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Research Article

Evaluating the Accuracy of Cephalometric Measurements Made on Hand Traced 2D Cephlogram, Digitally Traced 2D Cephalogram and Digitally Traced 3D Cephalogram from CBCT: A Comparison Study

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Abstract

Cephalometric tracing is still the most reliable method of diagnosing orthodontic discrepancies in patients and treatment planning. While the most common method of cephalometric tracing is by hand, newer digital methods are now starting the replace the traditional hand tracing method. 3 methods of Cephalometric tracing were compared – i) Manual Hand Tracing ii) 2D cephalogram digitally traced on Dolphin Imaging and iii) 3D cephalogram obtained from CBCT digitally traced by Anatomage. The Sample consisted of 30 Patients who were indicated for a CBCT at our clinic. 26 hard tissue and 15 soft tissue cephalometric landmarks were identified and 21 cephalometric measurements (12 angular and 9 linear) were performed using the 3 methods. The Hand tracing and digital tracing on Dolphin were performed by us, while the 3D tracing was sent to us by Anatomage. The 21 cephalometric measurements were obtained from all 3 methods and the measurements were compared using paired t-tests. Results showed that the 3D cephalometric analysis obtained from Anatomage is a fairly reliable method, like the traditional 2D cephalometric analysis. Two-dimensional linear cephalometric norms cannot be readily used for three dimensional measurements because of differences in measurement accuracy between the two methods. With the decrease in radiation exposure and costs in the future, 3D cephalometric can be a suitable alternative method to 2D cephalometry.

Keywords: Cephalogram; Cephalometry; Dolphin Imaging; Anatomage; CBCT; 3D Cephalogram

Introduction

Conventional cephalometry has been one of the standard diagnostic tools for analyzing maxillofacial deformities, orthodontic problems, and evaluating growth and/or treatment changes [1,2]. Digital technologies have introduced several benefits in cephalometric radiology, as it enables instantaneous image acquisition, requires a lower radiation dose, avoids the developing process, and simplifies image storing and sharing. Moreover, the quality of digital cephalograms can be improved using digital tools for image enhancement. 3Nevertheless, conventional cephalometry is limited, because it provides a two-dimensional (2D) representation of three-dimensional (3D) structures. New 3D technology has expanded the diagnostic possibilities, making 3D simulations of surgical and orthodontic procedures possible [2,4]. 3D imaging techniques are becoming increasingly popular and have allowed for the development of new possibilities in orthodontic diagnosis and treatment assessment [2].

The gold standard method for cephalometric imaging methods have been questioned due to a higher probability of errors while identifying landmarks, or making hand-traced measurements, and for the large amount of time consumed for the evaluations [5]. The accuracy of 3D-rendered images had been previously evaluated and the findings showed that direct 3D measurements were highly accurate, with no significant discrepancies from manual measurements [2]. Regarding the 2D manual and Dolphin tracings Huja., *et al* [6], Baskin., *et al* [7]. and Yitschaky., *et al* [8]. showed that cephalometric analyses using the most popular computer programs generate similar linear and angular measurements compared with hand measurements. More recently, Goracci and Ferrari [3] found that Tablet assisted cephalometry showed good agreement with PC-aided cephalometry and with manual tracing and might be preferred when user-friendliness and portability are prioritized. Cephalometric measurements, like all other measurements, involve errors that are classified as errors of projection and errors of identification. Errors of projection are due to the 2D head film, which causes a shadow of the 3D object [9,10]. Furthermore, rotation of the patient's head in the cephalostat in any plane and misalignment of the cephalostat also causes errors of projection [9]. The errors in identifying specific landmarks on the head films are the identification errors and are considered to be the major source of errors in cephalometric by many investigators [5]. Measurements on conventional cephalometric radiographs were found by van Vlijmen., *et al* [2]. to differ significantly from measurements on 3D models of the same skull. Nalcaci., *et al* [11]. also showed that the 3D angular cephalometric analysis is a fairly reliable method, like the traditional 2D cephalometric analysis. On the other hand, Gribel., *et al* [12]. observed that 2D cephalometric norms cannot be readily used for 3D measurements because of differences in measurement accuracy. All the methods tested proved to be reliable acceptable differences between the manually and digitally traced radiographs. Greater reliability was obtained from the CBCT scans.

A very popular method of digitally tracing cephalogram is using the Dolphin Imaging software (California, USA). It is an easy and reliable method where the clinician uploads the cephalogram on the software marks the required anatomical landmarks. The Dolphin Imaging software then traces the cephalogram and gives all the major analysis methods used. Various studies [20-22] have shown the Dolphin Imaging software to be accurate and reliable.

With increasing technology, a lot of clinicians are relying on cephalometric measurements from companies who send the clinicians the set of readings they require. These cephalograms are often traced by the companies who require the clinicians to send the CBCT of the patient. While this is a new trend, not much has been studied to see the reliability of these readings.

The aim of our study was to compare the accuracy of cephalometric measurements obtained from CBCT tracings when compared with digital and hand-tracing method.

Materials and Methods

Thirty patients, 17 males (mean age 31.6 yrs) and 13 females (mean age 29.1 yrs) indicated for a CBCT scan in the European University College were selected. All CBCT images were taken in the same time of cephalogram or in a short period (within 7 days after the cephalogram). All cephalometric radiographs were taken by the same machine. The exposure conditions were 68 kV and 5 mA, using a Kodak C 8000 machine (Kodak 9500 3D; Carestream Health, Inc., France). The head was positioned using an ear rod and head holder, and images were taken with the FH plane parallel to the surface of the floor.

The exposure sittings for CBCT (Kodak 9000C; Carestream Health, Inc., France) were set to 120 kV, 5 mA, and a 76 x 76 x 76 voxel size, and the scope of the shot was set to 50 x 37 mm.

The subjects were seated comfortably maintaining a maximum intercuspal position and asked to stare at their own eyes in a mirror reflection, with the mirror located 1.5m in front of them. Informed consent was obtained from all patients and the study was explained to them.

Cephalometric radiographs traced manually using 0.3 mm HB pencil on acetate paper 8" W x 10" L, .003" (.076mm) thickness in a darkened room using a light box.

Measurements obtained using a ruler and angle protractor. For digital tracing, high quality Dolphin software was used (Dolphin 10). Twenty six hard tissue and 15 soft tissue cephalometric landmarks were identified and 21 cephalometric measurements (12 angular and 8 linear) were performed. The same measurements were obtained from the CBCT image by Anatomodel (San Jose, California, USA) software (Figure1).

Statistical Analysis

Data was collected and stored using MS Excel and then converted to SPSS formatting for data analysis. Paired t-tests were used for inter-user and intra-user reliability.

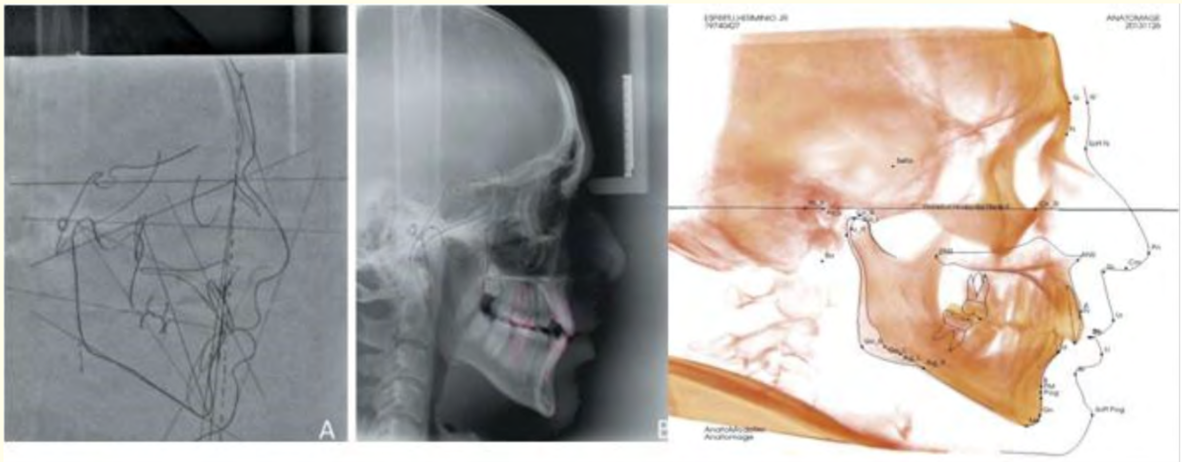

Figure 1: Hand, Dolphin and CBCT tracings.

Results

Manual versus dolphin methods

Descriptive values between three cephalometric analysis methods demonstrated that were no statistically significant differences in all hard tissue measurements between manual and Dolphin tracings except in SNA, SN-PP and inter-incisal angle (Table 1). The angular measurements of facial convexity and nasiolabial angle (NLA) were the only soft tissue measurements that were not significantly different between the manual and Dolphin tracing methods (Table 2).

Manual and dolphin 2D versus CBCT 3D methods

A comparison of 2D manual and Dolphin tracings with CBCT measurements demonstrated statistical differences in hard tissue SNB, Y-axis angle, and inter incisal angle; manual tracing was different than CBCT for hard tissue Wits, L1-APog and overjet while Dolphin was different than CBCT for hard tissue SNA and SN-PP (Table 1). Both hand and Dolphin 2D tracings were significantly different from CBCT soft tissue measurements for lower lip protrusion (L Lip P) and neither 2D tracing method was different from CBCT for facial convexity and upper face height (UFH); manual tracing compared to CBCT soft tissue measurements demonstrated differences in nasiolabial angle (NLA) and lower face height (LFH) while Dolphin tracing was different than CBCT for soft tissue measurement upper lip protrusion (U Lip P) (Table 2).

Variables	Methods	Mean	SD	P value
SNA	M	-1.2	2.882	0.03
	D	1.033	2.965	0.066
	CBCT	2.233	3.549	0.002
SNB	M	-0.8	2.235	0.06
	D	1.433	2.622	0.006
	CBCT	2.233	3.441	0.001
ANB	M	0	3.332	1
	D	-0.3	2.409	0.501
	CBCT	-0.3	2.588	0.531
WITS	M	2.3	3.313	0.001
	D	-3.267	4.448	0
	CBCT	-5.567	4.531	0
SN-PP	M	1.033	2.606	0.038
	D	-6.067	17.667	0.07
	CBCT	-7.1	17.285	0.032
SN-GoGn	M	-0.367	1.921	0.304
	D	-0.067	3.162	0.909
	CBCT	0.3	2.961	0.583
PP-GoGn	M	0.233	4.24	0.765
	D	1.367	4.824	0.132
	CBCT	1.133	3.56	0.092
Y-Axis	M	0.3	2.366	0.493
	D	-1.2	3.044	0.039
	CBCT	-1.5	3.893	0.044

Table 1: Hard Tissue Measurements.

M: Manual Hand Traced; D: Digital Traced; CBCT: Traced on Cone Beam Computed Tomography

Variables	Methods	Mean	SD	P value
NLA	M	6.667	8.86	0
	D	9	15.965	0.004
	CBCT	2.333	17.038	0.459
Fac cnvx	M	-0.033	3.755	0.962
	D	-1.2	4.859	0.187
	CBCT	-1.167	4.12	0.132
UFH	M	1.633	3.337	0.012
	D	1.133	8.819	0.487
	CBCT	-0.5	8.862	0.76
LFH	M	4.733	5.219	0
	D	5.967	4.627	0
	CBCT	1.233	4.264	0.124
U Lip P	M	-4.833	3.992	0
	D	1.333	4.766	0.136
	CBCT	6.167	4.822	0
L Lip P	M	-2.8	3.478	0
	D	2.467	6.107	0.035
	CBCT	5.267	5.239	0

Table 2: Soft Tissue Measurements

M: Manual Hand Traced; D: Digital Traced; CBCT: Traced on Cone Beam Computed Tomography

Discussion

In practice, a high level of accuracy is needed to use 3D image-based measurements, and the accuracy of 3DCT has been investigated and confirmed with various studies as we move from traditional 2D cephalometric analysis to new 3D cephalometric techniques, it is often necessary to compare 2D with 3D data [13,14].

In the present study, cephalometric measurements from two 2D tracing methods were compared to measurements from the Anti-model 3D CBCT method which approved to be more accurate for craniofacial measurements.

The significant difference that was found in SNA and inter-incisal angle between the manual and Dolphin tracing was mainly because of error landmark identification of A-point and root apices. In addition, inter-incisal angle was significantly different between the three methods. Nalçaci., *et al* [11]. explained that the apex and incisal edge of the upper and lower incisor is difficult to locate with 2D conventional radiographs because the incisal point of the most prominent incisor is used; it is difficult to distinguish between central and lateral incisors on the cephalograms. Chan., *et al* [15], stated that an error can be expected if the lateral incisor is more prominent than the central incisors.

Furthermore, because of the poor contrast between the image of the root apex and the surrounding bone, the location of the apex is based more on general knowledge of the length of the tooth and the expected rate of taper perceived from the crown and visible portion of the root than on actually seeing the tip of the root. In particular, it is difficult to locate the incisor tooth on the cephalograms of patients with crowded anterior teeth. However, with 3D CT imaging, these landmarks can be easily located, and reliable measurements obtained [11,15-17].

Measurement SNB in the present study was found to be significantly different in the 3D measurement method when compared to the 2D methods. This finding was consistent with Chidiac., *et al* [18]. Who found that gonion and the lower incisor tip were furthest from the best estimate when located on a 3D image.

The significant difference in soft tissue was found in linear measurements in of facial heights and upper and lower lip protrusion was comparable with other studies for the accuracy of CBCT angular measurement only, this is because in a cephalostat, the distance between the mid sagittal plane of the head and the radiation source is fixed, as is the distance from the mid sagittal plane to the film. In the CBCT device, the radiation source moves around the patient, very much as in an orthopantogram. These differences may lead to variations in magnifications and distortion [18-22].

Understanding how the image is distorted at each measurement may help us develop ways to correct these distortions and derive normal values for 3D measurements based on already existing cephalometric norms.

The 2D cephalometric radiographs have been used successfully for over 70 years in orthodontics, and it appears that this method will survive for many more years. In the present study, 3D cephalometric analysis was judged to be a fairly reliable method, like direct cephalometric analysis. Nowadays, owing to the cost of CT scanning of the skull and radiation exposure to the patient, the 3D system is likely to be more suited to those cases with complex maxillofacial deformities.

In the near future, with the decrease in radiation exposure and costs, 3D cephalometric analysis will be routinely used during orthodontic diagnosis and might eventually replace many conventional orthodontic records used today.

Conclusions

- The 3D angular cephalometric analysis obtained from Anatomodel is a fairly reliable method, like the traditional 2D cephalometric analysis.
- Two-dimensional linear cephalometric norms cannot be readily used for three dimensional measurements because of differences in measurement accuracy between the two methods.
- With the decrease in radiation exposure and costs in the future, 3D cephalometric can be a suitable alternative method to 2D cephalometry.

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