unstable and unfavorable anatomy, a unilateral construct with good screw purchase is likely a better choice than a bilateral construct that offers fair to poor screw purchase (Figure 6).[38] As previously discussed, preoperative evaluation of 3D imaging is critical.

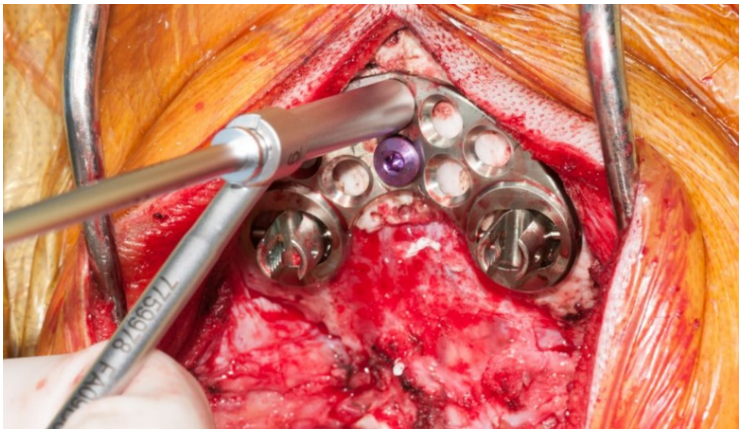

Figure 5. *Hand drilling for this occipital plate (placed just inferior to the EOP) is performed with a 6mm stop drill guide and using midline screws. (Copyright Children's Orthopedic Surgery Foundation Boston)*

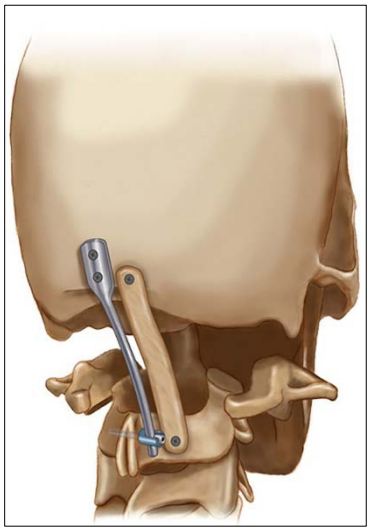

Figure 6*. Illustration of a posterior construct that uses a C2 translaminar screw to anchor to the occipital device for a unilateral craniocervical construct. (Copyright Department of Neurosurgery, University of Utah.)*

C1 Lateral Mass Screw Placement

The Goel-Harms construct (C1 lateral mass screws coupled to C2 pars screws) is a popular option for atlantoaxial fixation (Figure 7). A safe C1 lateral mass screw trajectory can usually be identified in children, but screw placement is made more challenging by the presence of the venous plexus near the area of entry. As a result, some surgeons routinely resect the C2 nerve root during the C1 lateral mass dissection which has been shown to

be safe and effective.[39] Once the inferior portion of the lateral C1 arch is drilled away and the inferior lateral mass is identified, there are two choices for an entry and trajectory: 1) enter in the midline of the lateral mass and aim approximately 5 degrees medial, or 2) enter 2–3mm medial to the midline of the lateral mass and aim straight. On lateral fluoroscopy, the target should be the just above the midline of the anterior C1 ring. In order to avoid placing screw threads in the vicinity of the C1 venous plexus, most surgeons choose to place a partially threaded or lag screw in the lateral mass of C1. That way, the top-loading portion of the screw rides well above the entry point and will make the placement of the connecting rod to C2 a simple matter.

C2 Pars Interarticularis Fixation

Screw placement into the C2 pars is typically very straightforward, making it the preferred method for C2 fixation by many surgeons (Figure 8). The entry point of the pilot hole is at the midpoint of the C2-3 facet joint and is aimed slightly superiorly into the thickest part of the pars which is typically slightly medial (2–5 degrees). All drilling should be done under fluoroscopic guidance, with an instrument placed on the dorsal aspect of the pars for reference. Stopping short of the vertebral artery canal is extremely important, but in most cases, the amount of screw purchase obtained is surprising and allows for excellent fixation.

C2 Pedicle Screw Fixation

A screw placed into the C2 pedicle has some biomechanical advantages in that it is slightly stronger than a C2 pars screw, but it is also more difficult to place. The landmarks for C2 pedicle screw placement are not straightforward; therefore, the surgeon should consider using intraoperative CT navigation for assistance. The entry point is superior and lateral to the C2 pars screw entry point, and the trajectory is superior and medial. Given such challenges, unless one is well-versed in placing them, C2 pedicle screws are not routinely used in most pediatric spine centers (Figure 9).

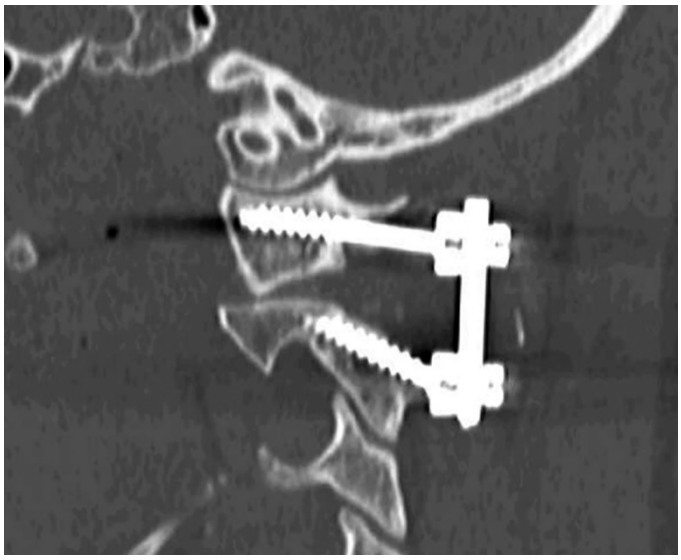

Figure 7. *Sagittal CT scan of a Goel-Harms atlantoaxial construct showing the placement of a partially threaded C1 lateral mass screw and a fully threaded C2 pars interarticularis screw.*

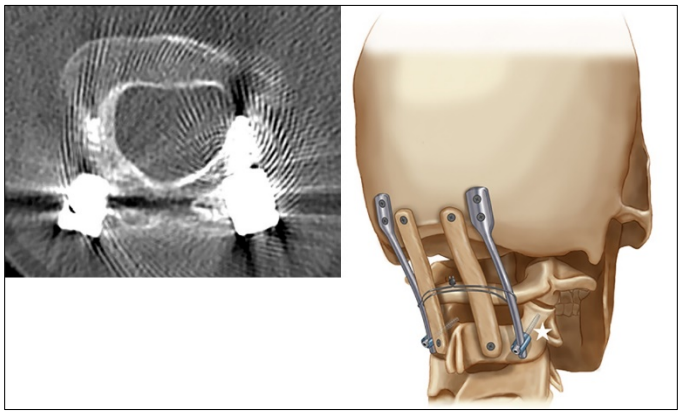

Figure 8. *(Left) Axial CT image showing the placement of bilateral C2 pars interarticularis screws. (Right) Illustration of a craniocervical construct using bilateral C2 pars interarticularis screws, with the star pointing out the typical location for screw placement. (Copyright Department of Neurosurgery, University of Utah.)*

C2 Translaminar Screw Placement

Since its initial description in 2004 by Wright et al.,[40] C2 translaminar screws have become a popular method of cervical fixation (Figure 10). Close inspection of the preoperative CT scan allows a surgeon to determine whether use of a translaminar screw is feasible. Because of their unique trajectory, translaminar screws are typically placed freehand, without fluoroscopic guidance.

A small dental dissector can be placed under the lamina of C2 to determine if a bone-breach into the canal occurs. If bilateral translaminar screws are placed, the surgeon needs to "stack" the screws one above the other to have enough room for purchase.

One potential downfall of C2 translaminar screws is the tendency for the top-loading portion of the screw to block a considerable amount of bone on the C2 lamina, thus limiting the amount of C2 bony surface area available for fusion. Another is the relative lack of biomechanical strength if an intraoperative atlantoaxial or craniocervical reduction is needed. However, a C2 translaminar screw is a good fallback option if no other options are available.[28]

C1-2 Transarticular Screw

To place a C1-2 transarticular screw, it is mandatory to preoperatively review multiplanar CT reconstructions of the patient's anatomy. The surgeon begins by looking at the parasagittal reconstructions, with screw trajectories based on the size and orientation of the C2 pars. There has to be adequate space for a screw in the C2 pars and sufficient C1 lateral mass to capture at the distal end. The entry is selected close to the C2-3 joint on each side. The site of origin has been described as "3mm superior to the C2-3 facet joint line and 3mm lateral to the lamina lateral mass junction."[30] Once the entry points are selected, an axial reconstruction is reviewed to determine the medial-lateral angle of the screw trajectory, typically 2–5 degrees medial. Next, a slightly off-parasagittal axis reconstruction is re-reviewed to assure the screw remains within bone for its entire course. For completeness, and to assure the best possible trajectory, the trajectory origin can be moved a small increment lateral or medial and the process above repeated. The best trajectory is then selected. The screw should pass through the C2 pars interarticularis, the C1-2 joint space, and the lateral mass of C1 (Figure 11). The target location for the screw tip is at the anterior tubercle of C1 while visualized intraoperatively with fluoroscopy.

Figure 9*. This postoperative CT of bilateral C2 pedicle screws underscores the potential anatomic challenge of placing these screws in pedicles that may be only the same width as the screw.*

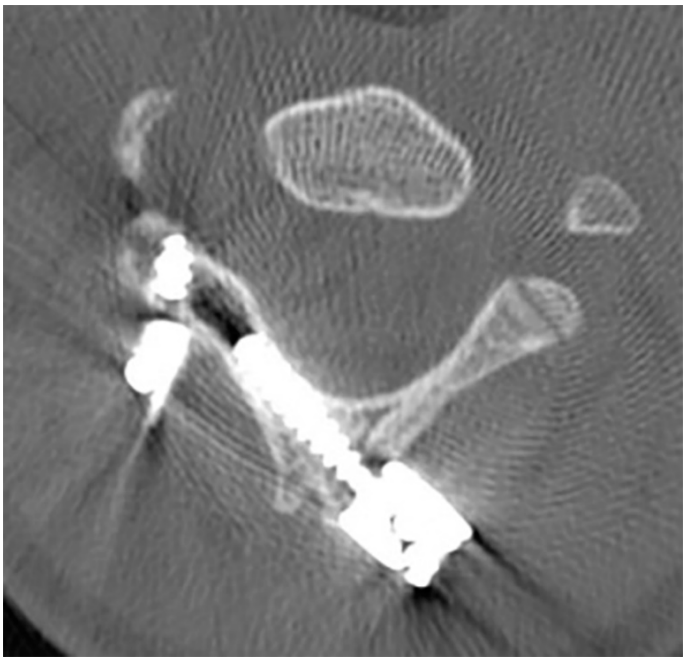

Figure 10. *Axial CT image showing placement of a C2 translaminar screw.*

Subaxial Posterior Fixation

Lateral mass screw fixation is the most common anchor utilized in the adult subaxial cervical spine and has been extended into the pediatric population.[28,32,41] Al-Shamy et al. evaluated CT scans of 70 pediatric patients and found all patients 4 years and older were able to accommodate a 3.5mm lateral mass screw[42] (Figure 12). As previously discussed at other levels, sublaminar fixation can be an option here as well, including in conjunction with lateral mass screws for augmented fixation, though instrumentation failure and fusion rates are not as favorable.[43]

The authors prefer lateral mass screw placement using the Magerl technique. This is performed by creating a pilot hole 1mm caudal and medial to the center of the lateral mass. A drill is then angled approximately 20 degrees lateral and 20 degrees rostral to avoid injury to the vertebral artery and nerve root (Figure 13). Violation of the facet joint should be avoided to minimize adjacent level changes.[32] Al-Shamy demonstrated that placement of a lateral mass screw in C7 is possible in pediatric patients.[42] However, consideration can be given to placement of a C7 pedicle or translaminar screw if the C7 lateral mass is thin and/or has a steep trajectory.[44] Liu et al. demonstrated that >85% of C7 pedicles and C7 laminas in CT scans of 92 patients as young as three years of age would accommodate a 3.5mm diameter screw.[45]

Anterior Fixation

Anterior cervical arthrodesis is less commonly performed when compared to the posterior approach in the pediatric population.[46] In the young patient, the small vertebral body size and the lack of appropriately sized cervical plates and screws limit its routine use. Since the anterior approach is not routinely performed in the pediatric setting, it may be necessary to have some surgical assistance from ENT or an adult spine colleague for the exposure depending on one's comfort with the anatomy of the anterior neck.

The most common indications for anterior cervical arthrodesis include trauma, cervical sagittal plane deformity, especially from tumor, infection, and herniation in the subaxial spine. Anterior column failure or neurologic injury from anterior compression caused by trauma or extensive infection or tumor necessitates anterior decompression and stabilization (Figure 14).

Figure 11. *Lateral cervical spine x-ray showing placement of C1-2 transarticular screws, along with posterior allograft and sublaminar cable arthrodesis.*

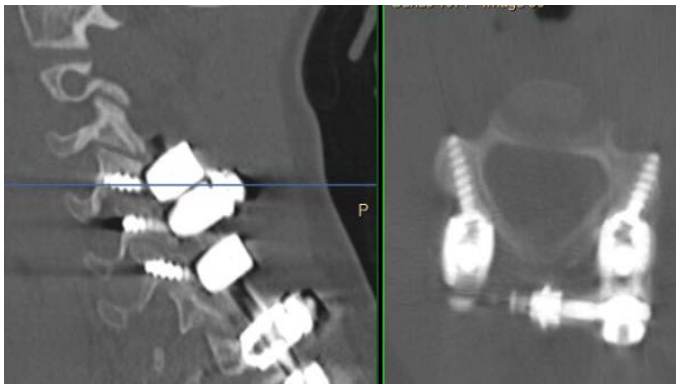

Figure 12. *A 6-year-old treated for a tumor with a 2-level corpectomy and anterior and posterior fusion. These images highlight lateral mass screw placement at C4, C5, and C6.*

Unlike the thoracolumbar spine, where pedicle screws can provide fixation across all three spinal columns, the lack of anterior and middle column control from most posterior cervical instrumentation requires adequate

structural support to maintain anterior column height. In some cases, an anterior arthrodesis may be used to supplement a posterior arthrodesis when there is risk of nonunion or risk of posterior implant failure. Disc herniations, extremely rare in the pediatric population, can be managed similarly with anterior approach, discectomy, and fusion.[47,48] In deformity, the anterior approach is most often needed for sagittal abnormalities, such as the kyphosis seen in Larsen's syndrome or neurofibromatosis.[46,49]

As mentioned above, anterior cervical procedures will require some form of interbody support and grafting to ensure a stable fusion. Performing single or multilevel discectomies or a corpectomy without support will shorten the anterior column resulting in kyphosis and narrowing of the intervertebral foramen. Historically, autologous bone graft harvested from the iliac crest, fibula, or rib was the most commonly used graft. The cortical and cancellous components of the graft provided both the structural support as well as the osteo-inductive properties for successful arthrodesis. Additionally, the abundant source and ability to custom size the graft intraoperatively made it appealing to use in most patients. Morbidity, especially donor site pain, has diminished its routine use, especially when considering the propensity for children to fuse. A recent study demonstrated success with allograft in the setting of pediatric cervical spine fusions.[50] While the cases were not limited to anterior-only procedures, the rate of fusion with allograft (88%) was equal to autograft (87%).

Stabilization for anterior cervical arthrodesis is typically performed using plates and screws. In older adolescents and teenage patients with normal size anatomy, there is an abundant selection of plates and screws that can be used in single to multilevel constructs. In smaller patients, preoperative planning and sizing are based on a CT and is critical to ensure the appropriate availability at the time of surgery. In toddlers or younger patients, creative solutions have been reported, including the use of craniofacial or hand miniplates[51,52] (Figure 15). In some cases, the use of anterior cervical instrumentation is not always required. A well-fitting and secure anterior interbody graft can be adequately supported by posterior instrumentation. While not reported in the pediatric literature, the adult literature has even demonstrated success with stand-alone interbody cages.[53] The main concern with stand-alone anterior procedure is the risk of graft subsidence and loss of cervical lordosis. In cases where there is concern about the fixation, rigid external immobilization, including a halo vest, should be considered to ensure success of the procedure.

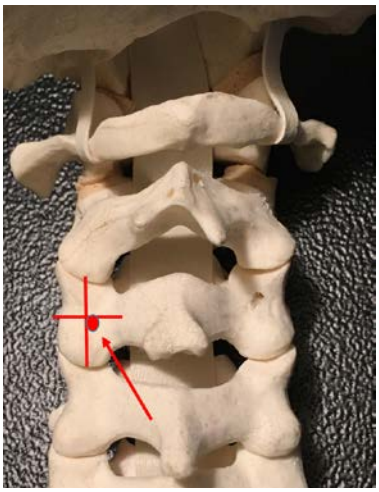

Figure 13. *Red dot showing lateral mass entry point, red arrow with trajectory of screw.*

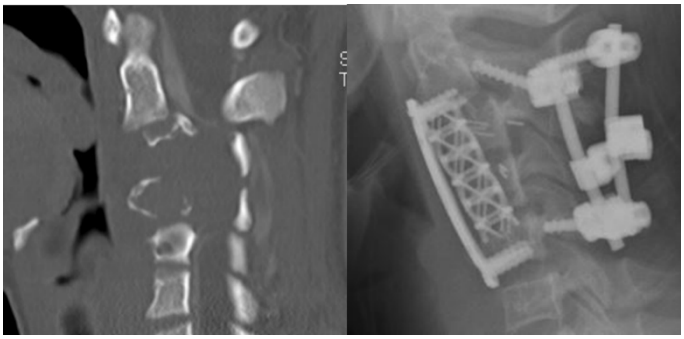

Figure 14. *A 12-year-old patient with a schwannoma underwent anterior tumor resection with anterior column interbody cage support with plate fixation in addition to posterior fixation.*

Complications

The use of cervical spine instrumentation is associated with a low rate of complications; however, given the challenging anatomical nature of the surgery, the potential for significant morbidity exists. Neurophysiologic monitoring is paramount and includes transcranial motor

evoked potentials, somatosensory evoked potentials, and EMGs.[54] The rate of neurologic deficit after surgery for cervical deformity is low and usually related to preoperative dysfunction.[55] As such, pre- and post-positioning monitoring is critical for patients with known preoperative deficits, instability, or significant stenosis. Perioperative deficits may be expected to improve over time in the absence of cord compression or screw malposition. The use of a halo vest for turning the patient prone can be an important factor for avoiding any positioning complications which can lead to neurologic dysfunction in the case of instability, as can the use or preoperative traction to obtain gradual correction of cervical deformities prior to correction.[55]

Specific intraoperative implant complications may be avoided by understanding the anatomy of the vertebral artery. Obtaining 3D imaging to understand the relationship of the vertebral artery to the bony elements is critical to understanding screw fixation at all levels but specifically at C2 as mentioned above. This is because of C2's importance to most children's construct stability, as well as the proximity of the artery to the isthmus of C2. True vascular studies may be considered in patients with significant connective tissue disorders and cervical instability/deformity such as Loeys-Dietz or Marfan syndromes.

Loss of fixation or implant dislodgement is a rare complication and can be avoided by understanding the preoperative anatomy as well as the limitations of fixation due to the child's size and age. Use of intraoperative 3D imaging after screw placement in the operating room can help avoid postoperative complications by confirming correct implant placement prior to leaving the operating room[56] (Figure 16). Noninvasive halo use as well as custom orthoses also have a role in the postoperative period to help prevent unwarranted stress on implants.[57]

Nonunion after attempted cervical fusion is rare and almost always related to either poor biomechanical strength of constructs or underlying connective tissue disorder. Multiples studies, even with modern implants,

Figure 15. *A 2-year-old with congenital kyphosis and myelopathy was treated with one level corpectomy, structural allograft with craniofacial plate fixation, and posterior non-instrumented fusion.*

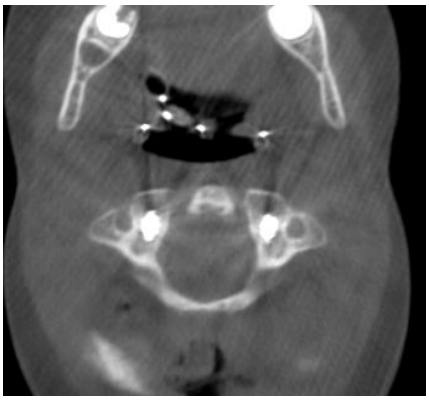

Figure 16. *Intraoperative 3D imaging confirming correct C1 screw placement in a 4 year old.*

have shown that children with trisomy 21 are at highest risk for the complication of nonunion.[58,59] The rate of nonunion may be minimized by the use of iliac crest graft at the cranial-cervical junction, the use of halo-vest in the perioperative period, as well as with the use of BMP for posterior revision surgery. The risk of nonunion in the subaxial spine is almost nonexistent given that the posterior elements are close together and the robustness of the periosteum is highly osteogenic.[18] Allograft in the subaxial spine is adequate in all cases, and care must be taken not to overexpose the spine as this alone may lead to autofusion.[50]

The risk of infection following instrumented cervical spine fusion is 2% and is highest in patients with connective tissue disorders.[60] Wound problems in these patients may be avoided by meticulous retraction, soft-

tissue handling, and consideration of a halo vest in order to avoid any shear forces on the incision related to cervical collars or noninvasive orthoses.[61]

Conclusion

The anatomy of pediatric occiput and cervical spine can present a challenge for surgical fusion, but modern rigid fixation has proven safe and effective. A number of fixation options exist, and surgeons should be comfortable applying several in order to accommodate individual anatomic differences, especially in the youngest patients. Appropriate preoperative planning and anatomic understanding are vital to avoid complications.

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