Original Article

Atlas instrumentation guided by the medial edge of the posterior arch: An anatomic and radiologic study

ABSTRACT

Study Design: This was an interventional human cadaver study and radiological study.

Objectives: Atlas instrumentation is frequently involved in fusion procedures involving the craniocervical junction area. Identification of the entry point at the center of atlas lateral mass (ALM) is challenging because of its rounded posterior surface and the surrounding venous plexus. This report examines using the medial edge of atlas posterior arch (MEC1) as a fixed and reliable anatomic reference to guide the entry point of ALM screws.

Methods: Fifty, normal, cervical spine computed tomography studies were reviewed. ALM screw trajectories were planned at one point along MEC1 and another point 2 mm lateral to MEC1. Free-hand ALM instrumentation was performed in ten fresh human cadavers using the 2 mm entry point, with a sagittal trajectory parallel to atlas inferior arch (IAC1); three-dimensional imaging was then performed to confirm instrumentation accuracy.

Results: The average ALM diameter was 12.35 mm. Inserting a screw using the entry point 2 mm lateral to MEC1 was closer to ALM midpoint than using the entry point along MEC1 ($P < 0.0001$). Twenty ALM screws were successfully inserted in the ten cadavers. No encroachments into the spinal canal or foramen transversarium occurred. However, two screws were superiorly directed and violated the occipitocervical joint; they were not parallel to IAC1.

Conclusion: MEC1 provides a fixed and reliable landmark for ALM instrumentation. An entry point 2 mm point lateral to MEC1 is close to ALM midpoint. IAC1 also provides a guide for the sagittal trajectory. Attention to anatomic landmarks may help reduce complications associated with atlas instrumentation but should be verified in future clinical studies.

Keywords: Atlantoaxial instrumentation, atlas instrumentation, atlas lateral mass, atlas medial arch, C1 inferior arch border, craniocervical instrumentation

INTRODUCTION

Atlas instrumentation is a common procedure for the treatment of craniocervical area instability caused by a variety of pathologic conditions.[1-4] The atlantoaxial area is highly mobile and has a complex anatomy,[4] making precision and accuracy during the instrumentation procedure essential. Careful preoperative evaluation, the use of reliable intraoperative anatomic landmarks, and intraoperative imaging are all valuable steps for minimizing the risk of complications. A careful technique is particularly important when encountering an unfavorable bony anatomy or abnormal positioning of the vertebral artery.[1,3,4]

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Numerous safe and effective atlantoaxial stabilization techniques have evolved.[1,5-10] Rigid atlantoaxial fixation could

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be achieved using either transarticular screws or a screw-rod construct of C1 lateral mass screws connected to C2 pedicle or pars screw (ALM-C2).[11] In 1988, Goel et al initially performed ALM-C2 technique with plates and screws to provide a rigid fixation while avoid the potential risk of vertebral artery injury associated with the transarticular screw technique.[6] One of the drawbacks of the original technique was that resection of the C2 ganglion led to some patients complaining of anesthesia in the occipital scalp area.[8] This can be avoided by utilizing the Harms and Melcher modification, which involves a polyaxial screw and rod system to preserve the C2 ganglion.[1] The risk of vertebral artery injury was estimated to be approximately 2%, using the ALM-C2 pars screw method; the risk is greatest during lateral dissection of the C1 arch and during insertion of the C2 screws.[4,8,12,13]

The identification of a reliable C1 entry point is critical for safe and reliable instrumentation. Considering the ALM-C2 construct, Goel *et al*. preferred to insert the C1 screw at the center of the posterior surface of the ALM, 1–2 mm above the articular surface.[6,8] Harms and Melcher suggested that the C1 screw entry point should be in the middle of the junction of the posterior arch of the atlas and the midpoint of the posterior inferior part of the ALM.[1] Identification of this midpoint requires the medial and lateral dissection of the ALM. However, the rounded posterior surface of the ALM and the surrounding large paravertebral venous plexus makes such dissections challenging.

This study evaluated using the medial edge of the posterior arch (MEC1) of the atlas as a reliable intraoperative anatomic landmark for indicating the middle of the ALM. The use of this landmark may improve the safety and accuracy of ALM instrumentation, and it may also obviate the need for extensive dissection to identify the ALM midpoint. Thus, this technique may help minimize the risk of venous bleeding or vertebral artery injury.

METHODS

Design

The current study consisted of quantitative ALM assessments from fifty consecutive, adult cervical spine computed tomography (CT) studies, followed by ALM instrumentation in cadavers, using MEC1 as a landmark. Institutional Ethical Board approval was obtained before the start of the study from King Saud University, College of Medicine, Institutional Review Board (IRB); No. 15/0418/IRB. The main study outcome was the determination of ALM screw placement accuracy on an axial plane, using MEC1 as an anatomic reference.

Study variables

Radiologic atlas lateral mass evaluation and entry point assessment

One hundred ALMs were evaluated using cervical spine CT (VCT XTe scanner, GE Healthcare, Little Chalfont, UK) studies involving fifty consecutive adults. All cases were evaluated using a trauma protocol, with a slice thickness of 0.5 or 1.25 mm. We excluded cases with evidence of upper cervical injury, infection, tumors, anatomical abnormalities, or cases where the C1 vertebral images were unclear. Reconstruction of the atlas vertebra was performed and then isolated from the surrounding structures [Figure 1]. Both the reconstructions and measurements were performed using three-dimensional (3D) workstations (Volume Viewer, GE Healthcare). Measurements were performed using the axial view at the widest ALM diameter.

As previously reported, atlas instrumentation is safest when approaching the middle of the ALM;[1,6,8] therefore, the ALM midpoint was determined on the CT images. Using MEC1 as an anatomic reference, two entry points on the posterior surface of the ALM were determined. The first point (0 mm point) was along MEC1, whereas the second (2 mm point) was 2 mm lateral to MEC1 [Figure 1a]. Both points were compared for their proximity to the ALM midpoint and the distance from the medial edge of the ALM. The 2 mm point was chosen as an initial estimate for proximity to the ALM midpoint.

Cadaver atlas instrumentation

Ten fresh, adult human cadavers were utilized; none had been previously used for any other purpose. With the cadavers in a prone position, the atlas and axis posterior surfaces were exposed. All cadavers underwent a 3D baseline radiologic assessment using an O-arm (Medtronic PLC, Littleton, MA, USA) to assess anatomic variations.

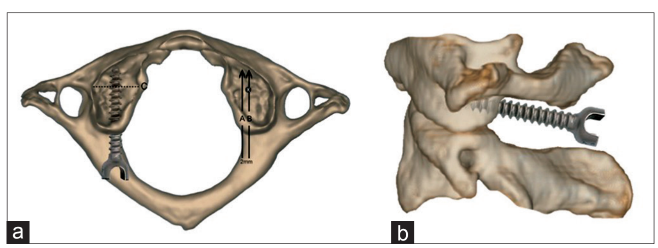

Figure 1: Reconstructed axial (a) and sagittal (b) computed tomography images of the atlas. (a) Measurements in the horizontal plane. C, atlas lateral mass width; X - Atlas lateral mass midpoint; A – 0 mm entry point along the medial edge of the atlas posterior arch; B - 2 mm entry point lateral to the medial edge of the atlas posterior arch. The 2 mm entry point is closer to the atlas lateral mass midpoint than the 0 mm point. The atlas lateral mass screw trajectory is perpendicular to the horizontal plane. (b) Sagittal view showing the ideal screw trajectory, on the sagittal plane, is parallel to the inferior border of the atlas posterior arch

Dissection of the medial edge of the atlas was performed under magnification. The ALM entry point was 2 mm lateral to MEC1. C1 cortex penetration was performed using a high-speed drill, and a tap was used to advance into the ALM. The planned trajectory was perpendicular to the horizontal plane and parallel to the inferior border of the C1 posterior arch (IAC1), as previously suggested.[1] Multiaxial screws (Vertex, Medtronic Sofamor Danek, Memphis, TN, USA) were used. All instrumentation was done without imaging guidance. Following screw insertion, 3D images were obtained, using an O-arm, to assess screw location.

Statistical analysis

Statistical analyses were performed using the Statistical Package for Social Science Software (PC + version 19.0; IBM, SPSS, Chicago, IL, USA). Descriptive statistics (means, ±standard deviations, and 95% confidence intervals [CI]) were determined. A result was considered statistically significant if $P < 0.05$.

RESULTS

Radiographic assessment of the atlas lateral mass entry point

The included cases, 36 males and 14 females, had a mean age of 30 years (range, 18–56 years). The recorded parameters from the ALM radiologic measurements are shown in Table 1. The overall mean axial diameter of the ALMs was 12.35 mm and was significantly larger in males than in females ($P < 0.0001$). The axial diameter of the right ALM was also greater than that of the left ALM ($P = 0.054$), possibly related to the more dominant vertebral artery more frequently occurring on the left, compared with the right side.[14]

The two imaginary ALM entry points are shown in Figure 1. The 2 mm entry point was significantly closer to the midpoint than the 0 mm entry point ($P < 0.0001$) [Table 2]. For both right and left ALMs, the 2 mm entry point was lateral to the ALM midpoint by a mean of 0.74 ± 0.92 mm (95% CI, 0.55–0.92 mm), whereas the 0 mm entry point was medial to the ALM midpoint by a mean of 1.42 ± 0.87 mm (95% CI, 1.24–1.60 mm). The proximities of either point to the ALM midpoint ($P = 0.389$ and $P = 0.395$, respectively) [Table 1] were not significantly different between the right and left sides. For both the right and left ALMs, the 0 and 2 mm entry points were lateral to the medial edge of the ALM by means of 4.75 and 6.91 mm, respectively [Table 2].

Cadaver atlas instrumentation

Twenty multiaxial screws were inserted into the ALMs of ten cadavers using the entry point 2 mm from MEC1. Postinsertion, O-arm 3D imaging confirmed that all screws were within ALMs and that no spinal canal or foramen transversarium breaches occurred [Figure 2a]. Two screws were superiorly directed and violated the occipitocervical joint because they were not parallel to IAC1 [Figure 2b]. At the 2 mm entry point, a nutrient foramen was frequently encountered with a vessel entering the C1 lateral mass. Studying the frequency of such foramens and arteries was not feasible within the scope of this study.

DISCUSSION

The availability of a constant and reliable anatomic landmark is essential during spinal surgical instrumentations. Our study supports the Goel approach of instrumenting atlas vertebras through the ALM midpoint.[1,6,8] However, identifying this midpoint is challenging given the ALM's rounded posterior surface, the narrow corridor into the lateral mass caused by

Table 1: Radiologic measurements of atlas lateral mass screws in fifty patients

Parameter	Right (n=50)	Left (n=50)	P
Average axial ALM diameter (mm)	12.45±1.37	12.24±1.28	0.054
ALM width midpoint#	6.22±0.68	6.12±0.64	0.054
Distance from 0 mm entry point to ALM midpoint* (95% CI)	1.40±0.68 (1.20-1.60)	1.44±0.64 (1.15-1.73)	0.389
Distance from 2 mm entry point to ALM midpoint** (95% CI)	0.77±0.68 (0.55-1)	0.71±0.64 (0.41-1.01)	0.395

#Midpoint - Middle of the ALM average axial diameter (mm) measured from the medial edge of the ALM; *0 mm point - Lateral mass entry point along the MEC1; **2 mm point - Lateral mass entry point 2 mm lateral to MEC1; ALM - Atlas lateral mass; CI - Confidence interval; MEC1 - Medial edge of the atlas posterior arch

Table 2: Comparison between the 0 and 2 mm points of 100 atlas lateral mass screws in 50 patients

Parameter	0 mm point* (95% CI)	2 mm point** (95% CI)	P
Distance to ALM midpoint (mm)	1.42±0.87 (1.24-1.60)	0.74±0.92 (0.55-0.92)	<0.0001
Distance to ALM medial edge (mm)	4.75±1.09 (4.53-4.97)	6.91±1.18 (6.68-7.15)	<0.0001

*0 mm point - Lateral mass entry point along the MEC1; **2 mm point - Lateral mass entry point 2 mm lateral to MEC1; MEC1 - Medial edge of the atlas posterior arch; ALM - Atlas lateral mass; CI - Confidence interval

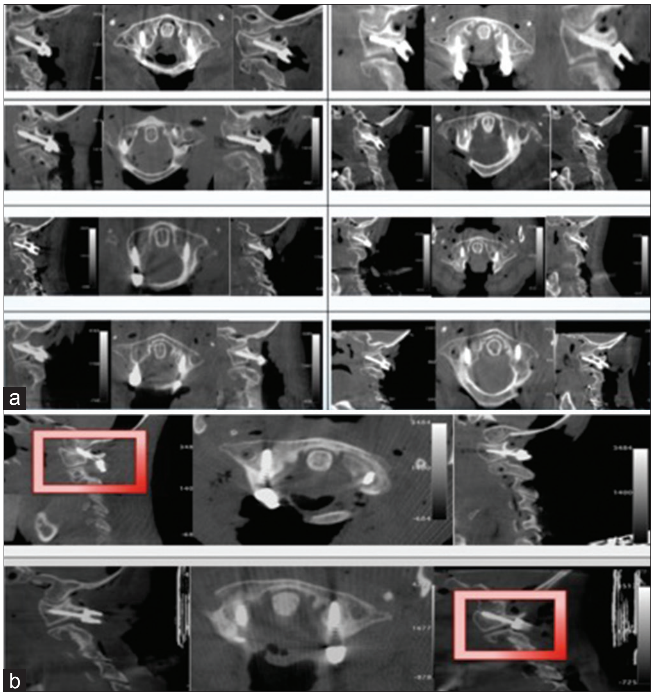

Figure 2: Images demonstrating atlas lateral mass instrumentation in ten cadavers. (a) Accurate screw placement using the 2 mm point, lateral to the medial edge of the atlas posterior arch. Postinsertion images confirm the absence of spinal canal or foramen transversarium breaches. (b) Two screws violated the occipitocervical joint as they were not parallel to the inferior border of the atlas posterior arch. However, they had accurate medial–lateral trajectories

the adjacent C2 nerve root, the surrounding venous plexus, and the proximity to the spinal cord and vertebral artery. However, the current study showed that MEC1 may be used as an intraoperative anatomic landmark to identify the ALM midpoint. Some reports have attempted to identify an entry point based on a fixed distance. For example, Hu *et al*. reported that the optimal ALM screw insertion point was 28.38 mm (males) or 26.86 mm (females) lateral to the posterior tubercle.[15] However, using a patient-specific intraoperative reference is more reliable due to the potential for anatomic variability between patients.

The current finding supports previously published literature. Blagg *et al*.[16] studied C1 morphology in fifty patients undergoing CT scans for cervical trauma. They suggested the use of the medial edge of the junction between the lamina and lateral mass as an ALM screw entry point. In their study, the average distance between the screw axis and vertebral foramen was either 9.0 mm (right) or 8.4 mm (left). None of their inserted screws breached the vertebral foramen, but in two patients, the screw was within 1 mm of the vertebral foramen. These authors also evaluated the use of the entry point described by Harms and Melcher and found that 23% of screws would abut the vertebral foramen, with one screw breaching the foramen. They concluded that using the lamina midpoint as the entry point puts the vertebral foramina at risk.

The current study found several advantages to using an entry point 2 mm lateral to MEC1 for ALM instrumentation. The 2 mm point was closer to the ALM midpoint than an entry point along MEC1. Other entry points, such as those 3 or 4 mm lateral to MEC1, may also be evaluated and tested. However, our results show that the 2 mm entry point is located lateral to the ALM midpoint by a mean of 0.74 mm. For this reason, a 3 or 4 mm entry point would be more lateral and farther from the ALM midpoint, theoretically increasing the risk of vertebral artery injury. The 2 mm point also provides a greater average distance from the ALM medial border (6.9 ± 1.2 mm) than the 0 mm point (4.8 ± 1.1 mm), allowing safer insertion of 3.5 or 4 mm screws. In addition, the 2 mm entry point is technically preferred because it accesses the C1 lateral mass on a flatter surface than the 0 mm point, avoiding potential entry into the spinal canal or breaching the medial border of the ALM.

Several other methods have been used to instrument C1 and are associated with considerable risk. Rocha *et al*. stated that the partial removal of the inferior portion of the posterior arch is necessary to facilitate screw placement but carries a high risk of vertebral artery injury.[17] In such cases, mobilization of the vertebral artery away from the superior surface of posterior arch may be required.[8] Lee *et al*. suggested using a higher screw entry point into the C1 arch to decrease the risk of occipital neuralgia;[18] however, this technique is not possible in some patients with thin C1 arches and may endanger the vertebral arteries.[19]

Using a proper ALM screw trajectory is necessary to reduce the risk of injuring the spinal cord, vertebral artery, nerve roots, and internal carotid artery. The ALM screw insertion trajectory, from the horizontal and sagittal perspectives, has been a subject of controversy. Rocha *et al*. calculated the maximum medial angle for screw insertion from the midline as 16.7° ± 1.3°.[19] Another study reported screw passage within the lateral mass at up to a 20° medial angulation,[16] and Hong *et al*. recommended a screw angulation of 14.7° relative to the axial plane.[20] Further, lateral angulation is considered unsafe as it may put the vertebral artery at risk;[16] Tan *et al*. recommended a screw trajectory perpendicular to the coronal plane.[21] The current findings also support a trajectory perpendicular to the horizontal plane from the 2 mm entry point, provided that there is no atlas rotation. Advancement into the ALM bone, using a bone tap, was also found to be safe and effective for creating a track for the screw.

Considering the sagittal plane trajectory, Hong *et al*. defined the sagittal angulation as 22.9°.[20] However, rod placement between two screws could be difficult with a too superiorly angulated C1 lateral mass screw. The risk of hypoglossal nerve injury has also been reported to increase when the screw is angulated too superiorly.[22] In our study, the sagittal angle was determined to be parallel to the inferior border of atlas posterior arch. In the current study, the two screws that did not follow the posterior arch trajectory encroached into the occipitocervical joint.

Study limitations

The current study has several limitations. An evaluation of the value of using MEC1 and the extent of bleeding from the surrounding venous plexus are better determined from clinical studies. In addition, biomechanical studies are required to determine the stability of the trajectory used in the current study. The current study is also limited by the relatively small sample size. Perhaps a future study with a larger sample size could clarify the findings. Furthermore, there could be ethnic differences in the anatomy of ALM measurements. Therefore, we recommend a careful assessment of each individual patient for the appropriate entry point, based on the MEC1 anatomic reference.

CONCLUSION

MEC1 provides a fixed and reliable anatomic reference for determining the entry point for ALM instrumentation. An entry point 2 mm lateral to MEC1 was closer to the ALM midpoint than the 0 mm entry point. MEC1 also provides a useful guide for determining the sagittal trajectory of an atlas screw. Combined with intraoperative imaging, these anatomic references may help avoid extensive dissection in a crowded area that has a rich venous plexus and may allow safe and effective atlas instrumentation. Clinical studies are recommended to evaluate bleeding and biomechanical strength associated with the current technique.

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Conflicts of interest

There are no conflicts of interest.

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