

Trajectory Matters: Medial Angulation Improves Feasibility and Safety of C1 Pedicle Screw Placement

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Introduction

C1 pedicle screw fixation is able to provide robust atlantoaxial stability, although it carries a risk of neurovascular injury from narrow osseous corridors and proximity of the vertebral and internal carotid arteries. Additionally, population-tailored fixation feasibility remains of importance as the morphology of the atlas varies among different ethnic populations. South Asian populations have previously shown to have smaller on average C1 dimensions than Western populations. We sought to determine the feasibility of C1 pedicle screw fixation in an adult Indian cohort and also to compare the safety profiles of two C1 pedicle trajectories, straight (S) and medially angulated (M).

Materials and Methods

In this CT-based morphometric study, one hundred adult cervical CT angiograms (50 males, 50 females, 200 C1 pedicles) were reconstructed in multiplanar and three-dimensional formats for morphometric interpretation and analyses. A total of twenty-three morphometric parameters were measured for both S and M C1 pedicle screw trajectories. Outcomes measured comprised of C1 Pedicle morphometry/dimensions, safe screw corridor trajectory, path lengths, trajectory clearance from the vertebral artery foramen (VAF) and from the internal carotid artery (ICA), margin of angular safety, and the trajectory zone of exit. Direct comparisons were made between the S and M cohorts for each parameter, with sex-based subgroup analyses.

Results

C1 pedicles were predominantly narrow and had an average height of 3.4 ± 0.6 mm. Only 44.5% were able to accommodate a standard 3.5-mm screw. M trajectories consistently produced wider screw corridors (8.3 mm vs 6.6 mm), greater clearance from the VAF (4.1 mm vs 3.3 mm) and ICA (9.9 mm vs 5.8 mm), and larger angular safety margins relative to both blood vessels (VAF: 24.5° vs 12.1° ; ICA: 20.3° vs 5.2° ; all $p < 0.01$). Both trajectories had equivalent fixation path lengths with both preserving bicortical purchase. The ICA was most commonly found lateral to the lateral mass, 77%, while M screw trajectories exited predominantly within the safest medial zone, 96%, with its trajectory anchored away from the typical surrounding vasculature. Males demonstrated significantly larger osseous dimensions and safety corridors than females ($p < 0.01$).

Conclusion

Standard C1 pedicle screw fixation is frequently constrained by narrow pedicle anatomy in adult Indian patients. M trajectories were found to optimize safe osseous corridors and neurovascular clearance for C1 fixation, without minimizing the fixation length. CT-based M trajectories may be safely performed in patients where C1 pedicle anatomy may be constrained.

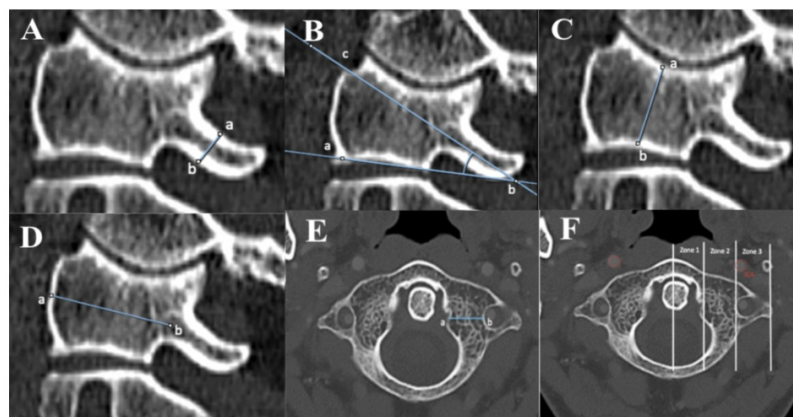


Figure 1. CT morphometrics of C1 lateral mass, pedicle and ICA zones.

(A) Pedicle height (PH) between superior and inferior cortices. (B) Pedicle Sagittal Angle (PSA). (C) Lateral mass height (LH). (D) Lateral mass length (LL). (E) Lateral mass Width (LW). (F) ICA zones (Zones 1-3) along the anterior C1 ring used to classify ICA location (ICAZ); ICA indicated in red.

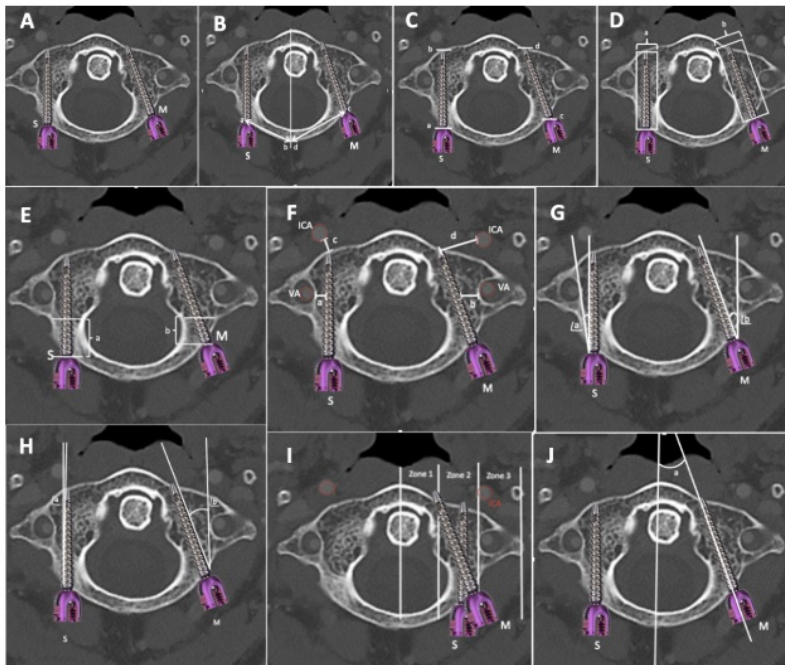


Figure 2. Axial CT simulation of straight (S) and medially angulated (M) C1 pedicle screw trajectories showing entry points, path lengths, angular corridors, and relationships to the vertebral foramen, ICA/VA, and anterior arch zones.

- (A) Overview of simulated S (Straight) and M (Medially angulated) screw paths.
- (B) Entry point-to-midline distances for each trajectory (ab for SEMD and cd for MEMD).
- (C) Axial screw path lengths from posterior to the anterior arch (ab for SAL and cd for MAL).
- (D) Axial "corridor"/trajectory width sampled around each path (a for SPW and b for MPW).
- (E) Pedicle length measured as the shortest length of bony mass between the posterior cortex of the posterior arch and the posterior cortex of the lateral mass along the pedicle screw trajectory (a for SPL and b for MPL).
- (F) Shortest distances from each screw to the vertebral artery foramen (a for SVD and b for MVD) and internal carotid artery (c for SID and d for MID); vessels marked in red.
- (G) Angle of freedom relative to the vertebral foramen ($\angle a$ for SVAF and $\angle b$ for MVAF).
- (H) Angle of freedom relative to the ICA ($\angle a$ for SIAF and $\angle b$ for MIAF).
- (I) Anterior arch ICA zones (Zones 1–3) used to classify ICA location (ICAZ) and screw exit zones (SSZ for S and MSZ for M).
- (J) Pedicle screw Transverse Angle for medially angulated screw ($\angle a$ for PTA).