神奈川歯学，57-2，98 ～ 103，2022

ORIGINAL ARTICLE

Keywords
orthodontics
cephalometry
CBCT
3D-imaging

Factors influencing the differences between three-dimensional measurement with cephalometric analysis and cone-beam computed tomography

Masataka ARIWA*, So KOIZUMI and Tetsutaro YAMAGUCHI

Department of Orthodontics, School of Dentistry, Kanagawa Dental University, Yokosuka, Japan

(Received: August 31, 2022,　Accepted: October 11, 2022)

Abstract

This study aimed to elucidate the factors influencing the differences between three-dimensional (3D) measurements taken with cone-beam computed tomography (CBCT) and cephalometric analysis. The ANB angle, a measure of the anteroposterior relationship between the maxilla and mandible, was selected as the object for this study. However, conventional cephalometric indices may not accurately evaluate measurements using 3D analysis on CBCT. Measurements were obtained from the laboratory data of 37 adults with no congenital diseases and no additional X-ray exposure at that time. No exposure occurred during the study. A paired-samples *t*-test (α=0.05) was performed to compare measurements taken with CBCT and cephalometric analysis. We applied multiple linear regression and step-wise methods to investigate factors influencing the differences between the ANB angle on CBCT (3D ANB) and conventional cephalometric analysis (two-dimensional [2D] ANB). The difference in ANB angles (3D ANB-2D ANB) was -1.09 (standard deviation=1.58, range=6.20)°. The results of the multiple linear regression and step-wise methods showed that the smaller the SNA in the cephalometric analysis, the larger the 3D ANB-2D ANB. Thus, the plot of point A in cephalometric analysis may be different from that in CBCT. This result supports the hypothesis that conventional cephalometric indices cannot be used for evaluation during 3D analysis. Furthermore, we demonstrated a relationship between conventional cephalometric analysis and 3D CBCT analysis of the ANB angle. These results suggest points for consideration when constructing a new 3D analysis index.

*Corresponding author: Masataka ARIWA
Department of Orthodontics, Kanagawa Dental University Graduate School of Dentistry, 82 Inaoka-cho, Yokosuka, Kanagawa 238-8580, Japan
TEL: 0468-22-8884 e-mail: ariwa@kdu.ac.jp

Introduction

Cephalometry is a standard tool in orthodontics used for both diagnosis and treatment planning. Since the introduction of cephalostats in 1930, various head measurement and analysis methods have been developed and widely applied[1]. Standard cephalometric analysis is performed by tracing two radiographs obtained in the sagittal and frontal planes. The skull is then transformed from three-dimensional (3D) to two-dimensional (2D) images using radiographs. The projected image obtained by radiography is affected by the magnification of anatomical structures located far from the film[2]. Distortions caused by the patient's posture during radiography have also been reported[3]. Even with well-considered imaging, non-uniform left-right magnification differences of lateral structures can increase the difficulty of tracing, resulting in identification errors and measurement inaccuracies in orthodontist analyses.

In recent years, the introduction of cone-beam computed tomography (CBCT) and the development of 3D technology has increased the demand for orth-

Table 1 Cephalometric variables used in this study.

SNA	Angle between SN plane and NA
SNB	Angle between SN plane and NB
ANB	Angle between straight line AN and NB
U-1 to FH	Angle between maxillary central incisor tooth axis and SN plane
U-1 to SN	Angle between maxillary central incisor tooth axis and FH plane
IMPA	Angle between mandibular central incisor tooth axis and mandibular plane angle
FMIA	Angle between the FH and mandibular planes
A'-Ms	Distance between A and Mo projected at right angles to palatal plane
Gn-Cd	Distance between Gn and Cd
A'-Ptm'	Distance between A and Ptm projected at right angles to palatal plane
Ii-Mo	Distance between Ii and Mo

odontic 3D simulation and conventional 3D structural assessment. The effectiveness and accuracy of CBCT in orthodontic treatment have also been reported[4]. However, the definitions of indices representing the criteria for evaluating maxillofacial structures using CBCT are unclear[5]. In this context, it is essential to consider a new method for assessing the jawbone relationship in three dimensions, which is different from conventional evaluation using a 2D index based on cephalometric analysis[6].

Although there is no statistical difference in the accuracy of 3D measurements of the actual skull and CBCT, cephalometric values are significantly different from those of the real skull[7]. The standard values used in conventional cephalometric analysis may not accurately determine the 3D assessment of jawbone relationships in CBCT[8]. Only a limited number of studies have examined the factors influencing the differences between CBCT and cephalography. Elucidating the influence of differences in measurements is vital for applying the findings of previous cephaloanalyses to CBCT. This study, therefore, aimed to evaluate the differences between CBCT and cephalometric analysis of maxillary and mandibular positioning, and to validate the plot sites of influence.

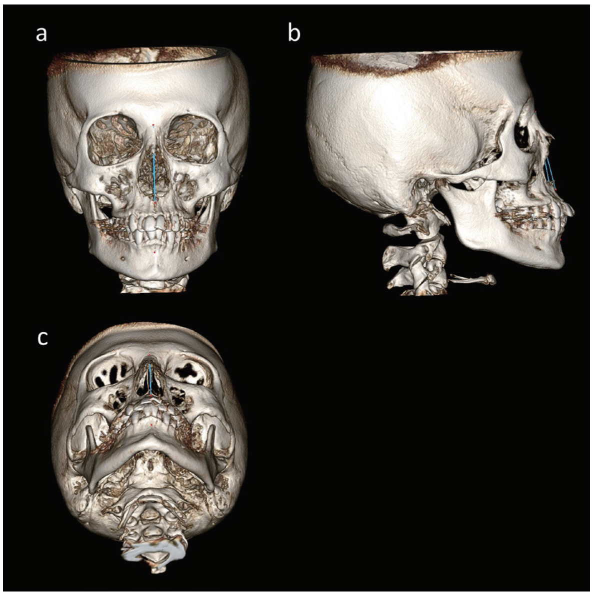

Figure 1. Diagram showing three-dimensional (3D) angle measurements.
Frontal plane (a). Horizontal plane (b). Sagittal plane (c).
The blue line is the ANB measurement line.

Materials and Methods

In this study, we used the examination data of 37 adult patients (5 male and 32 female; mean age, 27.97±12.50 years) who underwent examination at the Orthodontic Department of the University Hospital from June 2020 to May 2022. Patients were randomly selected from among those without congenital diseases. Two of the patients had congenitally absent teeth. The skeletal class was Class I in 16, Class II in 13, and Class III in 8 patients. The same technician performed all measurements to avoid the influence of inter-rater errors when plotting items. Several technologists in the Department of Diagnostic Imaging at the University performed the cephalogram and CBCT imaging using the same criteria. No additional radiographs were obtained for this experiment, and the patients were not subjected to any additional exposure.

A collimator type R20J (SHIMADZU, Kyoto, Japan) was used for cephaloimaging. The imaging conditions were set in accordance with the manufacturer's recom-

Table 2 Measured values on radiographic imaging.

Radiography Method	Measurement Items	Mean ± SD	95% CI SE
CBCT	ANB (˚)	3.08 ± 3.63	(1.87–4.28)
Cephalogram	ANB (˚)	4.17 ± 3.53	(2.99–5.34)
	SNA (˚)	82.08 ± 3.65	(80.86–83.30)
	SNB (˚)	77.91 ± 4.79	(76.32–79.51)
	U-1 to FH (˚)	111.78 ± 8.32	(109.00–114.55)
	U-1 to SN (˚)	101.04 ± 17.50	(95.20–106.87)
	IMPA (˚)	93.08 ± 7.87	(90.45–95.70)
	FMIA (˚)	29.46 ± 6.64	(27.24–31.67)
	A'-Ms (mm)	30.00 ± 3.09	(28.97–31.03)
	Gn-Cd (mm)	123.20 ± 7.01	(120.86–125.53)
	A'-Ptm' (mm)	44.82 ± 4.17	(43.43–46.21)
	Ii-Mo (mm)	30.69 ± 3.01	(29.69–31.70)

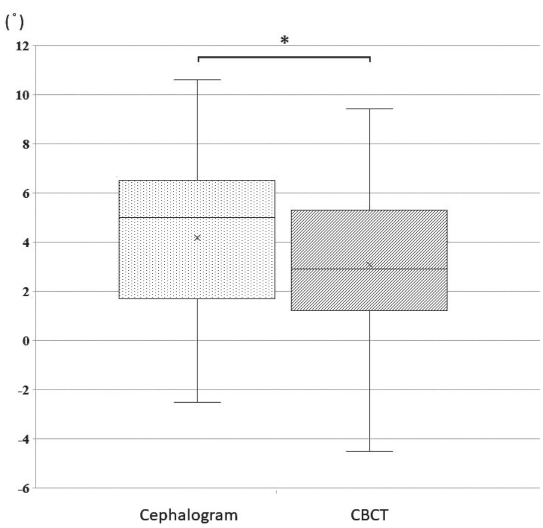

Figure 2. Paired-samples *t*-test for ANB angles in cephalogram and cone-beam computed tomography (CBCT).
Paired-samples *t*-test (α=0.05)
*ANB angles in cephalogram and CBCT (t[36]=4.181, p=0.000)

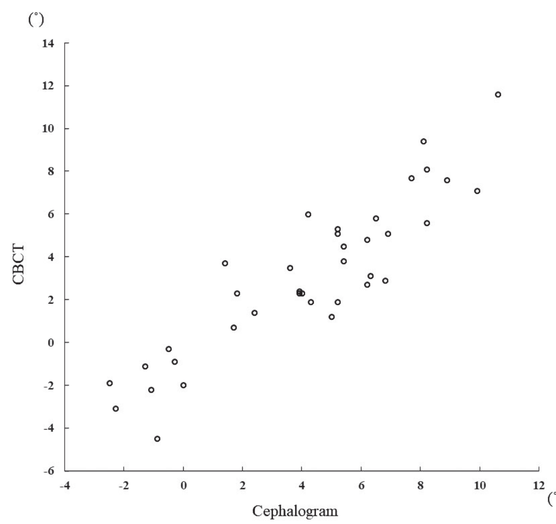

Figure 3. ANB angle and Spearman's rank correlation coefficient in cephalogram and cone-beam computed tomography (CBCT).
Spearman's rank correlation coefficient (α=0.05)
ANB angle in cephalogram and CBCT (r=0.873, p=0.000)

mendations (100 kV, 100 mA, and 200 ms). The exposure dose was 0.03 mSv. CephaloMetricsAtoZ ver. 22.0 (YASUNAGA Computer Systems Company, Fukui, Japan) was used for cephaloanalysis. The test methods used were multistage and linear analysis specified in the software. Items with overlapping meanings were excluded from the measurements. The extracted items are listed in Table 1.

CBCT imaging was performed using the Kavo OP 3D Vision (KaVo Dental Systems, Tokyo, Japan). The imaging conditions were set in accordance with the manufacturer's recommendations (120 kVp, 5 A, and 17.8 s). A voxel value of 0.3 mm was used. The exposure dose was 877.6 mGy/cm^2. We imported the DICOM data into Invivo™ 6 (KaVo Dental Systems, Tokyo, Japan) to display the volume renderings. We then plotted the A, B, and N points of the conventional cephalometric analysis at points corresponding to the 3D jawbone, and measured the ANB angle (3D ANB) from the three plotted points (Figure 1).

All statistical analyses were performed using SPSS statistical package version 25 (IBM, Chicago, IL, USA). The normality of the measured items was examined using Shapiro-Wilk test (α=0.05). A paired-samples

Table 3 Differences in the ANB angle and Spearman's rank correlation coefficient for each variable in cephalogram and cone-beam computed tomography (CBCT).

	SNA	SNB	Age	U-1 to FH	U-1 to SN	IMPA	Mandibular	A'-Ms	Gn-Cd	A'-Ptm'	Ii-Mo
ANB (CBCT-cephalogram)	-0.338*	-0.028	-0.004	0.140	0.150	0.080	0.019	-0.189	-0.029	-0.208	-0.076
SNA		0.645**	-0.158	0.029	0.325*	0.001	0.074	0.042	0.168	0.033	0.089
SNB			-0.071	0.352*	0.531**	-0.213	-0.320	-0.195	0.557**	0.076	0.193
Age				-0.139	-0.195	-0.019	0.067	-0.001	0.131	0.089	0.036
U-1 to FH					0.768**	0.100	-0.459**	-0.354*	0.422**	0.290	0.271
U-1 to SN						0.067	-0.204	-0.360*	0.329*	0.032	0.281
IMPA							-0.286	0.054	-0.248	0.201	0.412*
Mandibular								0.060	-0.366*	-0.239	-0.254
A'-Ms									-0.080	0.250	0.123
Gn-Cd										0.512**	0.355*
A'-Ptm'											0.426**

Spearman's rank correlation coefficient
** p-value<0.01, * p-value<0.05

Table 4 Multiple linear regression and step-wise method to investigate the difference in ANB angle for each variable in the cephalogram and cone-beamed computed tomography.

Variables	β	SE	R^2	F	p
SNA (˚)	-0.345	0.069	0.094	4.722	0.037

t-test (α=0.05) was used to compare ANB angles (2D ANB and 3D ANB) in the cephalometric analysis. We further used a sample size index of 30 or more for the paired-samples *t*-test (α=0.05), and performed multiple linear regression and step-wise methods to investigate the factors influencing the differences between 2D and 3D ANB.

This study was reviewed and approved by the Ethics Committee of Kanagawa Dental University(approval numbers 642 and 663).

Results

The normality of the variables was analyzed using Shapiro-Wilk test (α=0.05), and normality was confirmed for all but a few of the quantitative variables. The SNB, U-1 to FH, and U-1 to SN were unexpected. The 2D ANB was 4.17 (standard deviation=3.53, range=13.10°) and 3D ANB was 3.08 (standard deviation=3.63, range=16.10°). The measured values in the cephalogram and 3D ANB are listed in Table 2.

A paired-samples *t*-test (α=0.05) was used to compare 2D and 3D ANB. The results demonstrated a significant difference between the measurements (*t*[36]=-4.181, p=0.000) (Figure 2).

Spearman's rank correlation coefficient was used to analyze the correlation between 2D ANB and 3D ANB, and a significant positive correlation was observed (r=0.873, p=0.000) (Figure 3).

The difference in the ANB angle (3D ANB-2D ANB) and the correlation between variables were analyzed using Spearman's rank correlation coefficient. The results showed no correlation exceeding |r|>0.8 (Table 3).

We performed multiple linear regression and step-wise methods to determine 3D ANB-2D ANB. The 3D ANB-2D ANB was used as the criterion variable, and the extracted cephaloanalytic items were used as explanatory variables. All VIFs were less than 10.0, and there were no multicollinearity problems. The adjusted R2 value was 0.094 and the results were significant (F[1, 35]=4.722, p=0.037). The standard partial regression coefficient showed a significant negative coefficient for SNA (β=-0.345, p=0.037). The obtained regression equation indicated that the smaller the SNA, the larger the value of the 3D ANB-2D ANB (Table 4).

Discussion

In this study, we compared the differences between two measurement methods: conventional cephalometric analysis and CBCT volume-rendering 3D measurements. CBCT showed a more significant measurement error than cephalometric analysis in measuring the

ANB angle. This result suggests the possibility of errors due to landmark identification, which is consistent with the report by Van Vlijmen *et al*.[8]. The reported increase in measurement error in analysis items farther from the midsagittal plane suggests that the addition of a 3D axis may be the cause[9]. It is generally assumed that CBCT analysis in three dimensions shows a significant measurement error due to the addition of depth information to the 2D cephalometric analysis.

The ANB angle measurement showed a statistically significant difference (t[36]=-4.181, p=0.000) in the paired-samples t-test (α=0.05) between the cephalometric and CBCT 3D sizes. Spearman's rank correlation coefficient results demonstrated a high correlation (r=0.873, p=0.000), indicating a positive association between the 2D and 3D measurements. The 3D ANB-2D ANB value was -1.09 (standard deviation=1.58, range=6.20), which could be considered to be within a clinically acceptable error range[8].

The accuracy of cephalometric and CBCT 3D analyses has been verified using several methods. Some reports indicated that the accuracies of the measured values of dry skull and CBCT 3D measurements are comparable[7], while lateral cephalometric measurements have been reported to be more significant than actual skull measurements[10]. These reports suggest that the standard values of the measurements in 3D analysis should be considered separately from the standard values in cephalometric analysis.

The multiple linear regression and step-wise method results showed that the smaller the SNA in the cephalometric analysis, the larger the value of 3D ANB-2D ANB. The plot of point A in the cephalometric analysis may differ from that in CBCT. The resulting regression equation indicates that the evaluation of the plot of point A in the cephalometric analysis affects the measurement of ANB, supporting the hypothesis that the conventional cephalometric index cannot determine the review during 3D analysis.

It has further been reported that evaluation of point A, an ambiguous marker on a curved anatomical boundary in cephalometric analysis, may result in uncertainties[11]. The obtained regression equations were consistent with those previously reported.

Cephalometric items include those that are difficult to define in a 3D structure. For example, one of the measurement points in lateral cephalometric analysis is the articulare (Ar), where the shadow image of the inferior border of the skull base intersects the posterior edge of the mandibular branch. As shown by Ar, 3D analysis with CBCT includes 3D structures that are difficult to determine using conventional cephalometric analysis, and plot areas that affect the accuracy of evaluation[12,13]. Several reports have further examined new analytical reference points for more accurate evaluation[14].

This study had several limitations that should be noted. First, all the patients were candidates for orthodontic treatment and had a history of malocclusion, which may have introduced error. However, it was not ethically possible to use healthy subjects as controls from the perspective of exposure. Second, the measurements were performed by a single orthodontist to eliminate the influence of inter-rater errors, which may have introduced the possibility of a systematic error. However, the measurement is based on a uniform standard for identifying landmarks; therefore, reproducibility should have little impact.

This study focused on the ANB angle, comparing cephalometric and CBCT 3D analyses. The regression equations shows the influence of point A and the difference between the two analytical methods. This result suggests a point for consideration when constructing a new index for 3D analysis. In the future, it will be necessary to examine the ANB angle and other cephalometric parameters, and to study the index of measured values for 3D analysis in CBCT.

Conclusion

Differences were observed between conventional cephalometric analysis and 3D analysis with CBCT in the measurement of ANB angle. The regression equations obtained showed the influence of the A-point plot. Traditional cephalometric measurement indices may not accurately evaluate 3D analysis with CBCT. Further validation is required to compare the results of conventional cephalometric analysis with 3D CBCT measurements.

Conflicts of Interest

This research received no specific grants from any funding agency in the public, commercial, or not-for-profit sectors. The authors declare that they have no related conflicts of interest.

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