The reliability of cephalometric measurements in orthodontics: Cone beam computed tomography versus two-dimensional cephalograms

Original Article

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Abstract

Introduction: Due to the important role of imaging in the diagnosis and treatment plan in orthodontics, CBCT (Cone Beam Computed Tomography) images because of their three-dimensional nature, can minimize the disadvantages of two-dimensional images such as magnification, distortion, or superimposition

Materials and methods: In the first part, the distances between the 14 anatomical landmarks on the 5 dried human skulls (reference models) identified by metal spheres were measured by a digital caliper. In the next step, CBCT images were scanned from the same reference models. In the second part, radiographic images were taken from 26 patients enrolled according to inclusion and exclusion criteria in three stages, scanning CBCT images, digital LC (Lateral Cephalometric) images from the same CBCT images, manual tracing of digital LC images. Finally, using the obtained data, the accuracy of measurements performed directly on the reference models with CBCT images as well as the CBCT images, digital LC and traced digital LC images of the patients were evaluated together.

Results: The mean of direct measurements on the reference models was not significantly different from the measured values on CBCT images (ρ-value> 0.05). In other words, the measurement of the CBCT images was the same as the reference models. Also, in most cases, linear measurements between the traced LC image with digital LC images and the CBCT of patients were different (ρ-value > 0.05). Meaning traced LC images and digital LC in 8 cases, CBCT and digital LC in 4 cases and finally traced digital LC and CBCT in 5 cases were different.

Conclusion: The present study showed that the accuracy of CBCT image measurements was similar to the direct measurements obtained from the reference models. Also, the accuracy of linear measurements of CBCT images is higher and more reliable than that of digital LC images as well as traced digital LC images.

Key words:
•Orthodontics •Spiral Cone-Beam Computed Tomography •Cephalometry

Introduction

In general, imaging plays an important role in the diagnosis and treatment plan in orthodontics. Although medical history and clinical evaluations are important to achieve a comprehensive diagnosis, the value of interpreting radiographic information cannot be overlooked (1).

The use of two-dimensional (2D) imaging techniques in the diagnosis and treatment of developmental or congenital defects in the maxillofacial region dates back more than half a century (2). However, all clinicians are aware of the limitations and disadvantages of this type of image, such as magnification, distortion, superimposition, or the possibility of inaccurate reflection of the corresponding structures. In this regard, for example in 2D LC images, many landmarks are defined as the highest or lowest points on the structures. A point on the edge of an anatomical structure in 2D LC images may not correspond to the same point on coronal cephalometric images. Because the rays of the beam may be different in the two images. Therefore, the lack of spatial matching between 2D images is a major problem (3).

According to the mentioned disadvantages, efforts have been made in recent years to develop 3D imaging techniques to reduce the limitations of 2D images. Introducing CBCT images, and especially their use in the maxillofacial region has changed the way data was collected and reconstructed from 2D techniques to 3D techniques. The first example of CBCT scanners was introduced by Robb in 1983 (4). For use in the maxillofacial region in particular, CBCT scanners, specific to this work, were reported in a 1998 study by Mozzo et al. (5). 3D or digital LC radiographic images are a developed type of 2D LCs derived from CBCT images themselves. Recently, digital LC images have been suggested as an ideal tool in the process of diagnosis, treatment planning and also for use in follow-up courses.

The purpose of obtaining CBCT images in orthodontics is to identify morphological measurements of anatomical relationships in addition to identifying anatomical features. Anatomical features are orthodontic landmarks and items that help distinguish between normal and abnormal anatomy. The use of CBCT images over conventional 2D images has advantages such as high quality of information, high potential for diagnosis and treatment plan, ease of use compared to risks, interoperability with computer software to examine various treatment plans (6).

Diagnosis, treatment plan and evaluation of changes over time were usually based on landmark analysis in 2D LC images. These landmarks in 2D images can be affected by factors such as rotation, geometry, or head position change that increase the likelihood of error (7).

Such issues and limitations can lead to misrepresentation of landmarks or poor representation of some structures. While 3D images of these errors are largely absent, the use of CBCT in orthodontics for diagnosis and treatment planning is considered as a potent and effective potential. It is worth noting that, given the disadvantages of 2D images as well as the benefits of 3D images, the replacement of conventional radiographic films by 3D images is inevitable (8).

In their review, Gribel et al. (9) stated that the measurements obtained by the CBCT technique were very accurate. However, in the study of Haririan et al. (10), it was found that judging the accuracy of CBCT images requires further studies, and despite all the benefits of this technique; Orthodontic treatment is still used and cannot be easily substituted by 3D images.

The purpose of this study was to evaluate the reliability of cephalometric measurements in orthodontics by comparing the CBCT scans with two-dimensional cephalograms.

Materials and Methods

In this cross-sectional-analytical study, all samples were selected from the anatomy department as well as patients referred to the Guilan University of Medical Sciences clinic. To determine the sample size, according to the repetition of the sizes for each method, the dispersion of the sizes was taken into account in the sample size calculation (the U1 tip size was chosen close to the measured values with the highest standard deviation). For this purpose, the formula is used to fit the duplicate sizes. Considering 2 replications, correlation of 0.5, the statistical power of 80%, error level of 0.05 and standard deviation of previous studies (5) equal to 1.35 and minimum sample size equal to 26 individuals.

Initially, 14 points (Nasion, Orbitale, Anterior nasal spine (ANS), Point A, Point B, Pogonion, Gnathion, Menton, Condylon, Sella turcica, Basion, Porion, Gonion, Posterior nasal spine (PNS)) on 5 dried human skulls (reference models) were selected to determine anatomical landmarks using stainless steel metal spheres with a diameter of 1.0 mm and fixed on the skulls using instantaneous ligation. Also, 10 inter-point distances (NA, Or-Po, Ba-S, N-Or, ANS-PNS, NS, Co-Go, B-Pog, B-Me, Me-Gn) from Landmarks by a digital measuring caliper (GUANGLU Digital Caliper, China) were measured and recorded as controls. The caliper used had a measurement accuracy of ± 0.02 mm.

In the next step, CBCT images were obtained from reference models using the i-CAT (1719 Cone Beam 3D Dental Imaging System, Germany) and In-Vivo Dental software (Anatomage, V.06, USA) for analyzing CBCT images (13.5 cm 16 16.5 cm, scan time: 26.9 secs, Voxel resolution: 0.25 mm and Recovery time: <2 minutes). The CBCT images in the scanning room were uploaded to the recipient's computer and stored in DICOM format. The stored files were then processed by in-Vivo Dental software and the final 3D images were obtained. It should be noted that the cranium, as well as the mandibular bone, were scanned separately for each reference model.

Then, radiographic images were obtained from 26 patients enrolled in the study according to inclusion and exclusion criteria as well as informed consent form before the commencement of the study by the following methods:

1) CBCT images of patients were obtained using i-CAT then processed and evaluated by in-vivo Dental software (CBCT group).

2) To produce digital LC images, the same CBCT images as in the previous step, a sagittal cross-section was obtained. Digital LC images were analyzed using AutoCAD software (Autodesk, V 2014, SanRafael, California USA) (Digital LC Group).

3) All digital LC radiographs obtained in the previous step were printed on a transparent plastic sheet (29.7×21 cm, A4) and then traced points and distances between them done on the acetate sheet using a 0.5 mm tip pencil. Inter-distance measurements were also performed by digital calipers (manual measurement group).

The 14 landmarks marked and 10 linear distances were measured in all of the above. To evaluate the reliability of the measurements, 10 measurements were repeated at a one-week interval. Inter-Class Correlation (ICC) method was used to evaluate the accuracy of the measurements and only those with a measurement accuracy above 0.70 were confirmed.

All printed LC radiographs were evaluated in front of the negatoscope and without magnification and digital images were also examined by the 14" monitors (Madiran, Iran) in a room illuminated in low light and without any contrast and color alteration. Imaging was also performed to observe a 1:1 ratio from a constant distance and angle between the radiation source, the samples, and the radiograph or sensor. Finally, using the data obtained, a comparison was made between the accuracy of the measurements on the skull and the CBCT images as well as between the CBCT images, digital LCs and traced digital LCs.

Inclusion criteria comprised: young patients with permanent dental system, need of fixed orthodontic treatment to correct dental crowding, class I molar relationship. Exclusion criteria also comprised: patients with history of head and neck or systemic pathology, craniofacial defects, orthodontic treatment in the past, trauma, multiple dental caries and skeletal malocclusions.

Data were analyzed using Kolmogorov-Smirnov test and homogeneity of variances using Levon's test. ICC method was used to evaluate the reliability of the measurements and Bland – Altman plots were used for agreement between the two methods. Paired Samples test was used to compare sizes in two methods. It should also be noted that these calculations were made using SPSS V.24 software. A ρ-value less than 0.05 was considered significant.

Results

In this study, 5 human dried skulls were used as reference models. Scans of CBCT images were also obtained from the same models. As mentioned earlier, the ICC method was used to evaluate the inter-observer agreement. According to this study, the correlation coefficient in the present study ranged from 0.87 to 0.94 (ρ-value<0.05).

Table 1 shows the relationship between the measurements of points directly on the human skull as well as on the CBCT images. According to the results based on paired t-test, the difference between mean of direct measurements on reference models with the same measurements on CBCT images was not statistically significant (ρ-value>0.05). In other words, the values on the CBCT images are similar to the reference models.

Table 1- Relationship between the measurements of points directly on the human skull and CBCT

Linear measurements	Directly on skull (Mean ± SD)	CBCT (Mean ± SD)	ρ–value
N-A	57.91± 1.89	58.01 ± 1.84	0.933
Or-Po	85.01 ± 0.90	85.10 ± 1.00	0.882
Ba-S	47.02 ± 2.07	47.16 ± 1.96	0.917
N-Or	44.12 ± 3.42	44.19 ± 3.38	0.976
ANS-PNS	51.82 ± 0.31	51.96 ± 0.44	0.589
N-S	76.92 ± 1.02	77.00 ± 1.17	0.909
Co-Go	60.83 ± 1.19	60.95 ± 1.15	0.868
B-Pog	12.42 ± 0.52	12.49 ± 0.58	0.859
B-Me	18.35 ± 1.44	18.45 ± 1.45	0.916
Me-Gn	3.23 ± 0.23	3.26 ± 0.26	0.841

This study also compared the data obtained from CBCT images, digital LC images, and traced LC images of 26 patients. Table 2 illustrates the relationship between the measurement of the distances on these images. These differences were significant by paired t-test (p-value<0.05). Also, in most cases, linear measurements between traced LC images technique with digital LC images and CBCT images were different, so that traced LC images with digital LC images in 8 cases, digital LC and CBCT images in 4 cases and also traced LC images and CBCT differed in 5 cases.

Table 2- Relationship between the measurements between CBCT, digital LC and traced digital LC

Groups		Linear measurements (Mean ± SD)	p-value
N-A	Traced Digital LC	50.40 ± 2.78	< 0.001 *
	Digital LC	54.18 ± 3.05	
	CBCT	55.74 ± 2.93	
Or-Po	Traced Digital LC	71.83 ± 5.75	< 0.001 *
	Digital LC	76.54 ± 4.27	
	CBCT	78.08 ± 3.86	
Ba-S	Traced Digital LC	46.02 ± 3.33	≤0.071
	Digital LC	48.92 ± 4.48	
	CBCT	50.18 ± 9.38	
N-Or	Traced Digital LC	28.19 ± 1.92	< 0.001 *
	Digital LC	29.17 ± 2.71	
	CBCT	45.35 ± 5.25	
ANS-PNS	Traced Digital LC	48.17 ± 3.94	< 0.009 *
	Digital LC	52.90 ± 6.44	
	CBCT	49.28 ± 5.47	
N-S	Traced Digital LC	59.46 ± 4.91	0.001 *
	Digital LC	63.09 ± 2.58	
	CBCT	63.54 ± 4.00	
Co-Go	Traced Digital LC	54.98 ± 4.78	0.003 *
	Digital LC	59.32 ± 5.71	
	CBCT	59.97 ± 5.21	
B-Pog	Traced Digital LC	12.67 ± 2.17	< 0.002 *
	Digital LC	15.24 ± 3.56	
	CBCT	12.39 ± 2.82	
B-Me	Traced Digital LC	18.21 ± 2.82	< 0.001 *
	Digital LC	22.34 ± 2.88	
	CBCT	19.72 ± 3.16	
Me-Gn	Traced Digital LC	3.60 ± 0.75	< 0.001 *
	Digital LC	5.54 ± 1.57	

Table 1. Demographic characteristics of the samples by study groups

		Group			P
		M3-	M3+	Total	
		(%) Number	(%) Number	(%) Number	
Gender	Male	(23.9%) 16	(41.8%) 28	(32.8%) 44	0.027
	Female	(76.1%) 51	(58.2%) 39	(57.2%) 60	
	Total	(100%) 67	(100%) 67	(100%) 134	
Age Mean+SD		3.1 ± 26.58	4.48 ± 27.04	3.84 ± 26.91	0.488
Jaw	Maxilla	(49.3%) 33	(53.8%) 36	(51.5%) 69	0.710
	Mandibule	(% 50.7) 34	(46.2%) 31	(48.5%) 65	
	Total	(100%) 67	(100%) 67	(100%) 134	

Table 2. Comparison of CAL , BOP , PPD , GI and PI indices in two groups and in two jaws

		Jaw								
		Mandibule			Maxilla			Maxilla+ Mandibule		
		M3-	M3+	P	M3-	M3+	P	M3-	M3+	P
PI	Mean ± SD	0.641 ± 0.09	1.07 ± 0.45	0.84	0.66 ± 0.53	1.20 ± 0.53	0.001*	0.88 ± 0.62	1.14 ± 0.49	0.004*
GI	Mean ± SD	0.44 ± 0.56	0.69 ± 0.66	0.133	0.36 ± 0.43	0.95 ± 0.65	0.001*	0.40 ± 0.50	0.83 ± 0.64	0.001*
PPD	Mean ± SD	1.58 ± 0.61	2.42 ± 0.85	0.003*	1.91 ± 0.58	2.39 ± 0.64	0.002*	1.88 ± 0.59	2.40 ± 0.74	0.001*
BOP	Mean ± SD	23.89 ± 23.31	28.47 ± 28.91	0.663	21.12 ± 14.65	35.61 ± 28.48	0.002*	19.34 ± 22.57	32.31 ± 28.8	0.011*
CAL	Mean ± SD	1.94 ± 0.65	2.55 ± 0.89	0.002*	1.97 ± 0.68	2.78 ± 0.87	0.001*	1.96 ± 0.66	2.67 ± 0.88	0.001*

*means significant

Table 3. Comparison of caries percentage in distal surface of second molar in two groups and in two jaws

		Jaw								
		Madi-bule Number (%)			Maxilla Number (%)			Maxilla+ Mandibule Number (%)		
		M3-	M3+	Total	M3-	M3+	Total	M3-	M3+	Total
Distal caries	Distal caries +	14 (41%)	16 (52%)	30 (46%)	9 (27%)	14 (38%)	23 (33%)	23 (34%)	30 (45%)	53 (39%)
	Distal caries -	20 (59%)	15 (48%)	35 (53%)	24 (72%)	22 (61%)	46 (66%)	44 (66%)	37 (55%)	81 (60%)
	P		0.02*			0.041*			0.035*	

*means significant

Discussion

Accurate diagnosis and treatment plans for orthodontic patients require an overview of the patient's face and craniofacial supporting structures, and also diagnostic records are required to obtain a visualization of such structures. These documents enable clinicians to study soft tissues, bone structures, airways, and teeth to determine the best treatment plan for the patient after obtaining a favorable diagnosis (11).

Despite the benefits of diagnostic information in 2D imaging in treatment planning, growth prediction, and evaluation of orthodontic outcomes, this technique has various drawbacks. However, many structures will not be understood as complex 3D structures reflected on a 2D plane. Also, the magnification and inherent heterogeneity found in 2D radiographic techniques make it difficult to accurately evaluate the patient's anatomy (12, 13).

Today, many efforts are being made to develop a 3D accurate imaging in the head and neck region. This technique is capable of producing dynamic or static 3D images of the mentioned areas and ultimately results in virtual imaging of the patient's facial structures for the diagnosis, treatment plan, prediction, and evaluation of treatment outcomes. The benefits of CBCT images in orthodontics are more about the geometrical accuracy of the image. Magnification and image heterogeneity, which is part of 2D radiography, is well known among clinicians. In LC images, the structures on the left side due to proximity to the radiographic film are magnified less than those on the right. However, the presence of a 1:1 magnification ratio in CBCT images allows accurate measurement of objects and dimensions (14, 15).

There is little debate, according to some authors, that CBCT provides highly detailed radiographic images suitable for diagnosis and treatment planning in orthodontics. The debate arises when CBCT imaging is prescribed while LC images provide the necessary diagnostic details (16, 17). LC images do not require as much radiation as CBCT imaging and often provide sufficient data to provide an optimal diagnosis and treatment plan (18). It has therefore been suggested that CBCT imaging should not be used repeatedly and should only be prescribed where conventional 2D imaging would not be adequately sufficient (19).

In this study, human dried skulls were used for baseline comparative measurement. The absence of soft tissues and the possibility of direct measurements, the use of dry skulls has been confirmed in many studies. The absence of soft tissue also reduces distortion and makes the identification of bone landmarks more accurate (9, 20, 21).

In a similar study performed by Berco et al. (20) to determine the accuracy and reliability of 3D craniofacial measurements, it was found that CBCT imaging enables accurate measurement of the skull and facial complex. Skull orientation during CBCT scanning does not affect the accuracy or validity of these measurements. Kumar et al. (22), as well as Moshiri et al. (23), revealed in their study that the measurements of a 3D model are comparable to those of direct skull measurements. This is in line with the findings of the present study.

When traced measurements of digital LC images were compared with those of digital LC images, there was a statistically significant difference in most cases. This is consistent with many studies (24-26). In the present study, the accuracy of traced measurements of digital LC images was significantly lower than digital LC and CBCT images. Although traced printing of LC images was performed after calibration of 0-10 mm, still some errors such as magnification can be considered, which has resulted in reduced measurement values.

When comparing digital LC images with CBCT scans, statistically significant differences were observed in 4 out of 8 mid-sagittal plane measurements (N-Or, ANS-PNS, B-Pog, Me-Gn). However, the comparison between the rest of the measurements did not show a significant statistical difference. This is consistent with many studies (9, 27, 28). Landmarks and structures that are not located on the mid-sagittal plane are usually bilateral, resulting in a dual image in radiography. However, even bilateral structures do not overlap even in a perfectly symmetrical skull, because the beam radiates through the head, causing divergence between images of bilateral structures. Rotating the patient's head during imaging will also cause an image error. In general, image errors occur because the film taken from the head and neck is a 2D representation of a 3D object (29-32).

In general, due to the high accuracy of 3D imaging techniques compared to 2D images as well as the high quality of information, its high potential in diagnosis and treatment plan, ease of use compared to risks, interoperability with computer software to examine treatment plans, the use of such images seems to substitute the earlier methods and provide more desirable treatment outcomes (6).

Conclusion

The present study showed that the accuracy of CBCT image measurements was similar to the direct measurements obtained from the reference models. Also, the accuracy of linear measurements of CBCT images is higher and more reliable than digital LC images as well as traced digital LC images.

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