Rigid/screw fixation at C1–2 has become the primary treatment option for C1–2 instability. There are several advantages of C1–2 rod/screw fixation versus transarticular screw fixation: for example, the screw angle is less steep, so it should be useful in obese patients or in patients with thoracic kyphosis, and a decrease in VA injuries would be expected. Unfamiliarity with certain aspects of the surrounding neurovascular structures, however, and lack of experience with the procedure can make C-1 posterior screw placement extremely challenging.

Several anatomical variations have been reported around the C1–2 complex such as a posterior ponticulus, Va segment anomaly, and bifid C-1 arch. Ignoring these anatomical variations can lead to injury of the surrounding neurovascular structures and potentially serious complications. For example, a posterior ponticulus can be easily mistaken for broad lamina. If a posterior ponticulus is present, placing the screw too superiorly might cause Va injury. Also, screw insertion into the inferior lateral mass can be dangerous in cases of a persistent first intersegmental artery where the Va courses abnormally below the C-1 arch.

Therefore, this study had 2 goals: 1) to analyze the incidence of potentially dangerous anatomical conditions around the posterior atlantal arch; and 2) to describe the usefulness of 3D CT angiography for evaluating anatomical variations of the Va.

Abbreviations used in this paper: CT = computed tomography; CVJ = craniovertebral junction; MR = magnetic resonance; PICA = posterior inferior cerebellar artery; VA = vertebral artery.
Clinical Material and Methods

Patient Population

The study consisted of a review of the records of 1013 Korean patients who underwent CT angiography for reasons other than evaluation of VA disease. There were 567 females and 446 males, ranging in age from 6 to 93 years (average 55.7 years). Between December 2005 and January 2007, these patients underwent 3D CT angiography for the evaluation of various disease entities such as cerebral ischemia, headache, trauma, and spine disease.

To obtain data from a normal population, we excluded patients with CVJ disease and other congenital anomalies such as rheumatoid arthritis, Down syndrome, assimilation of atlas, and Klippel–Feil syndrome. We also discarded data showing VA aplasia on CT angiography to exclude patients with VA disease.

Imaging Technique

Three-dimensional CT angiography analyses were performed using Lightspeed scanners (GE) with a single acquisition of 3-mm contiguous helical images. Immediately following scanning, axial reconstructions were performed at a 1.0-mm–slice thickness. The total dose of contrast agent, the injection rates, and the scan delays were customized according to the individual patient. Nonionic contrast material (Oxilan 300, Cook Medical) was intravenously administered to all patients, with a total dose ranging from 100-150 ml. The injection rate varied according to the patient’s clinical condition, cardiac status, and intravenous access. Scan delays ranged from 15 to 25 seconds. Our 3D analysis lab reconstructed sagittal and coronal maximal intensity projections and surface-rendered images.

Anatomical Variation Analysis

To be considered unequal in size, the diameter of the VA on one side had to be more than twice that of the other side. In such cases, the larger side was called dominant and the other was labeled as hypoplastic. Anomalous V segment pathways were evaluated using 3D CT angiography to avoid intraoperative VA injury during surgery on the CVJ.

The posterior arches of the 1013 cases were examined to evaluate the incidence and shape of any posterior ponticuli.

Statistical Methods

The size of the C-1 transverse foramen was measured on axial CT images. The size of the foramen was calculated by applying the formula used for an ellipse: Area (A) = π × M/2 × m/2, where M represents the maximal diameter of the transverse foramen and m represents the minimal diameter of the transverse foramen. When the VA coursed abnormally below the C-1 arch, the area of the un-filled transverse foramen was compared with the size of the contralateral filled foramen. Statistical analysis was performed by analysis of variance using SPSS version 10.0 (SPSS, Inc.). A probability value of < 0.05 was regarded as statistically significant. Age differences between the population with and without a posterior ponticulus were analyzed using a one-tailed paired Student t-test.

Results

Posterior Ponticulus

The prevalence of a posterior ponticulus in these Korean patients was 15.6%. The incidence in the male population was 19.3%, whereas in the female population it was 12.8%. A unilateral posterior ponticulus (57.2%) was more common than a bilateral posterior ponticulus (42.8%).

The posterior ponticuli were classified according to anatomical characteristics of the bone bridge. Four types could be identified (Fig. 1, Table 1): Type I, a partial posterior ponticulus is noted as a bony spicule extending only from the superior articular facet (14.0%); Type II, a partial posterior ponticulus in which a bony spicule projects from the posterior arch of the atlas toward the superior articular facet (9.6%); Type III, a bony spicule of a partial posterior ponticulus originates both from the superior articular facet and the posterior arch (34.6%); and Type IV, a complete posterior ponticulus (41.7%). The overall incidence rate of a lateral bridge in which a bony spicule extended from the lateral mass to the transverse process was 3.2%. A lateral bridge was found in 4.4% of the patients with a posterior ponticulus.

It is noteworthy that the mean age of the patients in the...
incomplete posterior ponticulus group (55.7 years) was sig-
ificantly younger (p = 0.018) than that of the patients
in the complete posterior ponticulus group (57.6 years),
which suggests that the formation of a posterior ponticulus
would appear to be similar to osteophyte formation, a con-
dition also related to age. There were no significant age dif-
fferences between the group with a posterior ponticulus and
the group without it.

Anomaly of the V₃ Segment of the VA

The incidence rates of a right- and left-dominant VA
were 9.8% and 22.3%, respectively. Anatomical variations
of the V₃ segment were detected in 55 cases (5.4%). Table
2 lists the 5 different types of anomalies. The most preva-
lent type of variation was a unilateral persistent first inter-
segmental artery (39 cases, 3.8%), in which the VA cours-
es below the C-1 arch after exiting the transverse foramen
of the axis, and subsequently enters the spinal canal with-
out passing through the C-1 transverse foramen. There
were 8 cases (0.8%) of a bilateral persistent first interseg-
mental artery, and 1 case (0.1%) of a persistent first inter-
segmental artery on one side with a fenestrated VA on the
other side. Also, there were 6 cases of a fenestrated VA
(0.6%) and 2 cases of an anomalous origin of the PICA, in
which the PICA originated between C-1 (atlas) and C-2
(axis) and coursed into the spinal canal at the atlas (Figs. 2
and 3).

The area of the unfilled C-1 transverse foramen due to a
persistent first intersegmental artery was significantly
smaller than that of the normal C-1 transverse foramen area
(7.6 versus 26.3 mm², p < 0.001; Fig. 4). There was a deep
groove on the inner aspect of the C-1 posterior arch where
the aberrant V₃ segment courses into the spinal canal in
cases of a persistent first intersegmental artery or fenestrat-
ed VA (Figs. 4 and 5).

Discussion

Atlantoaxial fusion is a challenging procedure for most
spine surgeons because of the variable anatomy of this
region and its proximity to the important neurovascular
structures. Injury to the VA during placement of a posteri-
or C-1 screw, especially when it occurs on the dominant
side, may result in very serious complications. There have
been several reports of VA injury as a complication of C-1
lateral mass screw fixation. Injuries include the formation
of an arteriovenous fistula, occlusion, dissection of the VA,
and massive bleeding.

**TABLE 1**

<table>
<thead>
<tr>
<th>Type of Pst Ponticuli</th>
<th>Incidence Rate (%)</th>
<th>Feature of Pst Ponticulus</th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td>14.0</td>
<td>incomplete</td>
</tr>
<tr>
<td>II</td>
<td>9.6</td>
<td>incomplete</td>
</tr>
<tr>
<td>III</td>
<td>34.6</td>
<td>incomplete</td>
</tr>
<tr>
<td>IV</td>
<td>41.7</td>
<td>complete</td>
</tr>
</tbody>
</table>

* Pst = posterior.

**TABLE 2**

<table>
<thead>
<tr>
<th>Course of V₃ Segment</th>
<th>No. of Cases</th>
<th>Incidence Rate (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>normal</td>
<td>958</td>
<td>94.6</td>
</tr>
<tr>
<td>unilat PIA</td>
<td>39</td>
<td>3.8</td>
</tr>
<tr>
<td>bilat PIA</td>
<td>8</td>
<td>0.8</td>
</tr>
<tr>
<td>unilat FA</td>
<td>5</td>
<td>0.5</td>
</tr>
<tr>
<td>unilat PIA &amp; contralat FA</td>
<td>1</td>
<td>0.1</td>
</tr>
<tr>
<td>PICA btwn C-1 &amp; C-2</td>
<td>2</td>
<td>0.2</td>
</tr>
</tbody>
</table>

* FA = fenestrated VA; PIA = persistent first intersegmental artery.

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FIG. 2. Three-dimensional CT angiography images show different types of anomalous VAs. **A**: Bilateral persistent first intersegmental artery is shown, which exists as the VA courses abnormal-
ly below the C-1 arch (arrows). **B**: Anomalous origin of the PICA (black arrowhead) is demon-
strated.
To avoid intraoperative damage to the VA, there have been several reports concerning optimal entry points for posterior C-1 screw insertion. The starting point of the atlantal lateral mass screw, initially described by Goel and Laheri in 1994 and by Harms and Melcher in 2001, was at the inferior lateral mass, just below the posterolateral arch of the atlas. But because there are many critical neurovascular structures such as the spinal cord, C-2 nerve root, and venous plexus surrounding the greater occipital nerve, it is a significant challenge to avoid injuring these structures because of the bleeding from the paravertebral plexus of vessels. In addition, if the VA courses abnormally below the C-1 arch, it can be dangerous to perform screw insertion at the inferior lateral mass.

Some surgeons have recommended inserting the screw at the superior aspect of the posterior arch of the atlas to minimize the risk of injury to the VA, C-2 nerve root, and C1–2 facet joint. A posterior ponticulus misidentified as a broad lamina, however, might deceive the surgeon into placing the insertion site too superiorly, thereby injuring the VA. Therefore, it is crucial to preoperatively detect any anatomical variations around the C1–2 complex to avoid injuring the VA during surgery.

In this study, the incidence of a posterior ponticulus was 15.6%, which closely approximates rates given in previous reports. Stubbs found that a posterior ponticulus was more common in males, but other authors have found a slightly greater incidence rate in females and a variable incidence rate between races. In this study, the incidence rate in the male population (19.3%) was found to be more frequent than among females (12.8%). It is presumed that irrespective of sex, the posterior ponticulus is more common in individuals who sustain greater stress in the region of the CVJ and the incidence rate can be different among various races around the world.

In this study, the posterior ponticuli were classified into 4 groups according to the anatomical characteristics of the bone bridge. Except for Type I, all other types of a posterior ponticulus could be mistaken for a widened lamina. Considering that 86% of the patients in our study with a posterior ponticulus were classified as Type II, III, or IV, the risk that a posterior ponticulus would be mistaken for a widened lamina is significant. Therefore, surgeons should be cautious not to insert screws too superiorly in these types of cases.

Three types of VA anomalies have been reported after analysis using conventional catheter angiography. In the first anomaly, the VA courses below the C-1 arch after leav-
and the incidence of a fenestrated VA was 0.6%.

The incidence rate of a normal PICA origin was only 0.2%

The incidence rate of a Type I VA anomaly is greater than previously reported, therefore suggesting that a persistent first intersegmental artery could be more common than expected. One reason for the disparity in results is the chosen imaging modality. Compared with conventional catheter angiography and MR angiography, 3D CT angiography has been reported as a superior diagnostic tool to identify VA abnormalities because it has the following advantages: 1) accurate depiction of the VA image and unrestricted reconstruction of the image; 2) ability to draw the VA and the circumferential osseous tissue and analyze the reciprocal anatomy of both tissues; 3) ability to conduct stereoscopic analysis from every direction; and 4) less invasive procedure and able to be performed in a much shorter time than catheter or MR angiography.

For these reasons, recent 3D CT angiography can show much more detailed anatomical delineation for both bone and vascular structures around the CVJ than conventional angiography. By using 3D CT angiography, we were able to identify the anomalous VA more easily and recognize possible risks to the VA in advance. Magnetic resonance imaging and CT scans can also detect these variations of the VI segment. A signal void below the C-1 arch on parasagittal MR images or in the spinal canal at the C1–2 junction suggests the presence of a persistent first intersegmental artery. Also, these variations should be suspected if a circular enhanced shadow is detected in the spinal canal at the level of the atlas (Fig. 4). Additionally, this study demonstrates that if a C-1 transverse foramen appears to be asymmetrically small on a CT scan, a VA anomaly should also be suspected. In such cases, use of CT angiography is necessary to confirm the presence of a VA anomaly and to understand the anatomical relationship between the VA and the surrounding bone structures at the CVJ. Because vertebral vessels are a factor in the genesis of the transverse foramen, the presence of the VA and a variation in its course may influence the formation of the transverse foramen. If the VA does not pass through the transverse foramen and abnormally course below the C-1 arch to the C-1 spinal canal, the size of the transverse foramen usually became atretic. Also, the altered course of the artery is reflected in the posterior arch of C-1, which displays a deep groove on its inner aspect due to the chronic pulsation of the VA. Knowledge of this anatomical variation of the VI segment is important to avoid inadvertent VA trauma. Thus, surgeons should suspect VI segment anomalies when there is a hypoplastic C-1 transverse foramen or asymmetry of the C-1 posterior arch on preoperative images.

For patients with C1–2 instability who have anomalous VAs, surgical procedures including approach, dissection, and screw placement should be carefully planned. The identification of a persistent intersegmental artery is important when contemplating screw insertion at the inferior lateral mass of C-1, because the VA courses inferior to the C-1 arch and could easily be injured during the procedure. If a persistent intersegmental artery or fenestrated VA is detected, a more optimal entry point for fixation could be selected to avoid significant morbidities associated with VA injury. In these cases, 2 alternative techniques could be utilized to avoid VI segment injury. The first technique in-

![Fig. 4. Computed tomography scan (A) and box plot (B) showing data related to the transverse foramen. A: The area of the C-1 transverse foramen on the abnormal side (white arrow) was much smaller than the area of the foramen on the contralateral normal side (black arrow). The altered course of the artery is reflected in the posterior arch of C-1, which displays a deep groove on its inner aspect (black arrowhead). B: Comparison of the size of the transverse foramen shows that the filled (normal, containing the VA) transverse foramen was significantly larger (p < 0.001) than the unfilled (abnormal, no VA) transverse foramen (p < 0.01).](image-url)
volves C1–2 transarticular screw fixation to avoid injury of the abnormal VA below the C-1 arch, and the second method uses the superior lateral mass as an alternative starting point for C-1 posterior screw placement. In those situations that utilize C1–2 transarticular screw fixation, sagittal CT reconstructed images provide superior resolution compared with 3D CT angiography for identifying the internal bone anatomy, as well as for choosing the entry point and screw direction.

Conclusions

Our results suggest that although only a small percentage of patients demonstrated an anomalous course of the VA and abnormal bone architecture of the atlas, there exists the possibility for significant VA injury intraoperatively if surgeons fail to recognize these types of variations. These results also suggest that 3D CT angiography is useful in guiding surgical technique. Therefore, careful attention should be given to the possibility of VA anomalies during CVJ surgery.

References


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