Research Square

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Precision Image Planning and Measurement for C2 Pedicle Screw Placement Using 3D Slicer

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Abstract

Objective: This study aimed to utilize 3D Slicer software for three-dimensional imaging analysis and measurement of the axis (C2) pedicle to provide precise anatomical parameters for pedicle screw placement.
Methods: Cervical CT data from 100 healthy adults aged 20 to 30 years, collected between January 2024 and June 2025, were used. 3D models were reconstructed using 3D Slicer, and measurements included the pedicle isthmus diameter, simulated screw trajectory length, medial inclination angle, cephalad inclination angle, and entry point coordinates.
Results: The C2 pedicle isthmus diameter was (6.48 ± 1.85) mm, the simulated trajectory length was (24.58 ± 2.59) mm, the medial inclination angle was (23.42 ± 5.40)°, and the cephalad inclination angle was (37.43 ± 6.76)°. The entry point was (3.40 ± 1.02) mm from the laminar plane and (18.52 ± 1.57) mm from the midsagittal plane. No significant differences were found between left and right sides for any parameters ($P > 0.05$). However, males exhibited significantly larger isthmus diameters, trajectory lengths, and entry point distances from the midline compared to females ($P < 0.05$).
Conclusion: Imaging planning with 3D Slicer can provide individualized, reproducible anatomical references, aiding in improving the safety and accuracy of C2 pedicle screw placement, particularly in patients with significant anatomical variations.

Introduction

The axis (C2), serving as the "pivot" connecting the atlas and the subaxial cervical spine, often requires surgical intervention to maintain stability in conditions such as occipitocervical deformity, atlantoaxial dislocation, and cervical hangman's fracture, to prevent further injury [1, 2]. Among various internal fixation techniques, C2 pedicle screw fixation has become one of the "gold standard" techniques for posterior upper cervical fixation due to its high biomechanical strength, effectively promoting bony fusion and functional recovery [3, 4].

However, the primary challenge of this technique lies in the high risk associated with screw placement, stemming from the anatomical complexity of the region [5, 6]. When the pedicle cross-sectional area is too small, screws may breach the cortical bone, risking medially injury to the spinal cord within the vertebral canal and laterally injury to the vertebral artery. Therefore, preoperative CT evaluation is routinely necessary to assess feasibility before planning C2 pedicle screw placement.

This study aims to analyze the C2 pedicle using 3D Slicer software and measure the specific location of the screw entry point in different individuals. These results may help clarify the anatomical feasibility and potential clinical value of C2 pedicle screw fixation.

Materials and Methods

Patient Selection

Cervical CT scans performed between January 2024 and June 2025 were retrospectively retrieved from the hospital's imaging database.

Inclusion criteria: □ Age 20-30 years; □ No history of cervical spine disease, trauma, or surgery; □ No congenital malformation of the axis.

Exclusion criteria: □ Age ≤20 or ≥30 years; □ History of cervical spine surgery, tumors, or cervical deformity; □ Poor-quality imaging data.

CT Data Acquisition

All cervical CT data were acquired using a 64-slice Siemens Somatom Definition AS 128 spiral CT scanner. Scanning parameters were: tube voltage 120 kV, tube current 200 mA, pitch 1. Data were reconstructed post-scan using a bone reconstruction algorithm with a slice thickness of 1 mm and slice interval of 1 mm. The reconstructed 1 mm bone window data were imported into the open-source software 3D Slicer (https://www.slicer.org/) [7].

Data Segmentation and Model Reconstruction

Data Import and Preprocessing:

The reconstructed 1 mm data in DICOM format were imported into 3D Slicer. Using the Nnunet plugin within the software [8], the cortical and cancellous bone of the axis were automatically segmented and filled, and a three-dimensional model of the axis was reconstructed based on this segmentation.

Morphometric Measurement of the C2 Pedicle

Within 3D Slicer, the center of the axis pedicle was located in axial, coronal, sagittal, and 3D model views. Interactive reference lines were adjusted: in the sagittal view, the axial reference line was aligned parallel to the pedicle's long axis, and the coronal reference line was set perpendicular to it; in the axial view, the sagittal reference line was aligned parallel to the pedicle's long axis, and the coronal reference line was set perpendicular, ensuring both lines passed through the pedicle center. In the coronal view, the slice showing the narrowest part of the pedicle (isthmus) was identified. The Eraser tool in the Segment Editor was used to remove the posterior part of the pedicle for clear visualization of the cross-section. The Ring tool from the ExtraMarkups plugin was used to construct a circle tangent to the inner cortical margin. The circle's center and radius were adjusted in conjunction with the 3D view to ensure the circle did not intersect the medial cortical bone of the vertebral foramen. The radius was measured, and the diameter was calculated,as shown in Figures1A, B, C.

Construction and Measurement of Simulated Screw Trajectory

This study simulated trajectory planning for a 3.5 mm diameter screw. In the sagittal view, the intersection point of the posterior cortical margin of the C2 posterior arch and the axial reference line was defined as the entry point. Using the Line tool in the Markups module, a trajectory line was drawn

along the reference line cephalad, passing through the center of the isthmus cross-section circle, and terminating at the inner cortical margin of the pedicle's superior articular facet. This trajectory was perpendicular to the isthmus cross-section and parallel to the sagittal plane of the posterior arch. Its spatial position was confirmed in the 3D view, and the trajectory length was recorded,as shown in Figures 1D, E, F.

Measurement of Screw Entry Point Location

(1) Measurement of Medial Inclination Angle

In the axial view of the 3D Slicer multiplanar reconstruction, the sagittal reference line was adjusted to the midsagittal plane of the axis. Using the Plane tool in the Markups module, a plane was placed in the sagittal view. The angle between this plane and the screw trajectory constituted the medial inclination angle. For ease of measurement, the Enable translation tool could be used to translate this plane to the screw tip location with reference to the 3D view. In the axial view, the plane axis intersected the screw tip location, and the angle was measured, as shown in Figures 2A, B, C.

(2) Measurement of Cephalad Inclination Angle

In the sagittal view of the 3D Slicer multiplanar reconstruction, the axial reference line was adjusted parallel to the inferior vertebral endplate. A plane was placed in the axial view. In the 3D view, this plane was translated to the entry point location. In the sagittal view, the angle between the plane axis and the screw trajectory at the entry point constituted the cephalad inclination angle, as shown in Figures 2D, E, F.

(3) Measurement of Entry Point Coordinates

Using interactive tools, the crosshairs were adjusted in the coronal view to align the axial reference line parallel to the plane of the pedicle's superior margin. In the axial view, the sagittal reference line was aligned parallel to the axis midsagittal plane. Based on the coronal axial reference line, the axial slice was adjusted to the level of the pedicle's superior margin. Two planes were placed in the axial view. With the Visibility and Enable translation properties activated for the planes, one plane was translated inferiorly to the entry point location in the 3D view. In the coronal view, the vertical distance between the two plane axes, representing the distance from the vertebral body's superior margin to the entry point, was measured as the entry point distance from the laminar plane (ELD). Similarly, two planes were placed in the midsagittal position in the 3D view, and one was translated to the entry point location to measure the entry point distance from the midsagittal plane (EMD), as shown in Figures 2G, H, I.

Measurement Reliability and Accuracy

To ensure accuracy and minimize error, measurements were performed twice by two independent radiologists, with a two-week interval between sessions. The average of the four measurements was used for final analysis.

Statistical Analysis

Statistical analysis was performed using IBM SPSS Statistics (version 25.0, IBM Corp., Armonk, NY, USA). Normality of continuous variables was assessed using the Shapiro-Wilk test. Normally distributed variables are presented as mean ± standard deviation (x ± s). Independent samples t-test was used to compare differences between left/right sides and between male/female groups. A P-value < 0.05 was considered statistically significant.

Table 1. Parameters for C2 Pedicle Screw Placement.

Parameter	Left Side	Right Side	Total	*t*	*p*
Isthmic Diameter(mm)	6.58±1.88	6.39±1.89	6.48±1.85	-0.732	0.465
Screw Trajectory Length(mm)	24.54±2.50	24.62±2.75	24.58±2.59	0.216	0.829
Medial Inclination Angle(°)	23.40±5.15	23.44±5.76	23.42±5.40	0.044	0.965
Cephalad Inclination Angle(°)	37.29±6.55	37.57±7.06	37.43±6.76	0.297	0.767
ELD(mm)	3.37±1.01	3.44±1.07	3.40±1.02	0.465	0.642
EMD(mm)	18.52±1.60	18.53±1.63	18.52±1.57	0.011	0.991

Results

A total of 100 patients were included, aged 20–30 years, with 50 males and 50 females. The overall mean age was 24.95 ± 2.57 years (males: 24.84 ± 2.68 years; females: 25.06 ± 2.47 years), with no statistically significant difference in age between genders (P > 0.05).

Analysis of Parameters for C2 Pedicle Screw Placement

Regarding C2 pedicle anatomical dimensions: the isthmus diameter was (6.48 ± 1.85) mm, and the simulated screw trajectory length was (24.58 ± 2.59) mm. The entry point coordinates were: distance from the lamina plane (3.40 ± 1.02) mm, and distance from the midsagittal plane (18.52 ± 1.57) mm. Regarding spatial trajectory angles: the medial inclination angle was (23.42 ± 5.40)°, and the cranial inclination angle was (37.43 ± 6.76)° (see Table 1).

None of the measured parameters showed statistically significant differences between left and right sides (all P > 0.05), indicating high symmetry in the anatomical structure of the C2 pedicle.

Comparison of Anatomical Parameters by Gender

The male group had significantly larger isthmus diameter, screw trajectory length, and entry point distance from the midsagittal plane compared to the female group (P < 0.05). However, no statistically significant differences were found between genders for the medial inclination angle, cranial inclination angle, or entry point distance from the lamina plane (P > 0.05) (see Table 2).

Discussion

Studies have shown that C2 pedicle screw fixation provides superior stability compared to other posterior fixation techniques [9, 10]. However, challenges arise from the pedicle's relatively small size, significant individual anatomical variations [11, 12], and the severe consequences of complications in this region [13, 14]. Previous research has reported measurements of various pedicle dimensions and parameters to improve the accuracy of C2 pedicle screw placement. Wu et al. [15] measured parameters including pedicle width, screw projection length, transverse angle, and inclination angle in 60 Chinese adult C2 specimens, concluding that placement of a 3.5 mm C2 pedicle screw is anatomically feasible. Pragash et al. [16] reported that based on preoperative CT measurements in an Indian population, 28% of pedicles were too small to safely accommodate a standard 3.5 mm screw. The results obtained in this study using imaging analysis, 3D reconstruction, DICOM data processing, and 3D Slicer software are largely consistent with previous findings, further validating the reliability of the data.

The entry point coordinates measured in this study—(3.40 ± 1.02) mm from the lamina plane and (18.52 ± 1.57) mm from the midsagittal plane—provide clear, reproducible bony reference landmarks for intraoperative localization. Traditional entry point localization often relies on identifying the nutrient foramen on the posterior aspect of the lamina. However, the prevalence, location, and morphology of this foramen exhibit significant inter-individual variation, as confirmed by Liu et al. [17]. In contrast, our proposed method uses the constant anatomical planes of the posterior lamina edge and the midsagittal plane as a reference system, effectively creating an "intrinsic navigation system" unaffected by soft tissue coverage or individual anatomical variation. This "coordinate-based" entry point method is particularly advantageous in cases with limited surgical exposure, difficult identification of anatomical landmarks, or congenital variations. It enhances the generalizability of surgical planning and the objectivity of intraoperative execution, potentially reducing over-reliance on the surgeon's personal experience and thereby improving placement accuracy.

We found that males had significantly larger isthmus diameters, screw trajectory lengths, and entry point distances from the midline, reflecting the generally larger skeletal dimensions of the male upper cervical spine and suggesting a relatively lower risk of pedicle cortical breach. This finding aligns with reported anatomical risk trends: some studies indicate a higher incidence of narrow C2 pedicles in males compared to a higher incidence of high-riding vertebral artery in females, who are also observed to have a higher incidence of specific high-risk anatomical features on certain sides [18]. Therefore, for female patients with smaller isthmus diameters, preoperative meticulous assessment of the feasibility of using standard-diameter screws via precise imaging measurement is essential. Notably, the key spatial angles of the trajectory (medial and cranial inclination) showed no gender difference. This has important clinical implications: it suggests that surgeons can follow a unified range of implantation angles in the sagittal and transverse planes when planning surgery for patients of different genders. However, the selection of screw diameter and length should be more individualized.

This study has several limitations. First, the sample size is relatively limited (100 patients). While sufficient for preliminary morphometric analysis, it may not represent the full diversity of anatomical variations across all populations. Second, the retrospective design and single-institution source of CT data may introduce potential selection bias. Third, the study focused solely on morphometric measurements and did not include related biomechanical investigations.

Despite these limitations, this study provides important evidence supporting the anatomical feasibility of C2 pedicle screw fixation and paves the way for further biomechanical and clinical investigations.

Declarations

Author contributions

All authors contributed to the study's conception and design. This article was authored by Feng RH, while the preparation of materials, data collection, and analysis were completed by Pan BQ and Ye LS., and all authors commented on previous versions of the manuscript. All authors read and approved the final manuscript.

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Availability of data and materials

The datasets used and/or analysed during the current study are available from the corresponding author on reasonable request.

Ethics approval and consent to participate

This study was performed in accordance with the principles of the Declaration of Helsinki and approved by the Ethics Committee of Ningbo No.6 Hospital (Approval No. 2025-098). Given the retrospective nature of this study and the use of anonymized clinical imaging data, the requirement for informed consent was waived by the Ethics Committee of Ningbo No.6 Hospital. All patient data were fully anonymized before analysis to ensure participant privacy.

Consent for publication

All authors agree to submit and publish the article.

Competing interests

The authors declare that they have no competing interests

References

1. Reynolds JA, MacDonald JD. Direct C2 Pedicle Screw Fixation for Axis Body Fracture. World Neurosurg. 2016;93:279–85. https://doi.org/10.1016/j.wneu.2016.06.047.
2. Wang L, Tian JW, Liu C, Zhao QH, Yuan W. [Application of C1-C2 pedicle screw fixation in atlantoaxial complex fracture]. Zhonghua Yi Xue Za Zhi. 2012;92(11):760–3. Chinese.
3. Su BW, Shimer AL, Chinthakunta S, Salloum K, Ames CP, Vaccaro AR, Bucklen B. Comparison of fatigue strength of C2 pedicle screws, C2 pars screws, and a hybrid construct in C1-C2 fixation. Spine (Phila Pa 1976). 2014;39(1):E12–9. https://doi.org/10.1097/BRS.0000000000000634.
4. Wang C, Yin SM, Yan M, Zhou HT, Dang GT. [Posterior occipitocervical fixation using C2 pedicle screws and occipitocervical plate systems]. Zhonghua Wai Ke Za Zhi. 2004;42(12):707–11. Chinese.
5. Ebraheim N, Rollins JR Jr, Xu R, Jackson WT. Anatomic consideration of C2 pedicle screw placement. Spine (Phila Pa 1976). 1996;21(6):691–5. https://doi.org/10.1097/00007632-199603150-00005.
6. Ajayi O, Moisi M, Chapman J, Oskouian RJ, Tubbs RS. C2 Pedicle Screw Placement: A Novel Teaching Aid. Cureus. 2016;8(6):e630. https://doi.org/10.7759/cureus.630.
7. Pinter C, Lasso A, Fichtinger G. Polymorph segmentation representation for medical image computing. Comput Methods Programs Biomed. 2019;171:19–26. https://doi.org/10.1016/j.cmpb.2019.02.011.
8. Isensee F, Jaeger PF, Kohl SAA, Petersen J, Maier-Hein KH. nnU-Net: a self-configuring method for deep learning-based biomedical image segmentation. Nat Methods. 2021;18(2):203–11. https://doi.org/10.1038/s41592-020-01008-z.
9. Liu C, Kamara A, Yan Y. Biomechanical study of C1 posterior arch crossing screw and C2 lamina screw fixations for atlantoaxial joint instability. J Orthop Surg Res. 2020;15(1):156. https://doi.org/10.1186/s13018-020-01609-6.
10. Lasswell TL, Medley JB, Callaghan JP, Cronin DS, McKinnon CD, Singh S, Rasoulinejad P. Biomechanical comparison of a C1 posterior arch clamp with C1 lateral mass screws in constructs for C1-C2 fusion. Proc Inst Mech Eng H. 2021;235(12):1463–70. https://doi.org/10.1177/09544119211032479.
11. Heller JG, Alson MD, Schaffler MB, Garfin SR. Quantitative internal dens morphology. Spine (Phila Pa 1976). 1992;17(8):861–6. https://doi.org/10.1097/00007632-199208000-00001.
12. Ji-Hong F, Li-Ping W, Yi-Kai L, Bo-Jin L, Das M, Xiao-Yong F. Variable morphology of the axis vertebrae in 100 specimens: implications for clinical palpation and diagnostic imaging. J Manipulative Physiol Ther. 2010;33(2):125–31. https://doi.org/10.1016/j.jmpt.2009.12.002.
13. Ebraheim N, Rollins JR Jr, Xu R, Jackson WT. Anatomic consideration of C2 pedicle screw placement. Spine (Phila Pa 1976). 1996;21(6):691–5. .https://doi.org/10.1097/00007632-199603150-00005.

14. Ajayi O, Moisi M, Chapman J, Oskouian RJ, Tubbs RS. C2 Pedicle Screw Placement: A Novel Teaching Aid. Cureus. 2016;8(6):e630. https://doi.org/10.7759/cureus.630.
15. Wu ZH, Zheng Y, Yin QS, Ma XY, Yin YH. Anterior pedicle screw fixation of C2: an anatomic analysis of axis morphology and simulated surgical fixation. Eur Spine J. 2014;23(2):356–61. https://doi.org/10.1007/s00586-013-3042-8.
16. Pragash V, Douraiswami B, Subramani S. Axis vertebral dimensions for safe screw placement: A CT normative data analysis. J Clin Orthop Trauma. 2020 Sep-Oct;11(5):871–5. https://doi.org/10.1016/j.jcot.2020.06.026.
17. Liu JM, Jiang J, Liu ZL, Long XH, Chen WZ, Zhou Y, Gao S, He LC, Huang SH. A New Entrance Technique for C2 Pedicle Screw Placement and the Use in Patients With Atlantoaxial Instability. Clin Spine Surg. 2017;30(5):E573–7. https://doi.org/10.1097/BSD.0000000000000164.
18. Arslan D, Govsa F, Ozer MA, Kitis O. Assessment of failure risks during C2 vertebra pedicle screw insertion using three-dimensional computed tomography angiography analysis: the role of high-riding vertebral artery and narrow pedicles. Surg Radiol Anat. 2024;47(1):6. .https://doi.org/10.1007/s00276-024-03526-3.

Tables

Tables 2 is available in the Supplementary Files section.

Figures

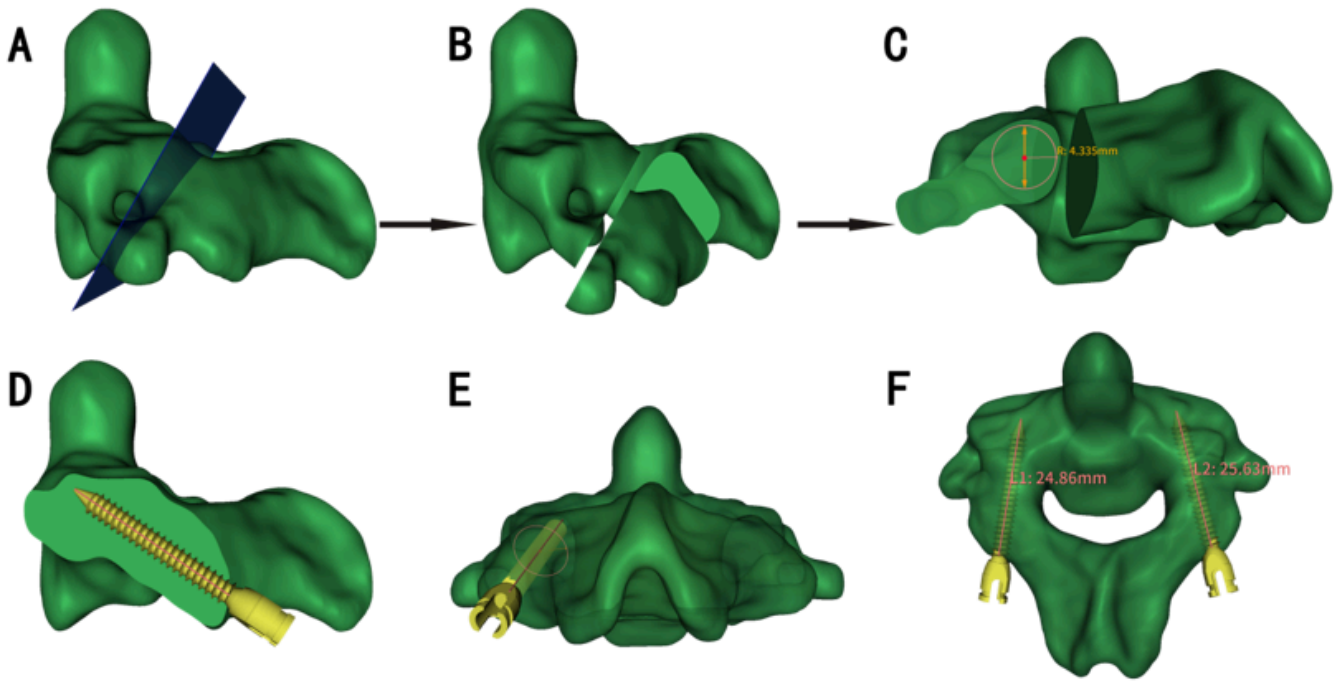


Figure 1

(A and B): Schematic of axis pedicle sectioning; (C): Pedicle isthmus cross-section, measuring radius R; (D and E): Spatial relationship of axis pedicle screw in sagittal and coronal planes; (F): Axial view of axis pedicle position and trajectory measurement.

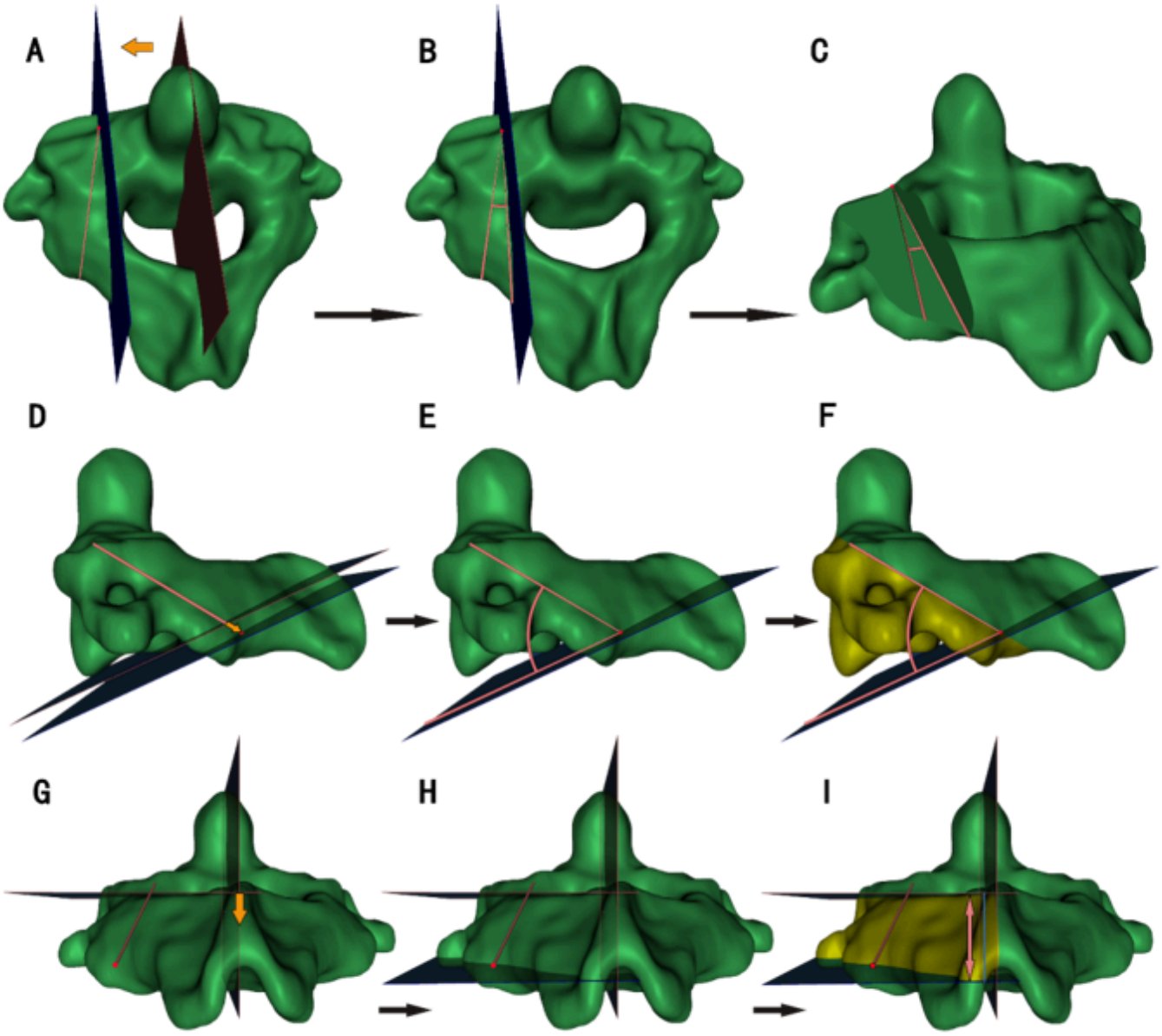


Figure 2

(A, B, C): Measurement of the medial inclination angle for the C2 pedicle screw trajectory; **(D, E, F):** Measurement of the cranial inclination angle for the C2 pedicle screw trajectory; **(G, H, I):** Measurement of distances for the simulated screw entry point.

Supplementary Files

This is a list of supplementary files associated with this preprint. Click to download.

- Data.xlsx
- Table2.docx