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Optimal X-ray Beam Angle for Nasal Tangential Radiography: A Phantom Study

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ABSTRACT: To determine the optimal caudal X-ray tube angle for nasal tangential radiography using the glabelloalveolar line (GAL) as an anatomical reference and to evaluate the effect of tube angulation on nasal bone visualization in a 3D-printed skull phantom. De-identified facial computed tomography data from 50 adult men were retrospectively reviewed to identify a representative nasal bone length for fabrication of a 3D-printed skull phantom. The phantom was positioned prone and imaged under standardized exposure conditions at caudal tube angles of 15°, 20°, 25°, and 30°. Projected nasal bone length was defined as the straight-line distance from the nasion to the rhinion and was measured using ImageJ. Five experienced radiologic technologists independently assessed image quality using a five-point scale based on five anatomical criteria: symmetry of the nasal bony structures, avoidance of overlap with the upper dentition, separation from the frontal bone, avoidance of overlap with the lower incisors, and alignment of the X-ray beam with the GAL. Quantitative differences among the four tube-angle conditions were evaluated using one-way analysis of variance. Mean projected nasal bone lengths were 11.88 ± 0.12 mm at 15°, 25.23 ± 0.12 mm at 20°, 20.50 ± 0.36 mm at 25°, and 14.39 ± 0.09 mm at 30°. A significant overall difference was observed among the four angles ($F = 4369.99$, $p < 0.001$). The 20° caudal angle produced the greatest projected nasal bone length and also received the highest qualitative score for each of the five anatomical image-quality criteria. These findings indicate that the 20° condition provided the most favorable combination of projected nasal bone length and anatomical separation under the standardized phantom conditions. A 20° caudal X-ray tube angle provided the most favorable overall visualization for GAL-based nasal tangential radiography among the four tested conditions. The agreement between the quantitative and qualitative findings supports 20° as a candidate angle for further validation. However, because this study used a single 3D-printed skull phantom and did not assess fracture-detection accuracy or radiation dose, additional clinical studies are required before this angle can be recommended as a universal patient-positioning standard.

1. INTRODUCTION

Nasal bone fractures are among the most common facial injuries and frequently result from sports activities, interpersonal violence, falls, and traffic-related trauma [1-3]. Because the nasal bones are thin and prominently positioned in the central face, they are particularly vulnerable to direct external forces. The extent of displacement and the orientation of fracture fragments can influence both functional and cosmetic outcomes. Accurate imaging of the nasal bones is therefore important for confirming the presence of a fracture and for evaluating the degree and direction of displacement during treatment planning. Several imaging modalities can be used to evaluate nasal trauma. Computed tomography provides high diagnostic performance because it can depict complex fracture patterns and adjacent facial structures in multiple planes [11,13-15]. However, CT may not always be necessary for isolated nasal bone injuries. Conventional radiography can still provide useful information in selected cases when a lower-complexity examination is sufficient or when follow-up imaging is required. Plain radiography also has advantages in terms of accessibility and examination simplicity. However, its diagnostic value depends strongly on appropriate patient positioning and projection geometry. One of the major limitations of conventional radiography is

superimposition of adjacent anatomical structures. The maxilla, frontal bone, teeth, and other craniofacial structures may overlap the nasal bones depending on the projection angle. Such overlap can reduce the visibility of subtle fracture lines and make assessment of displacement more difficult. In addition, small differences in head position or tube angulation can alter the projected shape and apparent length of the nasal bones. For this reason, reproducible positioning and standardized beam geometry are important for improving consistency in nasal radiography. Tangential radiography is intended to reduce superimposition by directing the X-ray beam in a manner that better separates the nasal bones from surrounding structures. A reproducible tangential projection may therefore improve anatomical visualization and may reduce variation between repeated examinations. However, the effectiveness of this technique depends on the relationship between the patient's craniofacial anatomy and the direction of the central ray.

The glabelloalveolar line (GAL) is defined by the line connecting the glabella and the alveolar ridge and can be used as a practical craniofacial reference for tangential positioning. Because this line can be identified externally during radiographic positioning, it may provide a useful anatomical reference for standardizing beam angulation. Nevertheless, a standardized tube angle for GAL-based nasal tangential radiography has not been clearly established. Differences in tube angle may change the degree of foreshortening and the amount of overlap with adjacent bony structures. Anatomical variation should also be considered when determining an appropriate projection angle. Nasal bone length and craniofacial morphology differ among individuals and populations [18]. These differences may affect how the nasal bones are projected on two-dimensional radiographs. Therefore, evaluating tube angulation using representative anatomical data may help identify a projection condition that provides more consistent visualization.

Three-dimensional printing has increasingly been used to create anatomically realistic phantoms for radiographic and dosimetric research [17]. A 3D-printed phantom allows imaging parameters and positioning conditions to be controlled while avoiding repeated radiation exposure to human participants. It also enables repeated acquisitions under identical experimental conditions and can therefore be useful for comparing projection angles in a standardized manner. Accordingly, the present study used a 3D-printed skull phantom derived from representative CT anatomy to compare four caudal X-ray tube angles for GAL-based nasal tangential radiography. Quantitative evaluation was performed using the projected nasal bone length from the nasion to the rhinion. Qualitative evaluation was conducted by experienced radiologic technologists using anatomical image-quality criteria related to symmetry, overlap, and beam alignment. The aim of this study was to identify the caudal tube angle that provided the most favorable quantitative and qualitative visualization of the nasal bones under standardized phantom conditions.

2. MATERIALS AND METHODS

2.1 Study Design and CT Dataset

This phantom-based radiographic study used de-identified facial CT data obtained from 50 adult male patients aged 19 years or older who had undergone facial CT examinations at Kyung Hee University Medical Center. The CT data were retrospectively reviewed to identify representative craniofacial anatomy for the fabrication of a three-dimensional skull phantom. Only de-identified imaging data were used for the anatomical measurements. Three-dimensional reconstructed CT images were generated from the facial CT datasets, and nasal bone length was measured from the nasion to the rhinion. These anatomical landmarks were selected because they represent the superior and inferior extent of the nasal bone on the midline. Measurements were performed on the reconstructed images to determine the distribution of nasal bone lengths within the study group. After all measurements were completed, the mean nasal bone length of the 50 subjects was calculated. The CT dataset from the patient whose nasal bone length was closest to the group mean was then selected as the representative anatomical dataset for phantom fabrication. This approach was used to avoid selecting an anatomically extreme case and to provide a phantom that more closely reflected the average nasal bone morphology of the study population. The selected dataset was subsequently used as the anatomical basis for the three-dimensional modeling process. Because the purpose of the CT dataset was limited to the selection of representative anatomy, no diagnostic evaluation or clinical outcome assessment was performed using the patient data.

2.2 Phantom Fabrication

A custom skull phantom was fabricated from the selected de-identified DICOM dataset using three-dimensional printing technology. The CT dataset was converted into a three-dimensional craniofacial model suitable for additive manufacturing. The

phantom was produced using fused filament fabrication with polylactic acid (PLA) filament. The fabrication process was designed to reproduce the craniofacial anatomy required for evaluation of nasal tangential radiography. Particular attention was given to preserving the anatomical contour of the nasal bone and adjacent facial structures because these structures directly influence superimposition and projected nasal bone length on tangential radiographs. PLA was selected as the printing material because it is widely used in fused filament fabrication and allows reproducible construction of rigid anatomical models. The completed phantom was used as a standardized imaging subject throughout the radiographic experiments so that tube angle could be varied while other anatomical and acquisition conditions remained unchanged.

The use of a 3D-printed phantom also allowed repeated image acquisition without exposing human participants to additional ionizing radiation. In addition, the same phantom geometry could be maintained across all imaging conditions, thereby reducing anatomical variability during comparison of the different tube angles. Three-dimensional printing has previously been used to produce radiographic and dosimetric phantoms for controlled imaging experiments [6].

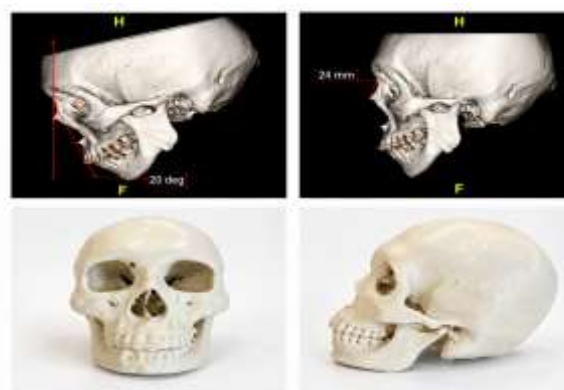


Figure 1. Three-dimensional CT reconstruction used to measure nasal bone length from the nasion to the rhinion.

2.3 Radiographic equipment and image acquisition

Radiographs were acquired using a YSIO Max digital radiography system (Siemens Healthineers, Erlangen, Germany) with a Minerva 2.0 collimator. The exposure parameters were fixed at 60 kVp and 6 mAs with a source-to-image receptor distance of 100 cm. The phantom was stabilized in the prone position using a positioning sponge. The median sagittal plane was maintained perpendicular to the image receptor. Four caudal tube angles were evaluated: 15°, 20°, 25°, and 30°. The central X-ray beam was aligned parallel to the glabelloalveolar line (GAL) and centered on the facial midline. The collimated field included the nasal region and mandible. All imaging parameters other than tube angle were kept constant.



Figure 2. Experimental setup for prone nasal tangential radiography using the 3D-printed skull phantom.

2.4 Quantitative Image Assessment

Projected nasal bone length was defined as the straight-line distance from the nasion to the rhinion on each tangential radiograph. These anatomical landmarks were used to assess the projected extent of the nasal bone. Measurements were performed using ImageJ software (National Institutes of Health, Bethesda, MD, USA). Five numerical measurements were available for each tube-angle condition and were used to calculate the mean projected nasal bone length and standard deviation. The same anatomical landmarks were identified for each measurement and the nasion-to-rhinion distance was recorded in millimeters using the linear measurement function in ImageJ. Projected nasal bone length was used as a quantitative indicator of geometric depiction of the nasal bone. The term “projected nasal bone length” was used throughout because the nasion-to-rhinion distance represents the nasal bone rather than the bony nasal septum.

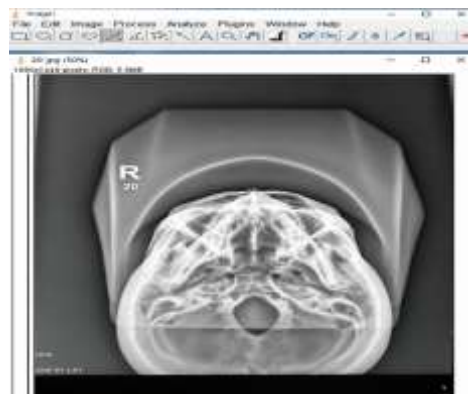


Figure 3. Example ImageJ measurement of projected nasal bone length on a tangential radiograph.

2.5 Qualitative image assessment

Five radiologic technologists with clinical experience independently evaluated the images on medical-grade displays under blinded conditions. Image quality was rated using a five-point scale from 1 (poor) to 5 (excellent). The five criteria were: (1) symmetry of the nasal bony structures; (2) avoidance of overlap between the nasal bone and upper dentition; (3) separation between the nasal bone and frontal bone; (4) avoidance of overlap between the nasal bone and lower incisors; and (5) alignment of the X-ray beam with the GAL. Mean scores were calculated for each criterion and tube-angle condition for descriptive comparison.

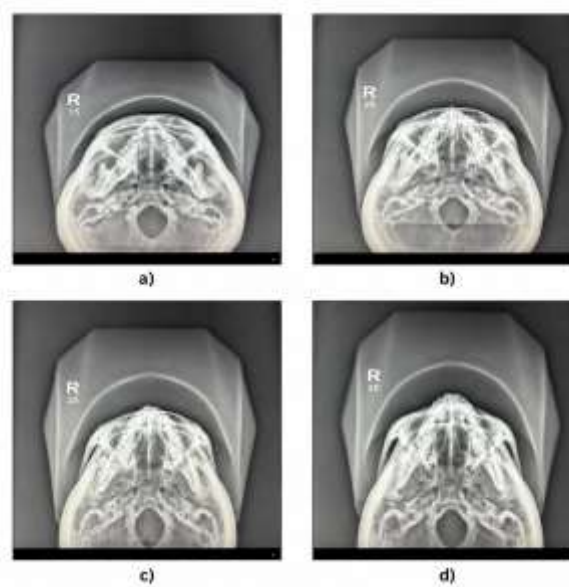


Figure 4. Representative nasal tangential radiographs obtained at caudal tube angles of (a) 15°, (b) 20°, (c) 25°, and (d) 30°.

2.6 Statistical analysis

Continuous data are presented as mean $\pm$ standard deviation (SD). Quantitative differences in projected nasal bone length among the four tube-angle conditions were evaluated using one-way analysis of variance (ANOVA). The analysis was based on five numerical measurements available for each angle. A two-sided p value < 0.05 was considered statistically significant. Because all measurements were obtained from the same skull phantom under repeated imaging conditions, the ANOVA results should be interpreted as exploratory. Future confirmatory studies should use a repeated-measures or mixed-effects approach when the dependency structure of repeated acquisitions can be modeled appropriately.

3. RESULTS

3.1 Quantitative Assessment

Projected nasal bone length differed significantly among the four caudal tube-angle conditions. One-way ANOVA demonstrated a statistically significant overall difference in projected nasal bone length among the 15°, 20°, 25°, and 30° groups ($F = 4369.99$, $p < 0.001$). This result indicates that the measured nasion-to-rhinion distance varied substantially according to the caudal tube angle under the standardized phantom conditions. Among the four tested conditions, the 20° caudal projection produced the greatest mean projected nasal bone length at 25.23 ± 0.12 mm. The second greatest value was observed at 25° with a mean length of 20.50 ± 0.36 mm. The corresponding values at 30° and 15° were 14.39 ± 0.09 mm and 11.88 ± 0.12 mm respectively. Thus, the quantitative measurements increased markedly from 15° to 20° and then progressively decreased as the tube angle increased from 20° to 25° and 30°. The difference between the 20° and 15° conditions was 13.35 mm. The projected length at 20° was also 4.73 mm greater than that at 25° and 10.84 mm greater than that at 30°. Although the 25° condition demonstrated a relatively large projected nasal bone length, its mean value remained lower than that obtained at 20°. In contrast, the 15° condition produced the shortest projected nasion-to-rhinion distance among all evaluated angles.

The pattern of the measurements showed that the maximum projected nasal bone length occurred at an intermediate caudal angulation rather than at the lowest or highest tube angle. Specifically, the mean projected length increased from 11.88 mm at 15° to 25.23 mm at 20° and then decreased to 20.50 mm at 25° and 14.39 mm at 30°. This pattern demonstrates that the projected appearance of the nasal bone was highly dependent on tube angulation within the range evaluated in this study. The relatively small SD values observed at 15°, 20°, and 30° indicate that the repeated measurements within each of these tube-angle conditions showed limited variability. The 25° condition showed the largest SD at 0.36 mm, although the variability remained small relative to the differences observed among the mean values of the four groups. Overall, the repeated measurements showed a consistent pattern in which the 20° caudal projection produced the greatest projected nasion-to-rhinion distance.

The mean and SD values were calculated from the five numerical measurements available for each tube-angle condition. The measurements showed a consistent pattern in which the 20° caudal projection produced the greatest projected nasion-to-rhinion distance. Taken together, the quantitative results demonstrated a clear dependence of projected nasal bone length on caudal tube angulation under the experimental conditions of this phantom study. These quantitative findings are summarized in Table 1.

Table 1. Projected nasal bone length according to caudal tube angle.

Tube angle	Measurement 1	Measurement 2	Measurement 3	Measurement 4	Measurement 5	Mean $\pm$ SD (mm)
15°	12.09	11.87	11.76	11.85	11.83	11.88 ± 0.12
20°	25.20	25.12	25.12	25.33	25.37	25.23 ± 0.12
25°	20.50	20.21	20.11	21.00	20.68	20.50 ± 0.36
30°	14.30	14.44	14.51	14.34	14.34	14.39 ± 0.09

Overall one-way ANOVA: $F = 4369.99$, $p < 0.001$.

3.2 Qualitative Assessment

The 20° caudal tube angle received the highest mean score for each of the five qualitative image-quality criteria. For symmetry of the nasal bony structures, the mean score at 20° was 4.44 ± 0.73 . For avoidance of overlap between the nasal bone and the upper dentition, the mean score was 4.30 ± 0.69 . Separation between the nasal bone and the frontal bone received a mean score of 4.36 ± 0.59 . Avoidance of overlap between the nasal bone and the lower incisors showed the highest mean value among the five criteria at 4.46 ± 0.70 . Beam alignment with the GAL also received a high mean score of 4.44 ± 0.57 . Across all five criteria, the 20° condition consistently demonstrated the most favorable qualitative evaluation compared with the 15°, 25°, and 30° conditions. This pattern indicates that the 20° caudal projection provided the best overall combination of anatomical symmetry, reduced dental overlap, separation from adjacent bony structures, and appropriate beam alignment under the standardized phantom conditions. The qualitative results also showed that image quality decreased when the tube angle deviated from 20°. Although the 25° condition generally produced relatively favorable scores, its values remained lower than those obtained at 20° for all five criteria. In contrast, the 15° and 30° conditions showed lower scores overall, suggesting less favorable anatomical projection and a greater degree of superimposition or misalignment.

Descriptive scores showed a consistent pattern across the four tube-angle conditions. The 20° condition had the highest mean score for each of the five qualitative criteria while the 25° condition generally showed the next most favorable values. The 15° and 30° conditions showed lower scores overall. Reviewer-level raw data were not available for independent recalculation of inferential statistics or inter-rater reliability. Therefore, the qualitative findings are presented and interpreted primarily on the basis of the reported mean $\pm$ SD values. The detailed scores are presented in Table 2.

Table 2. Qualitative image-quality scores according to caudal tube angle. Data are mean $\pm$ SD on a five-point scale.

Angle	Symmetry	Avoidance of upper-dentition overlap	Frontal-bone separation	Avoidance of lower-incisor overlap	GAL alignment
15°	2.84 ± 0.65	2.80 ± 0.46	2.88 ± 0.71	3.08 ± 0.63	2.90 ± 0.54
20°	4.44 ± 0.73	4.30 ± 0.69	4.36 ± 0.59	4.46 ± 0.70	4.44 ± 0.57
25°	4.14 ± 0.85	3.80 ± 0.64	3.82 ± 0.69	4.04 ± 0.75	3.82 ± 0.62
30°	2.70 ± 0.70	2.70 ± 0.45	3.06 ± 0.76	2.90 ± 0.58	2.64 ± 0.63

4. DISCUSSION

This phantom study compared four caudal tube angles for GAL-based nasal tangential radiography and demonstrated that the 20° condition produced the greatest projected nasal bone length and the highest qualitative scores across all five anatomical criteria. These findings indicate that projection geometry has a substantial influence on the radiographic appearance of the nasal bone and adjacent craniofacial structures. Because nasal bone fractures are common facial injuries [1-3], optimization of projection geometry may help improve the consistency of nasal bone visualization. The quantitative findings showed that projected nasal bone length varied markedly according to tube angulation. The projected nasion-to-rhinion distance was greatest at 20° and decreased at both lower and higher angles. This pattern can be explained by the principles of projection geometry. When the nasal bone is not appropriately aligned with the X-ray beam and image receptor, its projected length may be reduced because of foreshortening. Previous studies have shown that optimization of radiographic projection can influence image quality and examination efficiency [19,20]. Therefore, the greater projected length observed at 20° suggests a more favorable geometric relationship between the nasal bone and the incident X-ray beam.

The 25° condition also produced a relatively large projected nasal bone length but remained lower than the value observed at 20°. In contrast, the 15° and 30° conditions produced substantially shorter projected lengths. These results suggest that the most favorable geometric relationship occurs within a relatively limited angular range. Insufficient angulation may increase overlap with adjacent craniofacial structures while excessive angulation may increase distortion or foreshortening. The quantitative findings were consistent with the qualitative assessment. The 20° caudal angle received the highest mean score for all five image-quality criteria. In particular, this condition showed favorable symmetry and reduced overlap between the nasal bone and the upper and lower dentition. It also provided clearer separation from the frontal bone and more appropriate alignment with the GAL. This agreement between quantitative and qualitative findings supports the technical suitability of the 20° projection under the experimental conditions. Superimposition is an important limitation of conventional radiography because three-dimensional craniofacial structures are represented on a two-dimensional image. Previous studies comparing conventional radiography with ultrasonography and CT have shown differences in visualization and diagnostic performance for nasal bone fractures [11,13-15]. Conventional radiography is particularly dependent on projection angle. Therefore, standardized positioning and beam angulation may be important for improving reproducibility. Beam alignment with the GAL also received the highest qualitative score at 20°. The GAL was used as an anatomical reference because it provides a practical craniofacial landmark for positioning. A consistent anatomical reference may help reduce operator-dependent variation during image acquisition. However, anatomical variation should also be considered. Nasal bone dimensions and craniofacial morphology vary among individuals and populations [18]. Therefore, the 20° angle identified in this study should be regarded as an experimentally favorable condition rather than a universal angle for all patients.

The use of a 3D-printed phantom provided important methodological advantages. Three-dimensional printing has been applied to the development of radiographic and dosimetric phantoms [17]. In the present study, the same craniofacial anatomy could be repeatedly imaged while the tube angle was changed. This reduced anatomical variability and allowed the effect of tube angulation to be evaluated under controlled conditions. Repeated imaging could also be performed without additional radiation exposure to human participants. Nevertheless, the present findings should be interpreted with caution. The study did not include actual or simulated nasal fractures. Therefore, the higher image-quality scores at 20° should not be interpreted as evidence of improved diagnostic sensitivity or specificity. Previous studies have evaluated the diagnostic performance of conventional radiography, ultrasonography, and CT for nasal fractures [11-15]. Future studies should determine whether the improved technical image quality observed at 20° translates into improved fracture detection. Several limitations should also be considered. First, only one custom 3D-printed skull phantom was used. A single model cannot represent the full range of nasal bone length and craniofacial anatomy found clinically [18]. Second, the phantom was imaged in the prone position, which may not be feasible for all patients with acute facial trauma. Third, the phantom did not fully reproduce soft-tissue attenuation or post-traumatic swelling. Fourth, radiation dose was not measured. Therefore, no conclusions regarding dose reduction can be made [19,20]. Fifth, reviewer-level raw data were not available for independent recalculation of inter-rater reliability. Finally, repeated acquisitions from the same phantom create a dependent data structure. Future studies should therefore consider repeated-measures ANOVA or mixed-effects models. Despite these limitations, the agreement between the quantitative and qualitative findings supports further investigation of a 20° caudal tube angle for GAL-based nasal tangential radiography. Future studies should include multiple anthropomorphic phantoms or patients with varying craniofacial anatomy. The proposed projection should also be compared with conventional nasal bone views and evaluated for diagnostic accuracy, positioning reproducibility, clinical feasibility, and radiation dose.

5. CONCLUSION

Under the controlled conditions of this phantom study, a 20° caudal X-ray tube angle provided the most favorable overall image quality for GAL-based nasal tangential radiography among the four tested angles. This projection produced the greatest projected nasal bone length and consistently received the highest qualitative scores for anatomical symmetry, reduced overlap with the upper and lower dentition, separation from the frontal bone, and alignment with the GAL.

The agreement between the quantitative and qualitative findings suggests that the 20° caudal angle provides a favorable geometric relationship for visualizing the nasal bone in tangential projection. However, these results should be interpreted as technical optimization findings obtained from a single 3D-printed skull phantom.

Therefore, the 20° caudal angle may be considered a candidate projection for further validation rather than a definitive clinical standard. Future studies should include multiple phantoms or patients with varying craniofacial anatomy and should evaluate

fracture-detection accuracy, positioning reproducibility, clinical feasibility, and radiation dose before this technique is adopted for routine clinical use.

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