Computed tomography morphometric analysis for axial and subaxial translaminar screw placement in the pediatric cervical spine

Clinical article

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Object. The management of upper cervical spinal instability in children continues to represent a technical challenge. Traditionally, a number of wiring techniques followed by halo orthosis have been applied; however, they have been associated with a high rate of nonunion and poor tolerance for the halo. Alternatively, C1–2 transarticular screws and C-2 pars/pedicle screws allow more rigid fixation, but their placement is technically demanding and associated with vertebral artery injuries. Recently, C-2 translaminar screws have been added to the armamentarium of the pediatric spine surgeon as a technically simple and biomechanically efficient means of fixation. However, the use of subaxial translaminar screws have not been described in the general pediatric population. There are no published data that describe the anatomical considerations and potential limitations of this technique in the pediatric population.

Methods. The cervical vertebrae of 69 pediatric patients were studied on CT scans. Laminar height and thickness were measured. Statistical analysis was performed using unpaired Student t-tests (p < 0.05) and linear regression analysis.

Results. The mean laminar heights at C-2, C-3, C-4, C-5, C-6, and C-7, respectively, were 9.76 ± 2.22 mm, 8.22 ± 2.24 mm, 8.09 ± 2.38 mm, 8.51 ± 2.34 mm, 9.30 ± 2.54 mm, and 11.65 ± 2.65 mm. Mean laminar thickness at C-2, C-3, C-4, C-5, C-6, and C-7, respectively, were 5.07 ± 1.07 mm, 2.67 ± 0.79 mm, 2.18 ± 0.73 mm, 2.04 ± 0.60 mm, 2.52 ± 0.66 mm, and 3.84 ± 0.96 mm. In 50.7% of C-2 laminae, the anatomy could accept at least 1 translaminar screw (laminar thickness ≥ 4 mm).

Conclusions. Overall, the anatomy in 30.4% of patients younger than 16 years old could accept bilateral C-2 translaminar screws. However, the anatomy of the subaxial cervical spine only rarely could accept translaminar screws. This study establishes anatomical guidelines to allow for accurate and safe screw selection and insertion. Preoperative planning with thin-cut CT and sagittal reconstruction is essential for safe screw placement using this technique. (DOI: 10.3171/2008.11.PEDS08277)

Key Words • cervical fusion • computed tomography • pediatric spine • translaminar screw placement

The management of upper cervical spinal instability in children continues to represent a formidable therapeutic and technical challenge. In the pediatric age group, upper cervical instability can result from several conditions including trauma, congenital anomalies, and connective tissue disorders.

Only scarce data are available in the literature regarding upper cervical fusion in the pediatric population. Traditionally, wiring techniques followed by postoperative placement of a halo orthosis have been used in this patient population. More rigid screw fixation techniques have been advocated because they offer several advantages including a higher fusion rate and obviating the need for postoperative halo immobilization. However, screw insertion in the small and underdeveloped cervical spine of a child is technically demanding and entails significant risks.

At the level of the axis, the options for screw insertion usually include C1–2 transarticular and C-2 pars/pedicle screws. However, C1–2 transarticular screw placement is technically demanding because of the close proximity of the vertebral artery to the screw path. Vertebral artery injury has been reported to occur in 2–8% of cases in several large series. Pars/pedicle screws may have a lower incidence of arterial injury, but these screws still place the vertebral artery and spinal cord at risk.
Wright29,30 has described a new technique for rigid screw fixation of the axis, involving the insertion of polyaxial screws into the laminae of C-2 in a bilateral crossing fashion, and the feasibility of its application in the general adult population.4 Because the C-2 translaminar screws are not in proximity to the vertebral artery, this technique allows rigid fixation of C-2 through a safer technique.

Leonard and Wright19 have reported their experience with this technique in a small case series involving 3 children; however, only 1 child was younger than 16 years of age. Children 8 years of age or older have achieved adult spinal configuration.1,9,16

Recently, the placement of translaminar screws in the adult subaxial cervical spine26,28 and thoracic spine5,11,17,26 has been reported. There has not, however, been a report of the use of translaminar screws in the pediatric subaxial cervical spine except in association with Klippel-Feil deformity.13–15 Therefore, the applicability of this technique to the general pediatric population is not known.

To our knowledge, no published study has investigated the dorsal anatomy of the axis and the subaxial cervical vertebrae as it relates to placement of translaminar screws. The purpose of the present study was to determine the feasibility of axial and subaxial translaminar screws in the general pediatric population, and to establish useful guidelines for their placement.

**Methods**

Ninety-eight consecutive CT scans of the cervical spine were performed during a period from October 1, 2007, to April 30, 2008, at Texas Children's Hospital in Houston. Twenty-nine of these studies were excluded from this analysis because the patients were younger than 1.5 years or older than 16 years, because the studies were deemed to be incomplete due to a lack of sagittal and coronal reconstructions, or because of congenital anatomical anomalies of the cervical spine. Therefore, 69 complete CT scans of normal pediatric cervical spines were available for analysis. For purposes of the study, patient age was defined as the patient's age when the CT scan was performed, rounded to the closest digit. The mean age of the patients was 8.6 years (median 8 years).

Representative dimensions were defined as shown in Fig. 1. Measurements were analyzed for screw placement assuming the technique of Wright29,30 as shown in Fig. 2.
Axial and subaxial translaminar screws in children

The “A” dimension, or laminar height, was measured bilaterally in the parasagittal plane from C-2 through C-7. The “B” dimension, or laminar thickness, was measured bilaterally on all CTs from C-2 through C-7. This measurement was taken at the isthmus, or the thinnest part, of the laminae in the axial CT plane. These linear measurements were obtained with the standard measurement palette in our picture archiving and communications system (iSite PACS, Philips Radiology Informatics) and were automatically rounded to the nearest 0.1 mm. Comparisons based on sex and ages were recorded. Younger children were defined as those < 8 years of age. Older children were defined as those ≥ 8 years of age. Statistical analysis was performed with SPSS (SPSS Inc.). Graphical representation of our data were created using an Excel spreadsheet (Microsoft Corp.).

Results

The measurements of laminar height and laminar thickness are presented in Tables 1 and 2 and described below. The data are also presented graphically in Figs. 3–6.

Laminar Height

Height of C-2 Laminae. Mean laminar height for all patients was 9.76 ± 2.22 mm (range 5.2–14.8 mm). A total of 42.8% of the laminae had a height ≥ 10 mm, 57.2% had a height ≥ 9 mm, and 76.8% had a height ≥ 8 mm. Insignificant differences in laminar height were noted with respect to patient sex (p = 0.1657). Significant differences in laminar height were noted with respect to patient age (p < 0.0001).

Height of C-3 Laminae. Mean laminar height for all patients was 8.22 ± 2.24 mm (range 3.3–14.4 mm). A total of 22.5% of the laminae had a height ≥ 10 mm, 33.3% had a height ≥ 9 mm, and 47.8% had a height ≥ 8 mm. Insignificant differences in laminar height were noted with respect to patient sex (p = 0.8260). Significant differences in laminar height were noted with respect to patient age (p < 0.0001).

Height of C-4 Laminae. Mean laminar height for all patients was 8.09 ± 2.38 mm (range 3.4–15.0 mm). A total of 24.6% of the laminae had a height ≥ 10 mm, 38.4% had a height ≥ 9 mm, and 50.7% had a height ≥ 8 mm. Insignificant differences in laminar height were noted with respect to patient sex (p = 0.6129). Significant differences in laminar height were noted with respect to patient age (p < 0.0001).

Height of C-5 Laminae. Mean laminar height for all patients was 8.51 ± 2.34 mm (range 4.2–15.0 mm). A total of 30.0% of the laminae had a height ≥ 10 mm, 39.9% had a height ≥ 9 mm, and 55.1% had a height ≥ 8 mm. Insignificant differences in laminar height were noted with respect to patient sex (p = 0.9022). Significant differences in laminar height were noted with respect to patient age (p < 0.0001).

Height of C-6 Laminae. Mean laminar height for all patients was 9.30 ± 2.54 mm (range 4.6–16.4 mm). A total of 34.8% of the laminae had a height ≥ 10 mm, 39.9% had a height ≥ 9 mm, and 50.7% had a height ≥ 8 mm. Insignificant differences in laminar height were noted with respect to patient sex (p = 0.9901). Significant differences in laminar height were noted with respect to patient age (p < 0.0001).

Height of C-7 Laminae. Mean laminar height for all patients was 11.65 ± 2.65 mm (range 6.6–17.5 mm). A total of 22.5% of the laminae had a height ≥ 10 mm, 33.3% had a height ≥ 9 mm, and 47.8% had a height ≥ 8 mm. Insignificant differences in laminar height were noted with respect to patient sex (p = 0.8260). Significant differences in laminar height were noted with respect to patient age (p < 0.0001).

The mean laminar heights are presented in millimeters and appear ± SDs.

Table 1: Mean laminar height in 69 patients stratified by sex and age

<table>
<thead>
<tr>
<th>Vertebra</th>
<th>All Patients</th>
<th>M</th>
<th>F</th>
<th>p Value</th>
<th>Age &lt;8 yrs</th>
<th>Age ≥8 yrs</th>
<th>p Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>C-2</td>
<td>9.76 ± 2.22</td>
<td>9.98 ± 2.24</td>
<td>9.44 ± 2.15</td>
<td>0.1657</td>
<td>8.11 ± 1.28</td>
<td>11.20 ± 1.83</td>
<td>&lt;0.0001</td>
</tr>
<tr>
<td>C-3</td>
<td>8.22 ± 2.24</td>
<td>8.25 ± 2.33</td>
<td>8.17 ± 2.08</td>
<td>0.8260</td>
<td>6.49 ± 0.95</td>
<td>9.72 ± 1.93</td>
<td>&lt;0.0001</td>
</tr>
<tr>
<td>C-4</td>
<td>8.09 ± 2.38</td>
<td>7.93 ± 2.54</td>
<td>8.16 ± 2.28</td>
<td>0.6129</td>
<td>6.15 ± 1.34</td>
<td>9.77 ± 1.71</td>
<td>&lt;0.0001</td>
</tr>
<tr>
<td>C-5</td>
<td>8.51 ± 2.34</td>
<td>8.49 ± 2.40</td>
<td>8.54 ± 2.25</td>
<td>0.9022</td>
<td>6.66 ± 1.20</td>
<td>10.12 ± 1.84</td>
<td>&lt;0.0001</td>
</tr>
<tr>
<td>C-6</td>
<td>9.30 ± 2.54</td>
<td>9.30 ± 2.64</td>
<td>9.30 ± 2.38</td>
<td>0.9901</td>
<td>7.37 ± 1.40</td>
<td>10.97 ± 2.10</td>
<td>&lt;0.0001</td>
</tr>
<tr>
<td>C-7</td>
<td>11.65 ± 2.65</td>
<td>11.66 ± 2.66</td>
<td>11.63 ± 2.65</td>
<td>0.9476</td>
<td>9.57 ± 1.33</td>
<td>13.45 ± 2.15</td>
<td>&lt;0.0001</td>
</tr>
</tbody>
</table>

* The mean laminar heights are presented in millimeters and appear ± SDs.

Table 2: Mean laminar thickness in 69 patients stratified by sex and age

<table>
<thead>
<tr>
<th>Vertebra</th>
<th>All Patients</th>
<th>M</th>
<th>F</th>
<th>p Value</th>
<th>Age &lt;8 yrs</th>
<th>Age ≥8 yrs</th>
<th>p Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>C-2</td>
<td>5.07 ± 1.07</td>
<td>5.01 ± 1.07</td>
<td>5.17 ± 1.07</td>
<td>0.3962</td>
<td>4.99 ± 0.79</td>
<td>5.13 ± 1.28</td>
<td>0.3996</td>
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<tr>
<td>C-3</td>
<td>2.67 ± 0.79</td>
<td>2.60 ± 0.89</td>
<td>2.78 ± 0.59</td>
<td>0.2043</td>
<td>2.67 ± 0.61</td>
<td>2.67 ± 0.92</td>
<td>0.9738</td>
</tr>
<tr>
<td>C-4</td>
<td>2.18 ± 0.73</td>
<td>2.19 ± 0.92</td>
<td>2.18 ± 0.50</td>
<td>0.9245</td>
<td>2.25 ± 0.54</td>
<td>2.13 ± 0.86</td>
<td>0.3062</td>
</tr>
<tr>
<td>C-5</td>
<td>2.04 ± 0.60</td>
<td>2.12 ± 0.70</td>
<td>1.92 ± 0.34</td>
<td>0.0430</td>
<td>2.10 ± 0.52</td>
<td>2.00 ± 0.66</td>
<td>0.3074</td>
</tr>
<tr>
<td>C-6</td>
<td>2.52 ± 0.66</td>
<td>2.57 ± 0.72</td>
<td>2.44 ± 0.55</td>
<td>0.2327</td>
<td>2.57 ± 0.59</td>
<td>2.45 ± 0.72</td>
<td>0.3990</td>
</tr>
<tr>
<td>C-7</td>
<td>3.84 ± 0.96</td>
<td>3.87 ± 1.08</td>
<td>3.78 ± 0.75</td>
<td>0.5857</td>
<td>3.59 ± 0.71</td>
<td>4.04 ± 1.10</td>
<td>0.0056</td>
</tr>
</tbody>
</table>

* The mean laminar thicknesses are presented in millimeters and appear ± SDs.
Fig. 3. Graphs plotting laminar height (A–F) and thickness (G–L) against age at each cervical level. (See Results for the estimated growth rates.) A trend toward increase in height with increase in patient age was observed in all levels. In contrast, the laminar thickness changed minimally in the studied ages. Note that at the C3–6 levels, most of the laminar thickness measurement fell under the 4.5 mm threshold.
A total of 71.0% of the laminae had a height \( \geq 10 \) mm, 85.5% had a height \( \geq 9 \) mm, and 94.2% had a height \( \geq 8 \) mm. Insignificant differences in laminar height were noted with respect to patient sex \( (p = 0.9476) \). Significant differences in laminar height were also noted with respect to patient age \( (p < 0.0001) \).

**Thickness of C-2 Laminae.** Mean laminar thickness for all patients was \( 5.07 \pm 1.07 \) mm (range 2.3–8.3 mm). A total of 22.5% of the laminae had a thickness \( \geq 6 \) mm, 51.4% had a thickness \( \geq 5 \) mm, and 88.4% had a thickness \( \geq 4 \) mm. Insignificant differences in laminar thickness were noted with respect to patient sex \( (p = 0.3962) \). Insignificant differences in laminar thickness were also noted with respect to patient age \( (p = 0.3996) \).

**Thickness of C-3 Laminae.** Mean laminar thickness at C-3 for all patients was \( 2.67 \pm 0.79 \) mm (range 0.8–5.3 mm). None of the laminae had a thickness \( \geq 6 \) mm, 1.4% had a thickness \( \geq 5 \) mm, and 3.6% had a thickness \( \geq 4 \) mm. Insignificant differences in laminar thickness were noted with respect to patient sex \( (p = 0.2043) \). Insignificant differences in laminar thickness were also noted with respect to patient age \( (p = 0.9738) \).

**Thickness of C-4 Laminae.** Mean laminar thickness at C-4 for all patients was \( 2.18 \pm 0.73 \) mm (range 0.8–5.8 mm). None of the laminae had a thickness \( \geq 6 \) mm, 1.4% had a thickness \( \geq 5 \) mm, and 1.4% had a thickness \( \geq 4 \) mm. Insignificant differences in laminar thickness were noted with respect to patient sex \( (p = 0.9245) \). Insignificant differences in laminar thickness were also noted with respect to patient age \( (p = 0.3062) \).

**Thickness of C-5 Laminae.** Mean laminar thickness at C-5 for all patients was \( 2.04 \pm 0.60 \) mm (range 0.8–4.8 mm). None of the laminae had a thickness \( \geq 6 \) mm, none had a thickness \( \geq 5 \) mm, and 0.7% had a thickness \( \geq 4 \) mm. Significant differences in laminar thickness were noted
with respect to patient sex. Male patients had a somewhat greater thickness to female patients ($2.12 \pm 0.70$ mm vs $1.92 \pm 0.34$ mm, $p = 0.0430$). Insignificant differences in laminar thickness were noted with respect to patient age ($p = 0.3074$).

**Thickness of C-6 Laminae.** Mean laminar thickness at C-6 for all patients was $2.52 \pm 0.66$ mm (range 1.0–4.8 mm). None of the laminae had a thickness $\geq 6$ mm, none had a thickness $\geq 5$ mm, and 3.6% had a thickness $\geq 4$ mm. Insignificant differences in laminar thickness were noted with respect to patient sex ($p = 0.2327$). Insignificant differences in laminar thickness were also noted with respect to age ($p = 0.3990$).

**Thickness of C-7 Laminae.** Mean laminar thickness at C-7 for all patients was $3.84 \pm 0.96$ mm (range 1.0–7.2 mm). A total of 1.4% of the laminae had a thickness $\geq 6$ mm, 14.5% had a thickness $\geq 5$ mm, and 41.3% had a thickness $\geq 4$ mm. Insignificant differences in laminar thickness were noted with respect to patient sex ($p = 0.5857$). Significant differences in laminar thickness were noted with respect to age. Children 8 years of age or older showed a tendency for thicker laminae than children younger than 8 years of age ($4.04 \pm 1.10$ mm vs $3.59 \pm 0.71$ mm, $p = 0.0056$).

**Anatomical Limitations of Translaminar Screw Placement**

Based on these measurements, at the C-2 level a 3.5-mm screw could not be accommodated in either lamina in 34 patients, assuming the need for a 1.0-mm margin for a 3.5-mm screw; in 21 (30.4%) of 69 patients bilateral 3.5-mm translaminar screws could be accommodated at this level with this margin. In 45.9% of patients older than 8 years of age, the C-2 anatomy could safely accept placement of bilateral translaminar screws (Fig. 7).

At the C-3–6 levels, the anatomy was able to accommodate bilateral 3.5 mm translaminar screws (assuming a 1.0-mm margin) in 1 patient only.

At C-7, the anatomy could not accommodate a 3.5-mm screw in either lamina (assuming the need for a 1.0-mm margin) in 42 patients; in 9 (13.0%) of 69 patients, the anatomy could accommodate bilateral 3.5-mm translaminar screws with this margin.

The “B” dimension, or laminar thickness, represented the rate-limiting step in the placement of any translaminar screw, especially in the subaxial cervical spine (Fig. 3G–L).

**Estimated Growth Rates**

Using linear regression, the growth rates for each level were estimated. With respect to height, the rates were $0.40$ mm/year at C-2, $0.43$ mm/year at C-3, $0.46$ mm/year at C-4, $0.44$ mm/year at C-5, $0.48$ mm/year at C-6, and $0.51$ mm/year at C-7 (Fig. 3).

With respect to thickness, the growth rates were estimated to be $0.04$ mm/year at C-2, $0.02$ mm/year at C-3, $0.01$ mm/year at C-4, $0.00$ mm/year at C-5, $0.00$ mm/year at C-6, and $0.08$ mm/year at C-7.

**Discussion**

**Anatomical Descriptions of Pediatric Cervical Spine**

Multiple authors of other studies have commented on the configuration of the pediatric spine, mostly in comparison with the adult spine. Our study provides an anatomical description of the pediatric spine in patients between the ages of 1.5 and 16 years. Our data demonstrate that as a child ages, laminar height increases. The rate of growth is remarkably consistent throughout. One might expect a higher rate of growth during the adolescent years, but we did not find that to be the case. Perhaps more surprising is that the laminar thickness changes minimally in the studied age period. Our findings suggest that the thickening of bone occurs in the postadolescent period. Further studies using this methodology in young adults will be necessary to confirm this hypothesis.

**Translaminar Screws in Adults**

In 2004, Wright described a new technique for placement of C-2 translaminar laminar screws. The newly described technique was simple and relatively safe while still allowing rigid fixation of C-2, which explains its rapidity growing popularity in the adult patient population. The clinical experience in adults confirms that this procedure is associated with a significantly lower morbidity rate and a high rate of fusion.

The stability and stiffness of the construct created using the C-2 translaminar screws have also been the subject of a number of biomechanical studies. Lapsiwal et al. compared crossed laminar screw fixation, C-1 to C-2 pedicle screws, and posterior C1–2 transarticular screw fixation, and found that all 3 posterior screw constructs with supplemental cable fixation provide equal stiffness with regard to flexion-extension and axial rotation. Translaminar screw fixation restored resistance to lateral bending but not to the same degree as the other screw fixation techniques. Similarly, Claybrooks et al. found that C-1 lateral mass–C2 pedicle screw constructs were stiffer than C-1 lateral mass–C2 laminar screw constructs in lateral bending and axial rotation; the 2 constructs were equivalent in translation and flexion-extension. Other studies have also found that the laminar screws allowed...
more motion than pedicle screws but the difference was not clinically significant.\textsuperscript{10,23}

**Translaminar Screws in Children**

Leonard and Wright\textsuperscript{19} used C-2 laminar screw fixation in 3 pediatric patients with os odontoideum (1 of them was 3 years old and 2 were 16 years old). In all 3 cases, 4-mm-diameter polyaxial screws were used, with the length varying between 16 and 30 mm. All screws were inserted successfully with no complications. This is the only reported series of axial translaminar screw fixation in children. Although laminar screws have been used in the subaxial cervical spine\textsuperscript{24} in adults, no cases have been reported in the general pediatric population.

The clinical applicability of this fixation technique in the general pediatric population is not known. No studies have evaluated the dorsal cervical vertebral anatomy as it pertains to the use of translaminar screws in children.

Our results provide an anatomical description (Fig. 3) and establish useful guidelines for the placement of axial and subaxial cervical translaminar screws in the general pediatric population. The minimum thickness needed to allow for safe placement of a screw varies in the literature. While some studies report that a minimum diameter of 5 mm is needed for safe placement of a transarticular screw,\textsuperscript{21} others report that 4 mm may be sufficient if more accurate image-guided techniques are used.\textsuperscript{2,22} The ability to place a laminar screw under direct visualization may allow for a thickness between 4 and 5 mm to be acceptable, allowing for a safety margin between 0.5 and 1.5 mm.\textsuperscript{3,27}

Assuming a 4.5-mm tolerance for each screw, the minimum laminar height for bilateral screw placement would be 9 mm. According to these criteria (laminar height \( \geq 9 \) mm and laminar thickness \( \geq 4.5 \) mm), the anatomy in 30.4\% of patients between the ages of 1.5 and 16 years could accept bilateral translaminar screws safely at the C-2 level. Our data also show that the percentage of patients in whom the C-2 anatomy can accept bilateral translaminar screws increases as patients’ age increases; of patients 8 years old and older, 45.9\% had anatomy that allowed for placement of bilateral translaminar screws at this level (Fig. 7). Based on the same criteria, placement of translaminar screws from C-3 to C-6 could not be performed safely in nearly all of the patients in our series. At the level of C-7, placement of bilateral translaminar screws was possible in 13.0\% of our patients, mostly older children.

There were statistically significant age-related differences noted in laminar height at all cervical vertebral levels but no significant sex-related differences. There were statistically significant age-related differences noted in laminar thickness at C-7 and statistically significant sex-related differences in laminar thickness at C-5 (Table 2). These findings suggest that subaxial translaminar screw placement may be safer and technically easier in older boys than in younger girls. However, since the differences were noted at single levels only, it is not likely that they are clinically significant.

**Conclusions**

Fixation of C-2 by means of laminar screws has recently emerged as a new technique for surgical fusion. Although it has rapidly gained popularity in the treatment of adults, its use is still rarely reported in children. This study shows that C-2 translaminar screws can be safely used in a majority of pediatric patients. It gives the pediatric spine surgeon an alternative to the use of C-2 pars/ pedicle screws for C-2 fixation, nearly eliminating risk to the vertebral artery. In the subaxial cervical spine, translaminar screws can rarely be placed safely in a child. Thin-cut, preoperative CT is essential for identifying children in whom this technique is applicable.

**Disclaimer**

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

**References**


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