Anatomical feasibility of C-2 pedicle screw fixation: the effect of variable angle interpolation of axial CT scans

Clinical article

LAUREN M. BURKE, M.D., WARREN D. YU, M.D., ANTHONY HO, M.D., TIMOTHY WAGNER, B.S., AND JOSEPH R. O’BRIEN, M.D., M.P.H.

Department of Orthopaedic Surgery, George Washington University, Washington, DC

Object. Anatomical variability of the C-2 pedicle poses a challenge for C-2 fixation. The use of multidimensional CT scanning is not widely used but might be an asset to preoperative planning. Careful preoperative planning is imperative for instrumentation at C-2. Fine-cut, noncontrast CT scanning is a useful tool for delineating anatomy; however, the axis of the images is not always along the anatomical axis of the vertebra in question. The authors evaluated the suitability of C-2 pedicles for screw placement by using OsiriX (Pixmeo) software to change the gantry angle of CT angiograms to measure the anatomical dimensions of the C-2 pedicle.

Methods. The authors conducted a retrospective review of CT angiograms of the head and neck from 47 trauma patients seen consecutively at George Washington University Hospital. For each patient, 3 independent observers determined length and width of each C-2 pedicle (94 samples) by using OsiriX. OsiriX is a DICOM viewer that enables navigation and visualization in multidimensional imaging, such as 3D imaging, which was used for this study. Sex-specific measurements were also determined. Vertebral anatomy was studied to determine whether aberrant anatomy would preclude pedicle fixation. Statistical analyses were performed.

Results. Of the 47 patients, 27 were male. Overall mean C-2 pedicle widths and lengths were 8.272 ± 1.364 mm and 27.052 ± 3.471 mm, respectively. The average widths and lengths of the pedicle in female patients were 8.040 ± 1.262 mm and 27.241 ± 2.731 mm, respectively, and those in male patients were 8.444 ± 1.414 mm and 26.913 ± 3.933 mm, respectively. The sex difference was statistically significant for width (p = 0.012) but not for length (p = 0.41). On the basis of width, the percentages of pedicles that could tolerate a 3.5-mm and 4.0-mm screw were 98% and 97%, respectively. Vertebral anatomy precluded screw length greater than 14 mm for only 3 patients.

Conclusions. Using multidimensional CT or 3D imaging, the authors found that C-2 pedicles in over 90% of patients could tolerate 3.5-mm and 4.0-mm pedicle screws. Vertebral anatomy precluded use of screw lengths greater than 14 mm for only 3 (6%) of 47 patients. Therefore, the C-2 pedicle might be more tolerant of fixation than previously reported.

Key Words • C-2 pedicle • computed tomography • OsiriX • anatomical • cervical

Fixation at C-2 is performed by using a variety of techniques. Historically, wiring techniques have been used with success when arthrodesis including C-2 is required. However, for conditions with significant instability, screw fixation might be preferable. Screw fixation at C-2 is limited by the presence of the spinal cord and vertebral artery and must also address the complex 3D anatomy at C-2 to avoid operative complications.

Screw fixation at C-2 can include pedicle fixation, pars fixation, Magerl transarticular fixation, and, most recently, laminar fixation. Biomechanically, pedicle fixation has the strongest segmental control of the C-2 vertebra in all 3 planes. Magerl fixation is as strong but is an option only when arthrodesis includes the C-1 vertebra. Pars fixation is less technically demanding but also less biomechanically secure.

Studies have shown that pedicle fixation at C-2 is technically demanding. Other studies have shown that pedicle fixation would not be tolerated in up to 25% of patients because of vertebral artery anatomy. Many studies have relied on axial or sagittal imaging to make such determinations. Anatomical studies of pedicle morphology have shown that a pedicle screw would not be tolerated in up to 20% of patients.

Our objective was to determine whether a variable virtual gantry angle for axial and reconstructed images would yield different measurements than axial images obtained perpendicular to the long axis of the patient. Our hypothesis was that prior studies might overestimate the risk for injury to the vertebral artery during C-2 pedicle screw placement.

This article contains some figures that are displayed in color online but in black-and-white in the print edition.
Anatomical feasibility of C-2 pedicle screw fixation

Methods

After obtaining approval from the George Washington University institutional review board, we retrospectively reviewed data obtained in 47 trauma patients, consecutively admitted to the George Washington University Hospital emergency department, who had undergone CT angiography of the head and neck. These same patients had been reviewed in a prior study comparing C-2 laminar fixation with pedicle fixation.1

The CT protocol at George Washington University includes 2.6-mm cut imaging for patients with head and neck trauma; thus, for all patients reviewed in this study, 2.6-mm cut imaging was performed through the anatomical area in question. We loaded each CT angiogram into the OsiriX program. Using the 3D imaging option, we changed the virtual gantry angle along the anatomical axis of the C-2 pedicle. For all patients, 3 independent observers measured and recorded bilateral pedicle lengths and widths (Fig. 1), resulting in 94 measurements for each variable. The anatomy of the vertebral artery was assessed to determine whether aberrant location would preclude pedicle screw fixation. We also collected data on patient age and sex and compared these data between patients of each sex. We compared our results from OsiriX with results from a prior study at George Washington University that used the same cohort of patients.3 In that study, pedicle anatomy was obtained solely from standard transaxial and sagittal reconstructive CT views.

Statistical analyses were performed by using Microsoft Excel; significance was determined at p < 0.05. Reliability measures using Cronbach alpha were analyzed by using IBM SPSS software version 19.0. Alpha coefficients range from 0 to 1, and values greater than 0.7 were considered to be of acceptable variation.

Results

Among the 47 patients, the average age was 42 years and 27 were male. The overall average lengths and widths of the C-2 pedicle were 27.052 ± 3.471 mm (mean 26.666 mm right, 27.443 mm left) and 8.272 ± 1.364 mm (mean 27.052 ± 3.471 mm right, 8.311 mm left), respectively. Mean pedicle size (length × width) was 27.241 × 8.04 mm in female patients and 26.913 × 8.444 mm in male patients (Table 1). Comparing female and male patients, statistical analysis revealed a significant difference between pedicle width (p = 0.012) but not length (p = 0.41). The measurements obtained when using direct CT axial cuts (Fig. 2) differed from those obtained from reconstructed OsiriX images for the same patient (Fig. 1). Pedicle lengths and widths measured from the original standard axial CT images were 15.5 ± 3.5 mm and 4.7 ± 1.7 mm, respectively, which are statistically smaller than lengths and widths measured by using interpolated images (p < 0.05).

According to the above measurements and an assumption that a 1-mm margin was needed on each side of the screw, 2 pedicles (2.1%) from 2 patients (4.3%) could not tolerate a 3.5-mm screw, and 3 pedicles (3.2%) from 3 patients (9.4%) could not tolerate a 4.5-mm screw. This finding differs from that found on standard CT sets in which 24% and 30% of the patients’ pedicles could not tolerate the 3.5- and 4.5-mm screws, respectively. For 3 patients (6%), aberrant vertebral artery anatomy precluded the use of a pedicle screw longer than 14 mm. In these patients, the artery coursed anteromedially along the anterior aspect of the pedicle screw trajectory. As a result, projected screw length had to be shortened to avoid potential vertebral artery injury. In patients with normal anatomy, the artery is more laterally located, allowing projected screws to pass along the entire length of the pedicle without interference. Reliability testing demonstrated that the results for length and width were reproducible with acceptable variation among the 3 observers. Cronbach alpha was used as the reliability coefficient and was greater than 0.70 for both length and width (0.710 and 0.840, respectively) (Table 2).

Discussion

The anatomical differences between pedicle and pars fixation at C-2 should be reviewed. Simply defined, the pars interarticularis is the pillar of bone between the superior articular facet of C-2 (which articulates with the C-1 lateral mass) and the inferior articular facet. The pedicle connects the vertebral body with the posterior elements of C-2. Differentiating between a pars screw and a pedicle screw can be confusing, possibly because the C-2 superior articular process is almost as anterior as the vertebral body. However, one difference is that a pedicle screw penetrates the C-2 vertebral body. Starting points and trajectories also differ (Fig. 3).3

When planning posterior cervical fixation including arthrodesis to C-2, detailed understanding of anatomy is imperative. Preoperative plain radiographs and CT images are useful for evaluating bony anatomy as well as identifying aberrant vertebral artery anatomy that might preclude the use of certain fixation techniques, such as pedicle screw fixation. Our objective was to determine whether

<table>
<thead>
<tr>
<th>TABLE 1: Axial pedicle anatomical measurements determined by variable angle interpolation of axial CT scans*</th>
</tr>
</thead>
<tbody>
<tr>
<td>Patients</td>
</tr>
<tr>
<td>----------</td>
</tr>
<tr>
<td>women</td>
</tr>
<tr>
<td>men</td>
</tr>
<tr>
<td>all</td>
</tr>
</tbody>
</table>

* Values are presented as the mean ± SD.
measurements made by using a variable virtual gantry angle for axial and reconstructed images would differ from measurements made from axial images obtained perpendicular to the long axis of the patient.

Previous studies have found that pedicle screws at C-2 cannot be tolerated in up to 25% of patients because of anatomical constraints or aberrant vertebral artery anatomy. The study by Bhatnagar et al. in 2010 used CT angiograms from a random population of patients admitted for trauma. Our study described here retrospectively reviewed the same patient population and the same CT angiograms but used interpolated reconstructed images made with a multidimensional program, OsiriX. In the Bhatnagar and colleague study, the C-2 pedicle lengths and widths were found to be significantly less than those obtained when we used OsiriX to change the gantry angle. These differences result from the fact that the software used in this study enables evaluation of the bony anatomy along the axis of the pedicle instead of at an oblique angle to the pedicle. As a result, the C-2 pedicle anatomy can be better appreciated and more accurately assessed. In addition, although not evaluated in this study, variations in starting points and screw angles can probably be better understood via interpolated imaging; these aspects might not be fully appreciated by looking at standard CT images. Future work will focus on variations in angulation and starting points when using variable virtual gantry angle interpolation.

By using variable axis interpolation, we found that pedicles can tolerate 3.5-mm and 4.0-mm pedicle screws that penetrate the C-2 vertebral body in over 90% of patients. This percentage is substantially higher than percentages determined by prior studies that used axial or sagittal imaging. A comparison with anatomical manual measurements might be helpful. In an anatomical study, Naderi et al. described the pediculoisthmic component, consisting of the wider superior pedicle and the narrower inferior isthmus. They reported an average pedicle length of 28.8 mm and found the pedicle width to be 11 mm superiorly and 6 mm inferiorly. Our results are comparable to their anatomical findings.

A limitation of the present study is that the original study used 2.6-mm cuts and data were interpolated from these images. Finer (0.5-mm) cuts would probably provide more accurate information. However, the images obtained in the emergency department are often the images used by the surgeon to plan surgery for trauma patients; thus, the data used in this study represent a probable real-world scenario. With regard to interpolation accuracy, a future study might compare submillimeter cuts and 2.6-mm cuts.

**Conclusions**

Axial-cut CT angiography might overestimate the

---

**TABLE 2: Cronbach interobserver reliability of pedicle length and width measurements**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Cronbach Alpha</th>
</tr>
</thead>
<tbody>
<tr>
<td>length</td>
<td>0.840</td>
</tr>
<tr>
<td>width</td>
<td>0.781</td>
</tr>
</tbody>
</table>

---

**Fig. 2.** Measurements of pedicle length and width obtained directly from a CT axial cut obtained in the same patient featured in Fig. 1.

**Fig. 3.** Axial (upper) and coronal (lower) views of a vertebral segment, showing the difference between pedicle (A) and pars screw (B) placement and trajectory. The starting point for a pedicle screw is more cephalad and aims more caudally. Reproduced with permission from Helgeson et al.: Accuracy of the freehand technique for 3 fixation methods in the C-2 vertebrae. Neurosurg Focus 31(4):E11, 2011.
Anatomical feasibility of C-2 pedicle screw fixation

potential risk for vertebral artery injury. Variable gantry angle interpolation more closely approximates manual anatomical specimen measurements and might provide more accurate information for surgical planning. Results of this study might be confirmed by further work that uses submillimeter axial cuts for interpolation.

Disclosure

Dr. O’Brien is a consultant for Globus, NuVasive, Stryker, and Relevant. He receives royalties from Globus and NuVasive.

Author contributions to the study and manuscript preparation include the following. Conception and design: O’Brien, Burke, Yu. Acquisition of data: O’Brien, Burke, Ho, Wagner. Analysis and interpretation of data: O’Brien, Burke, Ho, Wagner. Drafting the article: O’Brien, Burke, Ho, Wagner. 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: O’Brien. Statistical analysis: all authors. Administrative/technical/material support: O’Brien, Yu. Study supervision: O’Brien, Yu.

References


Accepted February 25, 2013.
Please include this information when citing this paper: published online March 29, 2013; DOI: 10.3171/2013.2.SPINE12798.
Address correspondence to: Joseph O’Brien, M.D., M.P.H., Department of Orthopaedic Surgery, George Washington University, 2150 Pennsylvania Avenue NW, Washington, DC 20037. email: jobrien@mfa.gwu.edu.