Atlantoaxial Transarticular Screw Fixation for a High-Riding Vertebral Artery

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Study Design. The feasibility of inserting a screw for the narrow isthmus with a high-riding vertebral artery was evaluated in patients subjected to posterior atlantoaxial transarticular screw fixation.

Objective. To demonstrate the feasibility of inserting bilateral screws and obtaining a stable atlantoaxial complex for patients with a high-riding vertebral artery.

Summary of Background Data. Posterior atlantoaxial transarticular screw fixation entails the potential risk of vertebral artery injury, which may be lethal. The risk is much higher for the narrow isthmus caused by a high-riding vertebral artery, and many authors recommend that the procedure should be abandoned if the isthmus is too narrow. On the other hand, bilateral screw fixation is stronger than unilateral screw fixation.

Methods. For this study, 27 consecutive patients who submitted to atlantoaxial transarticular screw fixation were evaluated before surgery, for the position of the vertebral artery grooves, using computed tomography (CT) reconstruction. Several of the patients were defined as having a unilateral high-riding vertebral artery. For these patients, bilateral screw insertion through the most posterior and medial part of the isthmus was performed.

Results. No massive bleeding or major complications were encountered in any patient with a high-riding vertebral artery. Postoperative computed tomography reconstruction demonstrated that five of the screws cleared the vertebral artery grooves successfully, and two slightly and one not at all. No screws penetrated into the vertebral artery groove.

Conclusions. It is possible to insert a screw safely, even into the narrow isthmus with a high-riding vertebral artery, if the surgeon realizes where the screw should be inserted and has the requisite insertion technique. Bilateral screw fixation should provide a high fusion rate. Key words: atlantoaxial instability, atlantoaxial joint, transarticular screw fixation, vertebral artery.

Posterolateral transarticular screw fixation, developed by Magerl,[1] is an excellent technique that features more rigid fixation,[2–4] and consequently higher fusion rates,[5–10] than the conventional wiring techniques. This technique, however, has potential risks of vertebral artery (VA) injury, which may have lethal complications.[9,11–14] The reported rates of VA injury range from 4.1% to 8.2%.[5,14] Vertebral artery injury can occur not only because the screw path is very close to the VA, but also because the location of the VA is anatomically variable and consequently the isthmus, through which the screw is inserted, sometimes is too narrow.[9,12,16] The VA makes an acute lateral bend just under the superior articular facet of the axis in approximately 80% of individuals.[17] The transarticular screw must be inserted through the isthmus, that is, superiorly and posteriorly or posteromedially to the bending point of the VA. If this bending point is too medial, too posterior, and/or too high, the height and/or the width of the isthmus of the axis is narrowed, a condition described as a high-riding VA.

Therefore, many authors recommend that the height of the isthmus of C2 be evaluated preoperatively using computerized tomography (CT) reconstruction,[1,5,6,9,11,16,18,19] and advise that insertion of the screw should be abandoned if the isthmus is too narrow.[5,11,13,16,20] Song et al[20] abandoned bilateral screw fixation because of high-riding VA in 13 of 109 consecutive patients. These authors also reported that solid fusion was obtained in 18 of 19 patients subjected to unilateral fixation, concluding that unilateral atlantoaxial screw fixation with interspinous bone graft wiring is an excellent alternative for the treatment of atlantoaxial instability when bilateral screw fixation is contraindicated. However, bilateral screw fixation naturally provides more rigid stabilization than unilateral fixation. Naderi et al[3] compared four combinations of cable-graft-screw fixation at C1–C2 biomechanically in vitro using nondestructive flexibility testing. According to these authors, the stiffness after unilateral screw fixation is inferior to that after bilateral fixation in all directions, especially in axial rotation. Therefore, unilateral fixation may increase nonunion rates, and a trial of screw insertion into the narrowed isthmus is warranted.

Considering the anatomic course of the VA, the safest screw path is via the most posterior and medial part of the isthmus, and this should be applied to every case.[17] Jun[21] examined sagittal reconstructed CT images of 64 volunteers at 3.5 and 6 mm from the lateral border of the spinal canal. When the trajectories of the screws were inclined forward to intersect at 0%, 25%, 50%, 75%, and 100% of the anteroposterior diameter of the super-
Figure 1. Patient 6 with a case with triple distress. The VA groove is situated medially, posteriorly, and high. Preoperative sagittal computed tomography (CT) reconstruction images. A, The section near the left lateral edge of the spinal canal demonstrating that the vertebral artery (VA) groove (*) is situated more medially than usual. B, The section 3 mm lateral to section A demonstrating a high-riding VA with 2.6-mm internal height (between the white arrow) and a 3.3-mm isthmus height (between the arrowheads). C, The section 3 mm further lateral to section B. The VA groove is open to the dorsal cortex, meaning that the section passes through the medial edge of the transverse foramen, showing that no space is available for the screw in this plane. These images suggest that the screw should be inserted through the most posterior part of the isthmus, exactly in the plane of section B, that is, the most medial part of the isthmus. A medial deviation of the screw would cause it to penetrate the spinal canal, and lateral or inferior deviations would cause violation of the VA groove. D, The schematic drawing of C1–C2 demonstrating the relation between the VA groove, transverse foramen, spinal canal, atlantoaxial joint, and the screw. The sections of Figure IA, IB, and IC also are indicated. E and F, Postoperative anteroposterior and lateral radiogram demonstrating complete reduction of C1–C2 and good positioning of the screws. G, Postoperative sagittal CT reconstruction demonstrating that the screw was inserted exactly as planned. Although the screw seems to breach both the dorsal cortex of the isthmus and the cortex of the VA groove, the dorsal cortex was confirmed not to be violated under direct view during the operation. Postoperative magnetic resonance angiography demonstrated that the VA had not been injured.

Methods

In this study, 27 consecutive patients (6 men and 21 women) with atlantoaxial instability or osteoarthritis (age range, 11–77 years) were treated by posterior atlantoaxial transarticular screw fixation with a posterior iliac bone graft between August 2000 and March 2002. The original diagnosis included rheumatoid arthritis (15 patients), os odontoideum (5 patients), osteoarthritis (2 patients), trauma (2 patients), postinfection (1 patient), cerebral palsy (1 patient), and atlantoaxial inflammation of unknown origin (1 patient). The indications for the operation were occipitalgia alone (10 patients), occipitalgia and slight myelopathy (numbness) (7 patients), myelopathy only (7 patients), and no symptoms but an atlantodental interval (ADI) larger than 10 mm (3 patients). Three salvage operations for nonunion were included. Laminoplasty at other cervical levels was performed at the same time for two patients. Preoperative plain radiograms, including flexion–extension lateral radiograms, were taken in all patients. Furthermore, a CI scan with a 1-mm slice interval from C1 to C2 also was performed for each patient, and sagittal and coronal images were reconstructed at 3-mm intervals to evaluate the location of the VA groove. Usually, two or three sagittal slices were obtained for each lateral mass of C2. The authors selected the slice in which the isthmus of C2 was thickest (the slice of the most medial one in all the patients), and deemed that the VA was high-riding and therefore at high risk for the operation when the isthmus height was less than 5 mm or the internal height of the lateral mass (measured from the roof of the VA groove to the surface of the superior facet) was less than 2 mm (Figure 1B).
All operations were performed under fluoroscopic guidance. For transarticular screw fixation, the Reunion bone screw system (Surgical Dynamics, Norwalk, CT) was used in 24 patients, and the Olerud cervical system with an atlas claw (Nordopedic AB, Uppsala, Sweden) was used in 3 patients. Both types of screw have a diameter of 4 mm. An iliac bone strut was fixed on C1–C2 according to Galie23 (20 patients) or Brooks and Jenkins24 (4 patients) using a high-density polyethylene thread (Secure Strand; Surgical Dynamics, Norwalk, CT). Otherwise, bone chips were grafted on C1–C2 when an Olerud cervical atlas screw system was used (3 patients). In 21 patients, an aiming device was used to insert a screw. The detail of the technique for the device is described elsewhere.25 Briefly, the tip of the device is placed on the ridge of the isthmus of C2 just posteriorly to the atlantoaxial joint, which introduces a guidewire 1 mm under the device tip. That is, the guidewire is inserted into the most posterior part of the atlantoaxial joint through the most posterior and medial part of the isthmus. Then, the bone is drilled along the guidewire, using a cannulated drill, and a screw is inserted. The device was not used for four patients early in the series, nor for two revision patients in whom anatomic landmarks had been destroyed. In three patients, intraoperative complete reduction was not obtained (ADI >4 mm). However, laminectomy of C1 was not performed because the patient had no or minimal myelopathy, and partial reduction was achieved.

To evaluate the screw positions, postoperative plain radiographs were taken for all the patients. In 19 patients, including all those with a high-riding VA, CT reconstructions also were obtained using the same protocol as that used before surgery.

Results

Overall Patients

Screws were inserted bilaterally in all patients, and no massive bleeding was encountered. No other major complications, such as neurologic deficits, apoplexy, or infection, were encountered. Dural tear was experienced in a revision case when the previous metal wire was removed, resulting in no sequelae. In 17 cases of the standard operation (transarticular screw fixation and iliac bone strut graft according to Galie), the average operation time was 119 minutes (range, 95–142 minutes), and the average estimated blood loss was 72 mL (range, 10–230 mL). Some screw malpositions were encountered including occipitocervical joint (OC) violation in four patients (five screws); breaching of the posterior cortex of the isthmus, confirmed under direct view, in two patients (two screws), including one with a high-riding VA; breaching of the cortex of the VA groove on postoperative CT in two patients with a high-riding VA; and displacement of the screw medial to the lateral mass of C1 in one patient with incomplete reduction (one screw). However, these complications never adversely affected the postoperative course of the patients.

Although the follow-up period was very short, the clinical symptoms were improved, and at this writing, there is no sign of nonunion in any of the patients. The postoperative course of the patients is comparable with that of the authors' previous 25 cases. In all of these cases, posterior atlantoaxial transarticular screw fixation was performed without preoperative evaluation of the VA groove by CT reconstruction, and bone union was obtained.

Patients With a High-Riding Vertebral Artery

On CT reconstruction, seven patients were identified as having a unilateral high-riding VA, according to the authors' definition (Table 1). These included two patients with an internal height less than 2 mm, three patients with an isthmus height less than 5 mm, and two patients with both conditions. The high-riding VA was on the right in three patients and on the left in four patients. All the patients except patient 4 underwent primary operations, and the Olerud cervical system was used only in patient 7. The aiming device was used in five patients, but not in two early patients in the series. In five patients who submitted to the standard operation, excepting patients 4 and 7, the average operation time was 129 minutes and the average estimated blood loss was 105 mL. No massive or arterial bleeding was encountered in any patient. In patient 7, slight breaching of the dorsal cortex of the isthmus was confirmed during the operation, but this did not cause mechanical weakness. Postoperative radiography demonstrated a bilateral OC violation in patient 3. Postoperative CT scanning showed slight breaching of the VA groove in patients 4 and 6. In patient 4, the breaching was caused by a 1- or 2-mm lateral deviation of the screw from the planned position rather than a horizontal inclination of the screw in the sagittal plane. In patient 6, the isthmus height was

<table>
<thead>
<tr>
<th>Patient</th>
<th>Age (y.)</th>
<th>Sex</th>
<th>Laterality</th>
<th>Int. Height (mm)</th>
<th>Isth. Height (mm)</th>
<th>Aiming Device</th>
<th>Op. Time (min)</th>
<th>Blood Loss (mL)</th>
<th>Postop. ADI</th>
<th>Breaching of the VA Groove (CT)</th>
<th>Complications and Screw Malpositions</th>
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<tr>
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<td>77</td>
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<td>R</td>
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<td>4.2</td>
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<td>134</td>
<td>238</td>
<td>0</td>
<td>No</td>
<td>Bil. OC violation</td>
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<td>F</td>
<td>R</td>
<td>1.8</td>
<td>6.1</td>
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<td>141</td>
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<td>L</td>
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<td>63</td>
<td>1</td>
<td>Bil. OC violation</td>
<td>Breaching of the dorsal cortex of the isthmus</td>
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</table>

Int. height = internal height; Isth. height = isthmus height; Op. time = operation time; Postop. ADI = Postoperative ADI; Bil. OC violation = bilateral occipitocervical joint violation.
smaller than the screw diameter. No screws were found to have penetrated the VA groove.

Two of the most challenging cases are shown in the figures. Figure 1 shows the case of patient 6, in whom the isthmus height was the smallest observed in this series (3.3 mm), and in whom the isthmus width also was very narrow. Figure 2 shows patient 5, in whom intraoperative complete reduction was impossible. Some authors emphasize that transarticular screw fixation is dangerous if the reduction is incomplete.5,18

Discussion

Posterior atlantoaxial transarticular screw fixation is an excellent technique, characterized by rigid mechanical fixation and high fusion rates.9-10 However, some severe or lethal complications resulting from VA injury have been reported.9,11-14 One reason why it is difficult to avoid these complications completely is because the course of the VA in C2 is variable, with consequent variability in the height and width of the isthmus of C2 through which the screw is inserted.9,15,16 In approximately 80% of patients, the VA makes an acute reverse bend in the center of the lateral half of the superior articular facet of the axis. In 15% of these patients, the VA can occupy almost two thirds of the superior facet of the axis.25 To avoid VA injury, the transarticular screw must be inserted superiorly and posteriorly or postero-medially to the bending point of the VA (Figure 1D). Therefore, if the bending point and the course of the VA are situated too medially, too posteriorly, and/or too high, the risk of VA injury becomes greater.

Because the variation of the VA course should be considered three-dimensionally, an objective evaluation is clinically difficult.21 The authors defined the high-riding VA on the basis of CT reconstruction, which is a simple and widely accepted method of evaluation.3,5,9,11,13,16,18,19 They adopted Bloch et al’s22 definition of the high-riding VA: an internal height less than 2 mm, an isthmus height less than 5 mm, or both. However, the isthmus height is more important because the screw goes through the isthmus itself regardless of the internal height. Therefore, patients 1 and 3 in the current study, who had internal heights less than 2 mm but an isthmus height exceeding 5 mm, were less prone to risk than the other patients. On the other hand, some patients defined as not having a high-riding VA in the current study may have been more prone to risk because they had a narrower isthmus width. That is, it seemed that they had sufficient space for screw insertion in one section of CT reconstruction, but no available space in the next section 3 mm lateral to it. This means that a slight lateral deviation of the screw could have injured the VA. In the current study, the rate of high-riding VA according to Bloch et al was 7/54 (13%), consistent with the previous studies, in which the rates of risky VA based on various examination methods and definitions ranged from 11.7% to 23%.9,12,16

In the current study, it was possible to insert a screw, even in patients with a high-riding VA when the surgeon aimed for the most posterior and medial part of the isthmus and had perfected the technique for inserting the screw exactly as aimed. Two screws seemed to breach the cortex of the VA groove on CT. The one violation was caused by a 1- or 2-mm lateral deviation of the screw from its planned position rather than by the horizontal inclination of the screw (patient 4). The other occurred because the screw diameter was larger than the isthmus height (patient 6). However, it is empirically known that a slight breaching of the VA groove does not necessarily injure the artery. In patient 6, postoperative magnetic resonance angiography showed the integrity of the VA. Abumi26 mentioned that although screw perforation often is seen, VA injury rarely is noticed because there is a relatively large space between the bone and the artery. Although it is difficult to determine the situations in which insertion of the screw should be abandoned, the authors were able to insert a screw into a narrow isthmus only 3.5 mm high, which suggests that it should be possible to insert screws bilaterally in almost all patients.

The authors have actively performed atlantoaxial fixation, even for patients in whom a complete reduction was impossible, to reduce the range of the fusion area, provided the patient had no or minimal myelopathy. In
the current study, they also demonstrated that screw insertion is possible for incompletely reduced patients, a situation that some authors regard as a risk factor.

The point is that the screw should be inserted in the same way as in completely reduced patients, regardless of the position of the anterior arch of C1. That is, the screw trajectory should always go through the most posterior and medial part of the isthmus. If the surgeon aims for the anterior arch of C1, the screw trajectory may be inclined horizontally and the VA may be injured (Figure 2). The following points, however, need to be considered in the case of incomplete reduction. One point is to check before surgery if the screw can purchase the lateral mass of C1 because a steeply inclined screw may miss the lateral mass of C1 in the case of a large C1 displacement. The second point is to insert the screw in a sagittal plane that is parallel to the body axis because the screw may miss the lateral mass of C1 if the surgeon aims medially.

The current authors chose the most medial and posterior trajectory in every case regardless of the VA position rather than the usual trajectory aiming for the anterior arch of the C1. One reason is that a slightly lateral deviation of the screw may injure the VA even if the patient is defined as not having a high-riding VA, as mentioned earlier. It is wise to allow a wider safety margin in every case. The second reason is that the purchase made on the C1 lateral mass by the screw would be greater, resulting in more secure fixation (Figure 1E). To insert a screw on this trajectory, adequate exposure of the isthmus of C2 and intraoperative fluoroscopic control are most important. Although the use of an aiming device is not mandatory, as in patients 1 and 2, its use makes this procedure less stressful for the surgeon, especially in challenging cases with an isthmus height that is too small, as in patients 6 or 7.

In conclusion, the safest trajectory of the screw is the most medial and posterior part of the isthmus of C2. If the surgeon possesses a technique for inserting a screw exactly on this trajectory, it is possible to insert a screw bilaterally and to provide a rigid fixation, even in a patient with a high-riding VA.

**Key Points**

- Among 27 candidates for posterior atlantoaxial transarticular screw fixation, 7 were identified as having a unilateral narrow isthmus caused by a high-riding vertebral artery (VA), which may be a contraindication for inserting a screw.
- The safest screw trajectory is considered to be via the most medial and posterior part of the isthmus of C2.
- It was possible to insert a screw safely into the narrow isthmus by maintaining such a trajectory in all patients with a high-riding VA.

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**References**