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Evaluation of a method to predict positioning errors in orthopantomography using cephalography

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A B S T R A C T

Introduction: Various radiographic examinations are used to diagnose diseases and determine treatment plans, and the quality of radiographic images affects diagnostic accuracy. This study assessed the relationship between orthopantomography and cephalometric analysis in predicting positioning errors before orthopantomography.
Methods: This study evaluated four human head phantom types and included 300 patients aged ≥18 years who underwent orthopantomography. The correlation between the Frankfort horizontal plane and occlusal plane angles in the orthopantomogram was analyzed. The occlusal plane angle at a Frankfort horizontal plane of 0° was estimated using a linear approximation formula. Frankfort horizontal plane and occlusal plane angles were measured on the cephalograms, and their differences were analyzed for correlation with the occlusal plane angle at a Frankfort horizontal plane of 0° in the corresponding orthopantomograms. The cephalogram's condylar plane–corpus line angle was also compared with orthopantomogram measurements.
Results: Frankfort horizontal and occlusal plane angles demonstrated a strong negative correlation ($r < -0.9$) in phantom studies and moderate negative correlation ($r < -0.4$) in clinical orthopantomograms. In the phantoms, the occlusal plane at a Frankfort horizontal of 0° in the orthopantomogram strongly correlated with the difference between the Frankfort horizontal and condylar plane–corpus line angles in the cephalogram.
Conclusion: Adjusting patient positioning based on individual skeletal differences and angles may reduce positioning errors and improve image quality. Cephalogram analysis could help determine an appropriate Frankfort plane angle for each patient when acquiring orthopantomograms.
Implications for practice: Integrating cephalometric analysis into positioning protocols enhances radiographic accuracy, reduces retakes, and improves diagnostic reliability in clinical positioning. This research could improve image quality by identifying reference indicators for orthopantomography by incorporating data from images other than cephalograms, such as computed tomography and magnetic resonance imaging.

Introduction

Radiological images are essential for medical diagnosis, and their quality directly affects diagnostic accuracy.[1,2] Various examinations are performed to diagnose diseases, with images easily accessible through health information systems and radiological image database servers.[3] Since radiological images are projections, their results may vary based on patient positioning and the angle of incidence, making proper positioning crucial for consistency in follow-up assessments.[4] To ensure optimal image quality, previous images from different medical imaging modalities are often referenced before radiographs are taken.[4–6]

Orthopantomography provides a comprehensive view of the dentition and is widely used for diagnosing and treating oral conditions, such as malocclusion, impacted teeth, and grossly carious teeth.[7–9] This imaging technique uses thin X-ray beams with slits to synchronize the rotation of the X-ray tube and detector, selectively blurring areas outside the target region of a specific thickness.[7,8] Owing to the mandibular bone structure varying among patients and the limited rotational and

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tomographic range of the device, even slight positioning errors can compromise image quality and diagnostic accuracy.[10,11]

Previous studies report that orthopantomograms have relatively high patient positioning errors, whereas more than 50 % (Loughlin et al.) or 80 % (Dhillon et al.) exhibit some form of positioning error.[11,12] Orthopantomography positioning requires the midsagittal plane to be vertical and Frankfort plane to be horizontal. The criteria of a good orthopantomogram are that the mandible is "U" shaped, the roots of the maxillary and mandibular anterior teeth are readily visible, and the occlusal plane exhibits a slight curve.[10] However, no standardized numerical guidelines exist for the ideal occlusal plane angle; this contributes to positioning errors and low reproducibility.[13] The lack of objective image-based standards makes education and training on orthopantomogram positioning subjective and challenging.[8]

Both orthopantomography and general radiography are digital imaging techniques that allow easy retakes; however, each additional exposure increases the radiation dose of the patient. Studies indicate that approximately 20 % of general radiographs require retakes, and assessing the risk of retakes in advance by reviewing images taken using other modalities may be beneficial.[14,15]

Cephalography and orthopantomography are important tools used in orthodontic treatment and dental care. Cephalograms provide numerical data for analyzing and evaluating individual anatomical structures using digital software or manual tracing techniques.[16,17] Cephalograms and orthopantomograms are often taken simultaneously, and we consider that previously taken cephalometric images could serve as reference images for optimal orthopantomography, without the need for additional imaging. This study explored the potential use of patient-specific cephalometric analysis to optimize patient positioning before orthopantomography.

We analyzed cephalograms and orthopantomograms to identify factors that improve image quality and minimize positioning errors. To the best of our knowledge, no previous studies have analyzed cephalograms or evaluated positioning errors in orthopantomograms. This new method determines the optimal positioning method for individual patients before an orthopantomogram is taken using past cephalograms. This study demonstrates the efficient use of imaging information of individual patients and is expected to improve the quality of diagnostic images.

Methods

Phantoms, patients, and materials

This study included both phantom and patient data. Four types of human head phantoms of unknown race and manufacturer (#1: SK100 skull phantom (The Phantom Laboratory, Salem, NY), #2: RS-108T (Radiological Support Devices, Long Beach, CA), #3 RS-108SK100 skull phantom (Kyoto Kagaku, Kyoto, Japan) were used for phantom analysis. A radio, and #4: SK100 skull phantom) were used for phantom analysis. A radiologist visually confirmed the lack of structural defects in the human head phantoms using a CT scanner (Aquilion Precision, Canon Medical Systems, Otawara, Japan).

This clinical study evaluated 300 patients aged ≥18 years who had undergone orthopantomography at our hospital between 2012 and 2022. The ages of the patients ranged from 18 to 89 years (median: 38 years). Cephalograms were taken using a Cephalogram X-ray scanner (CX-90SP, Asahi Roentgen, Kyoto, Japan), whereas orthopantomograms were taken using a VeraView Epocs2D panoramic machine (Morita Co, Kyoto, Japan). Image analysis was conducted using the measurement tool of the Image Storage System, Synapse (Fuji Medical Systems, Tokyo, Japan) and image analysis software, ImageJ/Fiji (version: 1.53f51, National Institutes of Health, Bethesda, MD, USA). In this study, phantom and patient data were analyzed to predict positioning before orthopantomography, and the relationships between the anatomical reference lines in the orthopantomograms and cephalograms were examined. Fig. 1 presents the experimental flowchart. All image evaluations and measurements were performed by a radiological technologist.

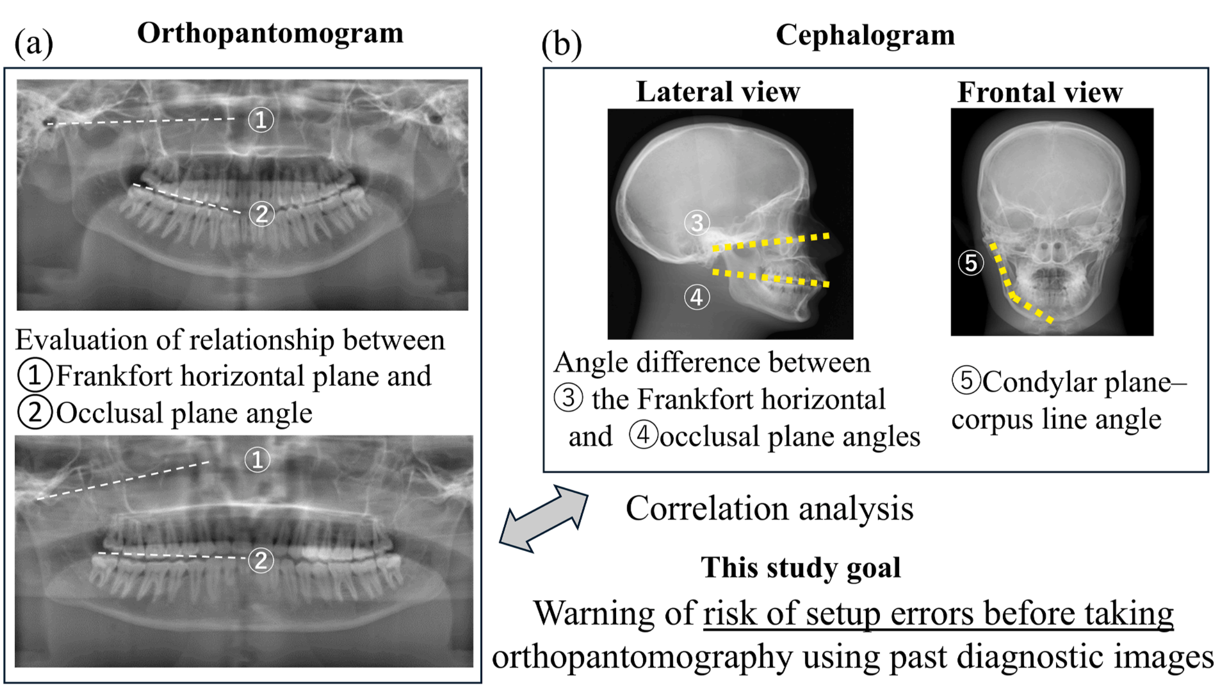

Figure 1. Study flow and reference lines. (a) Reference lines in the orthopantomograms: (1) Frankfort horizontal plane, (2) occlusal plane, (3) Frankfort horizontal plane, (4) maxillary occlusal plane, and (5) condylar plane–corpus line.

Analysis of the orthopantomograms and cephalograms of the human head phantoms

Orthopantomograms of four types of human head phantoms were taken using an auxiliary fixation device, and the human head phantom was positioned by aligning the Frankfort horizontal plane parallel to the floor, with the laser used to set the tomographic region centered on the canine. To assess the effect of tilt on positioning error, 11 orthopantomograms were taken incrementally, tilting from 0 to 10° in 2° increments for the Frankfort horizontal plane, ranging from a chin-up to a chin-down position. The Frankfort horizontal plane and occlusal plane angles of the orthopantomogram were measured using Synapse (Fig. 1a). The Frankfort horizontal plane angle was defined as the angle between the floor and Frankfort horizontal plane, which connects the external auditory canal and infraorbital rim. The occlusal plane angle was defined as the angle between the floor and the line connecting the anterior teeth to the second molars. ImageJ/Fiji was used to measure the mandibular angle in the frontal view, as well as the Frankfort horizontal plane and occlusal plane angles in the lateral cephalograms (Fig. 1b). Additionally, the angle between the condylar plane and corpus line on the left and right sides of the mandible was averaged.

Evaluation of the orthopantomograms and cephalograms of human head phantoms

The correlation between the Frankfort horizontal plane and occlusal plane angles in orthopantomograms was analyzed among the human head phantoms. The occlusal plane angle at a Frankfort horizontal plane angle of ±5°, ±4°, ±3°, ±2°, ±1°, and 0° on the orthopantomogram was calculated using a linear approximation equation obtained from correlation. The difference between the Frankfort horizontal plane and occlusal plane angles (F–O difference angle) in the lateral cephalogram was calculated (Fig. 1b). The occlusal plane angle at a Frankfort horizontal plane angle of 0° on the orthopantomogram was analyzed for correlation with the F–O difference angle and average angle of the left and right condylar plane-corpus lines in the frontal view cephalograms.

Image analysis of the clinical orthopantomograms and cephalograms

The Frankfort horizontal plane and occlusal plane angles were measured on the orthopantomograms of 300 patients using Synapse, and the median values were calculated. The correlation between the Frankfort horizontal plane and occlusal plane angles was analyzed. Additionally, the occlusal plane angle at a Frankfort horizontal plane angle of 0° was calculated using a linear approximation equation obtained from correlation.

Statistical analysis

The correlation between the anatomical characteristics of the orthopantomograms and cephalograms was determined using Pearson's correlation coefficient (r) in SPSS 29.0.2.0 (IBM SPSS Statistics, Armonk, NY, USA).

Ethical considerations

Ethical approval for this study was obtained from the Ethics Committee of Okayama University Hospital Institutional Review Board (Approval number: 2210-027). Patients with unclear anatomical structures, such as the external auditory foramen or orbit, were excluded.

Results

The relationship between the Frankfort horizontal plane and occlusal plane angles in the orthopantomograms showed a strong negative correlation for phantoms #1 ($r = -1.00$), #2 ($r = -1.00$), #3 ($r = -1.00$), and #4 ($r = -0.98$) (Fig. 2a).

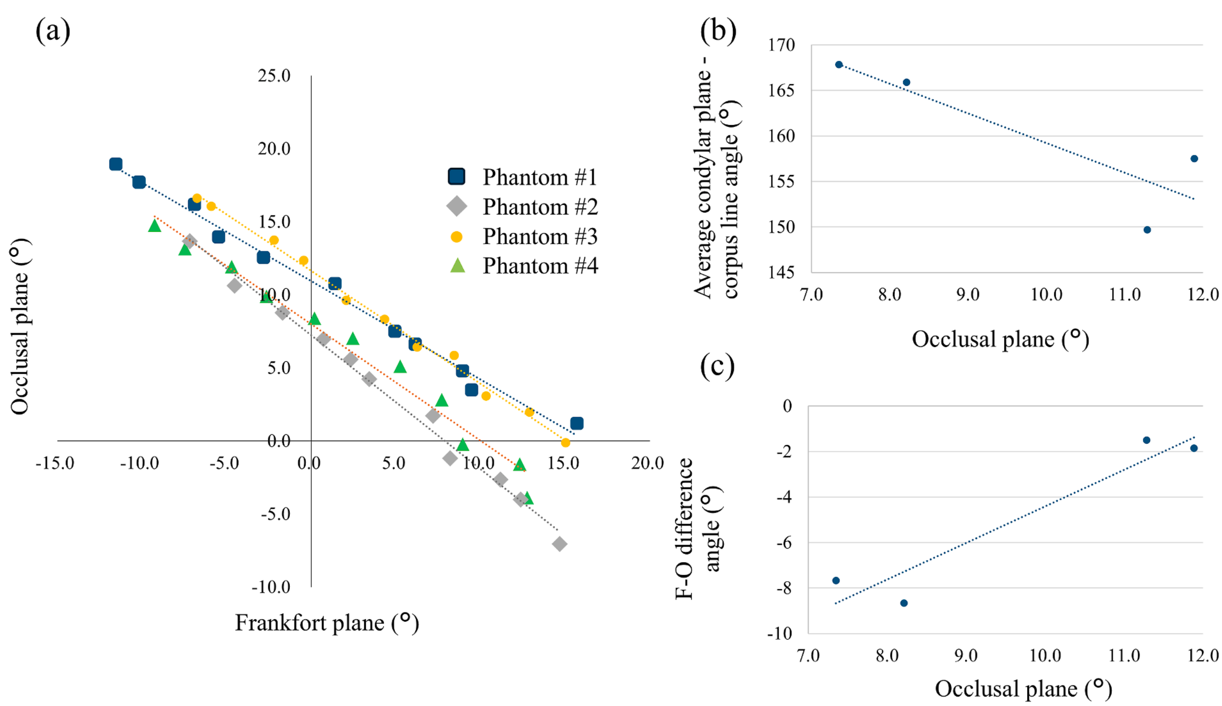

Figure 2. Relationship between each anatomical angle in the phantom study. Orthopantomogram: (a) Relationship between the occlusal plane and Frankfort plane angles. Cephalogram: (b) Average condylar plane–corpus line angle, and (c) Difference between the Frankfort horizontal (FH) and maxillary occlusal angle (O). The dotted line represents a linear approximation.

Table 1
Results of the cephalometric analysis for the human head phantoms.

Phantom			#1	#2	#3	#4
Frontal view cephalogram	Condylar plane–corpus line angle (°)	Left	147.1	162.8	158.1	168.5
		Right	152.3	173	157	163.4
	Average (°)		149.7	167.9	157.5	165.9
Lateral view cephalogram	Frankfort horizontal plane angle (°)		6.6	3.8	5.4	1.5
	Occlusal plane angle (°)		−8.1	−11.5	−7.2	−10.1
	Difference angle (°)		−1.5	−7.7	−1.9	−8.7

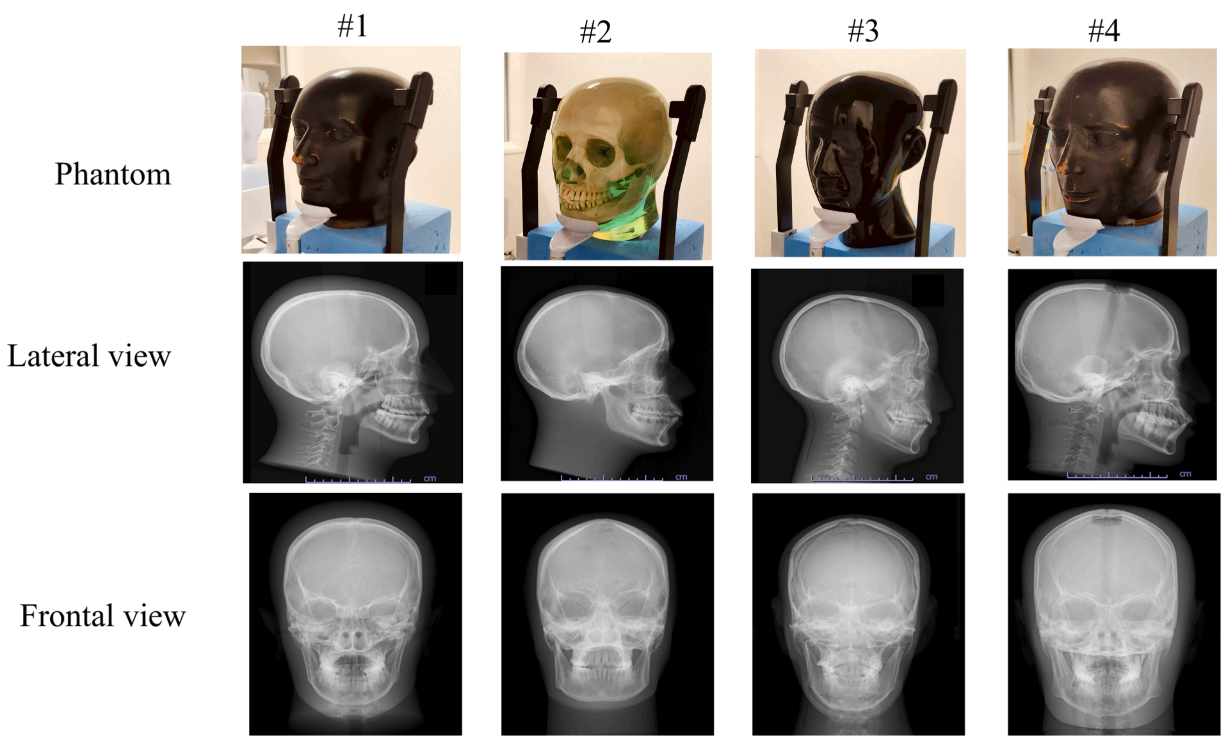

Figure 3. Four types of human head phantoms and their cephalograms.

The results of the cephalogram analysis for the human head phantoms are shown in Table 1. In the frontal view cephalograms, phantoms #1 and #3 had long, slender jaws (condylar plane–corpus line angle: <160°), whereas phantoms #2 and #4 had wider jaws (condylar plane–corpus line angle: >160°), with their angles being similar to each other (Table 1, Fig. 3). The occlusal plane angles relative to the Frankfort horizontal line in the orthopantomograms were as follows: 11.3° for phantom #1, 7.4° for phantom #2, 11.9° for phantom #3, and 8.2° for phantom #4. The occlusal plane angles were closely matched between phantoms #1 and #3 as well as between phantoms #2 and #4 (Table 2). The closest Frankfort horizontal plane angles for phantom #1 were: −4° for phantom #2; 1° for phantom #3; and −4° for phantom #4, with a maximum difference of approximately 5°. Additionally, a strong negative correlation ($r = -0.89$) was observed between the average values of the left and right condylar plane–corpus line angles and occlusal plane angles relative to the Frankfort horizontal line in the orthopantomograms (Fig. 2b). In the cephalogram analysis, the difference between the Frankfort horizontal and occlusal plane angles was similar between phantoms #1 (−1.5°) and #3 (−1.9°) as well as between phantoms #2 (−7.7°) and #4 (−8.7°) (Table 1). Additionally, a strong positive correlation ($r = 0.96$) was observed between the F–O difference angle of the cephalograms and occlusal plane angle relative to the 0° Frankfort horizontal in the orthopantomograms (Fig. 2c).

Table 2
Relationship between the occlusal plane angle relative to the Frankfort angle in the orthopantomograms and the results of the cephalometric analysis.

Frankfort Horizon angle (°)		−5°	−4°	−3°	−2°	−1°	0°	1°	2°	3°	4°	5°
#1		14.7	14.0	13.3	12.6	12.0	11.3	10.6	9.9	9.3	8.6	7.9
#2		12.0	11.1	10.1	9.2	8.3	7.4	6.4	5.5	4.6	3.6	2.7
#3		15.5	14.8	14.0	13.3	12.6	11.9	11.2	10.5	9.7	9.0	8.3
#4		11.8	11.1	10.4	9.6	8.9	8.2	7.5	6.8	6.1	5.3	4.6
r	F–O difference and occlusal plane angles	0.97	0.97	0.97	0.97	0.96	0.95	0.95	0.94	0.93	0.92	0.91
	Condylar plane–corpus line and occlusal plane angle	−0.83	−0.85	−0.86	−0.86	−0.87	−0.88	−0.88	−0.88	−0.88	−0.88	−0.88

F–O difference angle: Difference between the Frankfort horizontal plane and occlusal plane angles; r: Correlation Coefficient.

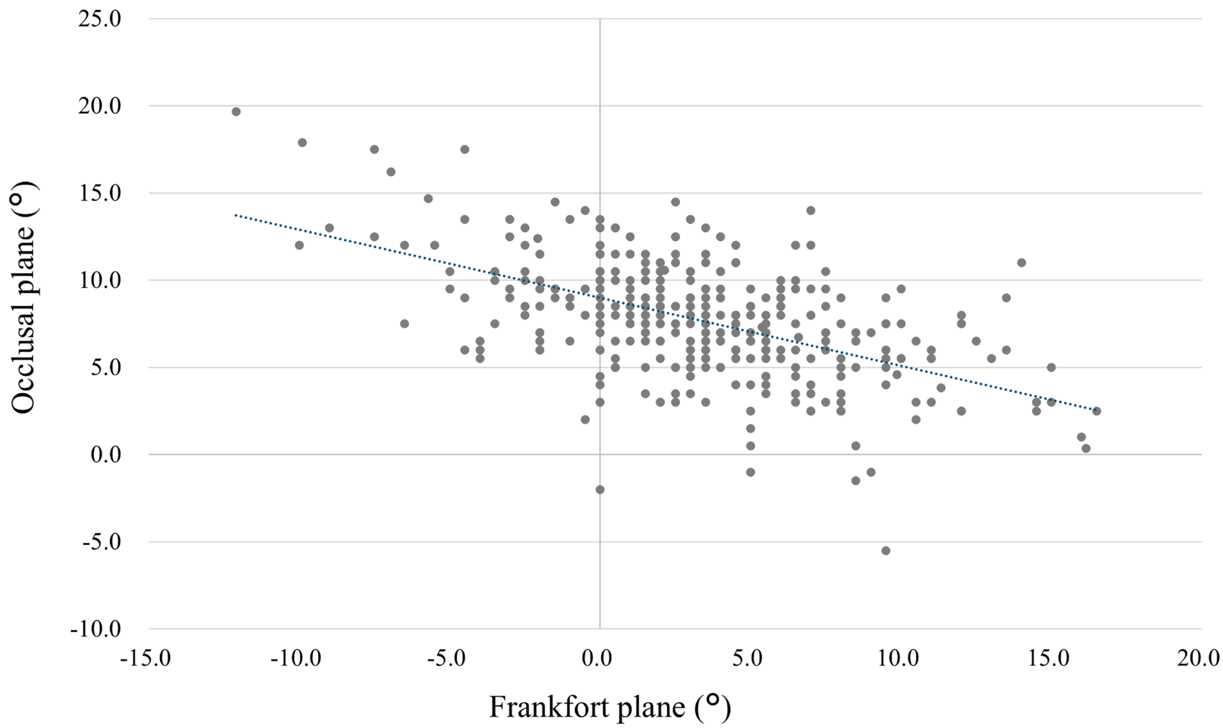

Figure 4. Relationship between the occlusal plane and Frankfort plane angles in the orthopantomograms used in the clinical study. The dotted line indicates a linear approximation.

The median (standard deviation) for the Frankfort horizontal plane angle was 3.5° (4.5) whereas that for the occlusal plane angle was 7.5° (3.2) in the clinical orthopantomograms. A moderate negative correlation ($r = -0.48$) was observed between the Frankfort horizontal and occlusal plane angles in the clinical orthopantomograms (Fig. 4). The calculated occlusal plane angle (8.99°) at 0° Frankfort horizontal of the clinical orthopantomogram that was calculated using the equation for their relationship, was closely correlated with the value obtained from the orthopantomogram of phantom #4 (8.2°) (Table 2).

Discussion

This study evaluated the relationship between cephalogram and orthopantomogram data to reduce positioning errors before orthopantomography is performed, using a cephalogram to obtain reference diagnostic data.

A strong negative correlation was observed between the Frankfort horizontal plane and occlusal plane angles in the orthopantomograms among the human head phantoms. This suggests that a specific occlusal plane angle can be achieved by adjusting the positioning to an optimal Frankfort plane angle. Variations in the linear approximation equation results among the phantoms are likely influenced by differences in their skeletal structures.[18]

The maximum difference in the Frankfort plane angles calculated from the orthopantomograms of the phantoms was approximately 5°. Similarly, the difference calculated from lateral view cephalograms was approximately 5°, yielding comparable results. This suggests that the relationship between the Frankfort plane and occlusal plane angles in the orthopantomograms can be estimated for each individual using cephalograms.[19]

In the phantoms, the Frankfort horizontal plane angle of the human head phantom orthopantomogram was strongly correlated with the difference in the left and right condylar plane–corpus line angles in the cephalograms, as well as with the difference between the Frankfort horizontal plane and occlusal plane angles (the F–O difference angle). This demonstrates a strong relationship between the cephalograms and orthopantomograms. As revealed by cephalometric analysis, the Frankfort plane and occlusal plane angles vary among individuals. Thus, aligning only the Frankfort plane horizontally during imaging does not ensure its correspondence with the occlusal plane, potentially compromising image quality. Therefore, we believe that analyzing cephalograms in advance and adjusting the appropriate chin positioning relative to the Frankfort plane for each patient will help minimize positioning errors during orthopantomography.[10,12]

In the clinical orthopantomograms, a moderate negative correlation was observed between the Frankfort horizontal plane and occlusal plane angles. As these images were obtained from 300 patients, we believe that individual skeletal differences, as in the phantom validation, contributed to the reduced correlation. Additionally, variation in the occlusal plane angle may be influenced by positioning errors.[20] As demonstrated using the phantom images, reviewing cephalograms in advance could help further reduce these errors. The novel method used in this study suggests that the pre-analysis of previous cephalograms as reference images for positioning may facilitate the taking of better orthopantomograms. These images would have good visibility of the roots of the maxillary and mandibular anterior teeth, reduced blur due to the proper trajectory, and lower radiation exposure than if a re-take were required, because they are taken at a positioning angle tailored to the patient's individual bone structure.[9,12]

The angle between the occlusal and Frankfort planes, as estimated using the approximation formula in this study, closely matched that of Phantom #4. Because human head phantoms of unknown ancestry were used in this study, the findings may contribute to assumptions about racial differences.[21] In future, the methods used in this study may be useful in developing a system that can determine the optimal Frankfort angle by performing template and deformation matching between individual patients and phantom cephalograms.

A limitation of this study is that image quality could not be directly evaluated. However, in previous studies, we used a different approach along with phantoms to assess the impact of positioning errors on image quality. The results of this research, along with the data obtained in the current study, may allow us to determine a more optimal occlusal plane angle.[8,22] Furthermore, since this study relied solely on cephalograms, incorporating computed tomography, magnetic resonance imaging scans, and patient medical records into future research could enhance pre-evaluation accuracy and help minimize positioning errors.[23,24]

Conclusion

This study examined the relationship between orthopantomograms and cephalograms to minimize positioning errors and enhance the accuracy of orthopantomography, using cephalograms for reference. The difference between the Frankfort and occlusal plane angles in cephalograms was strongly correlated with the occlusal plane angle in the orthopantomograms. This study has demonstrated numerically that the occlusal plane angle, an indicator of appropriate orthopantomograms, is related to the individual patient' s skeleton. The results of this study may help create guidelines for evaluation indicators for individual patients and clarify education methods using numerical indicators.

Ethics approval and consent to participate

Ethical approval for this study was obtained from Okayama University Hospital Institutinal Review Board (Approval number: 2210-027).

Written informed consent was obtained for anonymised patient information to be published in this article.

Availability of data

The data used to support the findings of this study are available from the corresponding authors upon reasonable request.

Author contributions

Taxonomy) roles: S. I., Y. T.
Conceptualization: S.I.
Data curation: S.I.
Formal analysis: Y. T.
Funding acquisition: Y. T.
Investigation: S.I.
Methodology: S.I, Y.T.
Project administration: S.I., Y. T.
Resources: S.I., Y.T.
Software: S.I., Y. T. Supervision: M. H., Y. T.
Validation: S. I., Y. T.
Visualization: Y. T.
Writing – original draft: S.I., Y. T.
Writing – review and editing: S. I., M. H., Y. T.

Generative AI use

None. This study was not used Generative AI.

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Conflict of interest statement

None.

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References

1. Castillo C, Steffens T, Sim L, Caffery L. The effect of clinical information on radiology reporting: a systematic review. *J Med Radiat Sci*. 2021;68(1):60–74. https://doi.org/10.1002/jmrs.424.
2. Decoster R, Ryan ML, Toomey R. The difference in image quality assessment between radiographers and radiologists and its relationship with diagnostic accuracy. *Radiography*. 2025;31(1):89–96. https://doi.org/10.1016/j.radi.2024.10.021.
3. França RP, Monteiro ACB, Arthur R, Iano Y. An overview of the impact of PACS as health informatics and technology e-health in healthcare management. In: *Cognitive systems and signal processing in image processing*. 2022:101–128. https://doi.org/10.1016/B978-0-12-824410-4.00007-6.
4. Koike M, Nose H, Takagi S, Akimoto A, Kaji T. A skyline-view imaging technique for axial projection of the patella: a clinical study. *Radiol Phys Technol*. 2015;8(2):174–177. https://doi.org/10.1007/s12194-014-0305-y.
5. Kumar A, Kim J, Cai W, Fulham M, Feng D. Content-based medical image retrieval: a survey of applications to multidimensional and multimodality data. *J Digit Imag*. 2013;26(6):1025–1039. https://doi.org/10.1007/s10278-013-9619-2.
6. Tanabe Y, Ishida T, Eto H, Sera T, Emoto Y. Optimizing planning CT using past CT images for prostate cancer volumetric modulated arc therapy. *Med Dosim*. 2020;45(3):213–218. https://doi.org/10.1016/j.meddos.2019.12.008.
7. Różyło-Kalinowska I. Panoramic radiography in dentistry. *Clin Dent Rev*. 2021;5(1):26. https://www.researchgate.net/publication/356842705_Panoramic_radiography_in_dentistry.
8. Imajo S, Tanabe Y, Nakamura N, Honda M, Kuroda M. Evaluating the index of panoramic X-ray image quality using K-means clustering method. *Egypt J Radiol Nucl Med*. 2024;55:4. https://ejrnm.springeropen.com/articles/10.1186/s43055-023-01176-w.
9. Pawar RR, Makdissi J. The role of focal block (trough/plane) in panoramic radiography: why do some structures appear blurred out on these images? *Radiography*. 2014;20(2):167–170. https://www.researchgate.net/publication/259520491_The_role_of_focal_block_troughplane_in_panoramic_radiography_Why_do_some_structures_appear_blurred_out_on_these_images.
10. Subbulakshmi AC, Mohan N, Thiruneervannan R, Naveen S, Gokulraj S. Positioning errors in digital panoramic radiographs: a study. *J Orofac Sci*. 2016;8(1):22–26. https://www.researchgate.net/publication/302062107_Positioning_errors_in_digital_panoramic_radiographs_A_study.
11. Loughlin A, Drage N, Greenall C, Farnell DJJ. An investigation in to the impact of acquisition location on error type and rate when undertaking panoramic radiography. *Radiography*. 2017;23(4):305–309. https://doi.org/10.1016/j.radi.2017.07.004.
12. Dhillon M, Raju SM, Verma S, Tomar D, Mohan RS, Lakhanpal M, et al. Positioning errors and quality assessment in panoramic radiography. *Imag Sci Dent*. 2012;42(4):207–212. https://doi.org/10.5624/isd.2012.42.4.207.
13. Sunilkumar AP, Parida BK, You W. Recent advances in dental panoramic X-ray synthesis and its clinical applications. *IEEE Access*; 2024. https://www.researchgate.net/publication/381982727_Recent_Advances_in_Dental_Panoramic_X-ray_Synthesis_and_its_Clinical_Applications.
14. Almojadah T, Alnowimi M, Banoqitah E, Alkhateeb SM. Digital radiography retake rates and effect on patient dose. *Radiat Phys Chem*. 2023;210(3):110991. https://www.researchgate.net/publication/371043496_Digital_radiography_retake_rates_and_effect_on_patient_dose.
15. Hung K, Hui L, Yeung AWK, Scarfe WC, Bornstein MM. Image retake rates of cone beam computed tomography in a dental institution. *Clin Oral Invest*. 2020;24(12):4501–4510. https://doi.org/10.1007/s00784-020-03315-3.
16. İzgi E, Pekiner FN. Comparative evaluation of conventional and OnyxCeph™ dental software measurements on cephalometric radiography. *Turkish J Orthod*. 2019;32(2):87–95. https://doi.org/10.5152/turkjorthod.2019.18038.
17. Akcam MO, Altiok T, Ozdiler E. Panoramic radiographs: a tool for investigating skeletal pattern. *Am J Orthod Dentofacial Orthop*. 2003;123(3):175–181. https://doi.org/10.1067/mod.2003.3.
18. Nejad AM, Jamilian A, Meibodi SE, Hafezi L, Khosravi S, Cappabianca S, et al. Reliability of panoramic radiographs to determine Gonial and Frankfurt Mandibular Horizontal Angles in different skeletal patterns. *Stomatol Edu J*. 2016;3(1–2):81–85. https://www.researchgate.net/publication/334404794_Reliability_of_panoramic_radiographs_to_determine_Gonial_and_Frankfurt_Mandibular_Horizontal_Angles_in_different_skeletal_patterns.
19. Araki M, Kiyosaki T, Sato M, Kohinata K, Matsumoto K, Honda K. Comparative analysis of the gonial angle on lateral cephalometric radiographs and panoramic radiographs. *J Oral Sci*. 2015;57(4):373–378. https://doi.org/10.2334/josnusd.57.373.
20. Nikneshan S, Sharafi M, Emadi N. Evaluation of the accuracy of linear and angular measurements on panoramic radiographs taken at different

positions. *Imag Sci Dent*. 2013;43(3):191–196. https://doi.org/10.5624/isd.2013.43.3.191.
21. Milošević D, Vodanović M, Galić I, Subašić M. Estimating biological gender from panoramic dental x-ray images. In: *2019 11th international symposium on image and signal processing and analysis (ISPA)*. IEEE; 2019:105–110. https://doi.org/10.1109/ISPA.2019.8868804.
22. Imajo S, Tanabe Y, Nakamura N, Honda M, Kuroda M. Objective evaluation method using multiple image analyses for panoramic radiography improvement. *Pol J Med Phys Eng*. 2023;29(2):85–91. https://doi.org/10.2478/pjmpe-2023-0010.
23. Rabba JA, Suhaimi FM, Jafri MM, Jaafar HA, Osman ND. Automated measurement for image distortion analysis in 2D panoramic imaging of dental CBCT system: a phantom study. *Radiography*. 2023;29(3):533–538. https://doi.org/10.1016/j.radi.2023.02.028.
24. Tanaka Y, Nakamoto A, Nishioka K, Kunii Y, Takahashi S, Tanabe Y. Evaluation of prostate movement trend using individual patient anatomical information for prostate volumetric modulated arc therapy. *Med Dosim*. 2025;50:270–275. https://doi.org/10.1016/j.meddos.2025.03.002.