SECONDARY atlantoaxial instability may result from various pathological conditions, including trauma, malformations, congenital anomalies, rheumatoid arthritis, Down syndrome, infections, and tumors.\(^{17,19}\) Instability is a potentially serious and progressive condition. If untreated, it can result in local pain, myelopathy, and ultimately death.

The proximity of the VA, spinal cord, and C-2 nerve root to the atlas has led to the assumption that the placement of C-1 lateral mass screws was infeasible. Atlantoaxial instability, however, usually requires fusion, and several techniques involving anterior,\(^{11,12,17,22,23}\) posterior,\(^{11,12,17,22,23}\) and combined\(^{17,19,20}\) approaches for atlantoaxial fixation have been developed. Atlantoaxial mass screw fixation, developed by Goel and Laheri\(^{11}\) in 1994 and popularized by Harms and Melcher\(^{12}\) in 2001, has gained significant recognition and has improved outcome in patients undergoing posterior C1–2 arthrodesis.

With the evolution of these new surgical methods, a better understanding of the geometry and quantitative dimensions of the atlantal anatomy and their clinical relevance is necessary. The authors of recent anatomical studies have evaluated the osseous anatomy of C-1,\(^{8,14,28,29}\) but investigations of the neurovascular anatomy relevant to the placement of C-1 lateral mass screws are lacking.

Compared with transarticular screw placement, the more superior and medial trajectory of lateral mass screws decreases the risk of VA injury.\(^{12}\) The use of lateral mass screws, however, does not preclude such injuries, and precise anatomical knowledge is crucial to avoid surgical com-

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Working area, safety zones, and angles of approach for posterior C-1 lateral mass screw placement: a quantitative anatomical and morphometric evaluation

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**Object.** The authors measured relevant quantitative anatomical parameters to define safety zones for the placement of C-1 posterior screws.

**Methods.** Nineteen linear, two angular, and four surface parameters of 20 dried atlantal specimens were evaluated. The Optotrak 3020 system was used to define the working area. Ideal angles for screw positioning were measured using digital radiographs and a free image-processing program. Six silicone-injected cadaveric heads were dissected bilaterally to study related neurovascular anatomy.

The depth (range 5.2–9.4 mm, mean 7.2 ± 1.1 mm) and width (range 5.2–8.1 mm, mean 6.5 ± 0.9 mm) of the transverse foramen varied considerably among specimens. The mean posterior working area was 43.3 mm\(^2\). All specimens accommodated 3.5-mm-diameter screws, and 93\% accepted 4-mm-diameter screws. In 10 specimens (50\%), partial removal of the posterior arch was necessary to accommodate a 4-mm screw. The mean maximum angle of medialization was 16.7 ± 1.3˚; the mean maximum superior angulation was 21.7 ± 4.7˚.

**Conclusions.** The anatomical configuration of the atlas and vertebral artery (VA) varied considerably among the cadaveric specimens. The heights of the C-1 pedicle, posterior arch, and posterior lamina determine the posterior working area available for screw placement. The inferior insertion of the posterior arch may have to be drilled to increase this working area, but doing so risks injury to the VA. A dense venous plexus with multiple anastomoses may cover the screw entry site, potentially obscuring the operative view and increasing the risk of hemorrhage.

**Key Words • working area • atlantal lateral mass screw • posterior atlantoaxial stabilization**

**Abbreviations used in this paper:** ICA = internal carotid artery; VA = vertebral artery.
We therefore undertook a study to examine quantitatively and qualitatively the atlas and its relationship to the adjacent neurovascular structures to address the clinical implications associated with placing C-1 lateral mass screws. To our knowledge, this investigation is the most comprehensive in vitro study of C-1 lateral mass screw placement to date.

Materials and Methods

Twenty dried adult cadaveric C-1 vertebrae (obtained in 10 men and 10 women) were used to evaluate the osseous anatomy of the atlas. Six fresh human adult cervical spines and six silicone-injected cadaveric heads (obtained in six women and six men) were dissected bilaterally to study the relationship among the lateral mass of the atlas and the VA, paravertebral venous plexus, and C-2 nerve root (Table 1, Figs. 1 and 2).

For each dried C-1 specimen, 19 linear (Figs. 3 and 4), two angular (Table 2, Fig. 5), and four surface (Fig. 6) parameters were evaluated anatomically and radiographically. All symmetrical structures were measured bilaterally. Anatomical measurements were made using a digital caliper (YATO Electronics Co., Ltd.; precision ±0.01 mm). The ideal angles for screw placement, using the technique described by Harms and Melcher,12 were measured on digital radiographs (Fig. 5) obtained in two projections (anteroposterior and lateral) by using a free image-processing and -analysis program (UTHSCSA ImageToolVersion 3.0, http://ddsdx.uthscsa.edu/dig/itdesc.html).

Results

Anatomical Measurements of the Atlas

There were significant anatomical variations among specimens but no significant differences between the male and female specimens. The overall anatomical variations were evident in the differences in the width of the atlas (Parameter L5 [see Table 1], range 66.5–86.6 mm). There were also considerable anatomical variances in the depth (Parameter L3, range 5.2–9.4 mm) and width (Parameter L8, range 5.2–8.1 mm) of the transverse foramen. The width of the posterior C-1 arch at the point of the VA overlap (Parameter L12) ranged from 2.6 to 6.5 mm. There were no significant differences between the left and right sides.

Relationship of the C-1 Lateral Mass to the C-2 Nerve, VA, and Venous Plexus

At the atlantoaxial interspace the C-2 nerve exited extra-
Atlantal screw placement

durally and divided into anterior and posterior rami. The nerve then passed medially and inferiorly to the joint of the C-1 lateral mass (Figs. 1 and 2). Typically, the C-2 nerve root ganglion could be retracted downward to expose the screw entry zone. In some cases, however, the ganglion of the C-2 nerve was very large and not easily mobilized and retracted.

The extradural section of the VA is usually divided into three segments. The suboccipital segment of the VA (V₃), which runs from the top of the C-2 transverse foramen to the site of dural penetration, was of particular concern in this study. This segment passed medially behind the C-1 lateral mass and occipitoatlasial joint and was pressed into the groove on the upper surface of the lateral portion of the posterior arch of the atlas.

Three layers of muscles usually covered V₃. The obliquus capitis superior and inferior muscles and the rectus

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**Fig. 1.** Photographs showing bilateral (upper) and unilateral (lower) views of the suboccipital region. The muscles have been dissected and removed to provide a view of the VA and venous plexus, which surrounds the artery and C-2 ganglion (C2G) and covers the C-1 lateral mass (C1LM) in the suboccipital triangle. This plexus is connected via the anterior and posterior condylar veins (PCV) to the jugular bulb and via the lateral condylar vein to the internal jugular vein (IJV) at the lateral aspect of the occipital condyle (OC). Upper: The C-2 ganglion is very large and covers almost the entire surface of the lateral mass. Lower: The ganglion is smaller and more lateral to the C-1 lateral mass.

**Fig. 2.** Enlarged views of the anatomy of the suboccipital region (left side) before (A) and after (B and C) partial removal of the venous plexus, demonstrating the horizontal segment of the VA (hVA). A: The superior and inferior oblique and rectus capitis major muscles have been dissected and removed to provide a view of the VA and its venous plexus, which surrounds the artery in the suboccipital triangle. The occipital artery (OA) has also been partially removed. The C-2 ganglion is completely covered by the venous plexus. B: Dissection and removal of the venous plexus show the VA, C-2 ganglion (C2G) with its ventral ramus, and the greater occipital nerve, which has been partially removed. The C-1 lateral mass (C1LM) is covered by the large C-2 ganglion. C: Removal of the occipital bone and the C-1 arch shows numerous small tributaries from the internal vertebral plexuses (between the vertebrae) that issue from the vertebral canal above the C-1 posterior arch. These small branches unite with deep veins of the suboccipital triangle through successive transverse foramina (arrows) and form the dense venous plexus around the VA.

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capitis posterior major muscle created the superior suboccipital triangle. The posterior arch of the atlas and the posterior occipitoatlantal membrane formed the floor of this triangle. Displacing the rectus capitis posterior major and minor muscles as well as the occipitoatlantal membrane exposed the \( V_3 \) segment. At deeper planes \( V_3 \) was surrounded by a venous plexus composed of anastomoses between the deep cervical and epidural veins (Fig. 2). Various venous structures can be distinguished in the suboccipital region, including the suboccipital cavernous sinus, VA venous plexus, and vertebral venous plexus.\(^{1,16,30}\) These structures are interconnected with numerous venous channels. The plexus surrounding the VA was connected to the suboccipital venous plexus, jugular vein, vertebral venous plexus, and occasionally the sigmoid sinus. At the level of the suboccipital triangle, the vertebral vein connected the VA venous plexus to the suboccipital venous plexus. The posterior condylar vein usually originated at the jugular bulb; in two specimens, it arose near the distal portion of the sigmoid sinus. It drained into the deep cervical vein and VA venous plexus. In all specimens, this dense venous plexus covered the screw entry site (C-1 lateral mass), VA, and C-2 ganglion (Figs. 1 and 2).

**Angular measurements relative to axial (y angle) and sagittal (x angle) planes**

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<tr>
<th>Angle</th>
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<tr>
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<td>( 16.7 ± 1.3 )</td>
<td>14.6–20.7</td>
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<tr>
<td>( y )</td>
<td>( 21.7 ± 4.7 )</td>
<td>16.4–31.1</td>
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Atlantal screw placement

![Image](image_url)

Fig. 5. Radiographs showing the ideal angles for screw placement in the C-1 lateral mass. **Upper:** In the axial plane, the vertical and horizontal solid lines are drawn through the midpoint of the facet joints. The screw trajectory (dashed line) and angle (y angle) are then determined relative to the midline. **Lower:** In the sagittal plane, the dashed line defines the screw angle (x angle) relative to midline (solid line).

The width of the lateral mass (L13) ranged from 7.7 to 12.8 mm (mean 9.6 mm), and its height (L14) ranged from 4.3 to 6.1 mm (mean 4.5 mm). All specimens accommodated 3.5-mm-diameter screws, and 93% accepted 4-mm-diameter screws. In 10 specimens (50%), the inferior insertion of the posterior arch had to be drilled and partially removed to accommodate and facilitate placement of a 4-mm C-1 lateral mass screw. The cranio-caudal limit of the screw exit area ranged from a horizontal line above the anterior tubercle of C-1 (Fig. 4C, Line a) to a horizontal line at the border of the anterior arch of C-1 (Fig. 4C, Line c). The mediolateral limits of the exit zone were a vertical line at the lateral border of the C-1 facet joint (Fig. 4C, Line d) and a vertical line at the middle of the C-1 facet joint (Fig. 4C, Line b). The mean distance between the midline and midpoint of the screw exit zone (Parameter L18) was 12.6 ± 3.5 mm (range 8.1–26.3 mm).

The angles of approach for screw placement relative to the axial (y angle, Fig. 5 upper) and sagittal (x angle, Fig. 5 lower) planes were also investigated (Table 2). The mean maximum angle of medialization was 16.7 ± 1.3° (range 14.6–20.7°). The mean maximum superior angulation for screw placement was 21.7 ± 4.7° (range 16.4–31.1°). The C-1 polyaxial lateral mass screws were placed bicortically; these screws ranged in lengths from 26 to 34 mm (mean 30.4 mm). The straight alignment of the C-1 and C-2 screw heads posed a problem in some cases, necessitating C-1 screws that were 1 to 2 mm longer for attachment of the rods.

Discussion

Since its introduction, the surgical treatment of atlantoaxial complex instability has changed significantly. Atlantoaxial posterior wiring techniques were among the first standardized operative methods for achieving fusion in the highly mobile upper cervical spine. Gallie described the first wire fixation technique in 1939. In 1978 Brooks and Jenkins pioneered another method to promote a wedge compression of C1–2. In an alternative method, the Halifax clamp technique, sublaminar hooks are linked through a screw. In 1979 Magerl et al. first conducted bilateral C1–2 transarticular screw fixation via the posterior midline. The first recorded clinical use of atlantal lateral mass screws was reported by Goel and Laheri in 1994. In 2001 this technique became more familiar to surgeons through the use of polyaxial screw–rod fixation, as introduced by Harms and Melcher. Recently, the use of atlantal lateral mass screws has become popular.

Atlantal Lateral Mass Screw Placement and Neurovascular Anatomy

In general, the placement of atlantal lateral mass screws appears to be safe, feasible, and associated with few clinical problems. The rate of VA injury associated with C-1 lateral mass screws is thought to be lower than that associated with transarticular screws. Occasionally, however, the placement of C-1 lateral mass screws violates the VA and causes significant bleeding. The ICA also may be at risk during bicortical screw fixation of the atlas. Currier et al. have indicated that the location of the ICA relative to the anterior aspect of the atlas may vary considerably and that this vessel may be located within 1 mm of the ideal exit point of the bicortical C-1 lateral mass screw.

During procedures involving the craniocervical junction, one should anticipate asymmetry and variability of the VA. Moreover, in some cases the VA must be dissected away from the surgical field for application of fixation screws. In our specimens considerable anatomical variances in the depth and width of the transverse process reflected the differences in the size and anatomy of the VA. In some patients with no osseous anomaly and in as many as 19.7% of those with osseous anomalies such as Klippel–Feil syndrome, the VA can course beneath the C-1 posterior arch without passing through the transverse foramen. Several authors have addressed the importance of identifying the location of the VA groove during upper cervical region surgery. Anatomically, the osseous groove on the superior surface of the posterior ring of the atlas represents the exact location of the VA. In our specimens, the mean distance between the midline and the VA groove on the C-1 posterior arch was 14.9 ± 1.6 mm (range 12.1–19.5 mm). Similarly, Naderi et al. found this distance to be 15.0 ± 1.2 mm. We also found wide variations in the distance between the midline and the medial wall of the C-1 transverse foramen (mean 23.9 ± 1.7 mm; range 20.2–27.6 mm). Consequently, in the clinical setting preoperative computed tomography scans must be studied carefully to evaluate the anatomy of the VA. We believe that the C-1 posterior arch can be dissected safely 15 to 20 mm lateral to the midline.

Another clinical controversy concerns the sectioning of the C-2 nerve root, as described by Goel et al. Some authors have reported that patients experience significant
discomfort, pain, and numbness involving the posterior aspect of the scalp when this nerve must be sectioned or sacrificed. In 2001 Harms and Melcher reported that in 37 patients the C-2 ganglion could usually be retracted caudally to expose the screw entry point and that it did not need to be sacrificed. In some of our specimens, the C-2 nerve was large, covering the entire width and height of the lateral mass. Based on our clinical experience, we found that the C-2 ganglion must occasionally be sacrificed to expose the lateral mass. Microsurgical sectioning of the preganglionic nerve fibers, ligation of the nerve, and closure of the dural defect to prevent cerebrospinal fluid leakage are then performed. In the clinical setting, no patients in our institutions have noted major postoperative symptoms such as headache and numbness.

Moreover, our anatomical dissections showed that the venous plexus can cover the lateral mass, nerve root, and VA. In 1997 Arnautovic and colleagues termed the venous plexus surrounding the horizontal portion of the VA the “suboccipital cavernous sinus.” They differentiated this plexus from both the VA venous plexus and the vertebral venous plexus. Intraoperative bleeding from these veins can obscure the surgical field, leading to injury of the VA and C-2 nerve. Dissection and appropriate exposure of the atlantoaxial region can be difficult, and troublesome hemorrhage can worsen the situation. In some cases an emissary vein also may be within the center of the lateral mass and can cause hemorrhage.

Incising and elevating the periosteum over the posterior arch of the atlas allow the VA segment to be mobilized to reduce the chance of injuring the venous plexus and concomitantly causing hemorrhage. To ensure careful preoperative evaluation of the venous anatomy surrounding the C-1 lateral mass and VA segment, the venous circulation of the craniocervical junction must be well visualized on contrast-enhanced fat-suppressed T1-weighted magnetic resonance images.

**Atlantal Lateral Mass Screw Placement and Quantitative Anatomy of the Atlas**

The entry point and trajectory of the C-1 lateral mass screws are of special interest. Harms and Melcher make the screw entry point at the middle of the junction of the C-1 posterior arch and the midpoint of the posteroinferior portion of the C-1 lateral mass. Goel et al. prefer to insert the screw at the center of the posterior surface of the lateral mass, 1 to 2 mm above the articular surface. They have suggested that drilling the inferior surface of the posterior arch of the atlas might provide additional space. In half of our specimens, drilling and partial removal of the inferior insertion of the posterior arch were necessary to facilitate placement of a 4-mm C-1 lateral mass screw.

In general, the entry point of the screw is in the middle of the lateral mass. We believe, however, that no specific point of entry can be determined and applied for all cases. Conversely, we determined that the working area on the C-1 lateral mass included the surface area of the lateral mass after retraction or dissection of the C-2 nerve. As defined by our measurements, the smallest available working area for screw placement in the posterior C-1 lateral mass was 43.3 mm² (Fig. 7).

The factor limiting the posterior lateral mass working area was its height, which ranged from 4.3 to 6.1 mm (mean 4.5 mm). This working area can be increased by drilling the C-1 posterior arch, but the width of the posterior or C-1 arch at the point of the VA overpass also varied. Therefore, in some cases, only partial removal of the C-1 arch is feasible. In such cases, both drilling and a cranio-caudal screw trajectory may risk injury to the VA.

In their study Harms and Melcher determined screw trajectory under fluoroscopic guidance, but they specified no particular trajectory for the screws. In our study the maximum angle of medialization from the midline was 16.7 ± 1.3° (range 14.6–20.7°). The angle of approach for screw placement relative to the sagittal plane was 21.7 ±
Atlantal screw placement

4.7°. These findings are similar to those of Hong and colleagues who reported the screw angulation to be 14.7° relative to the axial plane and 22.9° relative to the sagittal plane. In our study, however, the maximum angle of medialization was much smaller than the medial angulation of 25 to 45° proposed by Wang and Samudrala, who did not, however, investigate the cranio-caudal angulation of the screw. Whether they used radiographic images to investigate the angles of screw placement as we and Hong et al. did is unclear.

Another practical consideration is the choice of the screw length. In our study the length of screws ranged from 26 to 34 mm, but the alignment of the C-1 and C-2 screw heads may pose a problem. In our specimens a C-1 screw needed an additional 1 to 2 mm to facilitate attachment of the rods.

Because of the considerable differences in the height of the anterior aspect of the lateral mass and the distance between midline (the midpoint of the anterior tubercle) and the lateral aspect of the lateral mass, no specific exit point was ideal for all specimens. We therefore defined a screw exit area. The cranio-caudal limits of this area were the anterior C-1 tubercle and the border of the anterior arch of C-1. Its mediolateral limits were the C-1 facet joint and the middle of the C-1 facet joint. The mean distance between the midline and midpoint of the screw exit zone (Fig. 4C, parameter L18) was 12.6 ± 3.5 mm. This value confirms the need for careful intraoperative fluoroscopy. For optimal angulation, the superior aspect of the anterior surface of the C-1 lateral mass should be targeted on lateral fluoroscopic images with a mediolateral angle of approach of about 16° and a cranio-caudal angle of approach of approximately 20°. Increasing the medial angulation of a C-1 lateral mass screw has been recommended to prevent vascular injury of the ICA.

Conclusions

Placement of atlantal lateral mass screws is safe, feasible, and associated with few clinical problems. Variations in the atlas and VA warrant precise preoperative study of this anatomy. The heights of the C-1 pedicle, posterior arch, and posterior lamina—which determine the posterior working area for placing lateral mass screws—are highly variable. Drilling the inferior insertion of the posterior arch, which risks injury to the VA, may be necessary to increase the working area. A large venous plexus formed by anastomoses between the suboccipital cavernous sinus, vertebral plexus, posterior condylar emissary vein, and sigmoid sinus can cover the screw entry site and VA, obscuring the surgical view and thereby increasing the risk of hemorrhage. To optimize angulation, the superior aspect of the anterior tubercle should be targeted on lateral fluoroscopic images with a mediolateral angle of approach of approximately 16° and a cranio-caudal angle of about 20°.

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