TURKISH JOURNAL of ORTHODONTICS

DOI: 10.5152/TurkJOrthod.2020.19097

Original Article

Quantitative Comparison of Cephalogram and Cone-Beam Computed Tomography in the Evaluation of Alveolar Bone Thickness of Maxillary Incisors

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Cite this article as: Wei D, Zhang L, Li W, Jia Y. Quantitative Comparison of Cephalogram and Cone-Beam Computed Tomography in the Evaluation of Alveolar Bone Thickness of Maxillary Incisors. Turk J Orthod 2020; 33(2): 85-91.

ABSTRACT

Objective: This study aims to quantitatively compare cephalogram and cone-beam computed tomography (CBCT) when evaluating maxillary central incisor alveolar bone thickness.

Methods: We used 30 sets of lateral cephalograms and CBCT images that were recorded at the same time. Labial, buccal, and overall alveolar bone thicknesses were measured on three measurement lines of the forward-most incisor in lateral cephalograms and four maxillary incisors in CBCT images. Paired t-test, interclass correlation coefficient analysis, one-way analysis of variance (ANOVA), and Bland–Altman analysis were used to assess cephalometrically measured alveolar bone thickness of maxillary incisors and compare these measurements with those made using CBCT images.

Results: Significant differences were observed between cephalometric and CBCT-based measurements of maxillary incisor alveolar bone thickness; most values showed mild or moderate correlation between the two methods. In most cases, cephalometric measurements were greater than CBCT-based measurements. Bland–Altman plots and ANOVA revealed that measurement bias increased when measurement lines moved apically. Alveolar bone thickness was always overestimated on cephalograms.

Conclusion: Maxillary incisor alveolar bone thickness is always overestimated on cephalograms compared with CBCT-based measurements, with the overestimations ranging from 0.3 to 1.3 mm. Cephalometric measurement bias increases when measurement lines move apically. Thus, CBCT should be recommended when the accurate evaluation of alveolar bone thickness is warranted.

Keywords: Alveolar bone thickness, cephalogram, cone-beam computed tomography, maxillary incisor, orthodontic diagnosis

Main points:

- Maxillary incisor alveolar bone thickness is always overestimated on cephalograms compared with CBCT-based measurements.
- Cephalometric measurement bias increases when measurement lines move apically.
- CBCT should be recommended when the accurate evaluation of alveolar bone thickness is warranted.

INTRODUCTION

Lateral cephalogram is an essential and irreplaceable tool in clinical and academic orthodontics that provides elaborate information for diagnosis and treatment planning (1). With the advent of computed tomography technology, cone-beam computed tomography (CBCT) is gaining popularity as a promising modality in dental practice, with several obvious advantages compared with two-dimensional (2D) cephalograms.

CBCT images provide three-dimensional (3D) assessment of the life-size craniofacial complex without distortion or overlapping of anatomical structures (2-4). In addition, it provides a highly accurate method to evaluate bony architecture and has been previously used to quantify facial bone for orthodontic research as well as to measure bone volume following regenerative periodontal therapy (5, 6). CBCT scans may help in planning treatment,

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Received: August 16, 2019
Accepted: January 5, 2020

particularly for implant placement of the maxillary aesthetic region, because they can contribute to predictions of some possible pre- or post-surgical soft or hard tissue complications (7). Therefore, CBCT is the preferred measurement technique for determining alveolar bone thickness.

Extensive research has been conducted to investigate the accuracy and consistency of craniofacial measurements recorded using these two methods. Generally, CBCT images provide more precise identification of traditional cephalometric landmarks (8, 9), and in a clinical setting they provide more accurate and reliable 3D and linear measurements of the craniofacial complex (10-12).

In addition, CBCT can be used to evaluate alveolar thickness. The thickness of the supporting alveola is a critical issue that must be considered during orthodontic treatment, particularly when treating maxillary incisors, which always need a wide range of labiopalatal movement. According to Yodthong et al. (13), the rate of tooth movement, change in inclination, and extent of intrusion are significant factors that may influence alveolar bone thickness during upper incisor retraction. Ignorance of alveolar bone thickness along with wide tooth movement range may contribute to increased risk of bone fenestration and dehiscence. Therefore, these factors must be carefully monitored.

Although CBCT provides a relatively more reliable method to evaluate alveolar thickness, it is not routinely prescribed because of the radiation dose used and its cost. Most orthodontists use only lateral cephalograms to evaluate maxillary incisor alveolar thickness. However, there is limited clinical research regarding the accuracy of alveolar bone thickness measurements obtained by cephalograms as well as limited research involving the quantitative comparison of cephalograms and CBCT. Therefore, we must determine whether using cephalograms to measure maxillary incisor alveolar bone thickness in orthodontic treatment is reasonable and whether CBCT should be routinely prescribed for this purpose.

Herein, we aim to quantitatively compare cephalogram and CBCT for evaluating maxillary central incisor alveolar bone thickness. The findings of this study will enrich and expand the knowledge regarding whether and when CBCT is required to evaluate anterior maxillary alveolar bone thickness.

METHODS

Subjects

The study was approved by the local ethics committee of Peking University School of Stomatology, Beijing, China (PKUSSIRB-201838113). A total of 30 sets of CBCT images and cephalograms (13 men, 17 women; age, 18.9±6.02 years) were selected from the Department of Orthodontics, Peking University School of Stomatology. The exclusion criteria were as follows: cleft palate; missing or supernumerary anterior teeth; rotated, tipped, or torqued teeth; periodontal disease; deciduous anterior teeth; and other pathological manifestations of anterior teeth. CBCT images and lateral cephalograms were obtained on the same day. All the images were taken for the clinical orthodontic treatment.

Imaging and Processing

Lateral cephalograms were obtained using an orthopantomograph equipped with a cephalostat (Orthopantomograph® OP200 D, Instrumentirium Corp, Graven, Finland) with the following parameters: 77 kV, 16 mA, and exposure time of 0.63–1.0 seconds. The measurements were made using Photoshop 7.0 (Adobe® Systems, San Jose, CA).

CBCT images were obtained using the NewTom CBCT system (NewTom VG, Quantitative Radiology, Verona, Italy) with the following parameters: 120 kV; exposure time, 3.6 seconds; and axial thickness, 0.200 mm. The measurements from CBCT images were made using Ondemand3D (Cybermed, Seoul, Korea). The center of each tooth was measured on the sagittal plane.

Measurements

On the lateral cephalograms, the measurements were converted to 100% magnification. The scale ruler on the cephalogram was used to perform the mathematical conversion. Outlines of the most anterior part of the maxillary alveolar plates and maxillary incisor are shown in Figure 1. Four reference lines were used, which were perpendicular to the long axis of the upper incisor. Line A was drawn at the labial alveolar crest, line B was drawn 2.4 mm apically to line A, line C was 4.8 mm off, and line D was 7.2 mm off. The thicknesses of labial, palatal, and labiopalatal (overall) alveolar plates were measured at lines B, C, and D, respectively. Lines B, C, and D were selected to roughly represent crestal, mid-root, and apical levels of maxillary incisors, respectively.

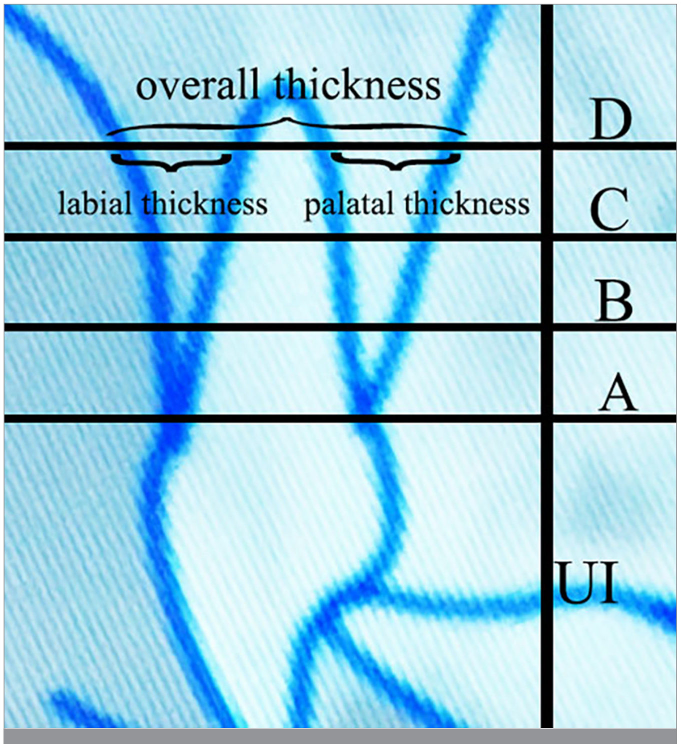

Figure 1. Cephalometric measurements of alveolar bone thickness Labial, palatal and overall thickness were all measured on lines B, C and D

On CBCT images, the mid-sagittal plane of each maxillary incisor was chosen as a reference line and the same measurements were made in each image (Figure 2).

An experienced clinical orthodontist from the Department of Orthodontics, Peking University School of Stomatology, performed all sets of digital measurements twice, with an interval of 1 week between the measurements.

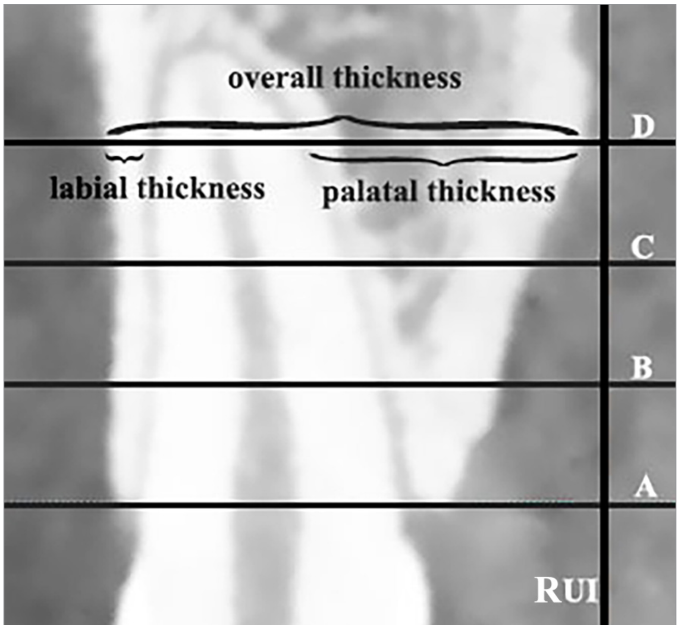

Figure 2. Measurements of alveolar bone thickness on a CBCT image. Same reference lines were used and same measurements were made on CBCT for all four incisors.

Table 1. Paired t-test for repeated measurements (mm) on cephalograms and CBCT (n=30)

Measurements	Mean	Std deviation	p
Cephalograms	-0.008	0.75	0.854
CBCT-based	-0.011	0.74	0.820

Std deviation: standard deviation.

Statistical Analysis

Paired t-tests, interclass correlation coefficient (ICC) analysis, and Dahlberg's formula were used to investigate the reproducibility of the operator's measurements and to perform comparisons between the measurement methods. Kolmogorov–Smirnov normality tests revealed that the data conformed to a normal distribution in all measurement areas. Mean value, standard deviation (SD), correlation analysis, and one-way analysis of variance (ANOVA) were used to identify the relationship between cephalometric and CBCT-based measurements. The significance level was set at $p=0.05$. These tests were performed using Statistical Package for Social Sciences software version 21 (IBM Corp.; Armonk, NY, USA). Bland–Altman analysis was used to assess the agreement of cephalometric and CBCT-based measurements, which were generated using MedCalc software (version 17.9.7; MedCalc Software, Mariakerke, Belgium).

RESULTS

No statistically significant differences were observed between the two repeated measurements on cephalograms as well as on CBCT images (Table 1, $p>0.05$). The average values of the two measurements were used.

Table 2 presents descriptive statistics of the differences that were always smaller in the central incisors. All labial bone thickness measurements, most palatal measurements, and overall thickness revealed highly significant differences between cephalometric and CBCT-based measurements.

Table 3 presents the correlation analysis. All ICCs of labial and palatal thickness were <0.50 mm, and most ICCs ranged in overall thickness from 0.40 to 0.70. Thus, the correlation between cephalometric and CBCT-based measurements was not sufficiently strong.

Table 2. Quantitative comparisons between cephalometric and CBCT-based measurements (mm)

		Labial			Palatal			Overall		
Reference Line		ΔMean	SD	p	ΔMean	SD	p	ΔMean	SD	p
B	11	0.33	0.32	<0.001**	0.28	0.94	0.118	-1.24	0.80	0.401
	21	0.29	0.33	<0.001**	0.50	0.82	0.002**	0.01	0.73	0.925
	12	0.46	0.41	<0.001**	0.71	1.15	0.002**	0.46	0.80	0.004**
	22	0.30	0.53	0.004**	0.60	1.15	0.007**	0.51	0.91	0.005**
C	11	0.55	0.48	<0.001**	0.40	1.05	0.047*	0.31	0.81	0.047*
	21	0.48	0.48	<0.001**	0.74	0.93	<0.001**	0.48	0.80	0.002**
	12	0.76	0.49	<0.001**	0.89	1.37	0.001**	0.88	1.00	<0.001**
	22	0.68	0.51	<0.001**	0.83	1.31	0.002**	1.06	1.04	<0.001**
D	11	0.98	1.03	<0.001**	-0.30	2.02	0.935	0.80	1.31	0.002**
	21	0.93	0.98	<0.001**	0.28	1.59	0.349	1.05	1.18	<0.001**
	12	1.31	0.94	<0.001**	0.29	1.83	0.393	1.20	1.44	<0.001**
	22	1.27	0.78	<0.001**	0.47	1.64	0.130	1.51	1.50	<0.001**

ΔMean: cephalometric measurements (labial\palatal\overall thickness on line B\C\D of the most forward incisor in cephalograms) minus; CBCT-based measurements (labial\palatal\overall thickness on line B\C\D of the four incisors in CBCT); SD: standard deviation; 11\21\12\22, right central incisor\left central incisor\ right lateral incisor\ left lateral incisor; **: p<0.01, statistically highly significant; *: p<0.05, statistically significant.

Table 3. Correlation coefficient (r) and Interclass Correlation Coefficient (ICC) between cephalometric and CBCT-based measurements

		Labial				Palatal				Overall			
Reference Line		**r**	**p**	**ICC**	**p**	**r**	**p**	**ICC**	**p**	**r**	**p**	**ICC**	**p**
B	11	0.405	0.026	0.250	0.013	-0.042	0.824	-0.042	0.589	0.417	0.022	0.417	0.010
	21	0.346	0.061	0.231	0.030	0.202	0.283	0.201	0.140	0.539	0.002	0.539	0.001
	12	0.181	0.338	0.091	0.165	-0.248	0.186	-0.236	0.899	0.303	0.104	0.295	0.053
	22	0.438	0.015	0.310	0.021	-0.106	0.579	-0.97	0.699	0.403	0.027	0.396	0.014
C	11	0.060	0.753	0.055	0.385	0.115	0.543	0.111	0.276	0.579	0.001	0.579	<0.001
	21	0.096	0.613	0.090	0.315	0.330	0.075	0.317	0.041	0.626	<0.001	0.623	<0.001
	12	0.049	0.796	0.046	0.403	-0.008	0.967	-0.007	0.514	0.349	0.059	0.349	0.027
	22	0.259	0.166	0.295	0.079	0.190	0.314	0.158	0.197	0.482	0.007	0.466	0.004
D	11	-0.203	0.283	-0.017	0.820	0.006	0.973	0.010	0.490	0.595	0.001	0.562	0.001
	21	-0.193	0.307	-0.146	0.784	0.278	0.137	0.233	0.104	0.613	<0.001	0.596	<0.001
	12	-0.003	0.989	-0.002	0.505	0.196	0.299	0.153	0.205	0.455	0.012	0.437	0.007
	22	0.409	0.025	0.362	0.023	0.309	0.097	0.251	0.087	0.519	0.003	0.478	0.003

r: correlation coefficient; ICC: Interclass Correlation Coefficient; 11\21\12\22, right central incisor\left central incisor\ right lateral incisor\ left lateral incisor.

Table 4. Comparison of absolute value of the difference between cephalometric and CBCT-based measurements on three reference lines

		11	21	12	22
Labial	B	b	b	c	b
	C	ab	b	b	b
	D	a	a	a	a
Palatal	B	b	b	b	a
	C	b	a	a	a
	D	a	ab	ab	a
Overall	B	b	b	b	c
	C	ab	ab	a	b
	D	a	a	a	a

a\b\c\d: subgroups of multiple comparisons; Subgroup 'a' had the greatest absolute values of difference, and different letters showed statistical significance between group. Measurements with the same subgroup letter do not differ significantly for multiple comparisons. 11\21\12\22: right central incisor\ left central incisor\ right lateral incisor\ left lateral incisor; B: measurements on reference line B; C: measurements on reference line C; D: measurements on reference line.

One-way ANOVA was used to assess the differences among the three measurement lines. Table 4 summarizes the results of this analysis. The absolute value of difference was analyzed, and the subgroup measurements indicated that differences increased when measurement lines moved apically.

In Bland–Altman plots, the limits of agreement were defined as±1.96 SD. The 95% limits of agreement were 0.4±1.60 (mean±1.96 SD), 0.7±1.80, and 0.8±2.90 mm for lines B, C, and D, respectively (Figure 3).

DISCUSSION

Ignoring high-risk periodontal conditions and inappropriate tooth movement can have negative iatrogenic effects on orthodontic treatment, including root resorption, artificial bone defects, gingival recession, and unexpected progressing tooth mobility (14).

Artificial bony defects such as fenestration and dehiscence are gaining more attention with the development of CBCT (15). Krishna et al. (16) reported that when incisors were retracted, a few patients demonstrated bone dehiscence, which was not visible macroscopically or cephalometrically. Meanwhile, some defects are inherent. Gang et al. (17) reported that the incidence of bone fenestration and dehiscence in the incisor region of skeletal Class II division 1 malocclusions was 30.78% and 36.15%, respectively, in Chinese individuals, and the left upper central incisor was the second-most commonly affected tooth with fenestration.

For orthodontists to accurately plan treatments and ensure positive outcomes, full-scale and accurate assessment of maxillary incisor alveolar bone thickness is highly important. Many researchers have measured maxillary incisor alveolar thickness using CBCT images, particularly in implant procedures. Fuentes et al. (18) evaluated the bone buccal to maxillary incisors and found that <10% sites showed more than a 2-mm thickness of the buccal bone wall. Lee et al. (19) measured the thickness of buccal and palatal alveolar plates of maxillary incisors in a Korean subpopulation using CBCT images and reported that the anterior buccal plate was very thin, within 1 mm, and the thickness of the palatal plate was relatively thick. Therefore, maxillary incisor alveolar bone thickness must be considered in orthodontic treatments.

Several researchers have investigated the diagnostic validity of lateral cephalograms in terms of alveolar bone thickness, but most of them have only focused on labial/buccal alveolar plates. Kula et al. (20) showed that the thickness of the bone buccal to root apices of the most forward maxillary incisor is greater when measured on 2D cephalograms than that measured on 3D CBCT images.

In addition to labial bone thickness, palatal and overall alveolar bone thicknesses are equally important. Thongudomporn et al. (21) reported statistically significant decreases in palatal and over-

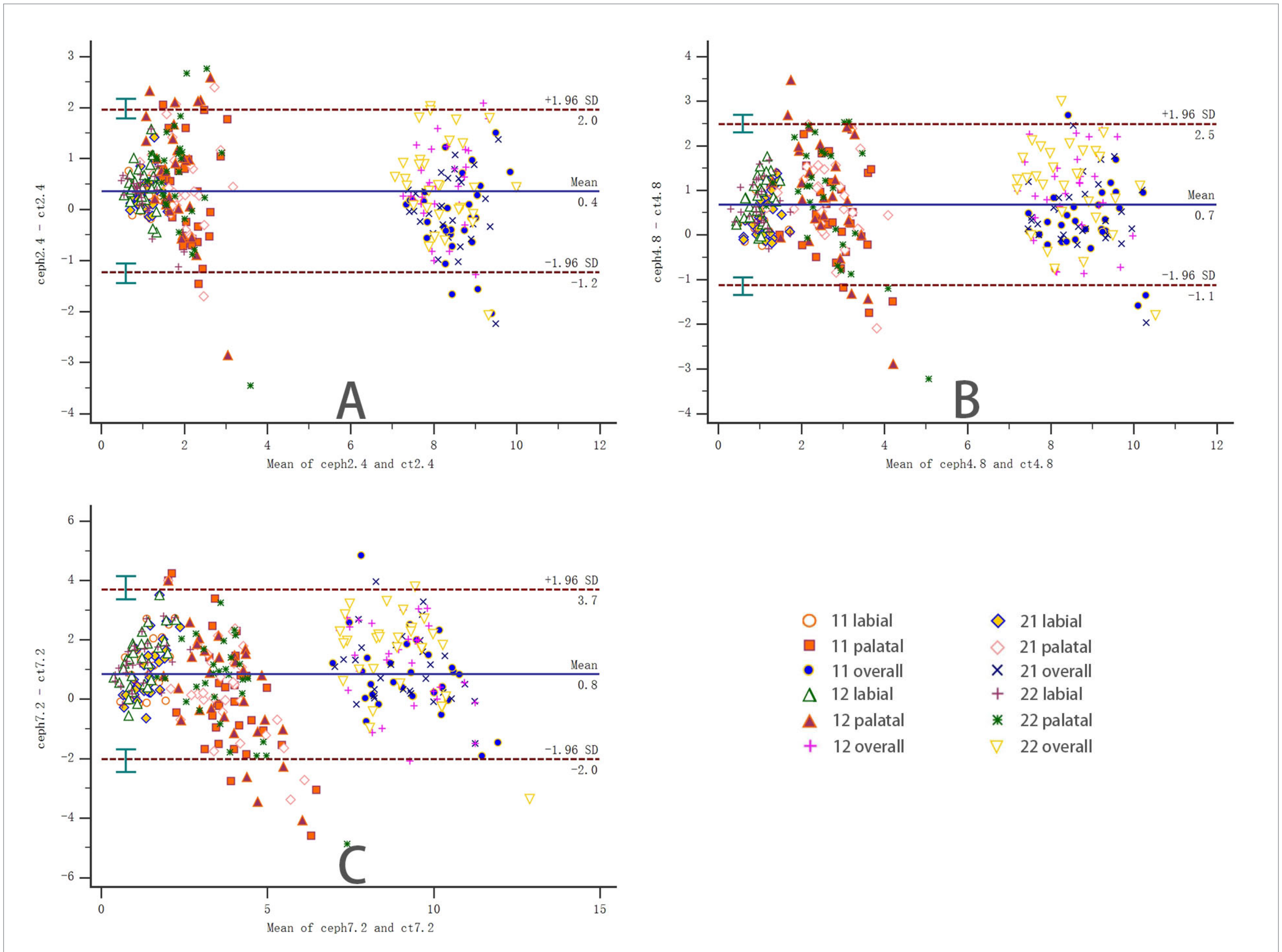

Figure 3. Bland-Altman analysis: difference against the mean (thick solid blue line in the middle) of cephalometric (ceph) and CBCT-based measurements
A: measurements on line B; B: measurements on line C; C: measurements on line D.

all bone thicknesses at mid-root and apical levels after maxillary incisors were proclined and extruded in a group of patients with Class III malocclusion. In fact, labial and lingual cortical plates at the level of the apex of an incisor may represent the anatomic limits of tooth movement (22). Thus, palatal as well as overall alveolar bone thicknesses of maxillary incisors must be evaluated.

Because labial, palatal, and overall alveolar bone thicknesses of maxillary incisors are highly important during orthodontic treatment planning, orthodontists must determine whether cephalograms accurately reflect bone thickness in comparison with CBCT. Thus, in the present study, labial, palatal, and overall thicknesses were measured on three reference lines on both lateral cephalograms and CBCT images.

Cephalometric measurements were greater than CBCT-based measurements in most cases (Table 2), indicating that perhaps alveolar bone thickness is always overestimated on cephalograms. The differences were highly significant between cephalometric and most CBCT values (Table 2). Moreover, the mean values of different measurements increased apically and were always smaller for central incisors than those for lateral ones. Furthermore, simple correlation analysis and ICC were conducted (Table 3), wherein most values showed mild or moderate correlation between cephalometric and CBCT-based measurements.

Lee et al. (23) suggested that the following three conditions must be met to conclude that the two methods for measuring a quantitative variable are interchangeable: 1) the methods must not exhibit marked additive or nonadditive systematic bias; 2) the difference between the two mean readings should not be statistically significant; and 3) the lower limit of 95% confidence interval of ICC should be at least 0.75 (indicating that there is a strong or very strong correlation). Thus, it can be easily concluded that cephalometric measurements were not interchangeable with CBCT-based measurements. Moreover, owing to the limitations of 2D imaging techniques, such as overlapping of anatomical structures, cephalometric measurements do not always reflect the actual measurements (24).

Measuring at three different levels was one of the advantages of the study. Of these locations, the crestal position may contribute most to the aesthetic problems because the crestal bone supports the gingival margin and resorption of bony structure leads to mucosal recession. The mid-root and apical positions are of equal importance; these can help clinicians to be aware of how teeth move as well as the torque used on maxillary incisors.

In Bland–Altman analysis (Figure 3), the measurements on line B showed the smallest mean differences and relatively small limits of agreement (0.4±1.60 mm), whereas the measurements on line D showed the largest mean differences (0.8±2.9 mm). This might be due to the overlap of the more complex anatomical structures when measurements lines were moved apically.

One-way ANOVA (Table 4) was conducted to compare measurements on different lines. Subgroup "a" had the greatest absolute values of difference. The measurements on line D had the greatest absolute difference, and in most cases, values on line B were significantly less different than those on line D. Thus, the accuracy of measurements decreased when measurement lines were moved apically. Clinicians should pay careful attention to alveolar bone thickness of the apical third of the root, particularly when the apices of incisors need a wide range of movement, and CBCT should be recommended in such cases.

A study has showed limitations for using CBCT to assess bone thickness, especially in thin bone areas such as the overestimation of bone dehiscence and fenestration (25). However, there is no gold standard to assess the alveolar bone thickness in these studies, and CBCT is a relatively more accurate method compared with conventional 2D radiographs (26).

A limitation to our study is that we examined generally healthy patients. The cephalometric measurement bias would therefore increase when the situation becomes more complicated such as in patients who meet the exclusion criteria. Skeletal discrepancy influences the inclination of the maxillary and mandibular incisors, which can influence the thickness of labial alveolar bone (27), and this factor can be considered in future studies. More attention should be paid to alveolar bone thickness in orthodontic treatment.

CONCLUSION

Maxillary incisor alveolar bone thickness is always overestimated in cephalograms compared with CBCT-based measurements. This overestimation ranges from 0.3 to 1.3 mm. Cephalometric measurement bias increases when measurement lines move apically. Therefore, CBCT should be recommended when the accurate evaluation of alveolar bone thickness is warranted.

Ethics Committee Approval: This study was approved by Ethics committee of Peking University School of Stomatology, Beijing, China (Approval No: PKUSSIRB-201838113).

Informed Consent: Verbal informed consent was obtained from the patients who agreed to take part in the study.

Peer-review: Externally peer-reviewed.

Acknowledgment: The authors would like to thank Dr. Li Gang from Department of Oral radiology, Peking University School of Stomatology, for the additional information provided.

Author Contributions: Supervision – Y.J., W.L.; Design – D.W.; Supervision – D.W.; Re-sources – L.Z.; Materials – D.W., L.Z., W.L., Y.J.; Data Collection and/or Processing – D.W., L.Z., W.L., Y.J.; Analysis and/or Interpretation – D.W.; Literature Search – D.W.; Writing Manuscript – D.W.; Critical Review - Y.J.

Conflict of Interest: The authors have no conflict of interest to declare.

Financial Disclosure: The authors declared that this study has received no financial support.

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