BIOMECHANICS

Harms C1–C2 Instrumentation Technique

Anatomo-Surgical Guide

Ronald Schulz, MD,* Nicolás Macchiavello, MD,* Elias Fernández,† Xabier Carredano, MD,‡ Osvaldo Garrido, MD,‡ Jorge Diaz, MD,§ and Robert P. Melcher, MD,¶

Study Design. Anatomic study.

Objective. To measure C1 and C2 critical areas related to the screws trajectory, according to Harms technique, in Latin specimens. To investigate vertebral artery course in cadavers.

Summary of Background Data. To our knowledge there are no studies addressing vertebral surface measurements for screw placement, according to Harms C1–C2 instrumentation technique, nor cadaveric measurements of the trajectory of the vertebral artery in Latin specimens.

Methods. C1 and C2 specimens were measured. C1 measurements: height, width, anteroposterior diameter (intrarosseous screw length) and convergence in the axial plane of the lateral mass; length from the posterior border of the posterior C1 arch to the anterior cortex of the articular mass (total screw length). C2 measurements: width, height, convergence and sagittal inclination of the pars interarticularis. Direction of the trajectory of the vertebral artery in the suboccipital region in fresh cadavers.

Results. C1: left mass width 14.20 mm, right: 14.32 mm; left intrarosseous screw length: 17.17 mm, right 16.9 mm; left total length of the screw: 27.14 mm, right: 26.72 mm; left mass height: 10.22 mm, right: 10.29 mm. Right mass convergence: 24.68°, left: 22.44°. C2: width: left 8.75 mm, right: 8.53 mm; height: left 10 mm, right 9.81 mm; convergence: left 42.15°, right: 38.98°; sagittal inclination: left 35.50°, right: 33.07°. Vertebral artery's medial border is between 13 and 22 mm from the middle line of C1 posterior arch.

Conclusion. Convergence and inclination of the pars are slightly greater than the suggested by Harms. Individual and/or racial variations must be considered. There is enough space for safe placement of a 3.5 mm screw in the lateral masses of C1 and through the pars of C2. Dissecting the superior face of the posterior arch of C1 laterally more than 10 mm from the posterior tubercle could injure the vertebral artery.

Key words: atlantoaxial fixation, vertebral artery, lateral mass screws.

Spine 2011;36:945–950

A unique anatomy and biomechanical properties make the atlantoaxial region a surgically challenging one.1–3 Posterior stabilization techniques with wires are still widely used, but they have many drawbacks. Neurologic risk during sublaminar wire passage, weak biomechanical properties which add the need of post operative immobilization, nonunion rates as high as 50%4 and a tendency to displace—rather than reduce—the atlantoaxial joint5 have been reported. The addition of Magerl's technique improved stability of the construct and fusion rates.5–7 However, it's far from being perfect, due to reported high risks of injury to the vertebral artery, which can go up to 18% depending on the series reviewed.2,6,8 Other disadvantages of this technique include the need of extending the approach (which carries proprioceptive impairment and pain) or making additional incisions for screw placement; indirect reduction of C1–C2, which must be kept during the whole procedure, can be difficult and not without risk. Finally, pronounced cervicothoracic kyphosis or some abnormalities of the vertebral artery make this technique useless.1,3,10

The technique published by Harms11,12 has addressed many of the problems described above.

Some studies show the feasibility of screw placement based on measurements on vertebrae specimens,13–16 and CT images.17 There is one study which evaluates the vertebral artery groove of C1 in dry vertebrae and addresses it's relationship with the midline.18 To our knowledge, there are no studies measuring Latin-American specimens, nor cadavers, to study the course of the vertebral artery in relation to Harms technique.

The purpose of this study is to correlate the original suggestions for screw placement, in C1 and C2, according to Harms instrumentation technique, with surface measurements taken on vertebrae of Chilean specimens. Significant anatomosurgical differences may exist between patients of different races that might prove relevant in a technique, which demands high precision in screw placement. Finally, cadaveric dissections of the C1–C2 region were performed to describe the course of the vertebral artery.
artery and determine anatomically its risk of injury during this technique.

**MATERIALS AND METHODS**

Twenty dry C1 and 20 C2 vertebrae were measured. The vertebrae were obtained from the Anatomy Department, Medical School, University of Chile. Demographic data of these specimens was not available. In addition, anatomic dissections of the suboccipital region were performed in 20 fresh male cadavers, ages 35 to 75, to measure the distance between the posterior tubercle of the posterior arch of C1 and the medial border of the vertebral artery, where it comes out of C1 in direction of the foramen magnum.

Measurements were made by the same investigator, using a digital caliper with a 0.02 mm accuracy (Uyustools, Iquique, Chile). The measurements taken were the following (Figure 1):

(A) Width of the articular mass of C1, at the level of the center of the transverse foramen.
(B) Height of C1 articular mass, measured at the point where screw trajectory is narrower.
(B) AP diameter of the inferior mass of C1, following the axis of the screw trajectory, according to Harms technique (intraosseous screw length).
(B) Length from the posterior border of the posterior arch to the anterior cortex of C1 articular mass, following the screw's direction (total screw length).
(B) Width of C2 pars, at the level of the center of the transverse foramen.
(B) Height of C2 pars, at the level of the center of the transverse foramen.

Digital pictures of the six faces (superior, inferior, anterior, posterior, and lateral) of each vertebra were taken. The pictures were then analyzed with Osirix™ version 2.5.1 software, to measure the following angles (Figure 2):

(A) Convergence of the lateral masses of C1 in the axial plane.
(B) Convergence of C2 pars.
(C) Sagittal inclination of C2 pars.

**Surgical Dissection and Screw Placement Technique**

The surgical dissection was performed after midline incision down to the suboccipital plane, the rectus capitis major and obliquus capitis inferior are dissected subperiostically from the spinous process of C2, to expose the laminae and C1–C2 joint.

After preparing the laminae of C2, the occipital bone is exposed partially, at the medial part, below the nuchal line.

Once the posterior tubercle of C1 is identified, the rectus capitis minor muscle is released from it.

The next step is to remove the muscular tissue from the atlantooccipital membrane, using blunt dissection, and expose the C2 nerve. Careful dissection of the tissue that surrounds the C2 dorsal root ganglion, below the arch of C1, is carried out.

At the end, exposure of the pars of C2 is carried on with help of a Penfield no. 4 dissector.

![Figure 1](image)
C1 Screws
The entry point of C1 lateral mass is in the middle of the junction of the C1 posterior arch and the midpoint of the posterior inferior part of the C1 lateral mass.

According to the technique described by Harms and Melcher, the screws follow a posterior to anterior direction, with $5^\circ$–$10^\circ$ of convergence. On the sagittal plane the trajectory must be completely parallel to the caudal aspect of the posterior arch of C1, pointing toward the middle of the anterior tubercule of C1.

C2 Screws
The entry point for C2 screws should be on the superior-medial aspect of a quadrant formed by the intersection of two lines, one which bisects C2 pars vertically and the other which bisects the lamina horizontally. The direction described is $20^\circ$ to $30^\circ$ medial, and $20^\circ$ to $30^\circ$ cephalad.

RESULTS

Dissection
The distance between the posterior tubercule of the posterior arch of C1 and the medial border of the vertebral artery, where it comes out of C1 in direction of the foramen magnum, measured between 13 and 22 mm (Figures 3 and 4, Table 1). We observed that the vertebral artery cannot be mobilized in the sulcus of C1 without risking its rupture. Differences were not significant between the right and the left side.

Anatomo-Surgical Correlation for C1 Screws
Table 2 shows the results for the measurements of C1.

<table>
<thead>
<tr>
<th>Distance (mm)</th>
<th>Minimum</th>
<th>Maximum</th>
<th>Mean</th>
<th>Std. Deviation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Left</td>
<td>13</td>
<td>17</td>
<td>14.55</td>
<td>1.43178</td>
</tr>
<tr>
<td>Right</td>
<td>13</td>
<td>22</td>
<td>14.8</td>
<td>2.21478</td>
</tr>
</tbody>
</table>
The width and thickness of C1 articular masses are big enough to allow safe insertion of 3.5 mm screws, with minimal risk of injury to the vertebral artery (laterally and cranially), the spinal cord (medially), C1–C2 joint (caudally) and less frequently to the C0–C1 joint. Nevertheless, notice should be taken in that the anatomic convergence of the lateral masses of C1 seems to be higher than suggested in Harms work. This anatomic variation might be explained, among

Convergence used in Harms technique (5°–10°) is lower than the mayor axis of C1 mass. The average convergence angle of the left mass (Figure 2A) was 22.4° (min 10.56°, max 41.76°). At the right side, the average was 24.68° (min 17.82°, max 38.81°).

When both sides were compared, significant differences were found in the length, measured between the posterior border of the posterior arch and the anterior cortical of C1 mass, following the direction of the screw (P = 0.0015; T test), and in the convergence of the lateral masses (P = 0.025; T test).

Anatomo-Surgical Correlation for C2 Screws
Table 3 shows the measurements of C2.

Comparing both sides, again significant differences were found in the measurements of the pars convergence (P = 0.002; T test).

DISCUSSION
Our dissections and measurements in vertebrae show that Harms C1–C2 instrumentation technique is feasible with reasonable safety.

The width and thickness of C1 articular masses are big enough to allow safe insertion of 3.5 mm screws, with minimal risk of injury to the vertebral artery (laterally and cranially), the spinal cord (medially), C1–C2 joint (caudally) and less frequently to the C0–C1 joint. Nevertheless, notice should be taken in that the anatomic convergence of the lateral masses of C1 seems to be higher than suggested in Harms work. This anatomic variation might be explained, among

Convergence used in Harms technique (5°–10°) is lower than the mayor axis of C1 mass. The average convergence angle of the left mass (Figure 2A) was 22.4° (min 10.56°, max 41.76°). At the right side, the average was 24.68° (min 17.82°, max 38.81°).

When both sides were compared, significant differences were found in the length, measured between the posterior border of the posterior arch and the anterior cortical of C1 mass, following the direction of the screw (P = 0.0015; T test), and in the convergence of the lateral masses (P = 0.025; T test).

Anatomo-Surgical Correlation for C2 Screws
Table 3 shows the measurements of C2.

Comparing both sides, again significant differences were found in the measurements of the pars convergence (P = 0.002; T test).

DISCUSSION
Our dissections and measurements in vertebrae show that Harms C1–C2 instrumentation technique is feasible with reasonable safety.

The width and thickness of C1 articular masses are big enough to allow safe insertion of 3.5 mm screws, with minimal risk of injury to the vertebral artery (laterally and cranially), the spinal cord (medially), C1–C2 joint (caudally) and less frequently to the C0–C1 joint. Nevertheless, notice should be taken in that the anatomic convergence of the lateral masses of C1 seems to be higher than suggested in Harms work. This anatomic variation might be explained, among

Convergence used in Harms technique (5°–10°) is lower than the mayor axis of C1 mass. The average convergence angle of the left mass (Figure 2A) was 22.4° (min 10.56°, max 41.76°). At the right side, the average was 24.68° (min 17.82°, max 38.81°).

When both sides were compared, significant differences were found in the length, measured between the posterior border of the posterior arch and the anterior cortical of C1 mass, following the direction of the screw (P = 0.0015; T test), and in the convergence of the lateral masses (P = 0.025; T test).

Anatomo-Surgical Correlation for C2 Screws
Table 3 shows the measurements of C2.

Comparing both sides, again significant differences were found in the measurements of the pars convergence (P = 0.002; T test).

DISCUSSION
Our dissections and measurements in vertebrae show that Harms C1–C2 instrumentation technique is feasible with reasonable safety.

The width and thickness of C1 articular masses are big enough to allow safe insertion of 3.5 mm screws, with minimal risk of injury to the vertebral artery (laterally and cranially), the spinal cord (medially), C1–C2 joint (caudally) and less frequently to the C0–C1 joint. Nevertheless, notice should be taken in that the anatomic convergence of the lateral masses of C1 seems to be higher than suggested in Harms work. This anatomic variation might be explained, among

Convergence used in Harms technique (5°–10°) is lower than the mayor axis of C1 mass. The average convergence angle of the left mass (Figure 2A) was 22.4° (min 10.56°, max 41.76°). At the right side, the average was 24.68° (min 17.82°, max 38.81°).

When both sides were compared, significant differences were found in the length, measured between the posterior border of the posterior arch and the anterior cortical of C1 mass, following the direction of the screw (P = 0.0015; T test), and in the convergence of the lateral masses (P = 0.025; T test).

Anatomo-Surgical Correlation for C2 Screws
Table 3 shows the measurements of C2.

Comparing both sides, again significant differences were found in the measurements of the pars convergence (P = 0.002; T test).

DISCUSSION
Our dissections and measurements in vertebrae show that Harms C1–C2 instrumentation technique is feasible with reasonable safety.
other things, by morphologic differences related to race. To our knowledge, most of the studies have been performed in Caucasian and Asiatic population. The reason for using a smaller convergence for C1 screw placement is that the lateral mass losses height from lateral to medial. A screw that follows the anatomic convergence is in risk of perforating the C1–C2 or C0–C1 joints.

In the technique described by Magerl,5 the highest risk for injuring the vertebral artery is at the level of C2 transverse foramen. According to Paramore,2 18% of the patients present with a C2 transverse foramen that is too high to allow the placement of a transarticular screw (Figure 5). In the same series, 5% of the patients had anatomic conditions that made the C1–C2 transarticular screw too dangerous. Theoretically, this risk is lower when using Harms technique, because the direction of the screw is convergent, thus moving away from the artery. Still, Harms technique is not free of danger, especially in patients with a high transverse foramen or a narrow pars (Figure 5). It is also important to point out the fact that the vertebral artery is also at risk during the dissection, at its path between C1 and C2, where it is almost impossible to move, due to its adherence to the articular capsule and the walls of the transverse foramen (Figure 6). According to our findings, a laminectomy or the dissection of the superior face of the posterior arc of C1 should not extend laterally more than 10 mm from the posterior tubercule, which could be considered arbitrarily as a “safe zone” (the lowest distance measured during our dissections, between the posterior tubercule of C1 and the medial border of the vertebral artery, was 13 mm). This distance is slightly bigger than the one suggested by Ebraheim.14 In his work on dry C1 specimens, the distance from the midline to the medial-most edge of the vertebral artery groove averaged 10 mm, with a minimum of 8 mm, which led him to suggest that dissection on the superior aspect of the posterior ring should remain within 8 mm of the midline.

Figure 6. Left: Posterior view of left C1–C2 joint. Right: lateral view. C1 indicates posterior arch of C1; nOM, mayor occipital nerve; C2, posterior arch of C2; CA, articular capsule; AV, vertebral artery; AC1–C2, C1–C2 joint.

Height and width of the pars allow the placement of a 3.5 mm screw. The direction suggested in the original technique (10°–30° medial and 20°–30° cranial) is slightly different from our measurements, which are bigger. This difference underlines the importance of preoperative planning in these patients, in which individual anatomic variations must be considered. Also, intraoperative documentation with radiographs should be always used.

Anecdottally, we noticed that there is a nutrient canal at the union of the lamina with the pars of C2, which usually matches the insertion point of the C2 screw.

The learning curve, and the anatomic variations that can be found in each patient, must be addressed by surgeons attempting this procedure. Probably, racial differences must also be considered. Appropriate training and familiarization with the technique, and a thorough preoperative examination, which must include CT and angio-CT scans, would help reduce the risks associated with this technique.

Key Points

- Measurements at critical areas of C1 and C2 for Harms technique were made in chilean specimens
- Cadaveric dissections for analysis of the trajectory of the vertebral artery were made.
- Vertebral artery is at risk while dissecting C1 posterior vertebra over 10 mm from the midline.
- Convergence and inclination of C2 pars interarticularis are greater than described in original technique.

Acknowledgments

The authors like to thank the Teaching and Research Department, Chilean Forensic Institute (Servicio Médico Legal de Chile) and Department of Anatomy and Developmental Biology, School of Medicine, University of Chile.

References