Original Article

Conventional frontal radiographs compared with frontal radiographs obtained from cone beam computed tomography

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ABSTRACT

Aim: To test the hypothesis that there is no difference between measurements performed on conventional frontal radiographs (FRs) and those performed on FRs obtained from cone beam computed tomography (CBCT) scans.

Materials and Methods: This study consisted of conventional FRs and CBCT-constructed FRs obtained from 30 young adult patients. Twenty-three landmarks were identified on both types of cephalometric radiographs. Twenty-one widely used cephalometric variables (14 linear distances, 4 angles, and 3 ratios) were calculated. Paired *t*-tests were performed to compare the means of corresponding measurements on two cephalometric radiographs of the same patient.

Results: Reproducibility of measurements ranged from 0.85 to 0.99 for CBCT-constructed FRs, and from 0.78 to 0.96 for conventional FRs. A statistically significant difference was observed between conventional FRs and CBCT-constructed FRs for all linear measurements (eurR-eurL, loR-loL, moR-moL, zygR-zygL, lapR-lapL, mxR-mxL, maR-maL, umR-umL, lmR-lmL, agR-agL, me-ans) ($P < .05$), except for the ans-cr measurement ($P > .05$). However, no statistically significant differences were noted between conventional FRs and CBCT-constructed FRs for ratios and angular measurements ($P > .05$).

Conclusions: The hypothesis was rejected. A difference has been noted between measurements performed on conventional FRs and those performed on CBCT-constructed FRs, particularly in terms of linear measurements. (*Angle Orthod.* 2012;82:579–584.)

KEY WORDS: Frontal radiographs; Cephalometrics; Cone beam computed tomography

INTRODUCTION

Radiographs were first used by Pacini[1] in the study of facial anthropometrics in 1922. Following publications by Broadbent[2] and Hofrath[3] on cephalometric procedures in 1931, lateral and frontal conventional cephalometry became widely used for diagnosis and treatment planning of orthodontic problems and for determination of growth and treatment effects.

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Frontal radiographs (FRs) provide crucial information regarding asymmetry and width of the jaws, and thus can be extremely beneficial for treatment planning of surgical cases. However, many orthodontic treatment procedures are geared toward resolving conditions that cannot be appraised adequately with the use of conventional two-dimensional radiographs. For example, many relationships of the craniofacial complex, such as the position of the mandibular condyles in the temporomandibular fossa with respect to the occlusal scheme, and the association of airway abnormalities with craniofacial morphology, cannot be evaluated with conventional imaging approaches. Thus, multislice computed tomography (MSCT) has become a facilitating technique in dental practice in recent decades.[4] Although this method provides an obvious advantage over conventional FR in providing three-dimensional (3D) scans, it was replaced by cone beam computed tomography (CBCT), which exposes the patient to much less radiation.[5] The therapeutic benefits of CBCT include measurement of the dentition and tooth volume, planning and evaluation of temporary anchorage devices, monitoring of alveolar bone

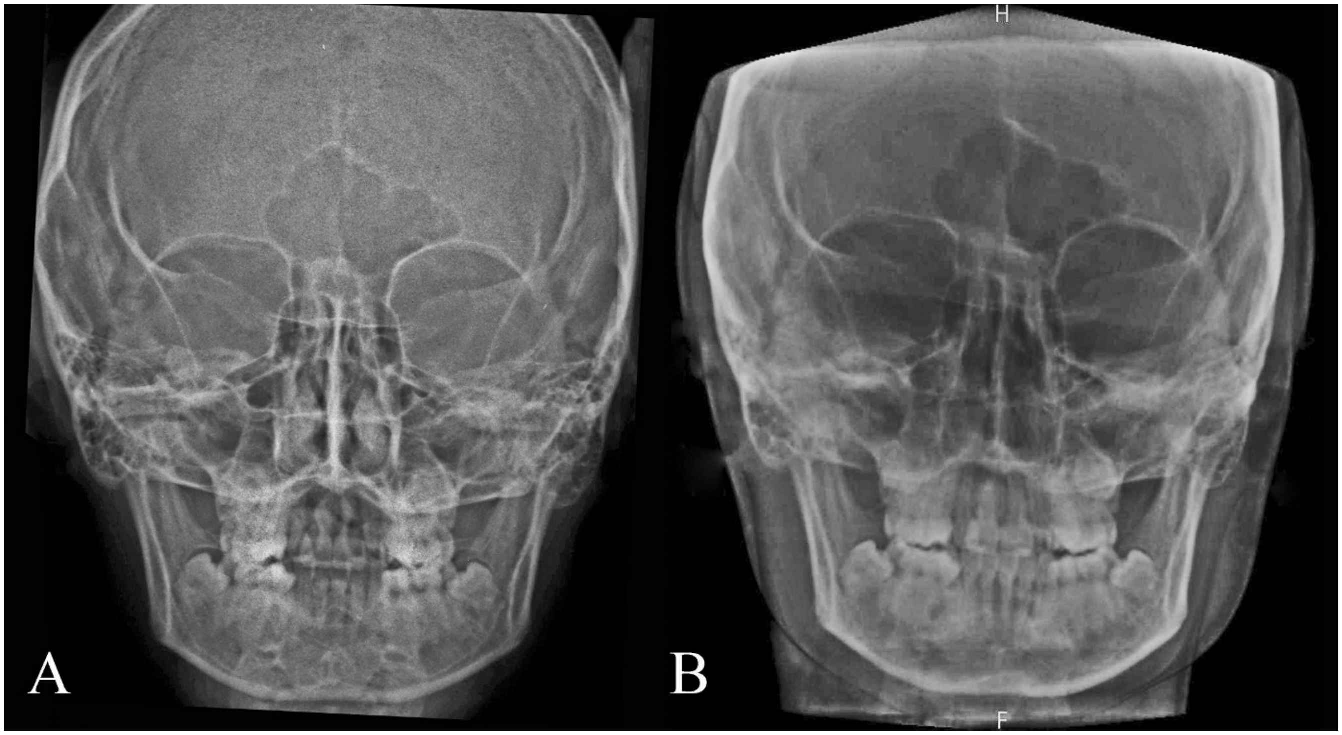

Figure 1. Frontal radiographs of the same patient. (A) Conventional radiograph. (B) CBCT-constructed radiograph.

density and height in interdisciplinary periodontal and orthodontic treatment, and 3D treatment simulation.[6–8] Most of these activities can be performed during a single imaging session with a radiation dose that is in the same range as that of conventional images, which do not provide the same quantity of data.

To our knowledge, after a bibliographic search in Medline using PubMed and the keywords ''frontal radiographs,'' ''cephalometrics,'' ''cone beam computed tomography,'' and ''human skull,'' no study has compared conventional FRs vs CBCT-constructed FRs obtained from the same patient. Most studies investigating this topic have focused on human skulls. However, images from dry skulls do not suffer from distortion caused by soft tissues, and we have to use radiographs obtained from patients with orthodontic anomalies for their treatment planning. Therefore, the aim of this study was to find out whether measurements obtained on conventional FRs are comparable with the same measurements obtained on CBCTconstructed FRs from the same patients for use in possible longitudinal researches where only two-dimensional records from the past were available.

MATERIALS AND METHODS

The sample size for the study was calculated on the basis of a significance level of .05 and a power of 80% to detect a clinically meaningful difference of 1.00 $\pm$ 1.35 mm for the moR-moL parameter. Power analysis showed that 30 patients were required. Thus, the study included the records of 30 patients (16 females and 14 males) between the ages of 18 and 23 years (mean age, 21 $\pm$ 1.1 years) who were randomly selected from the archive of the oral diagnosis and orthodontic departments at Karadeniz Technical University. Approval from the ethics committee was not required for this retrospective study. Inclusion criteria included the presence of (1) permanent upper and lower incisors; (2) the first permanent upper and lower molars; (3) a reproducible, stable occlusion; and (4) both conventional FR (Veraviewepocs, Morita, Kyoto, Japan) (Figure 1A) and CBCT scan (Kodak 9500 Cone Beam 3D System, Kodak Dental Systems, Carestream Health, Rochester, NY), which became available within a 2-month period (average, 35 days).

Radiography

Conventional FRs were taken according to the following radiographic settings: 80 kV, 10 mA, 0.2 s (Figure 1A). Patients were positioned in the cephalostat (Veraviewepocs, Morita) by fixing it between the ear rods. The ear rods were placed into external auditory canals, and the Frankfort horizontal plane was placed horizontally parallel to the floor. The central x-ray beam penetrated the patient's head in a posterior-anterior direction and bisected the transmeatal axis perpendicularly (focus film distance, 1650 mm; source to object distance, 1500 mm).

CBCT scans were performed at the following settings: field of view (FOV) $=$ 18.4 $\times$ 20.6 cm, voxel size $=$

Table 1. Cephalometric Landmarks Used in the Present Study

eurL	Euryon left	Most lateral points on the cranium parallel to the superior aspect of the orbits on the left side.
eurR	Euryon right	Most lateral points on the cranium parallel to the superior aspect of the orbits on the right side.
loL	Latero-orbitale left	The intersection of the lateral orbital contour with the innominate line on the left side.
loR	Latero-orbitale right	The intersection of the lateral orbital contour with the innominate line on the right side.
moL	Medio-orbitale left	The point on the medial orbital margin that is closest to the median plane on the left side.
moR	Medio-orbitale right	The point on the medial orbital margin that is closest to the median plane on the right side.
lapL	Lateral aperture left	The most lateral points on the nasal aperture on the left side.
lapR	Lateral aperture right	The most lateral points on the nasal aperture on the right side.
maL	Mastoid left	The lowest point of the mastoid process on the left side.
maR	Mastoid right	The lowest point of the mastoid process on the right side.
agL	Antegonion left	The antegonial notch at the lateral inferior margin of the antegonial protuberances on the left side.
agR	Antegonion right	The antegonial notch at the lateral inferior margin of the antegonial protuberances on the right side.
mxL	Maxillare left	At the jugal process the intersection of the outline of the maxillary tuberosity and the zygomatic buttress on the left side.
mxR	Maxillare right	At the jugal process the intersection of the outline of the maxillary tuberosity and the zygomatic buttress on the right side.
umL	Upper first molar distal left	Most lateral points on the buccal surface of the permanent maxillary first molar crown parallel to the occlusal plane on the left side.
umR	Upper first molar distal right	Most lateral points on the buccal surface of the permanent maxillary first molar crown parallel to the occlusal plane on the right side.
lmL	Lower first molar distal left	Most lateral points on the buccal surface of the mandibular permanent first molar crowns parallel to the occlusal plane on the left side.
lmR	Lower first molar distal right	Most lateral points on the buccal surface of the mandibular permanent first molar crowns parallel to the occlusal plane on the right side.
iif	Incisor inferior frontale	The midpoint between the mandibular central incisors at the level of the incisal edges.
isf	Incisor superior frontale	The midpoint between the maxillary central incisors at the level of the incisal edges.
ans	Anterior nasal spine	The tip of the anterior nasal spine.
cr	Crista gali	Most superior point at its intersection with the sphenoid.
me	Menton	Most inferior point of the symphysis of the mandible, as seen on the lateral jaw projection.

0.3 mm, scan time = 10.8 s, 90 kV, 10 mA. Each person was oriented through adjustment of the chin support until the Frankfort horizontal plane coincided with the horizontal laser reference. A cephalometric FR was constructed from the CBCT scan by frontal radiographic projection of the entire volume (Figure 1B).

Cephalometry

Upon cephalometric analysis, 23 conventional hard tissue cephalometric landmarks were identified (Table 1 and Figure 2). Twenty-one widely used cephalometric variables (14 linear distances, 4 angles, and 3 ratios) were calculated (Table 2). Conventional FRs were traced with a 0.3-mm 2H pencil on matte acetate paper and were measured with a digital caliper and protractor. CBCT-constructed FRs were imported into Kodak software (Kodak Dental Imaging software, version 6.11.7.0-B, Carestream Health). Relevant landmarks were identified, and measurements were calculated with the use of software. All cephalometric procedures were performed by a single examiner (MN) in random order.

Statistical Analysis

Parametric tests were used to analyze the data; the Kolmogorov-Smirnov test showed a normal distribution. Paired *t*-tests were used to compare the means of corresponding measurements on the two cephalometric radiographs (conventional and CBCT-constructed FRs). For each variable, mean and standard deviation values were calculated. To determine the method error, all tracings and measurements were repeated 2 weeks after the first examination, and intraobserver reliability was calculated by means of the Pearson correlation coefficient for first and second measurements. All statistical analyses were performed using the Statistical Package for the Social Sciences (SPSS) software package (SPSS for Windows 98, version 10.0, SPSS Inc, Chicago, Ill). $P < .05$ was considered statistically significant.

RESULTS

Intraobserver reliability for conventional and CBCT-constructed FRs was acceptable. Corresponding intraobserver correlation coefficients for both radiographs were greater than $r^2 = 0.78$. The correlation coefficient between first and second measurements ranged from 0.78 to 0.96 (average, 0.87) for conventional FRs and from 0.85 to 0.99 (average, 0.93) for CBCT-constructed FRs (Table 3).

Table 4 shows mean and standard deviation values and the results of paired *t*-tests comparing measurements obtained from conventional and CBCT-constructed

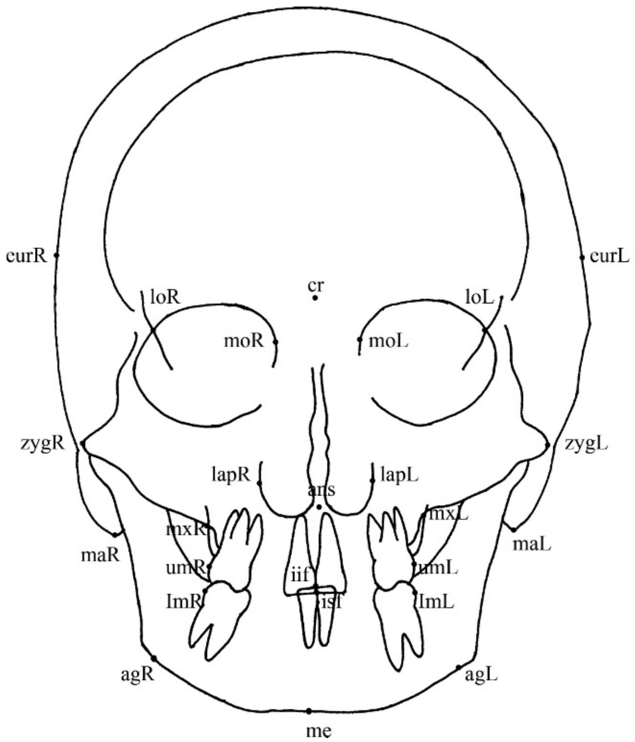

Figure 2. Landmarks used in the present study.

FRs. Statistical analysis showed a statistically significant difference between the two radiographic methods for all linear measurements ($P < .01$), except for the ans-cr parameter, which was a vertical linear measurement ($P > .05$). On the other hand, no statistically significant differences were noted for ratio (R me-ag, R mx-ans, R cr-lo) and angular measurements (me-agR-cr, me-agL-cr, agL-agR-loR).

DISCUSSION

In this study, 21 widely used cephalometric measurements on conventional FRs and on CBCT-constructed frontal cephalometric radiographs of patients randomly selected from the archive of the dental faculty were compared. Data from the archive were used in the present study because it is not ethically acceptable to expose patients to radiation through the use of both conventional radiography and CBCT.

Most of the studies[9–12] conducted to compare measurements on conventional FRs and CBCT-constructed frontal cephalometric radiographs used CBCT-constructed frontal cephalometric radiographs taken from dry human skulls. Dry human skulls do not suffer from distortion caused by soft tissues, thus the chance of error in landmark identification is reduced. However, in the clinic, CBCT-constructed frontal cephalometric radiographs are used, and these radiographs may be affected by distortion caused by soft tissues. To our knowledge, no study has compared conventional vs CBCT-constructed FRs obtained from the same patient.

In the studies of van Vlijmen et al.,[10,11] measurements were taken by a single observer. The authors indicate that systematic errors in the identification of landmarks were the same for both types of radiographs; thus it was justified to have a single observer for this type of study. For this reason, all measurements on both radiographs in the present study were performed by a single observer.

For all linear measurements, except one (ans-cr), statistically significant differences were found between conventional and CBCT-constructed FRs. Differences ranged from 1.13 to 15.06 mm, maximum for the eurR-eurL parameter and minimum for the moR-moL parameter. It is a known fact in conventional cephalometry that magnification increases as the distance from anatomic points to the film increases, and that magnification decreases as the film gets closer (as the distance diminishes).[13,14] Therefore, the difference between conventional and CBCT-constructed FRs for the eurR-eurL parameter might be maximum. In a recently published paper,[11] the mean differences for FRs were much greater than for lateral radiographs. The reason for this was that the landmarks for FRs are located in a greater number of tomographic planes compared with those for lateral cephalometry.

In recent studies,[9,10] the reproducibility of measurements obtained from CBCT scans was found to be greater than the reproducibility of those obtained from conventional FRs. In accordance with this finding, the reproducibility of measurements has ranged from 0.85 to 0.99 (average, 0.93) for CBCT-constructed FRs, and from 0.78 to 0.96 (average, 0.87) for conventional FRs.

On the other hand, it has been shown that positioning a patient while FRs are made is very critical, because rotation of the head results in measurement differences.[10,12,15] Because a CBCT device has no cephalostat, extra care should be taken when positioning the patient in the device. In addition, van Vlijmen et al.[10,11] recommended using extra light beams in doing so, to prevent unwanted tilt of the head. In the present study, to eliminate the odds of error during measurement in synthesized views, a correction was made to the orientation of the computed tomography (CT) volume through tasks of iterative adjustment and reassessment, and the head position was reoriented with the use of Kodak software, in keeping with the head positioning rules of conventional cephalometric projections.

Another important finding of the present study was that there was no statistically significant difference between angular and ratio measurements performed on conventional FRs, compared with CBCT-constructed FRs. Kumar et al.[16] compared measurements from synthesized CBCT cephalograms using orthogonal and

Table 2. Linear and Angular Parameters and Ratios Measured on Posterior-Anterior Radiographs

Transverse linear, mm	eurL-reuR (cranial width)	The width of the cranium from the most lateral points on the cranium parallel to the superior aspect of the orbits.
	loL-loR (interorbital width)	The width between points of the intersection of the lateral orbital contour with the innominate line.
	moL-moR (interorbital width)	The width between points on the medial orbital margin that is closest to the median plane.
	maL-maR (mastoidal width)	The width between the lowest points of the mastoid process.
	zygL-zygR (bizygomatic width)	The width of the zygomatic arch from the most lateral aspect.
	lapL-lapR (nasal width)	The width of the nasal cavity from the most lateral points on the nasal aperture taken parallel to the horizontal plane.
	mxL-mxR (maxillary width)	The width of the maxilla from bilateral points on the jugal process at the intersection of the outline of the tuberosity of the maxilla and the zygomatic buttress.
	agL-agR (mandibular width)	The width of the mandible from points at the antegonial notch at the lateral inferior margin of the antegonial protuberances.
	umL-umR (intermolar width of maxillary first molars)	The width between the most lateral points on the buccal surface of the permanent maxillary first molar crown parallel to the occlusal plane.
	lmL-lmR (intermolar width of mandibular first molars)	The width between the most lateral points on the buccal surface of the mandibular permanent first molar crowns parallel to the occlusal plane.
Vertical linear, mm	cr-ans (upper face height)	The distance between the intersection of the horizontal and midsagittal planes and the tip of the anterior nasal spine just below the nasal cavity and above the hard palate.
	ans-me (lower face height)	The distance between the tip of the anterior nasal spine just below the nasal cavity and above the hard palate and the most inferior point on the outline of the mandibular symphysis through the midsagittal plane.
	me-iif	The distance between the menton (the most inferior point of the symphysis of the mandible, as seen on the lateral jaw projection) and the incisor inferior frontale (the midpoint between the mandibular central incisors at the level of the incisal edges).
	ans-isf	The distance between the tip of the anterior nasal spine and the incisor superior frontale (the midpoint between the maxillary central incisors at the level of the incisal edges).
Ratio, %	R me-ag	Ratio between line me-ag left and line me-ag right.
	R mx-ans	Ratio between line mx left-ans and line mx right-ans.
	R cr-lo	Ratio between line cr-lo left and line cr-lo right.
Angular, degrees	me/agL/cr	Angle between line me-left ag and line left ag-cr.
	me/agR/cr	Angle between line me-right ag and line right ag-cr.
	agR/agL/loL	Angle between line ag left-ag right and line left lo-right lo.
	agL/agR/loR	Angle between line ag left- ag right and line ag right-lo right.

Table 3. Intraobserver Reliability of Measurements Obtained From Conventional and Cone Beam Computed Tomography–Constructed Frontal Radiographs

Parameters		Conventional r^2	Constructed r^2
eurR-eurL	mm	0.85	0.88
loR-loL	mm	0.83	0.87
moR-moL	mm	0.95	0.96
zygR-zygL	mm	0.87	0.97
lapR-lapL	mm	0.83	0.89
mxR-mxL	mm	0.81	0.88
maR-maL	mm	0.84	0.91
umR-umL	mm	0.79	0.86
lmR-lmL	mm	0.78	0.85
agR-agL	mm	0.87	0.96
R me-ag	%	0.78	0.94
R mx-ans	%	0.82	0.90
R cr-lo	%	0.92	0.97
me-agR-cr	degrees	0.95	0.99
me-agL-cr	degrees	0.95	0.99
agR-agL-loL	degrees	0.96	0.96
agL-agR-loR	degrees	0.93	0.97
me-ans	mm	0.94	0.99
ans-cr	mm	0.85	0.89
me-iif	mm	0.89	0.93
ans-isf	mm	0.87	0.90

perspective projections vs those derived from conventional cephalometric radiographs, and showed that angular measurements were not statistically different for any modality. However, van Vlijmen et al.[11] concluded that there was a clinically relevant difference between angular measurements obtained from conventional FRs and those obtained from CBCT-constructed 3D models. They stated that tracings of 3D models therefore were not suitable for longitudinal research in cases where only two-dimensional records from the past were available. This might be related to patient positioning, as already stated. If a 3D model is made and 3D analysis is performed, it is likely that positioning of the patient has no effect on measurements taken during 3D cephalometric analysis.

CONCLUSIONS

- Differences have been noted between measurements performed on conventional FRs, in comparison with measurements performed on frontal cephalometric radiographs constructed from CBCT scans, particularly for linear measurements.

Table 4. Mean, Standard Deviation, and Difference Values of Measurements Obtained From Conventional and Cone Beam Computed Tomography–Constructed Frontal Radiographs

		Conventional		Constructed					
Parameter		Mean	SD	Mean	SD	Difference	SD	*P* Value	
eurR-eurL	mm	159.23	6.91	144.17	6.08	15.06	3.33	.000	***
loR-loL	mm	91.26	9.53	87.96	9.16	3.30	2.01	.000	***
moR-moL	mm	25.58	2.32	24.44	2.17	1.13	0.75	.000	***
zygR-zygL	mm	136.04	5.15	126.77	4.58	9.26	2.49	.000	***
lapR-lapL	mm	34.53	3.21	30.33	2.92	4.19	1.88	.000	***
mxR-mxL	mm	62.61	4.31	59.58	3.99	3.03	1.63	.000	***
maR-maL	mm	113.25	6.57	100.81	12.79	12.43	13.67	.000	***
umR-umL	mm	62.15	3.78	59.75	4.12	2.4	3.24	.000	***
lmR-lmL	mm	61.41	2.89	57.93	3.02	3.48	1.79	.000	***
agR-agL	mm	88.59	6.08	81.07	4.86	7.52	3.18	.000	***
R me-ag	%	1.01	0.04	1.01	0.06	0.01	0.06	.436	NS
R mx-ans	%	1.01	0.04	1.00	0.04	0.01	0.04	.084	NS
R cr-lo	%	0.99	0.03	1.01	0.04	−0.04	0.05	.630	NS
me-agR-cr	degrees	91.02	5.69	92.06	5.44	−1.04	5.82	.335	NS
me-agL-cr	degrees	91.99	6.25	92.43	5.98	−0.44	5.34	.658	NS
agR-agL-loL	degrees	91.23	2.20	91.86	2.50	−0.63	2.17	.123	NS
agL-agR-loR	degrees	91.93	1.82	92.27	1.91	−0.34	1.76	.065	NS
me-ans	mm	64.55	4.78	61.48	4.47	3.06	2.34	.000	***
ans-cr	mm	63.11	4.37	62.57	5.14	0.64	2.43	.067	NS
me-iif	mm	39.30	3.30	37.15	3.21	2.15	1.46	.000	***
ans-isf	mm	27.76	3.23	25.83	1.86	1.93	3.08	.002	**

* $P < .05$; ** $P < .01$; *** $P < .001$; NS, not significant.

- However, no statistically significant difference has been observed between angular and ratio measurements performed on conventional FRs compared with CBCT-constructed FRs.
- Results suggest that frontal cephalometric radiographs constructed from CBCT scans should not be used for longitudinal research in cases where only two-dimensional records from the past are available.

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