Anatomical considerations for cervical pedicle screw insertion: the use of multiplanar computerized tomography reconstruction measurements

MASSA KI CHAZON O, M.D., PH.D., SHIGERU SOSHI, M.D., PH.D., TAKESHI I NOUE, M.D., YOSHIKUNI KIDA, M.D., AND CHIKARA USHIKU, M.D.
Department of Orthopaedic Surgery, Jikei University School of Medicine, Tokyo, Japan

Object. The purpose of this study was to evaluate the linear and angular parameters of the vertebral body (VB) required for cervical pedicle screw (CPS) insertion by using multiplanar computerized tomography (CT) reconstructions.

Methods. Three hundred fifteen vertebrae from C-3 to C-7 in 63 patients were studied. Pedicle dimensions such as pedicle transverse angle (PTA), pedicle sagittal angle (PSA), and pedicle outer width (POW) were measured on axial CT reconstructions, as were linear parameters including the lateral mass thickness (LMT), the anteroposterior (AP) and mediolateral distances between spinal canal and transverse foramen, and spinal canal longitudinal and transverse diameter. In addition, the correlations between PTA and other parameters were calculated using univariate linear regression analysis.

The overall mean LMT ranged from 10.7 to 12.6 mm. The smallest mean AP spinal canal–transverse foramen distance was found at C-7 (1.1 mm), whereas the largest mean distance was at C-4 (3.1 mm). The smallest mean mediolateral spinal canal–transverse foramen distance was found at C-4 (1.2 mm), whereas the largest mean distance was at C-7 (4.7 mm). There were significant intergroup differences between male and female patients except for PTA and spinal canal longitudinal diameter. The PTA had a direct linear correlation with AP and mediolateral spinal canal–transverse foramen distances. The largest Pearson coefficient was 0.71 between the PTA and AP spinal canal–transverse foramen distance and the inverse one was −0.73 between the PTA and mediolateral spinal canal–transverse foramen distance.

Conclusions. Analysis of the data obtained in this study suggests that not only pedicle dimensions but also linear and angular parameters of the VB can be useful data when inserting a CPS.

KEY WORDS • computerized tomography • cervical spine • pedicle screw • anatomy

Abbreviations used in this paper: AP = anteroposterior; CFAPD = canal–foramen AP distance; CFMLD = canal–foramen mediolateral distance; CPS = cervical pedicle screw; CT = computerized tomography; LMT = lateral mass thickness; POW = pedicle outer width; PSA = pedicle sagittal angle; PTA = pedicle transverse angle; SCLD = spinal canal longitudinal diameter; SCTD = spinal canal transverse diameter; SD = standard deviation; VA = vertebral artery; VB = vertebral body.

POSTERIOR wire and lateral mass plate implantation techniques have been used in thoracocervical spine for decades.7,14 Although posterior CPS-augmented fusion has been gaining popularity and is used for various spinal disorder–related conditions of instability such as degenerative, traumatic, and inflammatory diseases,1–4 this procedure is associated with a much higher risk of catastrophic damage to the neural and vascular structures.11 Preoperative radiographic data, especially that derived from CT scans, are essential for the successful intraoperative placement of CPSs. With advances in imaging technology, multiplanar reconstructed CT scans enable the desired morphology of the pedicle to be analyzed in three dimensions. Many cadaveric and radiographic studies of CPS dimensions such as pedicle diameter, PTA, and pedicle length have been reported.5,6,12,13,15 We believe, however, that more detailed anatomical knowledge is required to optimize this technically demanding procedure. The aim of the present study was to evaluate linear and angular parameters pertinent for safe and accurate CPS insertion as well as pedicle dimensions by using multiplanar CT reconstruction.

Clinical Material and Methods

Patient Population

Sixty-three patients in whom multiplanar CT reconstructions were obtained following myelography for cervical spine surgery were included in this study. There were
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36 patients with cervical spondylotic myelopathy, 12 with disc herniation, seven with OPLL, two with cervical spondylotic amyotrophy, and six with other diseases. There were 46 males and 17 females who ranged in age from 14 to 80 years (mean 58 years). Patients with inflammatory and neoplastic diseases of the VB or congenital spine malformations were excluded from this study.

Scanning Protocol

Postmyelography CT scanning was performed using a multislice scanner (SOMATOM Sensation 4; Siemens Medical Solutions, Erlangen, Germany). Image data were generated for a 1.25-mm effective thickness at 0.9-mm reconstruction intervals. All images were routinely reformatted into axial planes parallel to the endplates of the VB and the sagittal planes across to the midline of the VB. The CT films were scanned at 600 dpi with a scanning driver (Epson ES-10000G; Seiko-Epson, Tokyo, Japan) and edited using Photoshop version 7.0 software (Adobe System, Inc., San Jose, CA). Axial images of the largest pedicle diameter were selected from C-3 to C-7 and the following pedicle dimensions were determined PTA (that is, the angle between the pedicle axis and the midline of VB) and POW (that is, the mediolateral diameter of the pedicle isthmus perpendicular to the pedicle axis), and PSA (that is, the angle between a line parallel to the longitudinal pedicle axis and a line parallel to the superior endplate of VB). In addition, linear parameters including LMT (that is, the distance from the posterior cortex of the lateral mass to the posterior edge of the transverse foramen), CFAPD (that is, the distance from the anterior aspect of spinal canal to the posterior edge of the transverse foramen), CFMLD (that is, the distance from the lateral aspect of spinal canal to the medial edge of the transverse foramen), SCLD, and SCTD were measured (Figs. 1 and 2).

Statistical Analysis

The aforementioned measurements were made using public domain Scion image software (version alpha 4.0. 3.2; http://www.scioncorp.com). Means and SDs were calculated for all pedicle dimensions and the linear parameters adjacent to the pedicle. In addition, the frequency distribution of the POW was evaluated at the respective cervical level. Furthermore, the correlations between the linear parameters and PTA were calculated using univariate linear regression analysis and expressed as Pearson correlation coefficients. All statistical analyses were performed using SPSS software version 11.0 (SPSS, Inc., Chicago, IL).

Results

Axial and sagittal CT scans obtained in the 63 patients and showing 315 vertebrae from C-3 to C-7 were evaluated. The means and SDs of the angular and linear measurements were calculated for each level separately for male and female patients. There were significant intersex differences except for PTA and SCLD values (Table 1).

Pedicle Outer Width

The overall mean POW ranged from 5.4 to 6.6 mm (Fig. 3). The smallest mean POW was found at C-3 in both males (5.6 mm) and females (4.6 mm); the largest mean POW was at C-7 in both males (6.9 mm) and females (6 mm). The mean value gradually increased toward the caudal level. The POW in males was greater than in females at all levels, and this difference was significant at all levels (p < 0.01). The incidence of POW less than 4 mm was 8.5% at C-3, 7.9% at C-4, 1.6% at C-5, and 0% at C-6 and C-7 (Table 2).

Pedicle Transverse and Sagittal Angles

The overall mean PTA ranged from 33.6 to 50.2˚ (Fig. 4 upper). The smallest mean PTA was found at C-7 in both males (33.4˚) and females (34.1˚); the largest mean PTA was found at C-4 in both males (50.4˚) and females (49.6˚). There was no statistically significant interlevel difference in these values. On the other hand, the overall mean PSA varied from 13.7˚ in the cephalad direction at C-3 to 3.3˚ caudally at C-7 (Fig. 4 lower). The largest mean PSA was documented at C-3 in both males (14˚) and females (12.9˚), whereas the smallest was at C-7 in both males (−2.9˚) and females (−4.1˚). We found that transition of the neutral plane occurred at the C4–5 level. There were no significant differences in PSA except at C-5.

Lateral Mass Thickness

The overall mean LMT ranged from 10.7 to 12.6 mm. The mean LMT at C-7 was thinner than that at C-3 to C-6. The mean LMT in males was greater than that in females at all levels. The intersex differences were statistically significant at all levels (p < 0.05 [males] and p < 0.01 [females]).
The CFAPD and CFMLD

The overall mean CFAPD ranged from 1.1 to 3.1 mm. The smallest mean CFAPD was found at C-7 both in males (1.3 mm) and females (0.7 mm); the largest mean CFAPD was found at C-4 both in males (3.3 mm) and females (2.5 mm). At C-3, C-4, C-5, and C-6, the intersex differences were significant (p < 0.05 [males] and p < 0.01) [females]. The overall mean CFMLD ranged from 1.2 to 4.7 mm. The smallest mean CFMLD was found at C-4 both in males (1.5 mm) and females (0.7 mm), whereas the largest mean CFMLD was at C-7 both in males (5 mm) and females (4 mm). There were statistically significant intersex differences at C-3, C-4, C-5, and C-7 (p < 0.01).

### TABLE 1

Summary of linear and angular parameters of cervical pedicles and vertebrae obtained using multiplanar CT reconstructions*

<table>
<thead>
<tr>
<th>Vertebra</th>
<th>POW (mm)</th>
<th>PTA (°)</th>
<th>PSA (°)</th>
<th>LMT (mm)</th>
<th>CFAPD (mm)</th>
<th>CFMLD (mm)</th>
<th>SCLD (mm)</th>
<th>SCTD (mm)</th>
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<tbody>
<tr>
<td><strong>C-3</strong></td>
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<td></td>
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<tr>
<td>overall</td>
<td>5.4 ± 1.1</td>
<td>46.0 ± 4.7</td>
<td>13.7 ± 5.0</td>
<td>12.2 ± 1.6</td>
<td>2.5 ± 1.2</td>
<td>1.8 ± 1.2</td>
<td>11.8 ± 1.3</td>
<td>22.6 ± 1.7</td>
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<tr>
<td>male</td>
<td>5.7 ± 1.0</td>
<td>45.7 ± 4.9</td>
<td>14.0 ± 5.4</td>
<td>12.5 ± 1.4</td>
<td>2.6 ± 1.3</td>
<td>2.1 ± 1.2</td>
<td>11.8 ± 1.3</td>
<td>23.0 ± 1.6</td>
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<tr>
<td>female</td>
<td>4.6 ± 0.9</td>
<td>47.0 ± 3.9</td>
<td>12.9 ± 3.8</td>
<td>11.6 ± 1.7</td>
<td>1.9 ± 0.9</td>
<td>1.1 ± 1.0</td>
<td>11.8 ± 1.3</td>
<td>21.5 ± 1.6</td>
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<td><strong>C-4</strong></td>
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<tr>
<td>overall</td>
<td>5.5 ± 1.0</td>
<td>50.2 ± 4.7</td>
<td>5.3 ± 5.6</td>
<td>11.8 ± 1.5</td>
<td>3.1 ± 1.2</td>
<td>1.2 ± 0.9</td>
<td>11.0 ± 1.3</td>
<td>24.0 ± 1.6</td>
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<tr>
<td>male</td>
<td>5.8 ± 1.0</td>
<td>50.4 ± 4.6</td>
<td>5.7 ± 5.8</td>
<td>12.2 ± 1.3</td>
<td>3.3 ± 1.2</td>
<td>1.5 ± 0.8</td>
<td>11.0 ± 1.3</td>
<td>24.4 ± 1.5</td>
</tr>
<tr>
<td>female</td>
<td>4.9 ± 0.9</td>
<td>49.6 ± 5.1</td>
<td>4.1 ± 4.8</td>
<td>10.8 ± 1.4</td>
<td>2.5 ± 1.1</td>
<td>0.7 ± 1.0</td>
<td>11.0 ± 1.2</td>
<td>23.0 ± 1.4</td>
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<td><strong>C-5</strong></td>
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<tr>
<td>overall</td>
<td>5.7 ± 0.9</td>
<td>48.1 ± 6.2</td>
<td>−1.3 ± 4.1</td>
<td>12.3 ± 1.4</td>
<td>2.9 ± 1.3</td>
<td>1.5 ± 0.9</td>
<td>11.4 ± 1.3</td>
<td>25.2 ± 2.0</td>
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<tr>
<td>male</td>
<td>5.9 ± 0.9</td>
<td>47.8 ± 6.1</td>
<td>−0.5 ± 4.0</td>
<td>12.7 ± 1.2</td>
<td>3.1 ± 1.2</td>
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<td>11.3 ± 1.3</td>
<td>25.5 ± 2.0</td>
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<tr>
<td>female</td>
<td>4.9 ± 0.7</td>
<td>48.9 ± 6.3</td>
<td>−3.2 ± 4.0</td>
<td>11.3 ± 1.4</td>
<td>2.1 ± 1.3</td>
<td>1.0 ± 0.9</td>
<td>11.7 ± 1.2</td>
<td>24.3 ± 1.6</td>
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<td><strong>C-6</strong></td>
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<tr>
<td>overall</td>
<td>5.9 ± 0.8</td>
<td>43.3 ± 5.8</td>
<td>−3.0 ± 4.3</td>
<td>12.6 ± 1.6</td>
<td>2.2 ± 1.2</td>
<td>2.2 ± 0.8</td>
<td>11.9 ± 1.4</td>
<td>25.0 ± 1.7</td>
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<tr>
<td>male</td>
<td>6.1 ± 0.7</td>
<td>43.3 ± 5.6</td>
<td>−2.7 ± 4.0</td>
<td>13.0 ± 1.4</td>
<td>2.5 ± 1.2</td>
<td>2.3 ± 0.8</td>
<td>11.9 ± 1.4</td>
<td>25.3 ± 1.6</td>
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<tr>
<td>female</td>
<td>5.3 ± 0.7</td>
<td>43.2 ± 6.5</td>
<td>−3.7 ± 5.1</td>
<td>11.4 ± 1.5</td>
<td>1.6 ± 1.1</td>
<td>1.9 ± 0.9</td>
<td>11.9 ± 1.3</td>
<td>24.1 ± 1.8</td>
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<tr>
<td><strong>C-7</strong></td>
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<tr>
<td>overall</td>
<td>6.7 ± 1.1</td>
<td>33.6 ± 5.8</td>
<td>−3.3 ± 4.0</td>
<td>10.7 ± 2.0</td>
<td>1.1 ± 1.2</td>
<td>4.7 ± 1.3</td>
<td>12.4 ± 1.4</td>
<td>23.6 ± 1.7</td>
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<tr>
<td>male</td>
<td>7.0 ± 0.9</td>
<td>33.4 ± 5.7</td>
<td>−2.9 ± 4.5</td>
<td>11.2 ± 2.1</td>
<td>1.3 ± 1.3</td>
<td>5.0 ± 1.4</td>
<td>12.6 ± 1.4</td>
<td>24.0 ± 1.7</td>
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<tr>
<td>female</td>
<td>6.0 ± 1.0</td>
<td>34.1 ± 6.2</td>
<td>−4.1 ± 2.4</td>
<td>9.3 ± 1.1</td>
<td>0.7 ± 0.9</td>
<td>4.0 ± 0.6</td>
<td>12.1 ± 1.1</td>
<td>22.6 ± 1.6</td>
</tr>
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</table>

* Values are presented as the means ± SDs.
† Significant sex difference, p < 0.01.
‡ Significant sex difference, p < 0.05.
The SCLD and SCTD

The overall mean SCLD ranged from 11.0 to 12.4 mm. The smallest mean SCLD was found at C-4 both in males and females (11 mm), whereas the largest was at C-7 both in males (12.6 mm) and females (12.1 mm). Surprisingly, no statistically significant intersex difference was evident at any level. The overall mean SCTD ranged from 22.6 to 25.2 mm. The smallest mean SCTD was found at C-3 both in males (23 mm) and females (21.6 mm), whereas the largest was at C-5 both in males (25.5 mm) and females (24.3 mm). The dimensions in males were greater than those in females at all levels and this difference was statistically significant at all levels (p < 0.01).

Correlations With PTA

Linear regression analysis was performed to investigate the degree of correlation between PTA and the linear parameters. The correlation was examined using Pearson correlation coefficients. The highest correlation coefficient was 0.71 and the coefficient of determination between PTA and CFAPD was 0.5, whereas the highest inverse coefficient was -0.73 and the coefficient of determination between PTA and CFMLD was 0.53 (Table 3). Thus, the further transverse foramen extended anteriorly and medially to the lateral edge of spinal canal, the greater the PTA. According to the linear regression analysis of our study, PTA of 45° corresponded to a CFAPD of 2.46 mm or CFMLD of 2.16 mm.

Discussion

Several cadaveric and radiographic series involving the possibility of CPS insertion have been reported. Panjabi, et al., first reported the three-dimensional anatomy of cadaveric specimens of the cervical spine and found that the smallest level of pedicle transverse width was at C-3, with a subsequent increase in size down to C-7. Karaikovic, et al., investigated cervical pedicle morphometry by using manual and CT measurements. Using CT to obtain measurements in living individuals is believed to provide information that is more accurate than that possible by making manual measurement of specimens. In the present study we found that the mean PTA was approximately 45° from C-3 to C-6 and 33° at C-7, values consistent with previous studies. Although axial CT measurements facilitate CPS trajectory, multiplanar CT reconstruction enables sagittal pedicle dimensional information to be obtained as well as the axial measurements in vivo. With regard to the PSA in the present study, the C-3 and C-4 pedicle axes were slightly elevated compared with the superior endplate of the VB, and those at C-5, C-6, and C-7 were parallel and directed slightly downward. This trend was consistent with the findings presented in other reports, although the reference line to the sagittal pedicle axis differs slightly, depending on the data reported. In the clinical setting, fluoroscopic images can sometimes be difficult to interpret when obtained in the sagittal pedicle path because of the pedicle’s small size, a patient’s obesity, and overlying structures obscuring its anatomy. Therefore, the preoperative anatomical evaluation of the sagittal pedicle angulation also necessitates the intraoperative screw placement.

First, one of the radiographic criteria required for a surgeon to make a decision concerning screw size is POW. We found that the mean widths were significantly greater in males than in females at all levels. This finding indicates that sex differences in pedicle diameter should be carefully considered when performing CPS fixation.
the present study, however, we found that the POW was almost equivalent to that reported in other CT-based studies.\textsuperscript{9,13}

Second, special attention should be directed toward assessing the PTA. Abumi, et al.,\textsuperscript{3} have proposed that the optimal point of screw penetration in the C3–7 pedicles was slightly lateral to the center of the articular mass and close to the inferior margin of the inferior articular process of the cranially adjacent vertebra. In the transverse plane, the optimal insertion angle of the CPS from C3–7 was 25 to 45° medially. Furthermore, many investigators have evaluated pedicle axis length in cadaveric and CT-based studies to determine optimal screw length.\textsuperscript{8,9,13,15} The data reported in the aforementioned reports indicate that the diameter and angle of pedicle and the entry point at the posterior cortex of lateral mass are of paramount importance during transpedicular screw placement. Sakamoto, et al.,\textsuperscript{15} have reported that the screw insertion angle should be as close as possible to 50° in the transverse plane and that the entry point of the CPSs should be located as laterally as possible on the posterior surface of the lateral mass. During surgery, wide exposure of lateral portion of the lateral mass is required. Thus, the larger PTA and the longer the distance between the posterior cortex of lateral mass and the pedicle, the higher the risk is that the pedicle will be breached. In the present study, we attempted to measure the linear parameters as well as pedicle dimensions in the transverse plane to determine the optimal screw track as well as the limitation of screw insertion. Regarding the transverse diameter of the pedicle, the following were smaller or equal to 4 mm: 8.5% at C-3, 7.9% at C-4, and 1.6% at C-5, despite the fact that most of the pedicle outer

*Fig. 4. Graphs showing the mean PTA (upper) and the mean PSA (lower) in males and females.*
diameters in the present study were 4 mm or larger. These findings indicate the high degree of variability in sizes and imply anatomical limitation of screw penetration within the pedicle wall. Although the use of CPSs smaller than 4.5 mm was a suggestion posed in a previous study, our CT-based findings suggest that the choice of appropriate screw size should depend on the level at which the screw is to be inserted.

Last, the association between the transverse foramen and spinal canal at each level was investigated.Consequently, the following anatomical mapping of the VA in relation to the spinal canal was identified: the VA was located most anteriorly and medially to the spinal canal at C-4 and most laterally at C-7, based on the CFAPD and CFMLD values. Moreover, we found a linear correlation between PTA and the location of transverse foramen relative to the spinal canal: a PTA of 45˚ corresponded to a CFAPD of 2.46 mm or a CFMLD of 2.16 mm. Thus, the farther the transverse foramen extended to the anterior and medially to the lateral edge of spinal canal, the greater the PTA, suggesting that there may be increased risk of injury to the VA when inserting CPSs. We believe that a greater angle of the instrument is associated with a higher risk of injuring the neurovascular structure when using a standard midline posterior approach.

Conclusions

The findings of our CT-based anatomical study suggest that one should be alert to the relationship between the transverse foramen and spinal canal and that the screw angle and the optimal screw diameters required to engage the cortical shell of the pedicle should be evaluated preoperatively. Additional investigations and thorough knowledge of cervical anatomy will be needed for safe and accurate placement of CPSs.

References


Manuscript received February 8, 2006. Accepted in final form March 24, 2006. Address reprint requests to: Masaaki Chazono, M.D., Ph.D., Department of Orthopaedic Surgery, Jikei University School of Medicine, 3-25-8, Nishi-shinbash i, Minato-ku, Tokyo, 105-8461 Japan. email: chazono@jikei.ac.jp.