Modern Instrumentation of the Pediatric Occiput and Upper Cervical Spine

Review Article

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Abstract *Background:* Rigid screw rod techniques for cervical stabilization are widely used in adults. The benefits of rigid internal fixation include increased fusion rates, improvements in deformity correction, and diminished immobilization requirements. Applications of these techniques in children are challenging due to size constraints and the pathologic conditions encountered which require instrumented cervical fusions. Preparation as well as thorough understanding of the anatomy and surgical techniques is paramount to surgical safety in pediatric patients. *Questions/Purposes:* This review article serves as an educational tool regarding the use of modern posterior instrumentation techniques for pediatric cervical deformity. *Methods:* Expert review based on clinical expertise and literature review. *Results:* The use of rigid screw rod instrumentation for the pediatric occiput and upper cervical spine is discussed. Preoperative imaging requirements for pediatric patients undergoing cervical spine surgery are reviewed. Anatomy, morphologic studies, and surgical techniques are discussed for each area of instrumentation. *Conclusions:* Modern posterior cervical instrumentation techniques can be safely applied to the majority of pediatric patients who require an instrumented posterior cervical fusion. Patient safety revolves around thorough preoperative imaging tests, understanding of upper cervical anatomy, and meticulous surgical technique. Modern instrumentation leads to an improvement in fusion rates and a diminishment in immobilization requirements.

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Introduction

Pathologic conditions in the child's cervical spine are brought about by abnormal biologic conditions, neoplastic conditions, disordered anatomy, or prior operations. The ultimate goals of surgery for any child with a cervical spine disorder remain deformity reduction, decompression of the neural elements, stabilization, and arthrodesis. The age and size of pediatric patients makes them prone to develop cervical spine problems at the craniovertebral junction and upper cervical spine. These regions are noted to have more horizontal facets, are noted to have a greater plane of motion, and are under the influence of a relatively large cranial force than is the subaxial spine. While children remain largely an osteogenic population, the cranial cervical junction and atlanto-axial region are predisposed to pseudoarthrosis, given the larger surface area and inherent tendency toward motion. While cable or wire techniques afford some stability, they are inherently much less stable than rigid screw constructs in all planes of flexion-extension, lateral bending, and lateral rotation.

The benefits of screw fixation in the pediatric cervical spine are weighed against the challenges of placing screws in small patients with frequently disordered anatomy. Screw fixation has been shown to be effective in children and while challenging can be done with a thorough knowledge of the anatomy and with proper surgical technique. The purpose of this review is to discuss modern techniques of rigid fixation at the cranial cervical junction and atlanto-axial complex in children.

Methods

The literature used for this review was gathered from Pubmed searches and articles which have been placed in the author's own reference library regarding pediatric

cervical spine surgery. The similar literature search was performed in PubMed which would be reproducible with the search strategy including the following terms: (“Bone Screws”[Mesh] AND “Cervical Vertebrae”[Mesh]) OR cervical screw*[TW]. This search retrieved 1,322 papers which was further refined to 285 papers after applying the language (English) language and age group (childbirth 18 years) limiters. Additional search included the following terms: (“Occiput”[Mesh] AND “Instrumentation”[Mesh] AND “Anatomy”[Mesh]). The search revealed 56 English papers.

Results

Preoperative Imaging

The majority of pediatric patients requiring instrumentation and fusion will need a complete radiologic imaging including: plain radiographs, magnetic resonance imaging, and computed tomography scans. The ultimate goal of these combined imaging modalities is a clear understanding of the bony anatomy, the spinal cord and nerve roots, and the course of the vertebral artery. Magnetic resonance serves as the best way to document any neural compression or signal changes in the cord related to instability. While flexion-extension MRI is feasible, in reality it is rarely needed to document compression or instability.

Computed tomography remains the most important imaging modality to study the bony architecture and the course of the vertebral artery. CT scanning should be done with fine cut CT and done using a pediatric protocol in order to reduce the radiation dose to the patient. Three-dimensional reconstructions are useful to help clearly understand the course of the vertebral artery in relation to the isthmus of the axis, which has a significant effect on screw choice at that level. The reconstructions can also be helpful in understanding the bony abnormalities in congenital deformities. The routine use of angiography via traditional methods or with CT angiography or MR angiography has a limited role unless the patient has a neoplastic process, or has CT evidence of disordered anatomy of the vertebral artery, or in cases of significant connective tissue disorders with potential tortuous anatomy of the vertebral artery.

Occipital Fixation

Fixation to the occiput in the past has been done through either wiring via loop-rod constructs to the cranium or wiring in rib grafts to the cranium and cervical spine. Loop-rod constructs have been shown to be inferior to modern occipital plating techniques in all planes of motion when biomechanically tested [22]. There are a variety of occipital plates available commercially and all rely on screw fixation into the occiput. Anatomical studies have been done regarding the safest and thickest region of the occiput for screw placement [5, 24]. The external occipital protuberance (EOP) and the associated midline occipital keel remain the thickest area of bone for screw fixation [5, 8, 24]. Geck recently completed a tomographic analysis of the occiput and cervical spine of 50 children ages two to six in order to define anatomical suitability for screw placement [6]. In that

study, the mean thickness of the EOP varied from 8.6 to 10.3 mm and the midline occipital keel was able to accept screws in almost all cases.

The preoperative computed tomography scans need to be studied in all patients with special attention paid to the midline keel on the sagittal reformats as these cuts have the most information. We have found that clinically almost all children have anatomy suitable for screw placement and having a variety of plates available is beneficial to allow optimal screw configuration and fit (Fig. 1). Biomechanically, unicortical screws have been showed to be effective with occipital plating as the external table of the cranium offers the greatest strength for screw placement [24]. However, when at all possible, we try to place bicortical screws in all cases taking care to use a stop drill and then tapping, as most of the screws are blunt ended.

Connecting to the occipital plates is via rod systems, which then are connected to the remainder of the cervical spine via sub-occipital screws, which vary in number and location depending on the pathologic process. Hankinson recently completed a review of 70 pediatric patients treated with occipitocervical fusion for instability with rigid occipital plates and screw placement in C2 with or without C1 screw placement [9]. In that series, there was a low rate of complications and a high rate of fusion with occipital plating combined with C2 screw placement without directly instrumenting the lateral masses of C1.

Fixation to the Atlas

The majority of pediatric cervical problems arise from either cranial cervical instability or atlanto-axial instability. C1 remains a critical anatomical region for instrumentation in the pediatric spine. Traditionally, sublaminar cables have been used at C1 for fixation but the biomechanical weakness of this construct allowed for further investigation into screw fixation at C1 [19]. Fixation to C1 in the adult population using lateral mass screws has been studied and shown to be both biomechanically sound and clinically safe.

Fig. 1. Sagittal CT cut of a 10-year-old patient who has undergone occiput to C2 fusion for a congenital anomaly with instability. Note the position of the occipital screws in the thick midline region of the occiput. The arrow points at the thick midline bone just underneath the external occipital protuberance

Traditionally, C1 lateral mass screws have been attached to C2 pedicle screws, the so called “Harms” technique [11]. Clinical success using lateral mass screws in adults has led multiple authors to complete reviews of computed tomography scan in children to define anatomical feasibility. Geck studied the lateral masses of fifty children ages two to six via computed tomography scan and found that the C1 lateral mass was a reliable structure with a width of 15 to 16 mm in children even as young as two [6]. Chamoun analyzed the lateral masses of 76 children via CT and defined the medial and superior inclination of screws as being possible in 151 of the 152 lateral masses identified [3]. In that study, there was some variation of anatomy and the authors concluded preoperative CT scans were mandatory to determine the exact anatomy prior to placement of screws.

The use of C1 screws in children has been studied and shown to be feasible and safe in multiple studies [4, 16]. We currently routinely place lateral mass screw with attention paid to preoperative studies and meticulous attention to exposure of the entry point for screw placement. The correct entry point remains at the point where the C1 posterior arch meets the lateral mass. The starting point is underneath the arch and superior exposure laterally above the arch should be avoided due to the vertebral artery. The venous plexus is diffuse in the area and need to be coagulated using bipolar dissection along with exposure and mobilization of the C2 nerve root which we have not found mandatory to sacrifice although this has been described for exposure of the starting point [20]. Once adequate exposure has been done, the placement of screw needs to be done via routine drilling with a stop drill and then tapping just at the screw entry point, as occasionally the inferior aspect of where the arch meets the lateral mass of C1 is thick cortical bone (Fig. 2). The routine depth of screws in the lateral mass has been shown to be possible up to 20 mm in children [10]. We use lateral fluoroscopy to determine the length of drilling and have found that stopping short of the posterior aspect of the anterior ring outline is adequate, taking care to be lined up in the middle with regard to the cranial-caudal direction. The starting point of the screw is also well anterior to other cervical screws and thus an additional amount of length must be added so that the tulip of the screw sits proud enough to line up with a rod connected from above or below (Fig. 3).

We have not used navigation for placement of C1 lateral screws as we have found the most reliable way of placing screws safely is meticulous dissection of the lateral mass screw starting point followed by fluoroscopic guidance. Clinically, this has been shown to be a safe and effective way to place screws in children despite their small size. Desai looked at their experience with C1 screws for atlanto-axial instability and were able to place lateral mass screws in all patients without neurologic or vascular injury with resultant successful fusion in all when coupled to C2 screws [4]. While transarticular screws had become popular in pediatric patients, the current trend seems to be placement of C1 lateral mass screws in concert with C2 screws for upper cervical instability [4, 10, 16].

Fig. 2. Illustration showing the correct starting point of the C1 lateral mass entry point with a drill. Note the protection of the C2 nerve root with a retractor and the depth of the starting point

C2 Screw Fixation

Fixation to C2 via screws can either be with intralaminar screws or pars/pedicle screws. The biomechanical studies of these screws have shown greater rigidity as compared to traditional wiring techniques, and each screw presents a different set of risks. Ultimately, almost all pediatric patients will have anatomy that will allow for placement of screws into C2. Geck, in his study of morphology in pediatric patients, showed that the vast majority of children were able to accept intralaminar screws even as young as 2 years of age [6]. There was more variability in the pedicle size in the patient population suggesting that intralaminar screws in young children remain a reasonable first option for screw placement.

Fig. 3. Sagittal CT cut of a 6-year-old male who underwent C1–C2 fusion for instability associated with os odontoideum. The arrow is pointing at the C1 lateral mass. Note the starting point of the C1 lateral mass screw is inferior to the arch of C1 avoiding any potential injury to the vertebral artery. Also note the longer distance of the C1 screw so that the screw tulip can be in line with the inferior C2 pars screw

Intralaminar screws have gained popularity as they have been shown to be effective in clinical studies in adults. Lehman, in a biomechanical study, showed that intralaminar screws are superior to pars screws in cervical constructs [18]. Intralaminar screws are placed by starting on the contralateral side of the spinous process with a direct path down the lamina. The inherent risk of this technique is placing the screw through the ventral aspect of the lamina and into the spinal space. The inherent benefit is that these are biomechanically sound points of fixation in C2 that do not place the vertebral artery at risk. We have not found ventral misplacement to be a problem as a freer elevator may be placed under the lamina as a protective guide (Fig. 4). The screws are crossing and thus one must pay attention to the starting points on the spinous process with one starting point being more cranial and one being more caudal (Fig. 5).

The most rigid construct involving C2 would be with screws placed through the pedicle [18]. Screws placed through the isthmus of C2 may either be termed “pars” screws or “pedicle” screws. Pedicle screws have a starting point more cranial and lateral and while going through the C2 isthmus are directed medially inward through the pedicle and into the body of C2. The pedicle screws are bounded medially by the cord and anterolaterally by the vertebral artery. Placement of a “pars” screw is via a more inferior and medial starting point directed through the isthmus in line with the C1–C2 as would be the path of a transarticular C1–C2 screw. This trajectory needs to be studied on preoperative imaging as the vertebral artery is at risk during screw placement.

Many authors have reported on navigation techniques with C2 screw placement, which have gained interest as there have been studies revealing vertebral artery encroachment by screws in the absence of intraoperative hemorrhage [23]. We have found the greatest tool for avoiding screw malposition is meticulous dissection of the isthmus of C2, which gives a clear visualized medial-lateral orientation of

Fig. 4. Illustration showing the correct starting point and alignment for a C2 intralaminar screw. Note the freer elevator used as a guide for the ventral lamina

Fig. 5. Axial CT cut of a 5-year-old patient with skeletal dysplasia who underwent occiput to C2 fusion utilizing C2 crossed intralaminar screws

the screw [12]. The cranial-caudal orientation must be done with fluoroscopic guidance (Fig. 6). We have published our series of screw fixation in children at C2 and would agree that preoperative planning coupled with meticulous exposure leads to the safest placement of the screw [13, 15].

Our current recommendation for atlanto-axial instability is to couple C1 lateral mass screws with C2 pedicle screws if the anatomy dictates. If C2 pedicle screws are not feasible, then we place either C2 pars screws or C2 intralaminar screws. We continue to supplement our C1–C2 fusions with structural iliac crest graft, which is cabled down using titanium cables, passed under the ring of C1 and through the

Fig. 6. Lateral fluoroscopic view during drilling for a C2 pars screw. Note the appropriate cranial-caudal orientation in the lateral plane as well as the outline of the suction device that is placed on the medial isthmus for retraction

spinout process of C2 (Fig. 7). Iliac crest graft is placed in the posterolateral gutters. Fusions to the occiput are done with occipital plating coupled to C1 lateral mass screws and C2 screws. Although clinical series suggest that occipital plates coupled to C2 screws alone are adequate for fixation, we continue to try to maximize construct strength with C1 screws when feasible [9, 14].

Transarticular Screws

The earliest reports of rigid screw constructs for upper cervical instability in children were of transarticular screws [2, 21]. Brockmeyer has published a separate series using transarticular screws in young children, although even in experienced hands the risk to the vertebral artery is present [2, 7]. As with all upper cervical screw constructs, planning for transarticular screws must be made via CT analysis of the position of the vertebral artery and size of the C2 isthmus (Fig. 8). While clinical series suggest placement is feasible in most children, recent topographic studies suggest that in younger children there are significant anatomic constraints [6]. The presence of anomalous vertebral arteries occur in up to 25% of patients, and although there is some biomechanical strength to unilateral transarticular screws, the rigidity of coupled C1 and C2 screw rod constructs is sufficient [1, 17]. We have used transarticular screws for pediatric cervical fusions and published these results; however, we have favored more recent placement of C1 lateral mass screws with appropriate C2 screws [12]. Haque recently published their series of seventeen patients treated at a mean of 9 years of age with C1–C2 screw rod constructs with no vertebral artery injuries and no neurologic injuries with fusion obtained in all patients [10]. Their conclusion was in consideration

Fig. 7. Coronal CT cut of a 12-year-old boy who underwent C1–C2 screw rod construct with iliac crest cable grafting for an odontoid nonunion. Note the large horseshoe shaped iliac crest graft in between the screws secured to the ring of C1 and to the spinous process of C2

Fig. 8. Sagittal CT cut with the thin showing the high riding position of the vertebral artery and its relationship to the C2 isthmus. Transarticular screw placement is not possible with this variant of vertebral artery position. The arrow points to the starting point of a C2 pars screw

of this technique rather than transarticular screws in treatment of upper cervical instability.

Discussion

Screw placement in the upper cervical spine in children has been shown to be possible via CT studies and safe in numerous clinical studies. Even in the youngest of children requiring stabilization and arthrodesis, knowing the salient points of screw fixation and options available allow for effective rigid instrumentation. The use of preoperative computed tomography scans remains the most reliable roadmap to the anatomic differences in each patient. These studies allow for a definition of the bony anatomy required for planning of screws as well as with the vertebral artery course, which is paramount in determining the best option for screw fixation, especially on the axis. Although the earliest reports of rigid screw fixation in children were of transarticular screws, we currently recommend consideration of C1 lateral mass screws coupled with appropriate C2 screws as this helps avoid some of the inherent challenges with transarticular screws. Above all, meticulous exposure of the C1 starting point and the isthmus of C2 coupled with fluoroscopic control in the lateral views remain the most important part of placing screws successfully in the upper cervical spine. We continue to recommend autogenous iliac crest graft in fusions involving the cranial cervical junction and the C1–C2 interspace.

Disclosures

Conflict of Interest: Daniel Hedequist, MD has declared that he has no conflict of interest.

Human/Animal Rights: This article does not contain any studies with human or animal subjects performed by the any of the authors.

Informed Consent: N/A

Required Author Forms Disclosure forms provided by the authors are available with the online version of this article.

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