Computed tomography–based determination of a safe trajectory for placement of transarticular facet screws in the subaxial cervical spine

Clinical article

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Object. Placement of transarticular facet screws is one option for stabilization of the subaxial cervical spine. Small clinical series and biomechanical data support their role as a substitute for other posterior stabilization techniques; however, the application of transarticular facet screws in the subaxial cervical spine has not been widely adopted, possibly because of surgeon unfamiliarity with the trajectory. In this study, the authors’ objective is to define insertion points and angles of safe trajectory for transarticular facet screw placement in the subaxial cervical spine.

Methods. Thirty fine-cut CT scans of cervical spines were reconstructed in the multiplanar mode and evaluated for safe transarticular screw placement in the subaxial cervical spine (C2–3, C3–4, C4–5, C5–6, C6–7). As in placement of lateral mass screws, the vertebral artery and exiting nerve root were bypassed posterolaterally. The entry point was set 1 mm medial and 1 mm caudal to the center of the lateral mass. From this entry point, the sagittal angulation was set to traverse the facet joint plane approximately perpendicularly. For the axial angulation, the exit point was set posterolaterally to the transverse process. After ideal insertion angles and screw lengths were identified, the trajectory was simulated on CT scans of 20 different cervical spines to confirm safe screw placement.

Results. The mean optimal mediolateral insertion angles (± SD) were as follows: 23° ± 5° at C2–3; 24° ± 4° at C3–4; 25° ± 5° at C4–5; 25° ± 4° at C5–6; and 33° ± 6° at C6–7. The mean sagittal insertion angles measured to the sagittal projection of the facet joint space were as follows: 77° ± 10° at C2–3; 77° ± 10° at C3–4; 80° ± 11° at C4–5; 81° ± 8° at C5–6; and 100° ± 11° at C6–7. The mean trajectory lengths were 15 ± 2 mm at C2–3; 14 ± 1 mm at C3–4; 15 ± 1 mm at C4–5; 16 ± 2 mm at C5–6; and 23 ± 4 mm at C6–7. Simulation of these insertion angles on 20 different cervical spine CTs yielded a safe trajectory in 85%–95% of spines for C2–3, C3–4, C4–5, C5–6, and C6–7.

Conclusions. The calculated optimal insertion angles and lengths for each level may guide the safe placement of subaxial cervical transfacet screws.


KEY WORDS • cervical spine fusion • cervical spine fixation • transarticular screw • facet joint screw • subaxial spine

THE USE OF TRANSARTICULAR FACET SCREWS IS AN ESTABLISHED fixation technique for the atlantoaxial joint and has been shown to result in excellent stability.1 In the subaxial cervical spine, the use of transarticular facet screws for fixation was first pioneered by Roy-Camille and Saillant14 in 1972, but this technique has not been widely adopted in the spine surgery community. One reason may be that spine surgeons are less familiar with the trajectory of a subaxial cervical transarticular facet screw as compared with the routes used for other techniques such as placement of lateral mass screws.6,10,13 Nevertheless, available biomechanical data suggest that transarticular screw constructs achieve mechanical properties comparable to those of lateral mass screw constructs.2,7,12

Successful application of a transarticular facet screw relies on a safe trajectory that does not jeopardize the vertebral artery, the nerve root, or the spinal cord. Anatomical guidelines for a safe cervical transarticular screw insertion were recently established in cadaveric specimens.3 In the
For the sagittal trajectory was referenced to the sagittal projection of the vertebral body. The maximal angle was defined as the angle between a line that connects the entry point on the cephalad lateral mass with a straight AP line parallel to the vertebral body. This was about midway between the minimal and maximal angle. Screw or trajectory length was defined as distance from entry point to exit point and measured in the reconstructed axial plane.

**Methods**

**Study Population**

All cervical spine CT studies done for either trauma evaluation or for preoperative surgical planning between August 2010 and January 2011 at our institution were initially reviewed. Only studies for patients without fracture or dislocation of the cervical spine were included. Patients with advanced degenerative or inflammatory changes (for example, patients with ankylosing spondylitis) in the cervical spine were not included. Among the studies, we only evaluated those with a cut thickness of 1.25 mm or less. We used the first 30 consecutive fine-cut cervical CT scans for trajectory analysis and the next 20 for trajectory testing.

**Trajectory Simulation**

Cervical spine CT scans were viewed with the 32-bit research version of the DICOM viewer Osirix (Pixmeo) on an Apple Macintosh computer. The facet joints at C2–3, C3–4, C4–5, C5–6, and C6–7 were analyzed on both sides.

**Determination of Sagittal and Mediolateral Angles**

The multiplanar reconstruction mode was used to visually determine the sagittal and axial (mediolateral) trajectory of the transarticular facet screw. Because the axial view in the multiplanar mode corresponds to the chosen sagittal plane and vice versa, the combination of the 2 planes allows for a precise analysis of the screw trajectory. The sagittal insertion angle (α) was referenced to the sagittal projection of the joint surface. The mediolateral angle (β) was referenced to a straight AP line, parallel to the vertebral body (Fig. 1). Three angles were measured in the axial plane: the minimal, optimal, and maximal mediolateral angles. The minimal angle was defined as the angle between a line connecting the entry point on the cephalad lateral mass with the lateral border of the transverse foramen of the caudal vertebra and a straight AP sagittal line parallel to the vertebral body. The maximal angle was defined as the angle between a line that connects the entry point on the cephalad lateral mass with the lateral border of the caudal lateral mass and a straight AP line parallel to the vertebral body (Fig. 1). The sector between the minimal and maximal angle represented the safety zone. Optimal angle was defined as the angle between a line safely traversing the facet joint lateral to the transverse foramen and a straight AP line parallel to the vertebral body. This was about midway between the minimal and maximal angle. Screw or trajectory length was defined as distance from entry point to exit point and measured in the reconstructed axial plane.

**Results**

**Anatomical Basis for the Transarticular Trajectory**

The transarticular screw should safely pass through four cortices, be entirely encased by bone, and avoid injury to the exiting nerve root, vertebral artery, and spinal cord. In addition, the landmarks to guide this trajectory must lie within the limits of the exposure for a posterior approach to the cervical spine. In analogy to lateral mass screws, the vertebral artery and exiting nerve root are bypassed posterolaterally. The entry point for the C2–3 transarticular screw was in the cephalad and medial quadrant of the isthmus, which corresponds to the entry site for a C-2 pedicle screw. On the lateral masses of C-3 to C-6, the entry point was set 1 mm medial and 1 mm caudal to the center of the lateral masses (Fig. 2), as previously suggested. From this entry point, the sagittal trajectory was set to traverse the facet joint and incorporate the superior and inferior lateral masses (Fig. 2). For the axial trajectory, the exit point was set posterolateral to the transverse process in the middle of the safety zone for C2–3, C3–4, and C4–5 (Fig. 2). The lateral masses of C-3, C-4, and C-5 are relatively large and separated by a groove from their transverse processes, which are in turn relatively small. In contrast, the lateral mass and transverse process of C-7 show a transitional anatomy: the lateral mass is more shallow and less prominent whereas the transverse process is bigger and extends more laterally than at C3–5 (Fig. 3). Accordingly, there is practically no groove between the lateral mass and transverse process of C-7. Therefore, the axial trajectory for the transarticular screw C6–7 was set to pass into the transverse process of C-7. At C5–6, this relationship is somewhat inconsistent: a groove may be present or almost nonexistent (Fig. 4). Therefore, the trajectory of C5–6 is aimed to exit at the upper outer quadrant of the C-6 lateral mass, which may or may not be posterolateral to the C-6 transverse process.

**Ideal Trajectory Identification**

High-resolution CTs of 30 cervical spines were analyzed to find the insertion angles of the optimal transarticular trajectory. The mean patient age was 41 ± 13 years (range 17–64 years).

The mean optimal mediolateral insertion angles (β) were 23° ± 5° at C2–3; 24° ± 4° at C3–4; 25° ± 5° at C4–5; 25° ± 4° at C5–6; and 33° ± 6° at C6–7 (Table 1). The mean sagittal insertion angles (α) measured to the sagittal projection of the facet joint space were 77° ± 10° at C2–3; 77° ± 10° at C3–4; 77° ± 10° at C4–5; 77° ± 10° at C5–6; and 77° ± 10° at C6–7.
± 10° at C3–4; 80° ± 11° at C4–5; 81° ± 8° at C5–6; and 100° ± 11° at C6–7. The mean screw lengths were 15 ± 2 mm at C2–3; 14 ± 1 mm at C3–4; 15 ± 1 mm at C4–5; 16 ± 2 mm at C5–6; and 23 ± 4 mm at C6–7.

Trajectory Testing

The trajectory was tested on a different sample of 20 cervical spine CTs. The mean patient age was 44 ± 18 years (range 17–81 years). At C2–3, the trajectory was good for 90% of joints (36 of 40); it was too flat for 1 joint, too long for 1, and too short for 2. At C3–4, the trajectory was good for 95% of joints (38 of 40): it was too steep for 1 and too long for 1. At C4–5, the trajectory was good for 85% of the joints (34 of 40): it was too lateral and too flat for 1; too flat for 95% of joints (38 of 40): it was too steep for 1 and too long for 1. At C4–5, the trajectory was good for 85% of the joints (34 of 40): it was too lateral and too flat for 1; too flat for
Trajectory for subaxial cervical transarticular facet screws

for 3; too medial and too steep for 1; and too lateral, too flat, and too long for 1. At C5–6, the trajectory was good for 90% (36 of 40); it was too lateral for 1, too medial for 1, and too flat for 2. At C6–7, the trajectory was good for 95% (38 of 40); it was too flat for 1 and too lateral for 1. The trajectories that were too medial at C4–5 and C5–6 did not jeopardize the transverse foramen with use of a 15-mm- or 16-mm-length screw, respectively.

All trajectories were also tested for a screw length of 14 mm, and engagement of the inferior (distal) lateral mass by 4 mm or more was hypothesized to be sufficient. Seven (17.5%) of 40 trajectories were too short at C2–3; none were too short at C3–4, C4–5, or C5–6; and 8 (20%) were too short at C6–7.

Discussion

The findings of this CT-based study suggest that transarticular screws can safely be placed in the subaxial spine with an entry point that is 1 mm medial and 1 mm inferior to the center of the lateral mass of C-3 to C-6 and with a caudolateral trajectory. The entry point at C-2 is in the upper and medial quadrant of the isthmus, which corresponds to the entry point for a C-2 pedicle screw. The mean optimal sagittal insertion angle (α, Fig. 1) was referenced to the joint space, which is the centerpiece of the transfacet fixation. This angle was 77° at C2–3 and increased to 100° at C6–7 (Table 1). This finding supports the approximately perpendicular sagittal angle described in prior biomechanical studies. In analogy to lateral mass screws, transarticular facet screws may be placed by freehand technique using anatomical landmarks and correct insertion angles in the sagittal and axial plane. The right-angled tip of a dissector or Bovie cautery may be introduced into the joint space and the shaft of the instrument used to identify the drilling direction in the sagittal plane. Alternatively, fluoroscopic imaging of the facet joint space shows the reference plane for the sagittal angle, but the lower part of the cervical spine is often obscured by the shoulders. Also, fluoroscopy offers limited information to tailor the axial trajectory for a given transarticular screw. Again, knowledge of the axial trajectory angle in combination with an exposure of the lateral edge of the facet joints directs the freehand technique: from C2–3 to C5–6, the mediolateral angle ranges from 23° to 25°, and it is noticeably more lateral (33°) at C6–7 (Table 1). Nevertheless, Table 1 demonstrates the range for the optimal insertion angles in different cervical spines, and the mean angle may be too steep, too flat, too medial, or too lateral for a given spine. A trajectory that is chosen too shallow or too lateral may bypass the inferior lateral mass, and a trajectory that is too medial and too steep may jeopardize the exiting nerve root or vertebral artery (Table 2). Therefore, the angles should be virtually tested before surgery for applicability to the individual patient. Where available, image guidance may greatly assist the safe placement of a transarticular screw in the subaxial cervical spine.

Takayasu et al. used a straight dorsoventral angle as opposed to the mediolateral angle suggested herein. Although they did not report on any clinical violations of the vertebral artery, a recent cadaveric study demonstrated potential risks. Zhao et al. compared the mediolateral trajectory used by DalCanto et al. with the straight dorsoventral technique as proposed by Takayasu et al. No vertebral artery violation occurred with the former technique, but 8 of 32 screws that were inserted with the straight technique between C-4 to C-7 violated the vertebral artery: 3 at C5–6 and 5 at C6–7. Encroachment on the anterior branches of nerve roots was found in 11 of 32 screws with the Takayasu method and in 2 of 32 screws with the DalCanto technique. A further comparison showed superiority of the Klekamp method and in 2 of 32 screws with the DalCanto technique. No vertebral artery violation occurred with the former technique, but 8 of 32 screws that were inserted with the straight technique as proposed by Takayasu et al. No vertebral artery violation occurred with the latter technique. Zhao et al. compared the mediolateral trajectory used by DalCanto et al. with the straight dorsoventral technique as proposed by Takayasu et al. No vertebral artery violation occurred with the former technique, but 8 of 32 screws that were inserted with the straight technique between C-4 to C-7 violated the vertebral artery: 3 at C5–6 and 5 at C6–7. Encroachment on the anterior branches of nerve roots was found in 11 of 32 screws with the Takayasu method and in 2 of 32 screws with the DalCanto technique. A further comparison showed superiority of the Klekamp technique in terms of neurovascular risks and facet fractures. Using an entry point similar to the one we used in the present study, Klekamp et al. entered the superior lateral mass 1 mm medial and 1 mm inferior to the center, whereas DalCanto et al. entered 2 mm caudal to the center of the lateral mass.

To our knowledge, there is only one other study that has systematically searched for the optimal transarticular screw trajectory in the subaxial spine. Based on a cadaveric study of transarticular screws, Liu et al. recently suggested a mediolateral angle of 16° and a caudal sagittal angle of 37° for C2–3 through C5–6. The sagittal angle was referenced to the surface of the superior lateral mass and would also approximate a perpendicular passage through the joint space. Both angles are within the range of our study (Table 1), which does, however, propose a wider mean angle for the axial trajectory. As with Takayasu’s technique, a more medial trajectory might entail greater risks to the vertebral artery.

A trial of the mean trajectory findings on a different

<table>
<thead>
<tr>
<th>Level</th>
<th>Mediolateral Angle (°)</th>
<th>Optimal Sagittal Angle (°)</th>
<th>Screw Length (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Optimal</td>
<td>Minimal</td>
<td>Maximal</td>
</tr>
<tr>
<td>C2–3</td>
<td>23 ± 5 (14–34)</td>
<td>8 ± 5 (0–24)</td>
<td>46 ± 6 (30–59)</td>
</tr>
<tr>
<td>C3–4</td>
<td>24 ± 4 (17–33)</td>
<td>7 ± 4 (0–21)</td>
<td>47 ± 6 (34–60)</td>
</tr>
<tr>
<td>C4–5</td>
<td>25 ± 4 (10–34)</td>
<td>6 ± 4 (0–15)</td>
<td>44 ± 7 (30–60)</td>
</tr>
<tr>
<td>C5–6</td>
<td>25 ± 4 (17–36)</td>
<td>7 ± 4 (0–17)</td>
<td>44 ± 6 (34–64)</td>
</tr>
<tr>
<td>C6–7</td>
<td>33 ± 6 (21–50)</td>
<td>15 ± 5 (3–26)</td>
<td>52 ± 6 (42–69)</td>
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</table>

* Values are presented as means ± SD (range).
† Mediolateral angle in the axial plane.
‡ The sagittal angle is the rostrocaudal angle referenced to the joint surface (see Fig. 1).
sample of 20 subaxial cervical spine CTs yielded a safe screw placement in 85%–95% of spines. Of a total of 200 tested trajectories, 3 (1.5%) were too medial, imposing a potential risk of neurovascular injury. These findings suggest that the presented trajectories are safe for application of transarticular screws in the subaxial cervical spine. A trajectory length of 15 mm in C2–3 and 14 mm in C3–4, C4–5, and C5–6 appears to be appropriate for most transarticular screws; however, such a screw may stop short of the second cortical wall in the inferior lateral mass. How pullout strength is influenced by a tricortical versus a quadricortical purchase and its clinical significance should be the subject of future investigations. The ideal trajectory at C6–7, which may accommodate a screw length of about 23 mm, might require removal of the spinous process and the vertebral artery enters the transverse foramen at C-7 in only 0.6%–0.8% of cases, the transarticular trajectory for C6–7 appears safe for most cases, even if the screw tip breaches the ventral wall of the transverse process of C-7.14

Drawbacks of this study must be considered: this is a virtual assessment of the safe trajectory for transarticular screw placement. Whereas the original DICOM data sets were used and the software's accuracy is comparable with that of other multiplanar reconstruction applications,17 the practicability of this trajectory has not been assessed in a clinical series or in cadaveric cervical spine studies. Furthermore, the sample included a young population with a mean age of 41 years for the trajectory finding and 44 years for trajectory testing. Transarticular facet screws are likely to be used in older patients to stabilize and fuse the spine after laminectomy or to back up an anterior decompression and fusion. These patients may have advanced degenerative changes and less favorable bone, which may hamper the identification of landmarks and impede the application of transarticular facet screws. Concerns have been raised about the occiput impeding transarticular screw placement in the upper subaxial cervical spine.9 The present study setting did not allow assessment for this problem because the cervical spine CTs showed a neutral or slightly extended spine as opposed to the flexed position of the occipitocervical junction during surgery. In a clinical series of transarticular screws in the subaxial cervical spine, Takayasu et al.15 were able to place the majority of attempted C2–3 transarticular screws. Placement of the patient in the “military tuck” position will increase the clearance between the occiput and cervical spine, and a preoperative “military tuck” radiograph may reveal whether anatomical constraints must be anticipated (Table 3). Nevertheless, surgery in some patients might require specialized tools, such as angled drills and screwdrivers, for instrumentation.

Guidelines with lateral and caudal angles for transarticular screws cannot replace a careful assessment of a patient's preoperative cervical CT scan. Even though we found a high rate of safe screw trajectories by using our mean angles on a second sample of cervical spines, failure to modify the angles according to anatomical variability will lead to some screws being misplaced.

Laboratory investigations have demonstrated the promising role of subaxial transarticular screws as alternatives to lateral mass screws. In small cadaveric studies, transarticular facet screws, with or without rods, demonstrated biomechanical properties similar to those of lateral mass screws in terms of pullout strength2 and rigidity to flexion, extension, lateral bending, and axial torque, with or without connecting rods.2,12 Transarticular facet fixation to back up a double corpectomy with strut grafting resulted in lower stiffness for flexion and extension, but similar stiffness for lateral bending or axial torsion, when compared with a lateral mass screw-rod construct. After addition of an anterior plate, the 2 constructs performed identically.8

Contemporary lateral mass fixation systems are safe, versatile, and modular, but very costly. Rigidity relies on the connecting rods, which in turn can be used for intraoperative correction of deformities or luxations. The same lateral mass screws can be placed transarticularly, potentially saving a pair of screws at the caudal anchoring level. Alternatively, 3.5-mm AO cortical screws, as used in osteosynthesis of peripheral bones, can be used as stand-

### TABLE 3: The surgical steps for placement of transarticular facet screws in the subaxial cervical spine

<table>
<thead>
<tr>
<th>Trajectory Angle &amp; Length</th>
<th>Too Lateral</th>
<th>Too Medial &amp; Too Long</th>
</tr>
</thead>
<tbody>
<tr>
<td>Too Steep</td>
<td>bypasses inferior LM</td>
<td>jeopardizes exiting nerve root or VA</td>
</tr>
<tr>
<td>Too Shallow</td>
<td>bypasses inferior LM</td>
<td>jeopardizes inferior LM &amp; VA</td>
</tr>
</tbody>
</table>

* LM = lateral mass; VA = vertebral artery.
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alone fixation.” Transarticular facet fixation is applicable to trauma, posterior fixation after laminectomy, posterior backup after ventral decompression and fusion, and as potential bail-out for failed lateral mass screw placement. 3,8,15

Conclusions

The present study provides mediolateral and sagittal insertion angles for transarticular screw fixation of the subaxial cervical spine from C-2 to C-7 that can be applied for a safe trajectory in the majority of cases. Furthermore, the demonstrated method can easily be applied by any surgeon to confirm or modify the proposed insertion angles during preoperative planning.

Disclosure

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Author contributions to the study and manuscript preparation include the following. Conception and design: Jost, Schmidt, Bisson. Acquisition of data: Jost. Analysis and interpretation of data: Jost. Drafting the article: Jost. 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: Schmidt. Study supervision: Schmidt, Bisson.

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