Fixation with C-2 laminar screws in occipitocervical or C1–2 constructs in children 5 years of age or younger: a series of 18 patients

Clinical article

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Object. There are rare indications for upper cervical spine fusion in young children. Compared with nonrigid constructs, rigid instrumentation with screw fixation increases the fusion rate and reduces the need for halo fixation. Instrumentation may be technically challenging in younger children. A number of screw placement techniques have been described. Use of C-2 translaminar screws has been shown to be anatomically feasible, even in the youngest of children. However, there are few data detailing the clinical outcome. In this study, the authors describe the clinical and radiographic follow-up of 18 children 5 years of age or younger who had at least one C-2 translaminar screw as part of an occipitocervical or C1–2 fusion construct.

Methods. A retrospective review of all children treated with instrumented occipitocervical or C1–2 fusion between July 1, 2007, and June 30, 2013, at Riley Children’s Hospital and Texas Children’s Hospital was performed. All children 5 years of age or younger with incorporation of at least one C-2 translaminar screw were identified.

Results. Eighteen children were studied (7 boys and 11 girls). The mean age at surgery was 38.1 months (range 10–68 months). Indications for surgery included traumatic instability (6), os odontoideum (3), destructive processes (2), and congenital instability (7). A total of 24 C-2 translaminar screws were placed; 23 (95.8%) of 24 were satisfactorily placed (completely contained within the cortical walls). There was one medial cortex breach without neurological impingement. There were no complications with screw placement. Three patients required wound revisions. Two patients died as a result of their original condition (trauma, malignant tumor). The mean follow-up duration for the surviving patients was 17.5 months (range 3–60 months). Eleven (91.7%) of the 12 patients followed for 6 months or longer showed radiographic stability or completed fusion.

Conclusions. Use of C-2 translaminar screws provides an effective anchor for internal fixation of the upper cervical spine. In this study of children 5 years of age or younger, the authors found a high rate of radiographic fusion with a low rate of complications.

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Key Words • pediatric • cervical • spine • instrumentation • axis • translaminar screw • occipitocervical fusion • atlantoaxial dislocation

Rigid screw fixation improves fusion rate, decreases the need for halo fixation, and may have a lower complication rate compared with onlay or wiring techniques in cervical spine surgery.20 There are well-described techniques for screw instrumentation in adults. Successful screw placement may be technically difficult in very young children because of small size, congenital variations, possible growth potential, and immature ossification.4 The relatively large head size of a young child may increase the stress on the caudal screws of occipitocervical (OC) fusion constructs.

Translaminar screws offer potential advantages for young children, including efficacy, ease of placement, and safety. A C-2 translaminar screw provides an effective caudal anchor for upper cervical instrumentation. Although there are anatomical studies evaluating the feasibility of translaminar screws in children,6,24 there are very few published clinical outcome data. In this study,
the radiographic and clinical outcomes of 18 children 5 years of age or younger are reported. All patients underwent OC or Cl–2 instrumented fusion incorporating at least one C-2 translaminar screw.

**Methods**

**Patient Population**

Local internal review board approval was obtained at both institutions prior to initiating the study. A retrospective review was performed in 18 consecutive children 5 years of age or younger who received OC or Cl–2 instrumented fusion at Riley Children’s Hospital and Texas Children’s Hospital between July 1, 2007, and June 30, 2013. Surgeries were supervised by one of the senior authors (D.F. or A.J.).

**Operative Technique**

Prior to surgery the anatomy of the patient was defined, specifically examining the course of the vertebral arteries (VAs); integrity of the C-2 pars; and bony configuration of the C-1 lateral masses, occiput, and C-2. The standard exposure of the craniocervical junction was performed. Translaminar screws were placed using anatomical landmarks and the modified Wright technique.23,38 A small bur is used to create an entry point at the superior junction of the C-2 lamina and the spinous process. An exit point is created by drilling a small cortical defect in the contralateral lamina. The entry and exit points are connected with a freehand pass of a small pedicle probe. By direct visualization of the probe at the exit point, medial or inferior cortical breaches are avoided. The hole is then tapped and a screw is placed. All C-2 pars and pedicle screws, C-1 lateral mass screws, and occipital screws were placed under fluoroscopic guidance in the standard fashion.

All patients underwent CT scans confirming hardware position immediately postoperatively. “Appropriate” screw placement indicates that the entire screw is contained within the bony cortex, allowing for bicortical purchase in the contralateral lamina (Fig. 1). Postoperatively, patients were placed in a rigid cervical collar for 3 months. We did not use halo fixation.

**Clinical and Radiographic Follow-Up**

Two children died and were therefore excluded from further analysis. Follow-up images were obtained in the remainder of the cohort, generally at least at 6 months and 1 year. “Completed” fusion was defined as radiographically continuous bone formation across the treated levels based on CT scans. Stability was defined as lack of motion > 2 mm on flexion-extension radiographs.

**Results**

**Demographic Data**

The demographic information is shown in Table 1. The mean age (± SD) at surgery was 38.1 ± 16.6 months. The age range was 10–68 months, with a median of 34.5 months. Six patients underwent surgery for traumatic instability, 3 for os odontoideum, 2 for destructive processes (histiocytosis and sarcoma), and 7 for congenital anomalies.

**Operative Data**

A total of 24 C-2 translaminar screws were placed. Appropriate screw placement was accomplished with 23 (95.8%) of 24 screws. There was one medial breach (Case 5); the screw did not impinge on any neural elements and was not revised. There were no neurological or vascular complications. Three patients (16.7%) suffered wound complications; 2 required surgical revision, and 1 was treated for a superficial infection with antibiotics.

We used allograft or demineralized bone matrix as the graft material in all patients. Recombinant bone morphogenetic protein–2 (BMP-2) was used in 16 (88.9%) of 18. There were no complications specific to BMP-2,10,27,29 other than possibly the aforementioned wound problems.

**Postoperative Outcomes**

Table 2 shows the radiographic and clinical outcomes of the study group. Two patients died of sequelae of their disease process and were excluded from further analysis. One family withdrew care from a neurologically devastated child with atlantooccipital dislocation (Case 1). A second child died approximately 1 month after surgery from progression of a clival sarcoma (Case 3).

Four patients had 3-month follow-up data. One patient showed completed bony fusion based on CT scans. The other 3 showed early (but not complete) radiographic evidence of fusion.

Twelve patients have follow-up of 6 months or more, with a mean (± SD) of 22.2 ± 17 months (median 19
## TABLE 1: Demographic data for 18 pediatric patients with C-2 screw fixation

<table>
<thead>
<tr>
<th>Case No.</th>
<th>Age (mos), Sex</th>
<th>Diagnosis/Comorbidities</th>
<th>Construct</th>
<th>Arthrodesis Material</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>38, M</td>
<td>traumatic AO dislocation</td>
<td>Oc–C4: occipital screws w/ unilat C-2 pars screw, unilat C-2 translaminar screw, bilat C-4 lateral mass screws</td>
<td>BMP-2, bone matrix</td>
</tr>
<tr>
<td>2</td>
<td>53, M</td>
<td>congenital instability, segmental bone anomalies</td>
<td>Oc–C2: occipital screws w/ unilat C-2 pars screw, unilat C-2 translaminar screw</td>
<td>BMP-2, bone matrix</td>
</tr>
<tr>
<td>3</td>
<td>51, F</td>
<td>bone destruction from clival sarcoma</td>
<td>Oc–C2: occipital screws w/ unilat C-2 pars screw, unilat C-2 translaminar screw</td>
<td>cancellous allograft</td>
</tr>
<tr>
<td>4</td>
<td>63, F</td>
<td>os odontoideum</td>
<td>C1–2: bilat C-1 lateral mass screws w/ unilat C-2 pars screw, unilat C-2 translaminar screw</td>
<td>cancellous allograft</td>
</tr>
<tr>
<td>5</td>
<td>68, F</td>
<td>os odontoideum, Klippel-Feil syndrome, spinal cord contusion after fall</td>
<td>Oc–C3: bilat C-1 lateral mass screws, unilat C-2 translaminar screw, unilat C-3 translaminar screw</td>
<td>BMP-2, cancellous allograft</td>
</tr>
<tr>
<td>6</td>
<td>54, F</td>
<td>os odontoideum, Down syndrome</td>
<td>C1–2: bilat C-1 lateral mass screws, unilat C-2 translaminar screw, unilat C-2 pars screw</td>
<td>BMP-2, bone matrix</td>
</tr>
<tr>
<td>7</td>
<td>10, M</td>
<td>congenital instability, chondrodysplasia punctata</td>
<td>Oc–C4 fusion: occipital screws, unilat translaminar screws at C-2, C-3, &amp; C-4</td>
<td>BMP-2, bone matrix</td>
</tr>
<tr>
<td>8</td>
<td>35, F</td>
<td>traumatic AO dislocation</td>
<td>Oc–C2: unilat C-1 lateral mass screw, bilat C-2 translaminar screws</td>
<td>BMP-2, bone matrix</td>
</tr>
<tr>
<td>9</td>
<td>18, F</td>
<td>odontoid synchondrosis fracture</td>
<td>C1–2: bilat C-1 lateral mass screws, unilat C-2 pars screw, &amp; C-2 translaminar screw</td>
<td>BMP-2, bone matrix</td>
</tr>
<tr>
<td>10</td>
<td>21, F</td>
<td>lytic lesion of C-2 w/ C1–2 instability, Langerhans cell histiocytosis</td>
<td>C1–2: bilat C-1 lateral mass, unilat C-2 pars, &amp; C-2 translaminar screws</td>
<td>BMP-2, bone matrix</td>
</tr>
<tr>
<td>11</td>
<td>34, F</td>
<td>odontoid synchondrosis fracture</td>
<td>Oc–C2: occipital screws w/ bilat C-2 laminar screws</td>
<td>BMP-2, bone matrix</td>
</tr>
<tr>
<td>12</td>
<td>27, F</td>
<td>odontoid synchondrosis fracture</td>
<td>Oc–C2: occipital screws w/ bilat C-2 transalaminar screws</td>
<td>BMP-2, bone matrix</td>
</tr>
<tr>
<td>13</td>
<td>31, M</td>
<td>spinal epiphyseal dysplasia</td>
<td>Oc–C2: occipital screws w/ bilat C-2 transalaminar screws</td>
<td>BMP-2, bone matrix</td>
</tr>
<tr>
<td>14</td>
<td>57, M</td>
<td>Chiari w/ basilar invagination</td>
<td>Oc–C2: occipital screws w/ bilat C-2 transalaminar screws</td>
<td>BMP-2, bone matrix</td>
</tr>
<tr>
<td>15</td>
<td>23, M</td>
<td>rotary subluxation, fusion abnormality</td>
<td>Oc–autofused C2–3: occipital screws w/ unilat C-2 pars screw, unilat C-2 translaminar screw</td>
<td>BMP-2, cancellous allograft</td>
</tr>
<tr>
<td>16</td>
<td>25, F</td>
<td>congenital instability, syndromic craniosynostosis</td>
<td>Oc–C2: occipital screws w/ unilat C-2 pars screw, unilat C-2 transalaminar screw</td>
<td>BMP-2, cancellous allograft</td>
</tr>
<tr>
<td>17</td>
<td>46, F</td>
<td>basilar invagination, bony segmental abnormalities</td>
<td>Oc–C2: occipital screws w/ bilat C-2 transalaminar screws</td>
<td>BMP-2, autograft, cancellous allograft</td>
</tr>
<tr>
<td>18</td>
<td>32, M</td>
<td>basilar invagination, cerebral palsy</td>
<td>Oc–C2: occipital screws w/ unilat C-2 pars &amp; unilat C-2 translaminar screw</td>
<td>BMP-2, cancellous allograft</td>
</tr>
</tbody>
</table>

* AO = atlantooccipital; Oc = occipital.
TABLE 2: Radiographic and clinical outcome in 18 pediatric patients with C-2 screw fixation*

<table>
<thead>
<tr>
<th>Case No.</th>
<th>C-2 Translaminar Screw Placement</th>
<th>Surgical Complications</th>
<th>Surgical Revision</th>
<th>Hospital LOS (days)</th>
<th>Radiographic Bony Fusion/ Stability on Latest FU Image</th>
<th>FU (mos)</th>
<th>Clinical Outcome</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>appropriate</td>
<td>none</td>
<td>no</td>
<td>care withdrawn POD 4</td>
<td>NA</td>
<td>NA</td>
<td>care withdrawn</td>
</tr>
<tr>
<td>2</td>
<td>appropriate</td>
<td>none</td>
<td>no</td>
<td>3</td>
<td>yes</td>
<td>24</td>
<td>neurologically intact</td>
</tr>
<tr>
<td>3</td>
<td>appropriate</td>
<td>none</td>
<td>no</td>
<td>5</td>
<td>NA</td>
<td>NA</td>
<td>died of tumor progression 1 mo postop</td>
</tr>
<tr>
<td>4</td>
<td>appropriate</td>
<td>none</td>
<td>no</td>
<td>3</td>
<td>yes</td>
<td>6</td>
<td>neurologically intact</td>
</tr>
<tr>
<td>5</td>
<td>breach of medial laminar cortex</td>
<td>superficial wound infection</td>
<td>no</td>
<td>22</td>
<td>yes</td>
<td>60</td>
<td>neurologically intact</td>
</tr>
<tr>
<td>6</td>
<td>appropriate</td>
<td>poor wound healing requiring revision</td>
<td>yes</td>
<td>3</td>
<td>early signs of fusion</td>
<td>3</td>
<td>neurologically intact</td>
</tr>
<tr>
<td>7</td>
<td>appropriate</td>
<td>none</td>
<td>no</td>
<td>8</td>
<td>Oc–C1 pseudarthrosis, completed C2–4 fusion</td>
<td>27</td>
<td>stable quadriplegia</td>
</tr>
<tr>
<td>8</td>
<td>appropriate (×2)</td>
<td>none</td>
<td>no</td>
<td>6</td>
<td>yes</td>
<td>36</td>
<td>neurologically improved strength</td>
</tr>
<tr>
<td>9</td>
<td>appropriate</td>
<td>none</td>
<td>no</td>
<td>4</td>
<td>yes</td>
<td>42</td>
<td>neurologically intact</td>
</tr>
<tr>
<td>10</td>
<td>appropriate</td>
<td>none</td>
<td>no</td>
<td>4</td>
<td>yes</td>
<td>12</td>
<td>neurologically intact</td>
</tr>
<tr>
<td>11</td>
<td>appropriate (×2)</td>
<td>none</td>
<td>no</td>
<td>10</td>
<td>yes</td>
<td>3</td>
<td>neurologically intact</td>
</tr>
<tr>
<td>12</td>
<td>appropriate (×2)</td>
<td>infection requiring washout</td>
<td>yes</td>
<td>5</td>
<td>yes</td>
<td>24</td>
<td>healed synchondrosis; neurologically intact, lost to FU after 3 mos</td>
</tr>
<tr>
<td>13</td>
<td>appropriate (×2)</td>
<td>none</td>
<td>no</td>
<td>3</td>
<td>yes</td>
<td>9</td>
<td>neurologically intact</td>
</tr>
<tr>
<td>14</td>
<td>appropriate (×2)</td>
<td>none</td>
<td>no</td>
<td>4</td>
<td>yes</td>
<td>14</td>
<td>neurologically intact w/ resolution of preop syrinx</td>
</tr>
<tr>
<td>15</td>
<td>appropriate</td>
<td>none</td>
<td>no</td>
<td>3</td>
<td>early signs of fusion</td>
<td>6</td>
<td>neurologically intact w/ resolution of torticollis</td>
</tr>
<tr>
<td>16</td>
<td>appropriate</td>
<td>none</td>
<td>no</td>
<td>3</td>
<td>early signs of fusion</td>
<td>6</td>
<td>neurologically intact</td>
</tr>
<tr>
<td>17</td>
<td>appropriate</td>
<td>none</td>
<td>no</td>
<td>2</td>
<td>early signs of fusion</td>
<td>5</td>
<td>neurologically intact, improvement in head tilt</td>
</tr>
<tr>
<td>18</td>
<td>appropriate</td>
<td>none</td>
<td>no</td>
<td>3</td>
<td>yes</td>
<td>3</td>
<td>neurologically improved strength</td>
</tr>
</tbody>
</table>

* FU = follow-up; LOS = length of stay; NA = not applicable; POD = postoperative day.
Discussion

Traditionally, fusion of the upper cervical spine in children was accomplished by onlay or wiring techniques in conjunction with halo fixation. Biomechanical and clinical studies have shown that rigid screw fixation provides superior stabilization and fusion rates compared with these techniques.\textsuperscript{1,8,13,14,17,18,20,25,26,31,35}

Techniques for rigid surgical fixation of the upper cervical spine are well defined in adults. Similar techniques may be challenging or ineffective in very young children due to smaller bone size, relatively large head, increased flexibility, immature bone formation, or variable anatomy.\textsuperscript{20,25,35} Rigid screw fixation may eliminate the need for halo fixation.\textsuperscript{12,16,30} In a previous review, screw fixation had a lower overall complication rate compared with wiring techniques in pediatric cervical surgeries.\textsuperscript{20}

However, prior studies suggest that upper cervical spine instrumentation in young children carries a high complication rate.\textsuperscript{19,36} Potential complications with screw placement include neurological injury, vascular injury, dural laceration, and bone fracture. The smaller bone anatomy restricts the available area for screw placement. Young children may have small lateral masses; the surgeon may only be able to place a few threads of the smallest screw within bone. Small screws with little purchase may not be strong enough to fixate the upper cervical spine, especially with the child’s relatively large occiput. Transarticular screws place the VA at risk and are not anatomically feasible in 7%–23% of patients.\textsuperscript{1,2,30} The VA anatomy may be further distorted in patients who have experienced trauma with atlantoaxial dislocation.\textsuperscript{20}

Whereas C-1 lateral mass screws provide excellent bone purchase and can be placed safely even in young children,\textsuperscript{10} occipital screws may be challenging in small children. Occipital screw strength is improved with bicortical purchase and placement of the screws in the midline keel.\textsuperscript{4,19} Occipitocervical or C1–2 fusion constructs require a strong caudal fixation point. The subaxial lateral masses may be too small to provide significant bone purchase for screws. Therefore, many upper cervical instrumentation constructs rely on solid screw placement in C-2. Options include pars, pedicle, transarticular, and translaminar screws.

Translaminar screws offer a number of potential advantages over transarticular and C-2 pars and pedicle screws. The surgeon is able to place a relatively long screw with bicortical purchase under direct vision. The main vector of force in flexion-extension is perpendicular to a translaminar screw; thus the entire screw length resists pullout. This is in contrast to a more parallel pars or pedicle screw, in which only a few small-caliber threads provide pullout resistance. A VA injury is less likely with translaminar screws. The risk of dural or spinal cord injury is lessened with the modified Wright technique.\textsuperscript{23}

A number of studies have evaluated the anatomical feasibility of screw insertion in the pediatric cervical spine.\textsuperscript{5,9,24} Chern et al. performed a feasibility analysis of laminar screw fixation of the cervical spine based on morphological features (laminar height and thickness) demonstrated on CT scans. Overall, 30.4% of children younger than 8 years of age had an anatomy that could accept bilateral C-2 laminar screws. Five (27.8%) of our patients had bilateral, crossing C-2 translaminar screws placed. We have found that one C-2 translaminar screw can be placed in almost all children older than 2 years of age.

Biomechanical studies have shown equivalence of translaminar screw constructs with pedicle or transarticular fixation.\textsuperscript{15,34} Lapsiwala et al. showed that crossed laminar screw fixation, C1–2 pedicle screws, and C1–2 transarticular screws have equal rigidity in flexion-extension and axial rotation, when supplemented with cable.\textsuperscript{26} Claybrook et al. demonstrated that C-1 lateral mass–C-2 laminar screws were equal in flexion-extension and translation compared with C-1 lateral mass–C-2 pedicle screw constructs. However, the pedicle C-2 construct was stiffer in lateral bending and axial rotation.\textsuperscript{7}

There is an increasing number of clinical studies of translaminar screw constructs in adults. However, there are only a few clinical reports in children.\textsuperscript{4,22,28} In this study we restrict our analysis to children 5 years of age or younger. We consider these younger children to be the most challenging due to the factors described above.

In this small but focused cohort, we found a high rate of radiographic fusion or stability in children followed for 6 months or more. All 12 children showed fusion or stability on dynamic radiographs. There were few complications. We deemed C-2 translaminar screw placement to be satisfactory in 23 (95.8%) of 24 based on immediate postoperative CT scanning. There were no instances of neurological decline due to the surgery; note that 2 patients died of their underlying condition. Overall, we considered the C-2 translaminar screw to be an effective caudal anchor for OC or C1–2 constructs.

Bone Morphogenetic Protein–2

In our cohort, BMP-2 was used in 16 (88.9%) of 18 patients. Although it is not the focus of this manuscript, the use of BMP-2 is controversial and deserves comment. There are significant advantages to BMP-2 compared with the accepted “gold standard” of autologous bone, especially in the upper cervical spine where there is little available local bone for harvest. Potential advantages of BMP-2 include decreased operating time, decreased blood loss, decreased donor site morbidity (pain, infection, potential...
structural weakness in the iliac crest), ease of use, and efficacy. There is a growing body of literature reporting increasing use\textsuperscript{23} and efficacy in pediatric spine surgery, including the initial experience of one of the authors (A.J.).\textsuperscript{11} There are potential serious drawbacks to BMP-2, including cost, complications (seroma, infection, heterotopic bone growth, hydrocephalus, radiculopathy, bone resorption), and potential long-term effects that include the possibility of increasing future risk of cancer.\textsuperscript{3,29,32} In our study group, 3 (16.7\%) of 18 had wound healing problems and 2 (11.1\%) required a surgical wound revision. We are not able to ascertain if these wound problems were attributable to BMP-2 alone. We did not observe any of the other complications reported in the literature.

Although the use of BMP-2 remains controversial, we believe that a few simple steps can mitigate the associated complications. These steps include using the “low-dose” commercially available formulation and refraining from irrigating after the BMP-2 is placed. We do not recommend BMP-2 use in anterior approaches to the cervical spine. Our opinion currently is that the long-term toxicities are, as of yet, unproven. Although we encourage further study, we currently believe that the surgical benefits outweigh the risk. We believe that a thorough discussion with the parents during the surgical consent process of “off-label” use is mandatory.

\textit{Limitations of the Study}

There are rare indications for upper cervical fusion in very young children. Because of the rarity of these conditions, the population in this study is small. The follow-up time and imaging are variable. Although we focus on the C-2 translaminar screws, the efficacy of the instrumentation also depends on the stability of the occipital or C-1 screws. Although we acknowledge that this is a limited study, we believe that the objectives of evaluating the safety and efficacy in this focused population have been met.

\textbf{Conclusions}

Even in very young children, C-2 translaminar screws are safe and effective as part of an upper cervical screw construct. These screws provide an effective caudal anchor for OC and C1–2 constructs.

\textbf{Disclosure}

The authors report no conflict of interest concerning the materials or methods used in this study or the findings specified in this paper.

Author contributions to the study and manuscript preparation include the following. Conception and design: Fulkerson, Savage. Acquisition of data: Fulkerson, Savage, Sen, Thomas. Analysis and interpretation of data: Fulkerson, Jea. Drafting the article: Fulkerson, Savage, Sen, Thomas. Critically revising the article: all authors. Reviewed submitted version of manuscript: all authors. Approved the final version of the manuscript on behalf of all authors: Fulkerson. Study supervision: Fulkerson.

\textbf{References}


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