2D / 3D Cone-Beam CT images or conventional radiography: Which is more reliable?

Carolina Perez Couceiro**, Oswaldo de Vasconcellos Vilella***

Abstract

Objective: To compare the reliability of two different methods used for viewing and identifying cephalometric landmarks, i.e., (a) using conventional cephalometric radiographs, and (b) using 2D and 3D images generated by Cone-Beam Computed Tomography. **Methods:** The material consisted of lateral view 2D and 3D images obtained by Cone-Beam Computed Tomography printed on photo paper, and lateral cephalometric radiographs, taken in the same radiology clinic and on the same day, of two patients selected from the archives of the Specialization Program in Orthodontics, at the School of Dentistry, Fluminense Federal University (UFF). Ten students from the Specialization Program in Orthodontics at UFF identified landmarks on transparent acetate paper and measurements were made of the following cephalometric variables: ANB, FMIA, IMPA, FMA, interincisal angle, 1-NA (mm) and 1-NB (mm). Arithmetic means were then calculated, standard deviations and coefficients of variance of each variable for both patients. **Results and Conclusions:** The values of the measurements taken from 3D images showed less dispersion, suggesting greater reliability when identifying some cephalometric landmarks. However, since the printed 3D images used in this study did not allow us to view intracranial landmarks, the development of specific software is required before this type of examination can be used in routine orthodontic practice.

Keywords: Cone-Beam Computed Tomography. Radiography. Orthodontics.

Editor's summary

Cone-Beam Computed Tomography (CBCT) offers the advantage of enabling image reconstruction from a lateral radiograph in conventional orthodontic cephalometry. This investigation aimed to compare how reliably cephalometric landmarks can be identified when viewed on conventional radiographs (Fig 1), and when viewed on two different CBCT images, i.e., conventional 2D reconstruction and maximum intensity projection (MIP), depicted in Figures 2 and 3, by analyzing the dispersion of the values obtained from measurements performed on each image. CBCT-generated images were printed on photographic paper and cephalometric tracings were manually performed by 10 examiners at two different times.

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Coefficient of variance was applied with the purpose of assessing the dispersion of cephalometric values. Values from the measurements performed on the 3D CBCT images showed less dispersion in seven situations. This result was repeated—considering the data of patients 1 and 2, for the FMA angle only. This finding seems to suggest that three-dimensional images are more reliable for identifying some cephalometric landmarks which are difficult to detect in 2D images, such as porion (Po), orbitale (Or), subspinale (A), supramentale (B) and nasion (N). Likewise, the inferior mandibular border seemed easier to identify. Nevertheless, 3D images do not seem to be as reliable when identifying the intersection of the long axes of maxillary and mandibular central incisors. It is interesting to note also that printed 3D images, as used in this study, did not allow the viewing of intracranial points, often essential for cephalometric analysis. No difference was pointed out between conventional images and 2D Cone-Beam CT reconstruction.

FIGURE 1 - Lateral cephalometric radiograph.

FIGURE 2 - 2D image obtained with Cone-Beam Computed Tomography, in lateral view.

FIGURE 3 - 3D image obtained with the Cone-Beam Computed Tomography, in lateral view.

Questions to the authors

1) Did the examiners report any difficulties in marking the points on the 3D image?

No, the cephalometric landmarks were easily identified on the 3D image and the lines and angles were easily traced and measured, respectively. Not many differences were found compared to cephalometric tracings commonly performed by examiners on a conventional cephalometric image.

2) Did the examiners notice any differences in structure identification between conventional cephalometric images and 2D CBCT reconstruction?

The investigators reported greater difficulty in identifying cephalometric landmarks and in performing cephalometric tracings on the 2D CBCT-generated reconstruction.

3) Do the authors find it feasible to use 2D CBCT-generated reconstruction in cephalometry?

Yes. Not only in 2D but in 3D as well, provided that cephalometric analyses are adapted to three-dimensional images.

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Keywords: Cone-Beam Computed Tomography. Radiography. Orthodontics.

INTRODUCTION

With the advent of the first standardized cephalograms obtained with the aid of the cephalostat, developed by Broadbent[2] and Hofrath[8] as of 1931, it became possible to identify previously inaccessible reference points in living beings and dry skulls.[16] Since then, cephalometric examination has become essential for orthodontists, who can now count on a more reliable guide to diagnose, plan and predict malocclusion cases.[16]

Nonetheless, several factors can influence the identification of these points, such as definition accuracy, reproducibility of landmark location and image quality. Moreover, these points—especially those outside the sagittal plane—are subject to distortion.[1,11] Despite these potential errors, cephalometric radiographs are still in widespread use.[9,12]

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In the 1980s, devices emerged in the United States that employ the Cone-Beam technique. Cone-Beam is a special type of computed tomography in which the X-ray beam that generates the image features a special conic shape, unlike conventional CT (CCT), which uses a fan-shaped beam known as fan beam. Tomography obtained with this technology is also called volumetric computerized tomography (VCT).[5] The images are obtained in three dimensions and it is also possible to render 2D images through software.

These advances in imaging have improved considerably the identification of hard-to-detect structures, which may increase the accuracy and reliability of orthodontic diagnosis and treatment planning.[14] In comparison with conventional radiography, examination with computed tomography can potentially provide a wealth of additional information. Cone-Beam CT allows all conventional dental radiographs (panoramic, lateral and frontal cephalograms, occlusal, periapical and bite-wings) to be reconstructed and then added to the multiplanar and 3D reconstructions. Furthermore, measurements made from volumetric CT feature a 1:1[7] ratio, unlike conventional cephalometric radiography, whose magnification may vary from 4.6% to 7.2%.[1]

Considering that these two tests are currently available to orthodontists, this investigation aimed to compare how reliably cephalometric landmarks can be identified (a) when viewed on conventional radiographs, and (b) when viewed on 2D and 3D images generated by Cone-Beam CT, by analyzing the dispersion of the values obtained from the measurements performed on each image.

MATERIAL AND METHODS

Material

In this study, we used the examinations of two patients selected from the files of the Specialization Program in Orthodontics, School of Dentistry, Fluminense Federal University (UFF).

The material consisted of lateral 2D and 3D images obtained by Cone-Beam computed tomography and printed on photo paper at 1:1 ratio, and conventional cephalometric radiographs, taken in the same radiology clinic on the same day.

Methods

Cephalometric examination

Profile cephalometric radiographs were obtained by following the standards established during the First Roentgenographic Cephalometric Workshop, held in 1957 in the city of Cleveland, United States of America.[15]

The radiographs were taken after the patient's head had been immobilized in a cephalostat positioned in the Frankfurt horizontal plane. The head was fixed so that the sagittal plane remained parallel to the film and perpendicular to the ground (Fig 1).

FIGURE 1 - Profile cephalometric radiograph.

CT scan

The CT scans were obtained using i-CAT Volumetric Cone-Beam Computed Tomography device (Imaging Sciences). During image acquisition, patients sat in an open environment in their natural anatomic position while the equipment took one 360º spin around the head, which lasted from 20 to 40 seconds. The 3D images captured in the scanner were then exported to software viewer Visio i-CAT, which helped us to render 2D and 3D images (Figs 2 and 3).

These images were printed on the same type of photo paper.

Cephalometric landmark tracing

The landmarks were identified on transparent acetate paper, measuring 20.0 by 18.5 cm, and marked with black pencil. A light box (illuminator) was used for viewing the X-rays.

- Nasion (N): foremost point of the frontonasal suture, seen in lateral view.[16]
- Subspinale (A-point): deepest point in the contour of the premaxilla.[16]
- Supramentale (B-point): deepest point in the contour of the mandibular alveolar process.[16]
- Menton (Me): inferiormost point in the contour of the mandibular symphysis.[16]
- Orbitale (Or): inferiormost point on the inferior margin of the left orbit.[16]
- Porion (Po): highest point of the external auditory conduit.[16]

Planes and lines

- NA Line: joining the nasion (N) and subspinale (A) points.
- NB Line: joining the nasion (N) and supramentale (B) points.
- Long axis of upper central incisor.
- Long axis of lower central incisor.
- Mandibular plane: tangent to the lower border of the mandible in the posterior region, and to the menton (Me) in the symphysis region.
- Frankfurt horizontal plane: joining porion (Po) and orbitale (Or).

FIGURE 2 - 2D image obtained with Cone-Beam Computed Tomography, in lateral view.

FIGURE 3 - 3D image obtained with the Cone-Beam Computed Tomography, in lateral view.

Measurements (Fig 4)

- ANB: intersection of lines NA and NB.
- FMIA: intersection of the Frankfurt horizontal plane with the long axis of the lower central incisor.
- IMPA: intersection of the long axis of the lower central incisor with the mandibular plane.
- FMA: intersection of the mandibular plane with the Frankfurt horizontal plane.
- Interincisal angle: intersection of the long axes of the upper and lower central incisors.
- NA (mm): linear distance measured from the most prominent maxillary point on the central incisor crown to line NA.
- 1-NB (mm): linear distance measured from the most prominent maxillary point on the central incisor crown to line NB.

All measurements were performed by ten examiners, students from the Specialization Program in Orthodontics, Universidade Federal Fluminense (UFF). After one week the measurements were repeated in order to evaluate intraobserver error.

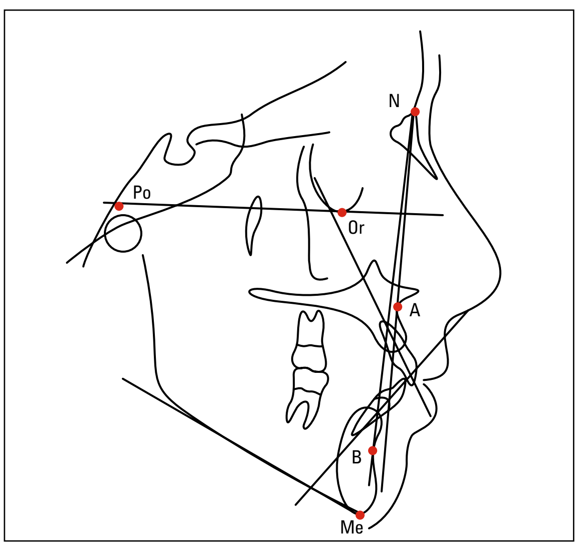

FIGURE 4 - Cephalometric tracing showing landmarks and lines.

The examiners were calibrated and briefed on the landmarks, planes and angles to ensure homogeneous measurements. The linear measurements were obtained with the aid of a millimeter ruler.

Statistical Analysis

Means, standard deviations and coefficients of variance were calculated. The Shapiro-Wilk test was used to check normality between the values obtained on two measurement occasions. When the existence of normal value distribution was noted, the paired t-test was applied to obtain the level of statistical significance. Otherwise, the sign test was used. In both cases a significance level of 1% was used.

RESULTS

Tables 1 and 2 show the means, standard deviations and coefficients of variance for the measurements taken on the lateral cephalometric radiographs and on the 2D and 3D images generated by Cone-Beam Computed Tomography.

Patient 1 was found to exhibit values of standard deviations and coefficients of variance that were lower—in the 3D images—for ANB, FMIA, FMA, and 1-NA (mm). Regarding IMPA and the interincisal angle, standard deviations and coefficients of variance were lower in the conventional radiographs. For variable 1-NB (mm), the standard deviation and coefficient of variance were smaller in the 2D images (Table 1).

Patient 2 was found to exhibit values of standard deviations and coefficients of variance that were lower—in the 3D images—for IMPA, FMA, and 1-NB (mm). For variables ANB, interincisal angle and 1-NA (mm) standard deviations and coefficients of variance were smaller in the 2D images. For angle FMIA, the standard deviation and coefficient of variance were lower in the conventional radiographs (Table 2).

A comparison between the two measurements (Table 3) showed that there were no statistically significant differences at 1% probability.

TABLE 1 - Values of means (M), standard deviations (SD) and coefficient of variance (CV) of the measurements in lateral cephalometric radiography and CT images, in 2D and 3D, Patient 1.

MEASURES	PATIENT 1								
	X-ray			2D			3D		
	M	SD	CV(%)	M	SD	CV(%)	M	SD	CV(%)
ANB	3.40	0.70	20.58	3.60	0.70	19.44	3.70	0.48	12.97
FMIA	45.60	3.72	8.15	50.20	4.68	9.32	50.20	3.01	6.00
IMPA	106.00	3.33	3.14	106.10	3.54	3.33	105.30	3.62	3.43
FMA	28.40	3.89	13.69	23.80	4.56	19.15	24.50	1.51	6.16
$\underline{1}$: $\overline{1}$	110.40	3.98	3.60	110.00	5.56	5.05	113.90	5.74	5.03
$\underline{1}$ -NA	6.35	0.88	13.85	5.65	1.11	19.64	5.20	0.63	12.11
$\overline{1}$ -NB	7.70	0.54	7.01	7.00	0.23	3.28	7.00	0.71	10.14

TABLE 2 - Values of means (M), standard deviations (SD) and coefficient of variance (CV) of the measurements in lateral cephalometric radiography and CT images, in 2D and 3D, Patient 2.

MEASURES	PATIENT 2								
	X-ray			2D			3D		
	M	SD	CV(%)	M	SD	CV(%)	M	SD	CV(%)
ANB	8.30	0.95	11.44	8.50	0.71	8.35	7.85	0.67	8.53
FMIA	45.10	1.37	3.04	49.10	2.81	5.72	46.80	2.35	5.02
IMPA	103.60	2.22	2.14	103.00	2.45	2.38	102.70	1.89	1.84
FMA	31.40	1.90	6.05	27.90	3.60	12.90	30.50	1.58	5.18
$\underline{1}$: $\overline{1}$	128.80	2.74	2.13	132.50	2.71	2.04	128.90	3.24	2.51
$\underline{1}$ -NA	3.25	1.62	49.85	2.25	0.54	24.00	2.80	0.88	31.43
$\overline{1}$ -NB	8.60	0.84	9.77	7.40	0.70	9.46	7.60	0.46	6.05

TABLE 3 - P-values for the paired t-test and sign test, according to the normal (or not normal) distribution of the variable values measured on two different occasions, for each image.

MEASURES	PATIENT 1			PATIENT 2		
	X-ray	2D	3D	X-ray	2D	3D
ANB	$0.754^{n.s.}$	$0.344^{n.s.}$	$0.344^{n.s.}$	$0.344^{n.s.}$	$0.754^{n.s.}$	$0.109^{n.s.}$
FMIA	$0.031^{n.s.}$	$0.016^{n.s.}$	$0.109^{n.s.}$	$0.344^{n.s.}$	$0.098^{n.s.}$	$0.294^{n.s.}$
IMPA	$0.270^{n.s.}$	$1.000^{n.s.}$	$0.535^{n.s.}$	$0.671^{n.s.}$	$0.625^{n.s.}$	$0.109^{n.s.}$
FMA	$0.379^{n.s.}$	$1.000^{n.s.}$	$0.754^{n.s.}$	$0.754^{n.s.}$	$0.145^{n.s.}$	$1.000^{n.s.}$
$\underline{1}$: $\underline{1}$	$0.109^{n.s.}$	$0.228^{n.s.}$	$0.109^{n.s.}$	$0.754^{n.s.}$	$0.522^{n.s.}$	$0.229^{n.s.}$
$\underline{1}$ -NA	$1.000^{n.s.}$	$0.021^{n.s.}$	$0.344^{n.s.}$	$0.754^{n.s.}$	$0.344^{n.s.}$	$0.344^{n.s.}$
$\underline{1}$ -NB	$0.109^{n.s.}$	$0.109^{n.s.}$	$1.000^{n.s.}$	$1.000^{n.s.}$	$0.754^{n.s.}$	$0.344^{n.s.}$

n.s. = non significant (p>0.01).

DISCUSSION

Since the introduction of the cephalostat, Broadbent (1931) underlined the importance of coordinating the lateral and posteroanterior cephalometric films (two extraoral radiographs orthogonal to each other would be taken to acquire a three-dimensional image of the patient) in order to arrive at a distortion-free definition of the craniofacial skeleton. But this approach is not truly three-dimensional as it relies on identifying the same spot in both radiographs and on the use of geometry to calculate the three-dimensional position. The major limitations of this method were obvious. Accuracy depended on a proper correspondence between the landmark locations in the two radiographs, and non-visible points could not be used.[6]

Nevertheless, innovations in digital imaging are changing the way these common methods are used in diagnosis and treatment planning.[14] Volumetric computerized tomography or Cone-Beam, was introduced into dentistry in 2000 at Loma Linda University (USA), and since then its clinical application has been widespread, side by side with significant technological development, bringing with it faster results and higher resolution images.[10]

These advances in imaging will certainly improve the ability to identify anatomical landmarks that are not easily detectable in the images currently available, thereby increasing the accuracy and reliability of orthodontic diagnosis and treatment planning.[14]

Some systems allow CT scan reconstructions that are comparable to cephalometric projections.[4] The purpose of this study was to compare how reliably different cephalometric landmarks could be identified when visualized on conventional radiographs versus on 2D and 3D images generated by Cone-Beam CT, by analyzing the dispersion of the values of measurements taken on each image.

The examiners were calibrated prior to identifying the landmark and taking the measurements, which were repeated after a one week interval in order to test intraobserver reliability. The results showed no statistically significant differences at 1% probability (Table 3). Thus, the values obtained at the time were acceptable for use in this research.

In order to evaluate the dispersion of the values of cephalometric variables, coefficient of variance was applied and the results are displayed in Tables 1 and 2. When data from both tables were analyzed in conjunction, we noted that the values of measurements performed on the images obtained from the 3D Cone-Beam CT showed less dispersion in seven situations, and this result was repeated—considering the data of patients 1 and 2—solely for the FMA angle. This finding seems to suggest that three-dimensional images are more reliable for the identification of some cephalometric landmarks which are difficult to detect in 2D images, such as porion (Po), orbitale (Or), subspinale (A), supramentale (B) and nasion (N). Likewise, the lower mandibular border seemed easier to identify. However, 3D images do not seem to be as reliable for identifying the long axes of the upper and lower incisors because they showed the highest coefficient of variance for IMPA angle values in one patient, and interincisal angle values in patient 2. It is interesting to note also that the printed 3D images, as used in this study, did not allow the visualization of intracranial points, often essential for cephalometric analysis. Therefore, the development of specific software is required before this type of examination can be used in routine orthodontic practice.

The values of the variables measured on conventional radiographs exhibited less dispersion in three situations (Tables 1 and 2). As lower coefficients of variance were found for the values of the IMPA, FMIA and interincisal angles, we can assume that this type of examination provides greater reliability when identifying images of the long axes of the upper and lower incisors. On the other hand, it showed the highest coefficient of variance in four situations. This ANB angle result was repeated in the examination of patients 1 and 2, which suggests that the subspinale (A) and supramentale (B) points are difficult to visualize radiographically.

The values of the variables measured on the 2D Cone-Beam CT images showed less dispersion in four situations. However, none of these was repeated in two patients (Tables 1 and 2), which seemed to indicate that this result is related to the anatomical peculiarities inherent in each image. The highest coefficients of variance were found in seven situations, considering the joint results of the two patients. It should be borne in mind, however, that the images of anatomical structures in the radiographic examination were visualized with the aid of a light box, unlike the 2D Cone-Beam CT images, which may be construed as an advantage for the former.

Measures 1-NB and ANB showed very discrepant results with respect to the coefficient of variance of the three images of patient 1, but this was not the case with patient 2. It is likely that this fact can be ascribed to their anatomical differences.

The results of this study are consistent with the findings published in 2005 by Nakajima et al[13] who, after evaluating Cone-Beam CT technology, concluded that 3D images provide useful information for orthodontic diagnosis and treatment planning.

Furthermore, it is relevant to mention that the measurements made by Cone-Beam Computed Tomography feature a 1:1[3,7] ratio while conventional radiography exhibits a magnification of up to 7.2%, according to Bergensen.[1]

One need not, however, abandon conventional two-dimensional cephalometric measurements in moving to three-dimensional technology since 3D images can be rendered in 2D, similarly to a radiograph. Besides, cephalometric landmarks can also be traced on 3D images. According to Halazonetis,[6] new cephalometric landmarks are likely to be introduced and many new cephalometric analyses, similar to existing two-dimensional analyses, are bound to be created.

CONCLUSIONS

The values of the measurements taken from 3D images showed less dispersion, suggesting greater reliability when identifying some cephalometric landmarks. However, as the printed 3D images used in this study did not allow us to view intracranial landmarks, the development of specific software is required before this type of test can be used in routine orthodontic practice.

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Submitted: December 2008
Revised and accepted: November 2009

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