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Original Article

Evaluation of the Mesiodistal and Faciolingual Inclination Angles of Upper Anterior Teeth Using a 3 D Panoramic Radiograph

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The purpose of the present study was to investigate the measurement error occurring in measurements of the mesiodistal and faciolingual inclinations of upper anterior teeth made on images obtained using 3 D panoramic radiograph equipment in comparison with measurements obtained using cone-beam computed tomography（CBCT）.

Radiographic images of a simulated or phantom human head were made using 3 D panoramic radiograph equipment and with CBCT. Mesiodistal and faciolingual inclination angles of upper anterior teeth were measured. In the 3 D panoramic radiographs, the faciolingual inclination angle of the tooth root axis was also measured. Measurement errors, i. e., differences between the 3 D panoramic radiographic measurements and the CBCT measurements, were determined. Differences between the measurement values using the two modalities were analyzed statistically.

Errors in the measurement of the mesiodistal inclination angle were small for all teeth. Significant differences were not found between the values for the 3 D panoramic radiograph and CBCT images. Concerning tooth faciolingual inclination angle, however, measurement errors were large and the values were significantly smaller than those determined by CBCT. When evaluating tooth root axes in the 3 D panoramic radiograph, however, measurement errors for the faciolingual angle were small for all teeth.

Measurement errors of the mesiodistal inclination angle were small on the axial inclination of upper anterior teeth evaluated using the 3 D panoramic radiograph. Measurement errors for the faciolingual inclination angle were large but were reduced by using the inclination angle of the tooth root axis.

Key words: panoramic radiograph, tooth inclination, mesiodistal inclination angle, faciolingual inclination angle

INTRODUCTION

In orthodontic practice, determining the inclination of tooth axes and the positional relationships between adjacent teeth is an important element of diagnosis, treatment planning, and the alignment of teeth. Establishing appropriate inclinations of tooth axes with near-parallel roots has been understood to be critical for maintaining a stable orthodontic result[1, 2]. Orthodontically closed extraction sites in premolar extraction cases are prone to reopen unless adjacent teeth are parallel[1)]. A method for quantitatively determining the inclination angle of the tooth axis is needed.

Although the mean values of mesiodistal and labiolingual inclinations have been determined in non-orthodontic patients with normal occlusion by measuring the tooth crowns on study models[3, 4], it has been shown to be somewhat difficult to identify the tooth axis because of variations in crown morphologies[5)].

Although conventional panoramic radiographs have routinely been used for the evaluation of the mesiodistal angulations of teeth[6–16)], such radiographs present several disadvantages, including non-constant magnification, image distortion, and a narrow image layer[17)]. In addition, there can be large discrepancies between the optimal and the actual beam directions, especially in the premolar area and the panoramic radiograph provides a poor representation of true mesiodistal root angulations[8, 18)].

Evaluating the faciolingual inclination of the tooth axis is important for positioning the tooth root within the alveolar bone. Lateral cephalometric radiographs have been used to evaluate the faciolingual inclination of the central incisor but cannot display the other teeth.

In recent years, cone-beam computed tomography（CBCT）has been widely used in dental fields. CBCT provides an accurate alternative to conventional panoramic radiographs, which may exhibit deviations in both mesial and distal directions for all teeth[9, 10]. A new method for measuring the angle of tooth axis inclination using CBCT has been reported[19)]. Although repeated examinations of the mesiodistal inclination of tooth axis are necessary for repositioning orthodontic brackets or placing bends in

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archwires during orthodontic treatment, repeated CT examinations are not recommended because of radiation exposure. As a result, the panoramic radiograph has been used for evaluating tooth axis inclination despite some disadvantages[20].

Three-dimensional (3 D) panoramic images can be obtained using a new panoramic radiograph with tomosynthesis and 3 D mapping technique[21]. The new panoramic radiograph is suitable for quantitative measurements because it provides a larger image layer than the conventional panoramic radiograph with no image distortion. Measurement errors with the new panoramic radiograph have been reported to be small and head positioning has little influence on the measurements[22]. If mesiodistal tooth angulation can be measured in the same way as with CBCT, the technique will be useful for the diagnosis and treatment of orthodontic patients.

The purpose of the present study was to investigate measurement error of the mesiodistal and faciolingual inclinations of maxillary anterior teeth using 3 D panoramic radiograph equipment in comparison with measurements obtained using CBCT.

MATERIALS AND METHODS

1. Subject

A simulated human head (Dental X-ray head phantom, Kyoto Kagaku, Co. Ltd., Kyoto, Japan) was used as the subject (Fig. 1). The subject is composed of soft tissue and hard tissue equivalent media with X-ray absorption rates equivalent to those of the human body.

2. Recording methods

Images of the phantom were recorded using 3 D panoramic radiograph equipment (QRmaster-P, Telesystems, Co., Ltd., Osaka, Japan) (Fig. 2). A 2.0mm thick occlusal bite was placed in the anterior teeth of the phantom. The rolling radii of the X-ray source and the detector were 504mm and 155mm, respectively. X-ray tube voltage and current were 80kVp and 4 mA, respectively. The phantom was positioned with the Frankfort plane parallel to the floor, the mid-sagittal plane perpendicular to the floor, and the maxillary right canine cusp tip aligned with the canine light guide. Tomosynthesis and 3 D mapping methods were used for data acquisition. Raw tomographic data consisted of multiple image stripes acquired with a detector. The tomosynthesis method was used for reconstruction of the tomographic slices at any desired plane. From these data, the layer that showed the highest frequency pixel was extracted with the edge analysis method and the 3 D location of the pixel was determined[21].

Fig. 1 Image of the simulated human head.

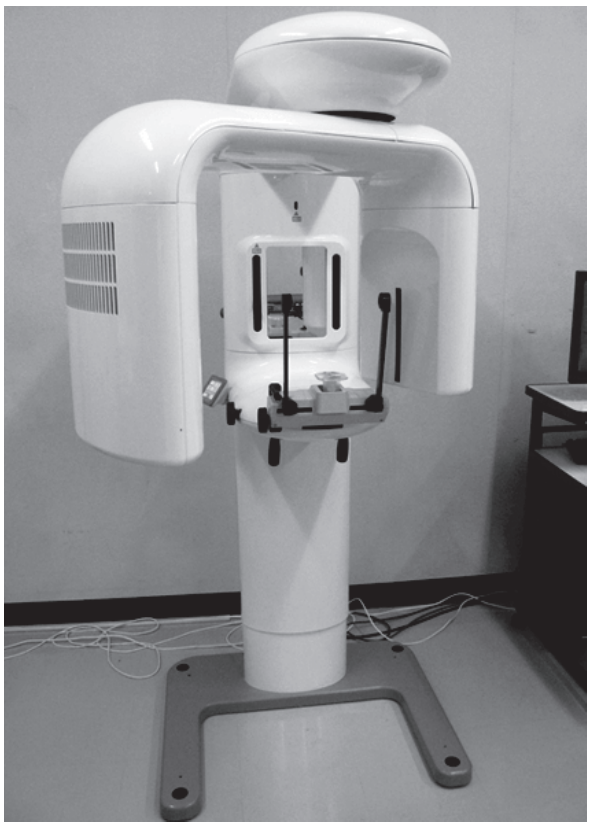

Fig. 2 3 D panoramic radiographic equipment (QRmaster-P, Telesytems, Co., Ltd., Osaka, Japan) used in this study.

CBCT images of the phantom were also recorded using a CBCT scanner (Alphard-3030, Asahi Roentgen Industry, Kyoto, Japan). The X-ray tube voltage and current were 80kVp and 5.0mA, respectively. Slice thickness was 0.3 mm with a one pixel size of 0.3mm.

3. Data analyses

The definitions of several points on the anterior teeth are given in Table 1 and Fig. 3. They were determined for the right and left sides in the upper jaw. Reference planes for evaluating the inclination angle of the tooth axis are shown in Fig. 4. Angular variable measurements are shown in Figs. 5-7.

Panoramic radiograph image data were transferred to a

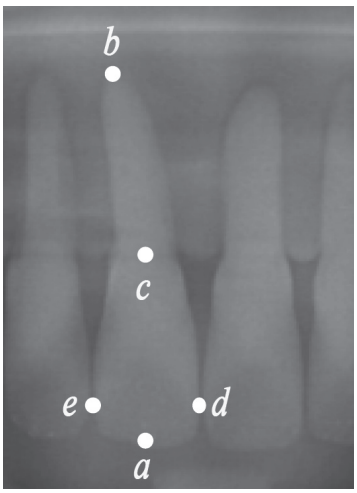

Fig. 3 The definitions of measurement points for the upper central incisor (*a*, central incisor edge; *b*, central incisor root apex; *c*, central incisor cervical point; *d*, central incisor mesial point; *e*, central incisor distal point)

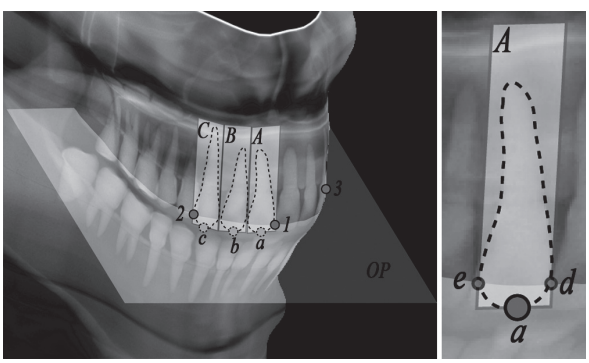

Fig. 4 Reference planes for evaluating the inclination angle of the tooth axis: *1*, the midpoint between right and left central incisor mesial points; *2*, left canine distal point; *3*, right canine distal point; *a*, central incisor edge; *b*, lateral incisor edge; *c*, canine cusp tip; *d*, central incisor mesial point; *e*, central incisor distal point; *OP*, Occlusal plane, a plane through point *1*, point *2*, and point *3*; *A*, Central incisor plane, a plane through point *a*, which is perpendicular to the occlusal plane and parallel to the straight line between point *d* and point *e*; *B* (Lateral incisor plane) and *C* (Canine plane) are defined as the central incisor plane.

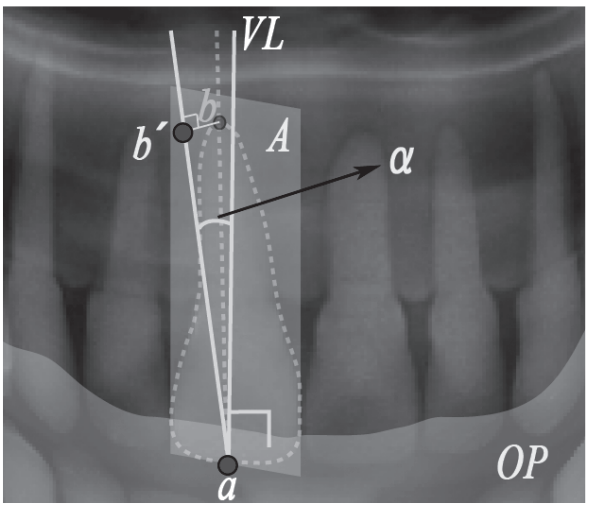

Fig. 5 Mesiodistal angle: *a*, central incisor edge; *b*, central incisor root apex; *b'*, central incisor root apex projected to the central incisor plane; *OP*, Occlusal plane; *A*, Central incisor plane; *VL*, Vertical line, the straight line through the point a perpendicular to the occlusal plane; α, Central Incisor Mesiodistal Angle (*CIMA*), angle between the central incisor axis projected to the central incisor plane and the vertical line (Lateral Incisor Mesiodistal Angle (*LIMA*) and Canine Mesiodistal Angle (*CMA*) are defined as the central incisor.)

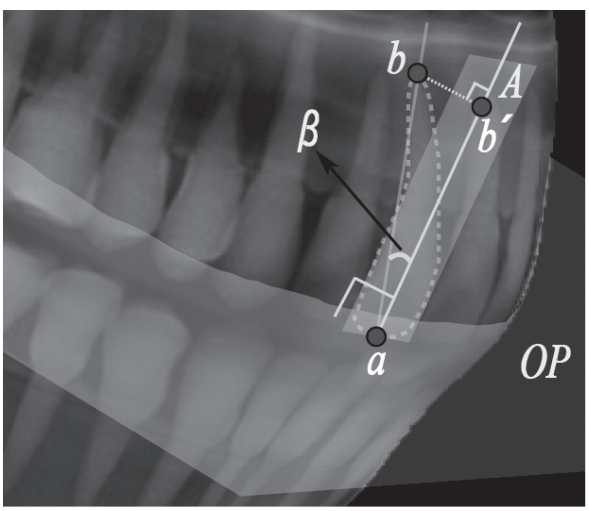

Fig. 6 Faciolingual angle: *a*, central incisor edge; *b*, central incisor root apex; *b'*, central incisor root apex projected to the central incisor plane; *OP*, Occlusal plane; *A*, Central incisor plane; β, Central Incisor Faciolingual Angle (*CIFA*), angle between the central incisor axis projected to the central incisor plane and the central incisor axis (Lateral Incisor Faciolingual Angle (*LIFA*) and Canine Faciolingual Angle (*CFA*) are defined as the central incisor.)

personal computer (Endeavor MR6900, Seiko Epson Corporation, Suwa, Japan). Several anatomic landmarks were determined visually and the variables were measured using the software for QRmaster-P (Telesystems, Co., Ltd., Osaka, Japan). All variables were measured ten times by one author with a minimum interval of one day between measurements. The mean of the ten values was then regarded as the measurement value determined from the 3 D panoramic radiograph.

In addition, only two variables (mesiodistal and faciolingual angles of tooth axis) were determined on the CBCT image. The CBCT images were transferred to a personal computer (HP Z210 Workstation, Hewlett-Packard Company, CA, USA) and measured using an imaging software package (Analyze™, Mayo Clinic and Foundation, Rochester, MN, USA). The mean of the ten values was then re-

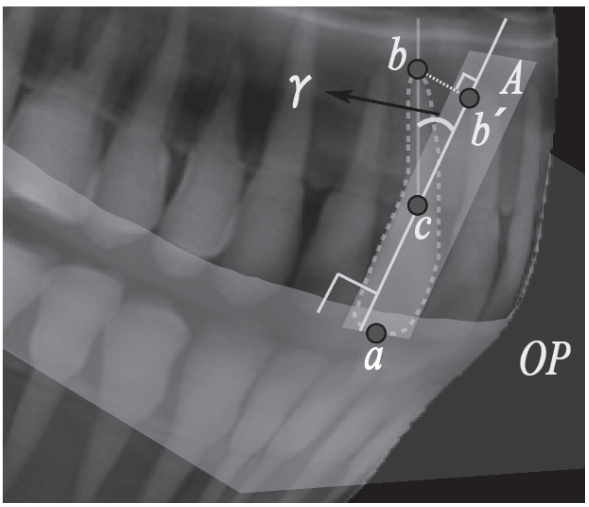

Fig. 7 Faciolingual angle of tooth root axis: *a*, central incisor edge; *b*, central incisor root apex; b, central incisor root apex projected to the central incisor plane; *c*, central incisor cervical point; *OP*, Occlusal plane; *A*, Central incisor plane; γ, Central Incisor Root Faciolingual Angle (*CIRFA*), angle between the central incisor root axis projected to the central incisor plane and the central incisor root axis (Lateral Incisor Root Faciolingual Angle (*LIRFA*) and Canine Root Faciolingual Angle (*CRFA*) are defined as the central incisor.)

garded as the measurement value determined by the CBCT.

Measurement error was then defined as an absolute value of the difference between the 3 D panorama value and the CBCT value. The faciolingual angle of the tooth root axis as determined by the 3 D panoramic radiograph was compared with the faciolingual angle determined by the CBCT.

4. Statistical analyses

Tests for significant differences between the values determined from the 3 D panoramic radiograph and the CBCT images were conducted using the Wilcoxon signed-rank test. The level of significance $p < 0.05$ was chosen for all tests. Analyses were performed using statistical software (SPSS14. 0, IBM, NY, USA).

RESULTS

Measurement values for 3 D panoramic radiograph and CBCT images, measurement errors, and significant differences for each angle are shown in Tables 2–4. For the mesiodistal inclination angle of the tooth axis, measurement error, defined as the difference between the panoramic radiograph and the CBCT measures, was between 0. 27° and 1. 48°. Measurement errors were small for all teeth. Significant differences were not found between the 3 D panoramic radiograph values and the CBCT values.

Concerning the faciolingual inclination angle of tooth axis, the range of the measurement error was between 4. 80° and 10. 71°. Measurement errors were large for all teeth. The angles for the 3 D panoramic radiographs were significantly smaller than those for the CBCT ($p < 0.05$).

Table 1. The definitions of measurement points

Measurement points	Definitions
Central incisor edge	The incisal edge midpoint of the central incisor
Central incisor cervicaI point	The cervical midpoint of the central incisor
Central incisor root apex	The root apex of the central incisor
Central incisor mesial point	The mesial widest contour of the central incisor
Central incisor distal point	The distal widest contour of the central incisor
Lateral incisor edge	The incisal edge midpoint of the lateral incisor
Lateral incisor cervical point	The cervical midpoint of the lateral incisor
Lateral incisor root apex	The root apex of the lateral incisor
Lateral incisor mesial point	The mesial widest contour of the lateral incisor
Lateral incisor distal point	The distal widest contour of the lateral incisor
Canine cusp tip	The cusp tip of the canine
Canine cervical point	The cervical midpoint of the canine
Canine root apex	The root apex of the canine
Canine cusp mesial point	The mesial widest contour of the canine
Canine cusp distal point	The distal widest contour of the canine

Table 2. The mesiodistal inclination angle of tooth axis

	3 D panoramic radiograph		CBCT		Errors(°)	Significant difference
	Mean	SD	Mean	SD		
Upper right *CIMA*	6. 56	1. 68	6. 29	1. 55	0. 27	NS
Upper right *LIMA*	4. 82	1. 61	4. 26	0. 65	0. 56	NS
Upper right *CMA*	3. 50	2. 70	3. 18	1. 16	0. 48	NS
Upper left *CIMA*	1. 09	0. 60	0. 73	0. 76	0. 36	NS
Upper left *LIMA*	1. 39	0. 60	0. 90	1. 07	0. 49	NS
Upper left *CMA*	5. 26	1. 90	4. 04	0. 60	1. 48	NS

(*CIMA*, Central Incisor Mesiodistal Angle; *LIMA*, Lateral Incisor Mesiodistal Angle; *CMA*, Canine Mesiodistal Angle; Errors, measurement errors; NS, no significant difference; Mean, mean value; SD, standard variation value)

Table 3. The faciolingual inclination angle of tooth axis

	3 D panoramic radiograph		CBCT		Errors(°)	Significant difference
	Mean	SD	Mean	SD		
Upper right *CIFA*	12. 78	0. 46	19. 56	0. 28	6. 78	*
Upper right *LIFA*	10. 12	0. 16	20. 83	0. 67	10. 71	*
Upper right *CFA*	6. 84	0. 71	13. 35	0. 85	6. 51	*
Upper left *CIFA*	12. 94	0. 18	19. 88	0. 34	6. 93	*
Upper left *LIFA*	10. 65	0. 17	17. 38	0. 65	6. 73	*
Upper left *CFA*	7. 38	0. 39	12. 18	0. 76	4. 80	*

(*CIFA*, Central Incisor Faciolingual Angle; *LIFA*, Lateral Incisor Faciolingual Angle; *CFA*, Canine Faciolingual Angle; Errors, measurement errors; * $P < 0.05$; Mean, mean value; SD, standard variation value)

Concerning the faciolingual inclination angle of tooth root axis, the range of the measurement error was between 0. 25° and 2. 04°. Measurement errors were small for all teeth. Significant differences were not found between the values for the 3 D panoramic radiographs and the CBCT s of upper left lateral incisor, upper right canine, or upper left canine. The values for the panoramic radiographs were significantly different from those for the CBCT in the upper right central incisor, upper left central incisor, and upper right lateral incisor ($p < 0.05$).

Table 4. The faciolingual inclination angle of tooth root axis

	3 D panoramic radiograph		Errors(°)	Significant difference
	Mean	SD		
Upper right *CIRFA*	20. 57	0. 17	1. 01	*
Upper right *LIRFA*	18. 79	0. 72	2. 04	*
Upper right *CRFA*	13. 82	0. 46	0. 47	NS
Upper left *CIRFA*	21. 43	0. 06	1. 55	*
Upper left *LIRFA*	17. 13	0. 85	0. 25	NS
Upper left *CRFA*	11. 29	0. 89	0. 89	NS

(*CIRFA*, Central Incisor Root Faciolingual Angle; *LIRFA*, Lateral Incisor Root Faciolingual Angle; *CRFA*, Canine Root Faciolingual Angle; Errors, measurement errors; * $P < 0.05$; NS, no significant difference; Mean, mean value; SD, standerd variation value)

DISCUSSION

The plane used in the present study is perpendicular to the occlusal plane and parallel to the mesiodistal line of the labial surface of each tooth. This plane is based on the plane used in a previous study which developed the Straight Wire Appliance (SWA)[4]. Accordingly, the mesiodistal inclination angle used in the present study is defined as the mesiodistal tip (crown angulation) of the SWA[4]. Several studies have used a similar plane to evaluate the mesiodistal angle using study models[23]or CBCT[19].

For the mesiodistal inclination angle of the tooth axis, measurement errors, defined as the difference between the new 3 D panoramic radiographic and the CBCT measurements, were small in the present study. Significant differences between the values for the 3 D panoramic radiograph and those for the CBCT were not found. CT is recognized as a modality which can be used to determine quantitative measurements with acceptable accuracy[24–26]. The present results indicate that measurements of the mesiodistal angle of upper anterior teeth using the 3 D panoramic radiograph are as accurate as those from CBCT scans. It has been reported that acceptable reproducibility has been observed for the vertical variables but that horizontal variables are clearly less reliable in conventional panoramic radiographs[27] with images of the canine and premolar teeth of both arches expressing the largest amount of distortion in the angular relationship of the long axis of the teeth[28]. Many studies have examined mesiodistal tooth angulation using the panoramic radiograph clinically[8–10, 13, 14, 29]. These reports have documented that measurement of mesiodistal tooth angulation is not accurate, particularly in the canine and premolar regions[14]. Assessment of mesiodistal tooth angulation using panoramic radiography should be approached with caution and reinforced with a thorough clinical examination of the dentition[10]. Therefore, mesiodistal tooth angulation of the canine, which is an evaluation endpoint used by the American Board of Orthodontics[20], has been omitted because of the distortion that frequently occurs within panoramic radiographs (http://www.americanboardortho.com/professionals / downloads / Grading % 20 System % 20 Casts-Radiographs. pdf). However, the results of the present study suggest that measurements obtained using the new 3 D panoramic radiography are likely to be accurate for the mesiodistal angle of upper anterior teeth. The accuracy could be explained by little image distortion of the new 3 D panoramic radiographic equipment. As a result, the new 3 D panoramic radiographic equipment is seen as a useful modality, which can document tooth inclination with minimum radiation exposure as shown in previous CBCT studies[19, 30, 31].

Concerning the faciolingual inclination angle of the tooth axis, in the present study measurement errors were large and the values were significantly smaller than those determined by CBCT. This could be explained by the 3 D mapping method used in the current panoramic radiograph equipment. In the 3 D mapping algorithm, the border between the upper and lower teeth is designed so that the image will be smooth. As a result, the image of the upper incisor edge may be influenced by the image of the lower incisor edge. To overcome the disadvantage of the algorithm, the upper and lower images could be evaluated separately. When evaluating the tooth root axis in the 3 D panoramic radiograph, the measurement error for the faciolingual angle was small for all teeth. The image of the upper tooth root may not be influenced by the lower tooth. The results suggest that evaluating the inclination of tooth root axis in the new 3 D panoramic radiograph can be useful for the analysis of the faciolingual inclination. Previously, a disadvantage of the conventional panoramic radiograph is that we cannot analyze the faciolingual characteristics[17]. However, the results in the present study suggest that the new 3 D panoramic radiograph can be applied to the analysis of faciolingual morphology.

Significant differences between the values for the 3 D panoramic radiograph and CBCT in upper left lateral incisor, upper right canine, and upper left canine were not found. The values as determined from the panoramic radiographs were significantly different from those for the CBCT for the upper right central incisor, upper left central incisor, and upper right lateral incisor. These results suggest that evaluation of the faciolingual inclination of canines may be more accurate than similar evaluations of incisors.

CONCLUSIONS

Measurement errors of the mesiodistal inclination angle were small on the axial inclination of upper anterior teeth evaluated by the 3 D panoramic radiograph. The measurement errors for faciolingual inclination angles were large but were substantially reduced with use of the inclination angle of tooth root axis.

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三次元パノラマX線装置による上顎前歯歯軸傾斜の評価

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本研究の目的は，トモシンセシス法を応用した三次元パノラマX線装置と歯科用コーンビームCT装置（CBCT）で撮影した頭部人工骨ファントムの画像を用いて，上顎前歯の近遠心的傾斜角度と唇舌的傾斜角度について，両装置で得られた値を比較して三次元パノラマX線画像の誤差を調べることである．

人体と同等のX線吸収率をもった等価材で構成された人工骨ファントムを被写体とし，画像データの記録は，三次元パノラマX線装置とCBCTを用いて行った．それぞれの画像を用いて，上顎前歯の近遠心的傾斜角度と唇舌的傾斜角度を測定した．三次元パノラマX線画像上では，歯根の唇舌的傾斜角度も測定した．三次元パノラマX線画像による計測値からCBCT画像による計測値を減じた値の絶対値を誤差として求めた．三次元パノラマX線画像の計測値とCBCT画像の計測値との間に有意の差があるかどうかを統計学的に検討した．

近遠心的傾斜角度についての誤差は小さい値を示した．いずれの歯においても，CBCT画像との間に有意の差は認められなかった．唇舌的傾斜角度については，誤差は大きい値を示し，いずれの歯においても，CBCT画像による計測値より有意に小さい値を示した．三次元パノラマX線画像による歯根唇舌的傾斜角度とCBCT画像による唇舌的傾斜角度と比較した場合の誤差について，誤差は小さい値を示した．

以上の結果より，近遠心的傾斜角度の誤差は中切歯，側切歯，犬歯のいずれの歯においても小さいこと，唇舌的傾斜角度の誤差は中切歯，側切歯，犬歯のいずれの歯においても大きいが，歯根の傾斜角度を調べることによって誤差が小さくなることが明らかになった．

キーワード：パノラマX線画像，歯軸傾斜，近遠心的傾斜角度，唇舌的傾斜角度

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