Operative nuances to safeguard anomalous vertebral artery without compromising the surgery for congenital atlantoaxial dislocation: untying a tough knot between vessel and bone

Clinical article

PRAVIN SALUNKE, M.Ch.,1 SAMEER FUTANE, M.Ch.,1 SUSHANT K. SAHOO, M.S.,1 MANDEEP S. GHUMAN, M.D.,2 AND NIRANJAN KHANDELWAL, M.D.2

Departments of 1Neurosurgery and 2Radiodiagnosis, Postgraduate Institute of Medical Education and Research (PGIMER), Chandigarh, India

Object. Stabilization of the craniovertebral junction (CVJ) by using lateral masses requires extensive dissection. The vertebral artery (VA) is commonly anomalous in patients with congenital CVJ anomaly. Such a vessel is likely to be injured during dissection or screw placement. In this study the authors discuss the importance of preoperative evaluation and certain intraoperative steps that reduce the chances of injury to such vessels.

Methods. A 3D CT angiogram was obtained in 15 consecutive patients undergoing surgery for congenital atlantoaxial dislocation. The course of the VA and its relationship to the C1–2 facets was studied in these patients. The anomalous VA was exposed intraoperatively, facet surfaces were drilled in all, and the screws were placed according to the disposition of the vessel.

Results. A skeletal anomaly was found in all 10 patients who had an anomalous VA. Four types of variations were noted: 1) the first intersegmental artery in 5 patients (bilateral in 1); 2) fenestration of VA in 1 patient; 3) anomalous posterior inferior cerebellar artery crossing the C1–2 joint in 1 patient; and 4) medial loop of VA in 5 patients. The anomalous vessel was dissected and the facet surfaces were drilled in all. The C-1 lateral mass screw was placed under vision, taking care not to compromise the anomalous vessel, although occipital screws or sublaminar wires were used in the initial cases. A medial loop of the VA necessitated placement of transpedicular or C-2 lateral mass screws instead of pars interarticularis screws. The anomalous vessel was injured in none.

Conclusions. Preoperative 3D CT angiography is a highly useful method of imaging the artery in patients with CVJ anomaly. It helps in identifying the anomalous VA or its branch and its relationship to the C1–2 facets. The normal side should be surgically treated and distracted first because this helps in opening the abnormal side, aiding in dissection. In the posterior approach the C-2 nerve root is always encountered before the anomalous vessel. The defined vascular anatomy helps in choosing the type of screw. The vessel should be mobilized so as to aid the drilling of facets and the placement of screws and spacers under vision, avoiding its injury (direct or indirect) or compression. With these steps, C1–2 (short segment) rigid fusion can be achieved despite the presence of anomalous VA.

Key words • vertebral artery anomaly • 3D computed tomography angiogram • congenital craniovertebral junction anomalies • cervical • operative steps • injury prevention

THE surgery for congenital craniovertebral junction (CVJ) anomalies has shifted from the less stable sublaminar wiring to the more rigid lateral mass fusion.1–3 However, these approaches have a greater risk of injuring the vertebral artery (VA). Besides, the probable presence of an anomalous artery in patients with congenital CVJ disorders increases the risk of jeopardizing it intraoperatively.

The recent literature lays emphasis on the preoperative diagnosis of such anomalous vessels in patients with CVJ disorders.4,5 However, little is mentioned about the operative techniques to prevent injury to such vessels. In fact, the steps described are those of tamponade with screw tightening once the injury has occurred. Such injuries can occasionally give rise to significant neurological deficits, depending on the amount of area it supplies and collateral flow, or they may lead to erosion of the vessel.4,5 Including sublaminar hooks or adjacent levels to circumvent these anomalous vessels has been described,4,5 but this may not be desirable because it comes at the expense of compromising the rigid bone fusion (due to not opening and drilling the facets), lack of rigid construct, or unnecessarily including multiple adjacent segments.

In addition to the preoperative diagnosis of anomalous
VA, we have attempted to highlight some operative nuances to prevent its injury during CVJ surgery without compromising on the rigid C1–2 (short segment) bone fusion.

Methods

The study was conducted in the last 2 years. Fifteen patients with congenital atlantoaxial dislocation (AAD) were studied. Preoperative 3D CT angiograms (CTAs) were obtained in all patients. The angiograms were studied to look for both of the VAs, from their exit from the transverse foramina of C-2 to their entry into the foramen magnum (extraosseous V3 segment). The anomalous VA’s relationship to the C1–2 facets was studied. Additionally, the congenital skeletal anomalies in the cervical spine were studied. Any asymmetry in the calibers of the 2 vessels was noted. Intraoperatively, the anomalous artery was exposed in all patients and its relationship to facets and C-2 nerve root was studied. Subperiosteal dissection was carried out. The joint surfaces were drilled in all cases to aid bone fusion. According to the disposition of the anomalous vessel, the screws were placed in the C-1 facet, occiput, C-2 pars interarticularis, lateral mass, or pedicle (depending on the part in which the screw had taken maximum purchase). Precautions taken to avoid injury have been described below. The facets were drilled depending on the inferior sagittal C-1 facet angles.6

Results

As shown in Table 1, 14 of 15 patients had skeletal abnormalities (occapitalized atlas and C2–3 fusion in 10, and os odontoideum in 4). Four patients had a normal VA anatomy and 1 had bilateral narrow VAs with variation intracranially. Ten patients had either an anomalous course or an abnormal branch of the extraosseous VA. Persistent first intersegmental artery (FIA) was seen in 5 patients, 1 of whom had it bilaterally. The VA in these 5 patients crossed posterior to the C1–2 joint space after exiting from the C-2 transverse foramen. One patient had a posterior inferior cerebellar artery (PICA) arising from this segment of VA and another had a fenestrated VA, both crossing the C1–2 facet joint. Significant asymmetry (> 50% difference in the caliber) was found in 6 patients, and 1 had bilateral narrowing (both VAs occupied less than half of the transverse foramina). An abnormal medial loop of the extraosseous segment was seen in 5 patients (one of them had a fenestrated VA and another had an FIA on the opposite side).

The anomalous VA or its branch crossing the C1–2 joint space was exposed in all patients. The C1–2 joint with normal or nondominant VA was approached first. The C-2 root ganglion was identified and dissected from other soft-tissue structures by using a blunt hook, and then it was cut. Monopolar cautery was not used while dissecting around the facets. The anomalous vessel was dissected along its length, mobilizing it. In cases of FIA, fenestration, and abnormal PICA (a total of 7 cases), the vessel crossed the joint space and then was in proximity with the posterior surface of the caudal portion of the occipitalized C-1 lateral mass. In all 7 cases the anomalous vessel was gently retracted superiorly to drill the C1–2 facet surface and to put in a spacer or bone graft. The C-1 lateral mass screw could be inserted in 3 patients, taking care not to compromise it during tightening. In the remaining cases (due to fracturing of a C-1 facet in one and lack of experience in handling such vessels in the others), precurved occipital rods or sublaminar wiring were chosen to avoid the use of a C-1 lateral mass screw. Figures 1–4 are 3D CTAs and intraoperative images showing handling of the FIA and fenestration of VA.

In 5 cases with a medial loop of VA, the C-2 transverse foramen was more medial than usual (Fig. 5). In 4 of these 5 cases a lateral mass or transpedicular screw was used (with the entry point just superior to the exit of the VA) instead of a pars interarticularis screw. Sublaminar wiring was used in 1 patient who had a medial loop. There were no vascular injuries. The postoperative outcomes including bone fusion and follow-up are listed in Table 1.

Discussion

The neurovascular structures housed by the CVJ make surgery in that area challenging. The surgical approaches to the CVJ have undergone a sea change in the last 2 decades. These are now directed toward direct posterior reduction and fusion by using the lateral masses.1–3 These approaches require a thorough understanding of the configuration of facets and the surrounding anatomy.6 The most important structure that skirts the C1–2 facets is the VA.

Anomalous VAs are more often found with congenital skeletal anomalies affecting the CVJ.8,9 Such anom-
<table>
<thead>
<tr>
<th>Case No.</th>
<th>Age (yrs), Sex</th>
<th>Diagnosis</th>
<th>Bone Anomaly</th>
<th>Normal VA or Its Anomaly</th>
<th>Procedure</th>
<th>Outcome (mos)</th>
<th>Bone Fusion</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>51, M</td>
<td>AAD (red)</td>
<td>Oc–C1 assimilation w/ C2–3 fusion</td>
<td>rt medial loop</td>
<td>open reduction w/ pst fusion w/ sublaminar wire</td>
<td>improved, minimal dependence on others (22)</td>
<td>absent, though no mobility on flexion-extension</td>
</tr>
<tr>
<td>2</td>
<td>9, F</td>
<td>AAD (irred)</td>
<td>Oc–C1 assimilation w/ C2–3 fusion</td>
<td>bilat FIA, lt narrower than rt</td>
<td>opening of joints, reduction w/ pst fusion w/ sublaminar wire</td>
<td>improved, partially dependent (16)</td>
<td>partially fused, no mobility on flexion-extension</td>
</tr>
<tr>
<td>3</td>
<td>40, F</td>
<td>AAD (red)</td>
<td>os odontoideum</td>
<td>normal</td>
<td>C1–2 fusion w/ sublaminar wire</td>
<td>improved, independent (15)</td>
<td>present</td>
</tr>
<tr>
<td>4</td>
<td>51, M</td>
<td>AAD (irred)</td>
<td>Oc–C1 assimilation w/ C2–3 fusion</td>
<td>rt FIA</td>
<td>transoral odontoidecomy w/ pst fusion w/ sublaminar wire</td>
<td>prolonged ventilatory support, died at 1 mo due to septicemia</td>
<td>NA</td>
</tr>
<tr>
<td>5</td>
<td>26, M</td>
<td>CM-I &amp; AAD (irred)</td>
<td>Oc–C1 assimilation w/ C2–3 fusion</td>
<td>rt VA fenestration (narrow); lt medial loop, lt narrower than rt</td>
<td>Oc–C2 fusion w/ precurved rods &amp; rt C-2 PI screws, lt C-2 transpedicular screws, &amp; FMD</td>
<td>improved, independent (13)</td>
<td>present</td>
</tr>
<tr>
<td>6</td>
<td>42, M</td>
<td>CM-I &amp; AAD (irred)</td>
<td>Oc–C1 assimilation w/ C2–3 fusion</td>
<td>normal</td>
<td>Oc–C2 fusion w/ precurved rods &amp; PI screws</td>
<td>improved, independent (12)</td>
<td>present</td>
</tr>
<tr>
<td>7</td>
<td>35, M</td>
<td>AAD (irred)</td>
<td>Oc–C1 assimilation w/ C2–3 fusion</td>
<td>lt FIA, lt VA narrower than rt</td>
<td>transoral odontoidecomy &amp; pst fusion w/ C-1 lat mass &amp; C-2 PI screws</td>
<td>improved, minimal dependence on others (12)</td>
<td>present</td>
</tr>
<tr>
<td>8</td>
<td>35, M</td>
<td>CM-I &amp; AAD (irred)</td>
<td>Oc–C1 assimilation w/ C2–3 fusion</td>
<td>rt medial loop, lt narrower than rt</td>
<td>C-1 lat mass, lt C-2 PI, &amp; rt C-2 lat mass screws, &amp; rod w/ spacer</td>
<td>improved, independent (10)</td>
<td>present</td>
</tr>
<tr>
<td>9</td>
<td>5, F</td>
<td>AAD (red) &amp; KFS</td>
<td>C2–3 &amp; C4–5 fusion</td>
<td>lt medial loop</td>
<td>C-1 lat mass, rt C-2 PI, &amp; lt C-2 lat mass screws, &amp; rod w/ spacer</td>
<td>improved, but partly dependent for activities (8)</td>
<td>present</td>
</tr>
<tr>
<td>10</td>
<td>8, F</td>
<td>AAD (red) &amp; Down syndrome</td>
<td>os odontoideum</td>
<td>extracranial origin of rt PICA (V segment) crossing C1–2 facet</td>
<td>C-1 lat mass &amp; C-2 PI screws &amp; rod</td>
<td>improved, but still dependent on others (6)</td>
<td>present</td>
</tr>
<tr>
<td>11</td>
<td>16, F</td>
<td>AAD (irred)</td>
<td>Oc–C1 assimilation w/ C2–3 fusion</td>
<td>lt FIA</td>
<td>C-1 lat mass &amp; C-2 PI screws &amp; rod w/ bone graft</td>
<td>improved, minimal dependence on others (6)</td>
<td>fused</td>
</tr>
<tr>
<td>12</td>
<td>6, M</td>
<td>AAD (red) &amp; Down syndrome</td>
<td>os odontoideum</td>
<td>blit narrow VAs, rt VA ending as PICA, lt VA joining PPTA to form BA</td>
<td>refused op</td>
<td>did not follow up</td>
<td>NA</td>
</tr>
<tr>
<td>13</td>
<td>26, M</td>
<td>AAD (irred), KFS, &amp; situs inversus w/ dextrocardia</td>
<td>Oc–C1 assimilation w/ C2–3 fusion; C2–3 &amp; C4–5 fusion</td>
<td>lt FIA, rt medial loop, rt narrower than lt</td>
<td>open reduction of facets w/ bone graft &amp; pst fusion, w/ rt C1–2 lat mass screws &amp; lt Oc–C2 precurved plate (C-1 fractured)</td>
<td>improved, independent (4)</td>
<td>fused</td>
</tr>
<tr>
<td>14</td>
<td>14, M</td>
<td>CM-I &amp; AAD (irred)</td>
<td>os odontoideum</td>
<td>normal</td>
<td>C-1 lat mass &amp; C-2 PI screws &amp; rod w/ spacer</td>
<td>improved, partially dependent (1.5)</td>
<td>FU too short to comment</td>
</tr>
<tr>
<td>15</td>
<td>9, M</td>
<td>AAD (red)</td>
<td>none</td>
<td>normal</td>
<td>C-1 lat mass &amp; C-2 PI screws &amp; rod w/ spacer</td>
<td>improved, independent (1.5)</td>
<td>FU too short to comment</td>
</tr>
</tbody>
</table>

* BA = basilar artery; CM-I = Chiari malformation Type I; FMD = foramen magnum decompression; FU = follow-up; irred = irreducible; KFS = Klippel-Feil syndrome; NA = not applicable; Oc = occiput; PI = pars interarticularis; PPTA = primitive persistent trigeminal artery; pst = posterior; red = reducible.
alous vessels are likely to get injured during dissection around the facets and the placement of screws. Preoperative evaluation of these vessels is of paramount importance in patients with congenital CVJ abnormalities.

Study of the transverse foramen and the narrow C-2 isthmus on preoperative CT scans gives some idea about the VA caliber and detects a high-riding VA that is likely to get injured while placing the transarticular screws. However, images of bone alone cannot detect the presence of an anomalous course of VA. The 3D CTA is helpful in delineating the vessel and its relation to the C1–2 facets.

With an occipitalized arch of the atlas, the VA after its exit from the transverse foramen of C-2 has been described to have 4 different types of course. In Type I (8.3%), the VA is below the occipitalized C-1 lateral mass and enters the foramen magnum without curving medially; in Type II (25%), the VA is below the occipitalized C-1 posterior arch, and enters the foramen magnum making a curve on the posterior surface of the occipitalized C-1 lateral mass; in Type III (61.1%), the VA ascends laterally to enter an osseous foramen created between the fused atlas and occiput, then reaches the cranium, and the anomalous pathway has its internal opening at the external edge or anterior part of the occipitalized C-1 lateral mass; and in Type IV (5.6%), the VA is absent on one side of the CVJ. We found the Type II variation in 5 of 9 patients (in 6 of 18 VAs) with an occipitalized arch of the atlas.

Additionally, 3 different variations in the extraosseous VA (after exiting from the C-2 transverse foramen) have been described in the past: 1) fenestration of the VA; 2) FIA; and 3) anomalous PICA arising from the third segment of VA and crossing the C1–2 facets. These variations have been described in 1% of the normal population but are quite often seen in those with congenital CVJ anomalies. The VA develops from the plexiform anastomoses between 7 cervical intersegmental arter-

![Fig. 2](image1.png)

**Fig. 2.** Intraoperative images of the patient (described in Fig. 1) with persistent FIA. A: Exposed C-2 pars with anomalous VA (asterisks) crossing the joint space. The cut C-2 nerve root ganglion can be appreciated just posterior to it. B: Blunt hook used to dissect the anomalous VA from the surrounding soft tissue, mobilizing it. C: Retracting the anomalous VA caudally to define the C-1 facet for screw insertion. D: Retracting the anomalous VA cranially while drilling the C1–2 joint space.

![Fig. 3](image2.png)

**Fig. 3.** A–D: Admission 3D CTAs showing the occipitalized C-1 (Occip C1). A: Posterior view showing anomalous medial loop of the right VA (asterisks) seen in close relation to the C-2 pars (pars interarticularis). Note the right VA crossing the C1–2 joint space as opposed to the left side. B: The relationship of normal left VA and joint space as seen in the left oblique view. C: Superior view showing the medial location of the C-2 transverse foramen and medial loop of the right VA compared with left side. D: The relationship of anomalous medial loop of the right VA and C1–2 joint space appreciated in the left oblique view. E: Intraoperative image of the same patient showing abnormal medial curvature of the right VA. Such a medial loop may be injured while dissecting the pars and C-2 facet.
Except for the seventh one, all others disappear. If the FIA remains without the normal VA, it gives rise to persistent FIA. If the FIA persists along with the normal VA, it gives rise to fenestration or it may join the future PICA, making its origin anomalous. Apart from these 3 variations we found a fourth; when the VA loops medially before entering the C-1 transverse foramen or the osseous canal (Fig. 6). In this variation the C-2 transverse foramen was relatively medial, probably a marker of a high-riding intraosseous VA and a narrow isthmus.

The literature describes including the adjacent C-3 or occiput or the use of sublaminar hooks, circumventing the anomalous VA. However, not opening the facets is less desirable because it affects the bone fusion. Besides this, including the adjacent levels for fusion compromises the range of motion further. Additionally, the use of hooks may not provide the rigid fixation required for such cases. Inadvertent injury to the VA has also been described. Screw insertion may be the most practical method of hemostasis, but it may lead to VA erosion with recurrent hemorrhage, distal embolization, or later infarction.

The detection of an anomalous course of the VA is the first step in preventing intraoperative injury. Once it has been preempted, monopolar cautery should be avoided while dissecting around the facets. The injury to the vessel can occur directly while dissection is being done, or it may occur due to excessive traction on its anomalous branch, that snaps it off from the parent vessel or a relatively fixed point. The C1–2 joint with normal or nondominant VA should be dissected first and the joint should be opened and distracted. This helps in opening up the space on the opposite side that is harboring the anomalous vessel, making the dissection easier. The anomalous artery or its branch was always noted anterior to the C-2 root ganglion. Dissection performed using a blunt hook helps separate the C-2 root ganglion from the anterior structures. The root is usually surrounded by venous plexus that requires bipolar cautery to prevent bleeding. Once the nerve root ganglion is cut, the soft tissue anterior to it is gently teased open to reveal the anomalous vessel. The identified vessel can then be dissected along its length and released from the soft tissue tethering it. This gives enough leverage for gentle retraction of the vessel superiorly or inferiorly, without injuring it directly or yanking it off from a fixed point or parent vessel (indirect injury), while drilling the facet surfaces and inserting the screws and the spacers. Additionally, care needs to be taken that the vessel is not compressed against the facet surface by the screw head after tightening.

The medial loop of the VA, although mobilized easily, usually makes an exit from the C-2 transverse foramen more medially. This suggests a narrow isthmus, thereby increasing the chances of injury to the VA while using the transarticular screw. The VA should be exposed right up to the C-2 transverse foramen, but using subperiosteal dissection. The use of monopolar cautery is extremely dangerous.
The entry point of the screw (lateral mass or transpedicular) can be chosen superior to the exit point of the VA.

**Conclusions**

With the technique discussed in this report we were able to safeguard the anomalous VA in all our cases. Although the artery was exposed and joint surfaces were drilled in all patients, sublaminar wires and occipitocervical fusion were used in our initial cases due to lack of expertise in handling such anomalous vessels. We have attempted to describe ways to diagnose preoperatively and avoid injury to the anomalous VA during surgery in the CVJ without compromising on the rigid C1–2 bone fusion.

**Disclosure**

The authors report no conflict of interest concerning the materials or methods used in this study or the findings specified in this paper.

Author contributions to the study and manuscript preparation include the following. Conception and design: Salunke. Acquisition of data: Salunke, Futane, Sahoo, Ghuman. Analysis and interpretation of data: Salunke, Futane, Khandelwal. Drafting the article: Salunke, Futane. 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: Salunke.

**References**