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Development and Phantom Evaluation of a Closed-Mouth Premaxillary Projection for Odontoid Imaging

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KEYWORDS:

odontoid process; closed-mouth projection; premaxilla; skull phantom; radiography; image quality

ABSTRACT: This study aimed to develop a closed-mouth premaxillary projection for odontoid imaging by determining an appropriate cephalad tube angle from CT-based craniofacial measurements and evaluating the resulting image quality using skull phantoms. Facial bone CT images from 150 patients without a history of spinal disease or acute trauma were retrospectively analyzed. The angles between the orbitomeatal line (OML), infraorbitomeatal line (IOML), external auditory meatus, dens, and acanthion were measured to establish candidate projection angles. Phantom radiographs were then obtained using three skull phantoms with cephalad tube angles ranging from 1° to 11° under standardized exposure conditions. Quantitative image quality was assessed using SNR and CNR, while qualitative image quality was independently evaluated by five radiologic technologists with more than 10 years of clinical experience using a five-point scale. Inter-rater reliability was assessed using ICC. The mean OML-IOML angle was $7.82 \pm 1.07^\circ$, while the mean dens-to-acanthion angles were $12.4 \pm 1.33^\circ$ for OML-based positioning and $4.57 \pm 1.09^\circ$ for IOML-based positioning. No statistically significant differences in SNR or CNR were detected among the tested projection angles for either OML- or IOML-based positioning. However, the 4° cephalad projection received the highest qualitative image-quality scores for both OML and IOML, with mean scores of 4.02 ± 0.30 and 4.03 ± 0.38 , respectively. Inter-rater reliability was acceptable to excellent across the evaluated angles. These findings suggest that a 4° cephalad closed-mouth premaxillary projection may provide diagnostically acceptable visualization of the odontoid process when standard open-mouth positioning is not feasible. Further prospective studies comparing this technique with conventional open-mouth radiography in patients are required before clinical implementation.

I. INTRODUCTION

The odontoid process acts as the central pivot of the atlantoaxial joint and plays an important role in head rotation and upper cervical stability. Owing to its anatomical location and biomechanical function, it is vulnerable to injury following high-energy trauma, such as motor vehicle collisions and falls. Odontoid fractures are generally classified into three types according to the location and extent of the fracture. Type I fractures involve the tip of the odontoid process, type II fractures occur at its base, and type III fractures extend into the body of C2. Accurate visualization of the odontoid process is therefore important for detecting fractures and assessing the structural integrity of the upper cervical spine.

The open-mouth view is the standard radiographic projection used to evaluate the odontoid process. The Fuchs and Judd methods may be considered when the standard projection does not adequately demonstrate the dens. However, these techniques require sufficient patient cooperation and precise positioning. For the open-mouth view, the patient must keep the mouth open while the head is positioned so that the occlusal plane and mastoid tip are properly aligned, thereby reducing

superimposition of the teeth and skull base over the odontoid process. In patients with acute trauma, severe pain, restricted mandibular movement, altered consciousness, or suspected cervical instability may prevent adequate positioning. These difficulties can lead to anatomical overlap, reduced diagnostic visibility, and repeated image acquisition. Modified projections have been proposed for patients who cannot tolerate conventional positioning. However, their reproducibility may be limited when tube angulation is determined without standardized anatomical reference lines. An alternative projection should minimize head and neck movement while allowing consistent visualization of the odontoid process. The orbitomeatal line (OML) and infraorbitomeatal line (IOML) are commonly used facial reference lines and may provide practical landmarks for standardizing patient positioning and tube angulation. In the proposed technique, the odontoid process is projected through the premaxillary region while the mouth remains closed. This region contains relatively few overlapping anatomical structures, and the wide dynamic range of digital radiography may permit visualization of the odontoid process despite superimposition of the facial bones. Instead of changing the patient's position, the technique primarily relies on adjustment of the cephalad tube angle according to the OML or IOML. The purpose of this study was to develop a closed-mouth premaxillary projection for odontoid imaging by determining an appropriate tube angle from computed tomography (CT)-based craniofacial measurements. The proposed technique was then evaluated using three skull phantoms through quantitative assessment of the signal-to-noise ratio (SNR) and contrast-to-noise ratio (CNR), as well as qualitative assessment by experienced radiologic technologists. This study aimed to provide preliminary technical evidence for an alternative radiographic projection when conventional open-mouth positioning is not feasible.

II. MATERIAL AND METHODS

2.1 Experimental Equipment

Radiographic images were acquired using a diagnostic digital X-ray system (GXR-40SD; DRGEM, Republic of Korea). Three anthropomorphic phantoms were used for the experiments: the PH-2B-1 skull phantom (Kyoto Kagaku, Japan), the PUB-60 skull phantom (Kyoto Kagaku, Japan), and the Alderson Radiation Therapy Female RANDO phantom (Radiation Management Services, Fluke Biomedical, USA) (Fig. 1).



Fig. 1 Anthropomorphic phantoms used in this study

a) PH-2B-1 skull phantom, b) PUB-60 skull phantom, c) RANDO phantom

2.2.1 Study Population

This retrospective study included 150 patients who underwent facial bone CT examinations in the radiology department of a university hospital in Seoul between March 2023 and February 2024. The study population comprised 81 men and 69 women, with a mean age of 41.9 years. Patients with a documented history of spinal disease were excluded. Patients who underwent CT following presentation to the emergency department because of acute trauma were also excluded to minimize the potential influence of traumatic injury or anatomical deformity on the angle measurements.

2.2.2 Angle Measurements

Sagittal facial bone CT images were reviewed using a picture archiving and communication system (PACS). First, the angle between the orbital reference point and the external auditory meatus (EAM) and the angle between the infraorbital margin and the EAM were measured using the two-dimensional angle measurement tool. These measurements were used to determine the anatomical relationship between OML and IOML. Second, the angle between the odontoid process and the premaxillary region was measured using the same tool according to OML- and IOML-based positioning. This measurement was performed to determine the tube angle required to project the odontoid process through the premaxillary region. Each angle was measured

three times, and the mean value of the three measurements was used for analysis. The measurement method and anatomical reference lines are shown in Fig. 2.

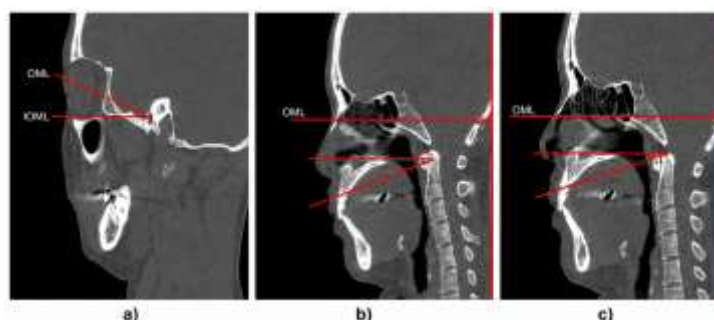


Fig. 2 CT-based measurement of craniofacial angles used to determine the tube angulation:

a) angle between the OML and IOML, b) angle between the OML and the line connecting the dens to the acanthion, c) angle between the IOML and the line connecting the dens to the acanthion

2.2.3 Radiographic Acquisition Conditions and Procedure

Based on the CT-derived anatomical measurements, phantom radiographs were obtained using OML- and IOML-based positioning to project the odontoid process through the premaxillary region. The exposure parameters were standardized at 70 kVp and 20 mAs, with a source-to-image receptor distance (SID) of 110 cm and a collimated field size of 12×10 cm. These parameters were selected with reference to the mean values recommended for anteroposterior head radiography in the 2019 Korean diagnostic reference level guidelines. For each projection, the phantom was positioned according to either the OML or IOML, and the X-ray tube was angled cephalad according to the predefined experimental angle. The central ray was directed to the acanthion. All acquisition parameters other than the tube angle and facial reference line were maintained consistently throughout the experiment. The positioning and direction of the central ray are shown in Fig. 3.

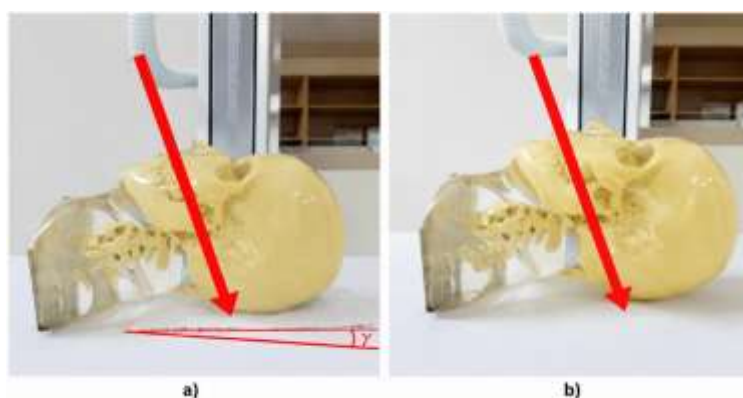


Fig. 3 Experimental positioning for the proposed closed-mouth odontoid projection

a) OML-based positioning, b) IOML-based positioning

2.2.4 Quantitative Image Assessment

Quantitative image analysis was performed using ImageJ software (version 1.43u; National Institutes of Health, Bethesda, MD, USA) to evaluate the image quality of the odontoid process and adjacent anatomical structures on the proposed closed-mouth projection images. ROIs were placed over the odontoid process, body of C2, and right lateral mass of C1. An additional ROI was placed in the upper-left background region to estimate image noise. The size and location of each ROI were kept as consistent as possible across all images. The mean pixel value and SD within each ROI were measured, and SNR and CNR were calculated to compare image quality among the tested projection angles. The ROI locations are shown in Fig. 4.



Fig. 4 Placement of ROIs for SNR and CNR measurements using ImageJ

(1) SNR Measurement

SNR was calculated by dividing the mean pixel value within each anatomical ROI by the SD of the background ROI, as shown in Eq. (1).

$$SNR = \frac{MPV_{ROI}}{SD_{background}} \quad (1)$$

(2) CNR Measurement

CNR was calculated by dividing the difference between the mean pixel values of the anatomical ROI and the reference ROI by the SD of the background ROI, as shown in Eq. (2).

$$CNR = \frac{MPV_{ROI} - MPV_{reference}}{SD_{background}} \quad (2)$$

Definitions: MPV_ROI, mean pixel value within the anatomical ROI; MPV_reference, mean pixel value within the selected reference anatomical ROI; SD_background, SD of pixel values within the background ROI.

2.2.5 Qualitative Image Assessment

Qualitative image quality was independently assessed by five radiologic technologists, each with more than 10 years of clinical experience. The images were evaluated using a five-point Likert scale: 5, excellent; 4, good; 3, fair; 2, poor; and 1, very poor. The evaluation criteria were adapted from the clinical image-quality criteria for open-mouth odontoid radiography described in the *Textbook of Radiographic Positioning and Clinical Diagnosis*. The mean score for each projection angle was calculated and used for comparison. The qualitative evaluation criteria are presented in Fig. 5 and Table



Fig. 5 Anatomical alignment criteria used for qualitative evaluation of the closed-mouth odontoid projection

Table 1. Qualitative evaluation criteria for the closed-mouth odontoid projection

Item	Evaluation criterion
1	The lateral masses of C1 should not project beyond the lateral margins of C2.

Item	Evaluation criterion
2	The articular spaces between the lateral masses of C1 and the body of C2 should appear symmetric.
3	The spaces between the dens and the lateral masses of C1 should appear symmetric.

2.3 Statistical Analysis

Statistical analyses were performed using SPSS Statistics version 21.0 (IBM Corp., Armonk, NY, USA). Continuous variables are presented as mean $\pm$ SD. Normality was assessed before statistical comparisons. Differences in the CT-derived anatomical angles and quantitative image-quality measurements among the study groups were evaluated using one-way ANOVA. Inter-rater reliability for the qualitative image assessments was evaluated using a two-way random-effects model for absolute agreement based on single measurements [ICC(2,1)]. ICC values were interpreted as poor (<0.40), moderate ($0.40-0.74$), or excellent (≥ 0.75). All statistical tests were two-sided, and $p < 0.05$ was considered statistically significant.

III. RESULT

3.1 Angle Measurement Results

3.1.1 OML–IOML Angle

The mean OML–IOML angle was $7.75 \pm 1.08^\circ$ in men and $7.90 \pm 1.07^\circ$ in women. The overall mean angle was $7.82 \pm 1.07^\circ$ (Table 2).

Table 2. OML-IOML angles by age group and sex

Age group	Male	Female
20s	7.57 ± 1.04	7.93 ± 1.09
30s	7.77 ± 1.11	8.15 ± 0.86
40s	7.98 ± 0.88	7.68 ± 1.56
50s	8.00 ± 1.45	8.10 ± 0.73
60s	7.59 ± 0.66	7.76 ± 0.93
70s	7.48 ± 0.76	7.89 ± 0.96
All ages	7.75 ± 1.08	7.90 ± 1.07
Overall	7.82 ± 1.07	

3.1.2 Dens-to-Acanthion Angle Relative to the OML

The mean dens-to-acanthion angle relative to the OML was $12.3 \pm 1.32^\circ$ in men and $12.4 \pm 1.35^\circ$ in women. The overall mean angle was $12.4 \pm 1.33^\circ$ (Table 3).

Table 3. Dens-to-acanthion angles relative to the OML by age group and sex

Age group	Male	Female
20s	12.1 ± 1.28	12.2 ± 1.237
30s	12.3 ± 1.18	12.08 ± 0.8

Age group	Male	Female
40s	11.8 ± 1.24	11.8 ± 1.56
50s	12.6 ± 1.64	12.2 ± 0.82
60s	12.5 ± 1.15	13.2 ± 1.3
70s	11.7 ± 0.79	14.09 ± 1.59
All ages	12.3 ± 1.32	12.4 ± 1.35
Overall	12.4 ± 1.33	

3.1.3 Dens-to-Acanthion Angle Relative to the IOML

The mean dens-to-acanthion angle relative to the IOML was $4.59 \pm 1.04^\circ$ in men and $4.56 \pm 1.15^\circ$ in women. The overall mean angle was $4.57 \pm 1.09^\circ$ (Table 4).

Table 4. Dens-to-acanthion angles relative to the IOML by age group and sex

Age group	Male	Female
20s	4.54 ± 0.88	4.30 ± 0.81
30s	4.57 ± 1.10	3.92 ± 0.67
40s	4.51 ± 1.44	4.19 ± 0.72
50s	4.64 ± 1.10	4.12 ± 0.39
60s	4.97 ± 0.96	5.47 ± 1.06
70s	4.30 ± 0.02	6.19 ± 2.48
All ages	4.59 ± 1.04	4.56 ± 1.15
Overall	4.57 ± 1.09	

3.2 Quantitative Image-Quality Assessment

The quantitative image-quality results for OML-based positioning according to the cephalad projection angle and phantom are presented in Table 5. The normality test showed no significant deviation from a normal distribution in any group (all $p > 0.05$). One-way ANOVA revealed no significant differences in SNR or CNR among the projection-angle and phantom groups (SNR, $p = 0.90$; CNR, $p = 0.80$).

Table 5. SNR and CNR by cephalad projection angle and phantom for OML-based positioning

Angle	SNR			CNR		
	P1	P2	P3	P1	P2	P3
Cephalad 1°	15.9 ± 0.17	17.0 ± 0.21	15.8 ± 0.17	13.5 ± 0.35	14.0 ± 0.17	12.8 ± 0.21
Cephalad 2°	15.9 ± 0.31	16.9 ± 0.17	15.8 ± 0.29	13.4 ± 0.12	13.8 ± 0.23	12.7 ± 0.17
Cephalad 3°	16.2 ± 0.17	16.9 ± 0.33	15.7 ± 0.25	13.3 ± 0.17	13.9 ± 0.24	13.1 ± 0.22

Angle	SNR			CNR		
Angle	P1	P2	P3	P1	P2	P3
Cephalad 4°	15.9 ± 0.26	16.9 ± 0.26	16.1 ± 0.25	13.4 ± 0.12	14.1 ± 0.29	12.8 ± 0.18
Cephalad 5°	16.1 ± 0.31	16.8 ± 0.31	15.7 ± 0.35	13.5 ± 0.12	13.9 ± 0.17	12.7 ± 0.17
Cephalad 6°	16.3 ± 0.33	16.9 ± 0.31	15.9 ± 0.17	13.3 ± 0.20	13.9 ± 0.30	12.7 ± 0.20
Cephalad 7°	16.3 ± 0.23	17.0 ± 0.21	15.9 ± 0.12	13.3 ± 0.33	13.9 ± 0.21	12.6 ± 0.30
Cephalad 8°	16.3 ± 0.22	17.0 ± 0.28	15.9 ± 0.17	13.3 ± 0.12	14.1 ± 0.20	13.0 ± 0.25
Cephalad 9°	16.3 ± 0.34	16.9 ± 0.26	15.9 ± 0.26	13.3 ± 0.12	14.1 ± 0.27	12.1 ± 0.29
Cephalad 10°	16.2 ± 0.44	16.9 ± 0.33	15.9 ± 0.23	13.2 ± 0.17	14.1 ± 0.16	12.9 ± 0.17
Cephalad 11°	16.3 ± 0.12	17.0 ± 0.40	15.9 ± 0.30	12.4 ± 0.14	14.0 ± 0.25	12.9 ± 0.23

The quantitative image-quality results for IOML-based positioning according to the cephalad projection angle and phantom are presented in Table 6. The normality test showed no significant deviation from a normal distribution in any group (all $p > 0.05$). One-way ANOVA revealed no significant differences in SNR or CNR among the projection-angle and phantom groups (SNR, $p = 0.09$; CNR, $p = 1.00$).

Table 6. SNR and CNR by cephalad projection angle and phantom for IOML-based positioning

Angle	SNR			CNR		
Angle	P1	P2	P3	P1	P2	P3
Cephalad 1°	16.3 ± 0.26	17.2 ± 0.20	15.9 ± 0.22	13.4 ± 0.17	13.9 ± 0.17	14.5 ± 0.20
Cephalad 2°	16.2 ± 0.22	16.9 ± 0.35	15.9 ± 0.41	13.3 ± 0.17	14.0 ± 0.21	12.8 ± 0.21
Cephalad 3°	16.1 ± 0.23	16.9 ± 0.21	16.0 ± 0.29	13.4 ± 0.18	14.0 ± 0.21	12.9 ± 0.25
Cephalad 4°	16.1 ± 0.29	16.9 ± 0.35	15.7 ± 0.17	13.3 ± 0.20	14.0 ± 0.31	12.9 ± 0.20
Cephalad 5°	15.9 ± 0.28	17.0 ± 0.33	16.0 ± 0.29	13.3 ± 0.17	14.0 ± 0.17	13.0 ± 0.18
Cephalad 6°	16.4 ± 0.51	16.7 ± 0.22	15.6 ± 0.30	13.4 ± 0.12	14.0 ± 0.26	12.8 ± 0.12
Cephalad 7°	15.8 ± 0.18	16.2 ± 0.16	16.0 ± 0.34	13.3 ± 0.22	13.9 ± 0.22	12.8 ± 0.22
Cephalad 8°	15.4 ± 0.34	16.9 ± 0.24	15.0 ± 0.27	13.3 ± 0.20	13.9 ± 0.12	12.9 ± 0.08
Cephalad 9°	15.9 ± 0.59	16.0 ± 0.44	15.9 ± 0.27	13.3 ± 0.18	13.9 ± 0.20	12.9 ± 0.12
Cephalad 10°	16.0 ± 0.38	16.2 ± 0.12	15.8 ± 0.29	13.3 ± 0.17	13.9 ± 0.22	12.8 ± 0.25
Cephalad 11°	15.8 ± 0.20	17.0 ± 0.31	15.4 ± 0.22	13.3 ± 0.20	13.9 ± 0.21	12.9 ± 0.20

Table 7. Individual qualitative scores by reviewer, phantom, and cephalad angle for OML-based positioning

Reviewer	Phantom	1°			2°			3°			4°			5°			6°			7°			8°			9°			10°			11°		
Reviewer	Phantom	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3
	Phantom A	3	2	2	3	2	2	4	3	3	5	3	5	5	3	5	4	3	5	4	3	5	3	4	3	3	4	2	1	4	1	1	5	1
R1	Phantom B	3	2	3	3	3	2	4	3	4	5	3	4	4	3	5	4	3	5	4	3	5	3	4	2	2	4	2	1	4	1	1	4	1
R1	Phantom C	3	2	2	3	2	2	4	3	4	5	3	5	5	3	5	4	3	5	4	4	5	3	4	4	3	4	2	1	4	1	1	5	1
R1	Phantom A	3	2	2	3	2	2	4	3	3	5	3	4	5	3	4	4	3	4	4	3	5	3	3	4	2	5	2	1	5	1	1	5	1
R2	Phantom B	2	2	2	3	2	3	3	2	3	5	3	4	4	3	4	4	3	4	4	3	4	3	3	4	3	4	2	1	5	1	1	4	1
R2	Phantom C	3	2	2	3	2	3	4	2	3	5	3	5	5	3	5	4	3	5	4	4	5	3	3	4	2	4	2	1	4	1	1	4	1
R2	Phantom A	2	2	2	3	3	2	4	2	3	5	3	4	4	3	5	4	3	5	4	3	5	4	3	4	3	4	2	1	3	1	1	4	1
R3	Phantom B	2	2	2	2	2	2	3	2	3	4	3	4	4	3	4	4	3	4	4	3	4	3	4	3	2	4	2	1	4	1	1	3	1
R3	Phantom C	3	2	2	2	3	2	4	3	3	5	3	5	5	3	5	4	3	5	4	4	5	4	3	4	3	4	2	1	4	1	1	4	1
R3	Phantom A	2	2	2	3	2	2	4	2	3	5	3	4	5	3	4	4	3	5	4	3	5	3	4	3	2	4	2	1	4	1	1	5	1
R4	Phantom B	2	2	2	3	2	2	4	2	3	5	3	5	5	3	4	4	3	4	4	3	4	3	4	3	3	4	2	1	4	1	1	4	1
R4	Phantom C	3	2	2	3	2	3	4	3	3	5	3	4	5	3	5	4	3	5	4	4	5	3	4	3	2	5	2	1	5	1	1	5	1
R4	Phantom A	3	2	2	3	2	3	4	2	3	4	3	4	4	3	4	4	3	4	4	3	4	3	4	3	3	4	2	1	4	1	1	4	1
R5	Phantom B	3	2	2	3	2	3	3	2	2	4	3	3	4	3	3	4	3	4	4	3	4	3	4	3	2	4	2	1	4	1	1	3	1
R5	Phantom C	3	2	2	3	2	3	4	3	4	5	3	5	5	3	5	4	3	5	4	4	5	3	4	3	3	5	2	1	5	1	1	4	1

3.3 Qualitative Image-Quality Assessment

The qualitative image-quality results for OML-based positioning are presented in Tables 7 and 8. Among the evaluated projection angles, the cephalad 4° projection yielded the highest mean score of 4.02 ± 0.30 , whereas the cephalad 11° projection yielded the lowest mean score of 2.04 ± 0.22 . Inter-rater reliability was excellent at all projection angles, with ICC values ≥ 0.75 , and all reliability estimates were statistically significant ($p < 0.05$) (Table 9).

Table 8. Mean qualitative scores by reviewer, phantom, and cephalad angle for OML-based positioning

Reviewer	Phantom	1°	2°	3°	4°	5°	6°	7°	8°	9°	10°	11°
	Phantom A	2.3 ± 0.5 7	2.3 ± 0.5 7	3.3 ± 0.5 7	4.3 ± 1.1 5	4.3 ± 1.1 5	4 ± 1	4 ± 1	3.3 ± 0.5 7	3 ± 1	2 ± 1.73	2.3 ± 2.3

Reviewer	Phantom	1°	2°	3°	4°	5°	6°	7°	8°	9°	10°	11°
R1	Phantom B	2.6±0.5 7	2.6±0.5 7	3.6±0.5 7	4±1	4±1	4±1	4±1	3±1	2.6±1.1 5	2±1.73	2±1.73
R1	Phantom C	2.3±0.5 7	2.3±0.5 7	3.6±0.5 7	4.3±1.1 5	4.3±1.1 5	4±10.57	4.3±0.5 7	3.6±0.5 7	3±1	2±1.73	2.3±2.3
R1	Phantom A	2.3±0.5 7	2.3±0.5 7	3.3±0.5 7	4±1	4±1	3.6±0.5 7	4±1	3.3±0.5 7	3±1.73	2.3±2.3	2.3±2.3
R2	Phantom B	2	2.6±0.5 7	2.6±0.5 7	4±1	3.6±0.5 7	3.6±0.5 7	3.6±0.5 7	3.3±0.5 7	3±1	2.3±2.3	2±1.73
R2	Phantom C	2.3±0.5 7	2.6±0.5 7	3±1	4.3±1.1 5	4.3±1.1 5	4±1	4.3±0.5 7	3.3±0.5 7	2.6±1.1 5	2±1.73	2±1.73
R2	Phantom A	2	2.6±0.5 7	3±1	4±1	4±1	4±1	4±1	3.6±0.5 7	3±1	1.6±1.1 5	2±1.73
R3	Phantom B	2	2	2.6±0.5 7	3.6±0.5 7	3.6±0.5 7	3.6±0.5 7	3.6±0.5 7	3.3±0.5 7	2.6±1.1 5	2±1.73	1.6±1.1 5
R3	Phantom C	2.3±0.5 7	2.3±0.5 7	3.3±0.5 7	4.3±1.1 5	4.3±1.1 5	4±1	4.3±0.5 7	3.6±0.5 7	3±1	2±1.73	2±1.73
R3	Phantom A	2	2.3±0.5 7	3±1	4±1	4±1	4±1	4±1	3.3±0.5 7	2.6±1.1 5	2±1.73	2.3±2.3
R4	Phantom B	2	2.3±0.5 7	3±1	4.3±1.1 5	4±1	3.6±0.5 7	3.6±0.5 7	3.3±0.5 7	3±1	2±1.73	2±1.73
R4	Phantom C	2.3±0.5 7	2.6±0.5 7	3.3±0.5 7	4±1	4.3±1.1 5	4±1	4.3±0.5 7	3.3±0.5 7	3±1.73	2.3±2.3	2.3±2.3
R4	Phantom A	2.3±0.5 7	2.6±0.5 7	3±1	3.6±0.5 7	3.6±0.5 7	3.6±0.5 7	3.6±0.5 7	3.3±0.5 7	3±1	2±1.73	2±1.73
R5	Phantom B	2.3±0.5 7	2.6±0.5 7	2.3±0.5 7	3.3±0.5 7	3.3±0.5 7	3.6±0.5 7	3.6±0.5 7	3.3±0.5 7	2.6±1.1 5	2±1.73	1.6±1.1 5
R5	Phantom C	2.3±0.5 7	2.6±0.5 7	3.6±0.5 7	4.3±1.1 5	4.3±1.1 5	4±1	4.3±0.5 7	3.3±0.5 7	3.3±1.5 2	2.3±2.3	2±1.73

Table 9. Inter-rater reliability of qualitative scores by cephalad angle for OML-based positioning

Angle	ICC(2,1)	95% CI	p value
Cephalad 1°	0.78	0.48-0.91	<0.001
Cephalad 2°	0.80	0.52-0.92	<0.001
Cephalad 3°	0.79	0.50-0.92	<0.001
Cephalad 4°	0.90	0.76-0.96	<0.001

Angle	ICC(2,1)	95% CI	p value
Cephalad 5°	0.88	0.66-0.96	<0.001
Cephalad 6°	0.95	0.85-0.97	<0.001
Cephalad 7°	0.81	0.46-0.93	<0.001
Cephalad 8°	0.78	0.49-0.92	<0.001
Cephalad 9°	0.93	0.85-0.97	<0.001
Cephalad 10°	0.98	0.97-0.99	<0.001
Cephalad 11°	0.98	0.96-0.99	<0.001

The qualitative image-quality results for IOML-based positioning are presented in Tables 10 and 11. Among the evaluated projection angles, the cephalad 4° projection yielded the highest mean score of 4.03 ± 0.38 , whereas the cephalad 11° projection yielded the lowest mean score of 2.20 ± 0.38 . Inter-rater reliability was excellent at all projection angles, with ICC values ≥ 0.75 , and all reliability estimates were statistically significant ($p < 0.05$) (Table 12).

Table 10. Individual qualitative scores by reviewer, phantom, and cephalad angle for IOML-based positioning

Reviewer	Phantom	1°			2°			3°			4°			5°			6°			7°			8°			9°			10°			11°		
Reviewer	Phantom	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3
	Phantom A	3	1	3	3	1	3	4	2	4	5	3	5	4	3	5	4	3	4	4	3	4	3	4	3	2	4	2	1	5	2	1	5	1
R1	Phantom B	2	1	2	2	2	3	3	2	3	4	2	4	4	2	4	3	2	4	3	2	3	3	4	3	2	4	3	2	4	2	1	4	1
R1	Phantom C	3	1	3	3	2	3	4	2	4	5	2	5	5	2	5	4	2	5	4	2	4	3	4	3	1	3	2	2	4	3	1	5	2
R1	Phantom A	3	2	3	3	2	3	4	1	3	5	3	5	5	3	5	4	3	5	4	3	4	4	3	4	3	2	4	2	4	2	4	1	1
R2	Phantom B	2	1	2	2	1	2	4	2	3	5	2	5	5	2	4	4	3	4	3	3	4	4	3	4	2	4	2	2	4	2	1	5	1
R2	Phantom C	3	1	3	3	1	3	4	2	4	5	3	5	5	3	5	4	2	4	4	2	3	4	3	4	2	4	2	2	3	2	1	4	2
R2	Phantom A	3	1	2	3	1	3	4	2	3	5	3	5	5	3	5	4	3	5	4	3	4	3	4	3	3	4	3	2	4	2	1	4	2
R3	Phantom B	2	1	2	2	1	2	3	1	3	4	2	4	4	2	4	4	3	4	4	3	4	3	4	3	2	4	2	3	4	2	2	5	1
R3	Phantom C	3	2	3	3	2	3	4	2	4	5	3	5	4	3	5	4	3	4	4	3	4	3	4	3	1	4	3	3	5	2	2	5	2
R3	Phantom A	3	2	3	3	2	3	4	2	4	5	3	5	5	3	5	4	3	5	4	3	4	4	3	4	3	4	2	2	4	3	1	5	3
R4	Phantom B	2	1	3	2	1	3	3	1	4	4	2	5	4	2	5	4	2	4	3	3	4	3	4	3	2	4	3	2	3	3	2	4	2

Reviewer	Phantom	1°			2°			3°			4°			5°			6°			7°			8°			9°			10°			11°		
Reviewer	Phantom	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3
R4	Phantom C	3	2	3	3	2	3	3	3	4	5	3	5	4	3	5	4	3	4	4	3	4	4	3	4	1	4	2	3	4	2	2	5	2
R4	Phantom A	3	1	3	3	1	3	4	2	4	5	3	5	4	3	5	4	3	4	3	3	4	3	3	4	2	4	3	1	4	2	1	5	1
R5	Phantom B	3	1	2	3	1	2	3	2	3	5	2	4	4	2	4	3	3	4	3	3	4	4	3	4	2	4	3	3	4	2	2	4	1
R5	Phantom C	3	2	3	3	2	3	4	2	4	5	3	5	5	3	5	4	3	5	4	3	4	4	3	3	2	4	2	2	5	1	2	5	1

Table 11. Mean qualitative scores by reviewer, phantom, and cephalad angle for IOML-based positioning

Reviewer	Phantom	1°	2°	3°	4°	5°	6°	7°	8°	9°	10°	11°
	Phantom A	2.3±1.1 5	2.3±1.1 5	3.3±1.1 5	4.3±1.1 5	4±1	3.6±0.5 7	3.6±0.5 7	3.3±0.5 7	2.6±1.1 5	2.6±2.0 8	2.3±2.3
R1	Phantom B	1.6±0.5 7	2.3±0.5 7	2.6±0.5 7	3.3±1.1 5	3.3±1.1 5	3±1	2.6±0.5 7	3.3±0.5 7	3±1	2.6±1.1 5	2±1.73
R1	Phantom C	2.3±1.1 5	2.6±0.5 7	3.3±1.1 5	4±1.73	4±1.73	3.6±1.5 2	3.3±1.1 5	3.3±0.5 7	2±1	3±1	2.6±2.0 8
R1	Phantom A	2.6±0.5 7	2.6±0.5 7	2.6±1.5 2	4.3±1.1 5	4.3±1.1 5	4±1	3.6±0.5 7	3.6±0.5 7	3±1	2.6±1.1 5	2±1.73
R2	Phantom B	1.6±0.5 7	1.6±0.5 7	3±1	4±1.73	3.6±1.5 2	3.6±0.5 7	3.3±0.5 7	3.6±0.5 7	2.6±1.1 5	2.6±1.1 5	2.3±2.3
R2	Phantom C	2.3±1.1 5	2.3±1.1 5	3.3±1.1 5	4.3±1.1 5	4.3±1.1 5	3.3±1.1 5	3±1	3.6±0.5 7	2.6±1.1 5	2.3±0.5 7	2.3±1.5 2
R2	Phantom A	2±1	2.3±1.1 5	3±1	4.3±1.1 5	4.3±1.1 5	4±1	3.6±0.5 7	3.3±0.5 7	3.3±0.5 7	2.6±1.1 5	2.3±1.5 2
R3	Phantom B	1.6±0.5 7	1.6±0.5 7	2.3±1.1 5	3.3±1.1 5	3.3±1.1 5	3.6±0.5 7	3.6±0.5 7	3.3±0.5 7	2.6±1.1 5	3±1	2.6±2.0 8
R3	Phantom C	2.6±0.5 7	2.6±0.5 7	3.3±1.1 5	4.3±1.1 5	4±1	3.6±0.5 7	3.6±0.5 7	3.3±0.5 7	2.6±1.5 2	3.3±1.5 2	3±1.73
R3	Phantom A	2.6±0.5 7	2.6±0.5 7	3.3±1.1 5	4.3±1.1 5	4.3±1.1 5	4±1	3.6±0.5 7	3.6±0.5 7	3±1	3±1	3±2
R4	Phantom B	2±1	2±1	2.6±1.5 2	3.6±1.5 2	3.6±1.5 2	3.3±1.1 5	3.3±0.5 7	3.3±0.5 7	3±1	2.6±0.5 7	2.6±1.1 5
R4	Phantom C	2.6±0.5	2.6±0.5	3.3±0.5	4.3±1.1	4±1	3.6±0.5	3.6±0.5	3.6±0.5	2.3±1.5	3±1	3±1.73

Reviewer	Phantom	1°	2°	3°	4°	5°	6°	7°	8°	9°	10°	11°
	C	7	7	7	5		7	7	7	2		
R4	Phantom A	2.3±1.15	2.3±1.15	3.3±1.15	4.3±1.15	4±1	3.6±0.57	3.3±0.57	3.3±0.57	3±1	2.3±1.52	2.3±2.3
R5	Phantom B	2±1	2±1	2.6±0.57	3.6±1.52	3.3±1.15	3.3±0.57	3.3±0.57	3.6±0.57	3±1	3±1	2.3±1.52
R5	Phantom C	2.6±0.57	2.6±0.57	3.3±1.15	4.3±1.15	4.3±1.15	4±1	3.6±0.57	3.3±0.57	2.6±1.15	2.6±2.08	2.6±2.08

Table 12. Inter-rater reliability of qualitative scores by cephalad angle for IOML-based positioning

Angle	ICC(2,1)	95% CI	p value
Cephalad 1°	0.83	0.41-0.94	<0.001
Cephalad 2°	0.81	0.44-0.93	<0.001
Cephalad 3°	0.88	0.65-0.96	<0.001
Cephalad 4°	0.93	0.62-0.98	<0.001
Cephalad 5°	0.90	0.62-0.98	<0.001
Cephalad 6°	0.86	0.66-0.94	<0.001
Cephalad 7°	0.79	0.52-0.92	<0.001
Cephalad 8°	0.79	0.51-0.92	<0.001
Cephalad 9°	0.77	0.47-0.91	<0.001
Cephalad 10°	0.89	0.75-0.96	<0.001
Cephalad 11°	0.88	0.72-0.95	<0.001

IV. DISCUSSION

The open-mouth odontoid projection is commonly used to visualize C1, C2, and the dens, which may not be adequately demonstrated on routine AP cervical spine radiographs. It may be particularly useful when a fracture or osseous abnormality is suspected on a lateral cervical spine radiograph but cannot be clearly identified. However, this examination requires the patient to open the mouth and maintain appropriate head positioning. These requirements may be difficult to achieve in patients with acute cervical trauma, suspected odontoid injury, impaired consciousness, severe pain, or limited mandibular movement. In addition, superimposition of the upper and lower teeth may obscure the dens and reduce its diagnostic visibility. The present study evaluated a closed-mouth premaxillary projection designed to visualize the dens without substantial head-position changes or mouth opening. In this method, the central ray was directed toward the acanthion while only the cephalad tube angle was adjusted. This approach may reduce the positioning demands placed on patients who cannot cooperate with the conventional open-mouth projection. However, because the present study was performed using anthropomorphic phantoms, reductions in cervical pain, patient discomfort, or the risk of secondary injury were not directly evaluated.

For OML-based positioning, no significant differences in SNR or CNR were observed among the evaluated cephalad projection angles and phantoms. Similarly, no significant differences in SNR or CNR were found for IOML-based positioning. These findings suggest that variations in cephalad tube angulation within the evaluated range did not substantially affect quantitative image quality. In contrast, the qualitative assessment showed that the cephalad 4° projection achieved the highest mean score for both OML- and IOML-based positioning. This discrepancy indicates that anatomical alignment and visual delineation of the dens may be more sensitive to changes in projection angle than SNR and CNR.

Based on the CT-derived anatomical measurements, the dens-to-acanthion angle was $12.4 \pm 1.33^\circ$ relative to the OML and $4.57 \pm 1.09^\circ$ relative to the IOML. Therefore, an approximately 12° cephalad angle for OML-based positioning and an approximately 4° cephalad angle for IOML-based positioning were theoretically expected to provide suitable visualization of the dens. However, the phantom evaluation demonstrated that a cephalad angle of 4° provided the highest qualitative image-quality score for both reference lines. This difference between the CT-derived anatomical angles and the experimentally preferred tube angle may be attributable to differences between two-dimensional anatomical measurements and actual radiographic projection geometry. Beam divergence, source-to-image distance, central-ray direction, phantom positioning, and superimposition of craniofacial structures may have influenced the resulting images. Therefore, the anatomical angle measured on sagittal CT images should not be interpreted as being directly equivalent to the optimal radiographic tube angle.

The conventional open-mouth projection benefits from the presence of air within the oral cavity, which produces a relatively clear contrast between the dens and surrounding structures. In the proposed closed-mouth projection, the dens is projected through craniofacial bony structures, resulting in greater anatomical superimposition and potentially lower inherent contrast. Nevertheless, the cephalad 4° projection provided the most favorable anatomical alignment in the qualitative assessment, while maintaining comparable SNR and CNR values across the evaluated angles. A field size of 12×10 cm was used throughout the phantom experiments under standardized exposure and positioning conditions. Although these conditions were selected to approximate clinical odontoid radiography, the present results do not establish that identical image quality would be obtained in actual patients. Patient anatomy, body habitus, cervical immobilization devices, positioning limitations, and motion may affect image quality. In clinical practice, the field size should be restricted to the minimum area required for diagnosis to reduce unnecessary radiation exposure.

This study has several limitations. First, although the projection angles were determined using CT data from patients across a broad age range, the radiographic evaluation was conducted using only three anthropomorphic phantoms. Consequently, individual variations in craniofacial anatomy and body mass index (BMI) were not fully represented. Second, the proposed projection was not directly compared with the conventional open-mouth projection under identical exposure conditions and image-quality criteria. Therefore, the present study cannot demonstrate superiority or equivalence to the conventional method. Third, radiation dose was not directly measured, and the effect of field-size reduction on patient exposure could not be evaluated. Fourth, clinical diagnostic performance was not assessed in patients with actual odontoid fractures or other upper cervical abnormalities. Finally, although the reviewers demonstrated excellent inter-rater reliability, the qualitative assessment remains dependent on visual judgment. Overall, a cephalad tube angle of 4° produced the highest qualitative image-quality scores for both OML- and IOML-based closed-mouth positioning, whereas no significant differences in SNR or CNR were observed among the evaluated angles. These results provide preliminary technical evidence that a closed-mouth premaxillary projection may be a feasible alternative when conventional open-mouth positioning is difficult. Further studies involving patients with suspected cervical trauma, direct comparisons with the conventional open-mouth projection, and radiation-dose measurements are required before routine clinical application can be recommended.

V. CONCLUSION

This phantom study evaluated a closed-mouth premaxillary projection as a potential alternative for visualizing the dens when conventional open-mouth positioning is difficult. Quantitative assessment showed no significant differences in SNR or CNR among the evaluated cephalad projection angles for either OML- or IOML-based positioning. In contrast, qualitative assessment demonstrated that a cephalad tube angle of 4° produced the highest image-quality scores for both positioning methods.

These findings provide preliminary technical evidence that a 4° cephalad closed-mouth premaxillary projection may facilitate visualization of the dens in patients who are unable to open their mouths. However, because the present study was limited to

phantom evaluation and did not assess patients with actual cervical trauma or odontoid abnormalities, further clinical validation is required before this method can be recommended for routine diagnostic use.

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