

# Comparison of two three-dimensional cephalometric analysis computer software

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## ABSTRACT

**Background:** Three-dimensional cephalometric analyses are getting more attraction in orthodontics. The aim of this study was to compare two softwares to evaluate three-dimensional cephalometric analyses of orthodontic treatment outcomes.

**Materials and Methods:** Twenty cone beam computed tomography images were obtained using i-CAT<sup>®</sup> imaging system from patient's records as part of their regular orthodontic records. The images were analyzed using InVivoDental5.0 (Anatomage Inc.) and 3DCeph<sup>™</sup> (University of Illinois at Chicago, Chicago, IL, USA) software. Before and after orthodontic treatments data were analyzed using *t*-test.

**Results:** Reliability test using interclass correlation coefficient was stronger for InVivoDental5.0 (0.83-0.98) compared with 3DCeph<sup>™</sup> (0.51-0.90). Paired *t*-test comparison of the two softwares shows no statistical significant difference in the measurements made in the two softwares.

**Conclusions:** InVivoDental5.0 measurements are more reproducible and user friendly when compared to 3DCeph<sup>™</sup>. No statistical difference between the two softwares in linear or angular measurements. 3DCeph<sup>™</sup> is more time-consuming in performing three-dimensional analysis compared with InVivoDental5.0.

**Clinical Implications:** InVivoDental5.0 utilizes less time in performing three-dimensional cephalometric measurements compared to 3DCeph<sup>™</sup> system.

**Key words:** 3DCeph<sup>™</sup>, cephalometric analysis, InVivoDental, software, three-dimensional

## INTRODUCTION

The use of three-dimensional imaging, especially cone beam computed tomography (CBCT) is becoming increasingly important in orthodontics.<sup>[1,2]</sup> Three-dimensional imaging has many advantages when compared with two-dimensional imaging which includes improved clinical and research diagnosis and consequently better orthodontic treatment planning.<sup>[3,4]</sup> Previous studies have shown that three-dimensional CBCT reconstructed images provide measurements that are both reliable and accurate when compared to measurements of teeth and skulls with high-precision digital calipers.<sup>[5]</sup> With increasing use of three-dimensional measurements in orthodontics, various software programs have been introduced to orthodontic clinicians such as Anatomage

InVivoDental5.0 (Anatomage Inc.) and 3DCeph<sup>™</sup> to accurately and reproducibly take three-dimensional linear and angular measurements. 3DCeph<sup>™</sup> (University of Illinois at Chicago, Chicago, IL, USA) is a window based application that generates three-dimensional wire frames for three-dimensional analysis of digital lateral and frontal, or lateral and basilar cephalometric tracings. The most recent version of the 3DCeph<sup>™</sup> software program has been reported to be acceptable for research purposes.<sup>[6,7]</sup> A study published by Nguyen *et al.*<sup>[8]</sup> determined that out of three different CBCT viewing methods, InVivoDental Volume Render measurements had the greatest correlation with caliper measurements of actual teeth. The reliability of anatomic landmarks in three-dimensional cephalometric analysis using CBCT has been studied recently.<sup>[9-11]</sup> It has been concluded that the most reliable and reproducible landmarks tested for use in CBCT are mental foramina, infraorbital foramina,

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inferior hamulus, dens axis, foramina transversarium of atlas, medial and lateral condyles of the mandible, superior clinoid processes, and mid-clinoid.<sup>[10]</sup> For clinicians, these landmarks identification and reproducibility is very time-consuming and require retraining of practicing clinicians. Furthermore, it has been concluded that some coordinate systems used in 3-D cephalometric analysis are not appropriate for clinical use.<sup>[11]</sup>

The aims of this study were to compare the two computer software programs InvivoDental5.0 and 3DCeph™ regarding their reliability, accuracy, and convenience of use to evaluate three-dimensional cephalometric measurements.

## MATERIALS AND METHODS

### Sample Size and Inclusion Criteria

This study was approved by Health Research Ethics Board, University of Alberta (Study ID: MS8\_Pro00001731). Before and after orthodontic treatment CBCT images were obtained using i-CAT® imaging for 10 patients, 5 female and 5 male, who finished orthodontic treatment for a total of 20 CBCT images. Age of the patients ranged from 12 to 23 years old. CBCT-generated lateral and posterior-anterior (PA) cephalograms were imported into Dolphin Imaging and 3DCeph™ software programs. The originally obtained volumetric digital imaging and communications in medicine (DICOM) data files were used in InvivoDental5.0 (Anatomage Inc.) without manipulation into lateral and PA cephalogram views. InvivoDental5.0 is a volumetric imaging software that has been used for cephalometric measurements has been recently validated.<sup>[7,12]</sup> DICOM files for the same patients were uploaded directly into the InvivoDental5.0 software program. Using the Volume Render component of the software, measurements were made directly onto the visible three-dimensional image, producing instant three-dimensional measurements [Figure 1]. The specific measurements taken from each patient's DICOM files (T1 and T2) were the same as those measured in the 3DCeph 2000 software as indicated in Table 1. Intermolar and intercanine crown and root distances of both upper and lower teeth were obtained for each patient at both time points (T1 and T2).

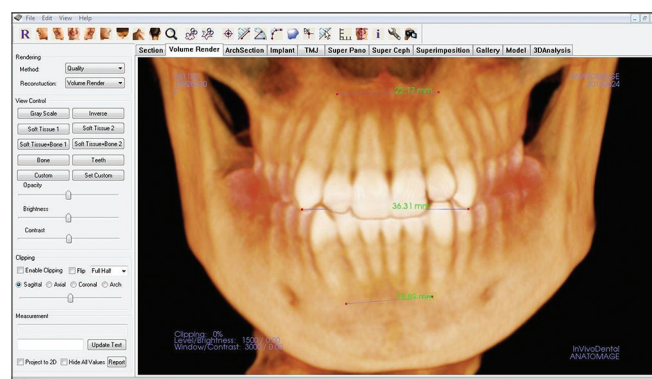


Figure 1: InvivoDental5.0 Volume Render with measurements

The CBCT-generated cephalometric views obtained to be traced using the two programs (3DCeph™ and InvivoDental5.0) were originally created using the Super Ceph module of the Anatomage software. All created cephalometric images were set to Bone Preset 1 and opacity was increased to 100% in the Super Ceph module of InvivoDental5.0. Captured lateral and posterior-anterior images were saved as JPEG files. The lateral cephalograms obtained from InvivoDental5.0 were digitized in Dolphin Imaging Version 11 Premium (Chatsworth, California) using Ricketts comprehensive analysis.<sup>[13]</sup> The ruler was set to 10 mm, and the image was aligned on the Frankfort plane. Each frontal cephalogram was digitally traced using Grummons, Grummons simplified frontal, Ricketts Simplified, Slick/Good and Standard analysis<sup>[14]</sup> with the ruler set to 10 mm. Upper and lower canine root apices and cusp tip landmarks were manually added to the tracing analysis of both the lateral and frontal cephalometric views [Table 1 and Figure 2]

Following tracing, the lateral and frontal cephalometric images were printed in a 1:1 ratio and the rulers of the images measured by manual ruler to ensure equal magnification factors. The images were then saved as JPEG formatted images and converted into high-quality PDF files. The PDF files were opened in Adobe Photoshop Elements 5.0 to align the lateral and frontal images along the Frankfort plane at each time point for every patient. Once aligned, the images were cropped to the same size and saved as bitmap files (red-green-blue color, 24 bit) for use with the 3DCeph™ software.

3DCeph™ (University of Illinois at Chicago, Chicago, IL, USA) consists of two modules, the first is 3DCeph 2000 which generates a two-dimensional wire-like frame [Figure 3] by plotting the digitized landmarks. The second module, 3DCeph Aligner, aligns wire-like frames generated from digitizing lateral and PA cephalometric radiographs so that three-dimensional measurements can be obtained using the 3DCeph 2000 module [Figure 4]. This technique has been described before

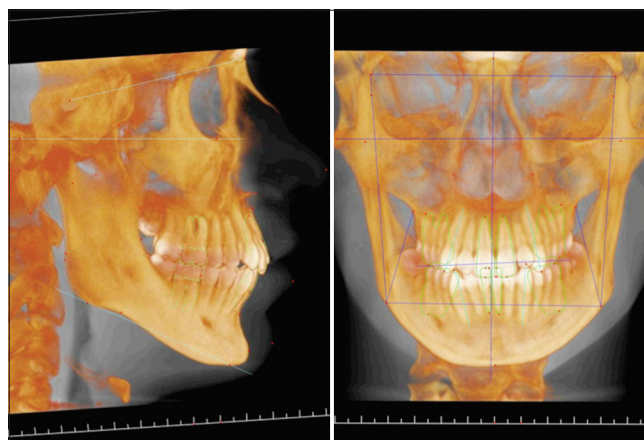


Figure 2: Digitized cone beam computed tomography anatomage generated lateral and posteroanterior cephalometric radiographs, landmarks in red

**Table 1: Lateral and posteroanterior cephalometric landmarks**

	Description
<b>Lateral landmark</b>	
Ruler point 1	A point on the lateral cephalometric image's ruler
Ruler point 2	A point 10 mm away from Ruler point 1 on the lateral cephalometric image's ruler
A point	Deepest point of the curve of the maxilla, between ANS and the dental alveolus
ANS	The tip of the ANS
Articulare	Posterior border of the neck of the condyle intersecting with base of sphenoid bone
B point	Most posterior point in the concavity along the anterior border of the symphysis
Basion	Most inferior posterior point of the occipital bone at the anterior margin of the occipital foramen
Condylion	Most posterior superior point of the condyle
DC point	Center of the neck of the condyle on the Nasion-Basion line
Distal L6	Distal surface of the lower first molar, perpendicular to the occlusal plane
Distal U6	Distal surface of the upper first molar, perpendicular to the occlusal plane
Gonion	Most convex point along the inferior border of the ramus
L1 root	Root apex of the lower central incisor
L1 tip	Tip of the lower central incisor
L6 occlusal	Point on the mesio-buccal occlusal surface of the crown of the lower first molar
Lower lip	Most anterior point on the curve of the lower lip
Menton	Most inferior point of the symphysis
Mesial L6	Mesial surface of the lower first molar, perpendicular to the occlusal plane
Mesial U6	Mesial surface of the upper first molar, perpendicular to the occlusal plane
Nasion	Intersection of the internasal suture with the nasofrontal suture in the midsagittal plane
Orbitale	Lowest point of the roof of the orbit; most inferior point of the external border of the orbital cavity
PNS	Tips of the posterior nasal spine
Pogonion	Most anterior point on the mid-sagittal symphysis
Porion	Highest point of the ear canal; most superior point of the external auditory meatus
PT point	Intersection of the inferior border of the foramen rotundum with the posterior wall of the pterygomaxillary fissure
R1 (mid ramus)	Most concave point on the interior of the ramus
R2	Most convex point on the exterior border of the ramus along the vertical
R3 (sigmoid notch)	Most inferior border along the top of the ramus
R4	Most superior border along the bottom of the ramus
Ramus point	Most posterior point up the border of the ramus
Sella	Center of the pituitary fossa of the sphenoid bone
ST pogonion	Point on the anterior curve of the ST chin
Tip of nose	Pronasale. Point of the anterior curve of the nose
U1 root	Root apex of the upper central incisor
U1 tip	Incisal tip of the upper central incisor
U6 occlusal	Point on the mesio-buccal occlusal surface crown of the upper first molar
<b>Posteroanterior landmark</b>	
Ruler point 1	A point on the front cephalometric image's ruler
Ruler point 2	A point 10mm away from ruler point 1 on the frontal cephalometric image's ruler
A point	Deepest point of the curve of the maxilla between the ANS and the dental alveolus
Antegonial notch R (AG)	Highest point in the antegonial notch on the patient's right side
Antegonial notch L (GA)	Highest point in the antegonial notch on the patient's left side
Condylion, left	Most superior point of the condylar head of the patient's left side
Condylion, right	Most superior point of the condylar head on the patient's right side
Crista galli	Most superior point on the crist galli
Jugular process, L	Intersection of the zygomatic buttress and outline of the tuberosity on the patient's left side
Jugular process, R	Intersection of the zygomatic buttress and outline of the tuberosity on the patient's right side
Lateral wall of nasal cavity, L	Most lateral and widest aspect of the bottom of the nose on patient's left side
Lateral wall of nasal cavity, R	Most lateral and widest aspect of the bottom of the nose on patient's right side
Latero-orbitale R	Most lateral point on the orbital rim on patient's right side
Latero-orbitale L	Most lateral point on the orbital rim on patient's left side
L1 mesial, L	Mesial tooth surface of the mandibular incisor on the patient's left side
L1 mesial, R	Mesial tooth surface of the mandibular incisor on the patient's right side

Contd...

Table 1: Contd...

	Description
L1 tip, L	Mandibular incisal tip on the patient's left side
L1 tip, R	Mandibular incisal tip on the patient's right side
L3 tip, L	Tip of the mandibular cuspid on the patient's left side
L3 tip, R	Tip of the mandibular cuspid on the patient's right side
L6 buccal, L	Most buccal point of the mandibular first molar on the patient's left side
L6 buccal, R	Most buccal point of the mandibular first molar on the patient's right side
L6 root, L	Root apex of left mandibular molar
L6 root, R	Root apex of right mandibular molar
Menton	Most inferior point on the border of the mandible, directly inferior to mental protuberance
U1 mesial, L	Mesial tooth surface of the maxillary incisor on the patient's left side
U1 mesial, R	Mesial tooth surface of the maxillary incisor on the patient's right side
U1 tip, L	Maxillary incisal tip on the patient's left side
U1 tip, R	Maxillary incisal tip on the patient's right side
U3 tip, L	Tip of the maxillary cuspid on the patient's left side
U3 tip, R	Tip of the maxillary cuspid on the patient's right side
U6 buccal, L	Most buccal point of the maxillary first molar on the patient's left side
U6 buccal, R	Most buccal point of the maxillary first molar on the patient's right side
U6 root, L	Mesio-buccal root apex of left maxillary first molar
U6 root, R	Mesio-buccal root apex of right maxillary first molar
Zygomatic arch, R	Center of the root of the right zygomatic arch, midpoint
Zygomatic arch, L	Center of the root of the left zygomatic arch midpoint
Fronto zygomatic suture, L	Zygomatic-frontal suture, intersecting the orbit on the patient's left side
Fronto zygomatic suture, R	Zygomatic-frontal suture, intersecting the orbit on the patient's right side

ANS – Anterior nasal spine; PNS – Posterior nasal spine; ST – Soft tissue

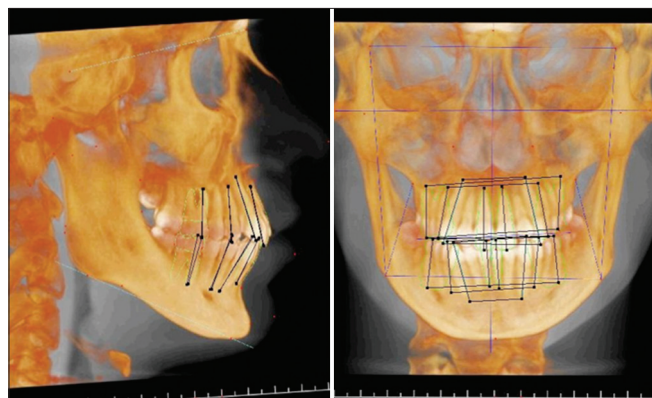


Figure 3: 3DCeph 2000 module, lateral and posteroanterior two-dimensional wire frame

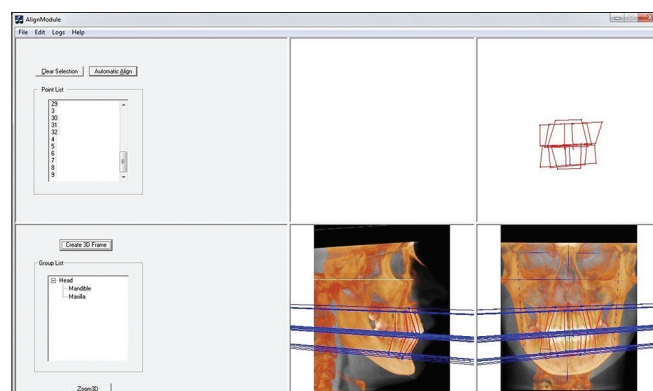


Figure 4: 3DAlign 2000 module showing three-dimensional wire frame (red) and aligned two-dimensional views

by Ehsani *et al.*<sup>[15]</sup> Bitmap digital images that were previously traced in Dolphin were loaded into the first module of the program to create a 2D wire-shaped diagram for each lateral and PA view and saved as a patient file with extension (.pat). The patient files are then opened in three-dimensional Aligner to create an accurate three-dimensional wire frame and a three-dimensional log that reports the three-dimensional measurements of each specified line in millimeters [Table 2].

### Reliability

Intra-examiner reliability (reproducibility) was performed by having one examiner (D.S.) traces and measures the records of all 10 subjects at both time points (T1 and T2) three separate times at an interval of at least 1-week in between measurement trials using both software programs. Intraclass correlation coefficients were calculated for each of the 8 different line measurements to test the reliability of 3DCeph™ and InvivoDental5.0 among three trials for intra-examiner reliability. Inter-examiner reliability was performed by having a second examiner (TEB) trace and measure the 4 inter root measurements (UMR, LMR, UCR, LCR) for only pre-treatment records (T1) of all 10 patients using both software programs. Inter root measurements were selected for inter-examiner reliability based on how subjective they are to examiner judgment, being the most difficult structures to identify consistently on both the lateral and frontal views.

### Statistical Analysis

The statistical analysis compared the three-dimensional transverse dental dimensions obtained by both



three-dimensional software programs, 3DCeph™ and InvivoDental5.0. A paired samples *t*-test was used with differences considered significant between the two softwares at  $P < 0.05$ , with the alpha set at 0.05.

Data obtained from InvivoDental5.0 Anatomage software program, and 3DCeph™ was also analyzed. A one sample *t*-test was used with an alpha set at 0.05 such that  $P < 0.05$  were considered significant. Data was analyzed using SPSS software (version 19.0; SPSS Inc.)

## RESULTS

As shown in Table 3, the correlation coefficient for intra-examiner reliability was large for both software programs, however, InvivoDental5.0 had a stronger correlation for each line measured compared to 3DCeph, showing the program gives more reliable measurements than 3DCeph between trials made by one examiner.

The intraclass correlation coefficients for inter-examiner reliability in Table 3 show that InvivoDental5.0 is more reliable than 3DCeph between different examiners for measured lines 1, 4 and 12 with the exception of line 9 in which 3DCeph produced more reliable measurements between examiners.

**Table 2: 3DCeph™ landmarks and linear measurements**

Line numbers and corresponding points	Description
Line 01: 01-29 (UR6 root – UL6 root)	Inter UMR distance
Line 02: 02-30 (UR6 crown – UL6 crown)	Inter UMC distance
Line 03: 03-31 (LR6 crown – LL6 crown)	Inter LMC distance
Line 04: 04-32 (LR6 root – LL6 root)	Inter LMR distance
Line 09: 09-21 (UR3 root – UL3 root)	Inter UCR distance
Line 10: 10-22 (UR3 crown – UL3 crown)	Inter UCC distance
Line 11: 11-23 (LR3 crown – LL3 crown)	Inter LCC distance
Line 12: 12-24 (LR3 root – LL3 root)	Inter LCR distance

UMR – Upper molar root; UMC – Upper molar crown; LMC – Lower molar crown;  
LMR – Lower molar root; UCR – Upper canine root; UCC – Upper canine crown;  
LCC – Lower canine crown; LCR – Lower canine root

**Table 3: Intraclass correlation coefficient values for intra-examiner and inter-examiner reliability tests**

Line measured	Intra-examiner reliability		Inter-examiner reliability	
	3DCeph™	Invivo Dental5.0	3DCeph™	Invivo Dental5.0
Line 01 (UMR)	0.79	0.97	0.51	0.94
Line 02 (UMC)	0.78	0.98		
Line 03 (LMC)	0.74	0.96		
Line 04 (LMR)	0.82	0.98	0.63	0.93
Line 09 (UCR)	0.89	0.97	0.87	0.64
Line 10 (UCC)	0.85	0.97		
Line 11 (LCC)	0.76	0.90		
Line 12 (LCR)	0.92	0.96	0.75	0.83

UMR – Upper molar root; UMC – Upper molar crown; LMC – Lower molar crown;  
LMR – Lower molar root; UCR – Upper canine root; UCC – Upper canine crown;  
LCC – Lower canine crown; LCR – Lower canine root

## Comparison of Software Programs

In comparing the two software programs, a paired *t*-test of the trial 1 set of data produced *P* values showing that there is no significant difference between the measurements from the two different softwares [Table 4].

## DISCUSSION

Although there has been increasing attention for the utilization of three-dimensional imaging in orthodontics and the increased development of computer softwares for 3DCeph analysis, the utilization of such techniques and softwares are not widely used in clinical orthodontics due to the reliability of these softwares and the inconvenience of their use due to the long time needed to do such analyses.

In our study, considering reliability and reproducibility, the results of using these programs showed that InvivoDental5.0 was consistently more reliable for a single examiner to make three-dimensional measurements of identified landmarks on CBCT images than 3DCeph. This can be due to the zoom and magnification feature in the InvivoDental5.0 Volume Render section of the software and the minimal amount of steps required to produce three-dimensional measurements in this program. This allows for accurate identification of cephalometric landmarks and less opportunity for error to be introduced into the analysis. In order to get three-dimensional measurements using Dolphin Imaging and 3DCeph™, each cephalometric landmark had to be identified twice prior to receiving a three-dimensional measurement allowing for the introduction of more sources of error. Furthermore, the cephalometric images could not be enlarged or magnified within the 3DCeph™ software during creation of the three-dimensional wire frame, which led to reducing the accuracy of landmark identification due to visual limitations.

Inter-examiner reliability was not consistently greater than intra-examiner reliability for all measured lines with InvivoDental5.0, with line 9 showing greater reliability between examiners for 3DCeph that was not in agreement with the majority of the results of the correlation analysis and was not as expected. This unexpected finding may be due to the small sample size in that variation between patients' lower canine crown measurements were less than the variation existing between examiner measurements. This was speculated because the statistics software expects variation to be greater between patients, resulted in a mathematical error. A larger sample size would be required to gather sufficient data before concluding that the line 9 measurements that were found more reliable between examiners with 3DCeph is a significant finding. This discrepancy between the reliability of the two softwares could be due to the fact that cephalometric images created by InvivoDental5.0 to be used with the 3DCeph™ software did not represent the three-dimensional nature of measurement. Despite 3DCeph being less reliable and more time consuming to utilize, a stereophotogrammetry-based software such as this may still be

**Table 4: A comparison of the equality of measurements made by 3DCeph™ versus InvivoDental5.0**

Line measured	Software comparison		InvivoDental5.0 transverse dimension $\Delta$		3DCeph™ transverse dimension $\Delta$	
	Mean $\pm$ SD	P	Mean $\pm$ SD	P	Mean $\pm$ SD	P
Line 01 (UMR)	-0.82 $\pm$ 2.13	0.10	1.18 $\pm$ 1.60	0.00***	0.95 $\pm$ 2.03	0.02*
Line 02 (UMC)	0.37 $\pm$ 1.46	0.27	1.15 $\pm$ 1.35	0.00***	1.64 $\pm$ 2.90	0.00***
Line 03 (LMC)	0.14 $\pm$ 1.52	0.68	0.51 $\pm$ 1.89	0.15	1.17 $\pm$ 2.65	0.02*
Line 04 (LMR)	0.34 $\pm$ 2.07	0.47	0.08 $\pm$ 2.12	0.83	0.17 $\pm$ 2.63	0.72
Line 09 (UCR)	0.17 $\pm$ 1.01	0.47	1.79 $\pm$ 1.35	0.00***	1.71 $\pm$ 1.45	0.00***
Line 10 (UCC)	-0.06 $\pm$ 1.29	0.85	0.35 $\pm$ 1.95	0.34	0.27 $\pm$ 2.52	0.56
Line 11 (LCC)	0.50 $\pm$ 1.30	0.10	-0.51 $\pm$ 1.63	0.10	0.52 $\pm$ 1.96	0.16
Line 12 (LCR)	-0.41 $\pm$ 1.34	0.19	1.46 $\pm$ 2.00	0.00***	2.06 $\pm$ 1.57	0.00***

UMR – Upper molar root; UMC – Upper molar crown; LMC – Lower molar crown; LMR – Lower molar root; UCR – Upper canine root; UCC – Upper canine crown; LCC – Lower canine crown; LCR – Lower canine root; SD – Standard deviation. InvivoDental5.0 and 3DCeph™ 3D measurements of transverse dimension

useful when three-dimensional CBCT data are not available such as in untreated control groups found in various growth centers.

The principal drawbacks of the CBCT three-dimensional cephalogram compared with deriving information from separate conventional lateral and PA cephalometric images are that the conventional 2D images have a lower radiation dose, are simpler to obtain and are more practical for quantitative and long-term analysis than three-dimensional imaging.<sup>[15-17]</sup> Therefore, CBCT generated cephalometric images for three-dimensional orthodontic analysis may not be regularly indicated due to the increased radiation exposure.

There was no significant statistical or clinical difference in the three-dimensional measurements obtained from InvivoDental5.0 in comparison to 3DCeph™. However, InvivoDental5.0 was more convenient to use than the 3DCeph software. The measurements using InvivoDental5.0 could easily be obtained in one-quarter of the time it would take to run CBCT generated lateral and PA cephalometric images through Dolphin Imaging for digitizing, followed by 3DCeph™ to generate the measurements. Moshiri *et al.*<sup>[18]</sup> reported that simulated cephalometric images generated from CBCT in most cases show more accurate 2D measurements than conventional 2D lateral cephalometric radiographs. Another benefit of using the CBCT imaging system and analysis of resulting images is that there are no magnification distortions with the CBCT due to the mathematical algorithm that eliminates magnification factors unlike the conventional lateral cephalogram, which is limited by a number of factors that can cause magnification errors.<sup>[14]</sup> As there is an increased interest to use CBCT images and volumetric software programs such as InvivoDental5.0 there will remain proponents for use of conventional 2D imaging and programs such as 3DCeph for three-dimensional analysis. The benefits of using CBCT images and InvivoDental5.0 routinely in diagnosis and treatment in orthodontics may not be justified when 3DCeph™ produces clinically similar three-dimensional measurements of those obtained from using InvivoDental5.0. Future studies of using three-dimensional softwares may be conducted to evaluate orthodontic treatment outcomes using different orthodontic techniques.

## CONCLUSION

InvivoDental5.0 is a more user friendly and convenient program to use for three-dimensional cephalometric analysis of CBCT images. Clinicians must also take into account the benefit of using CBCT generated cephalometric images and volumetric DICOM files as opposed to conventional 2D diagnostic images as conventional cephalometric radiographs cannot be used with InvivoDental5.0 software to obtain three dimensional measurements. However, this statement should be interpreted with high care that although CBCT generated images are more accurate than regular 2D cephalometric radiographs, increased radiation with CBCT still is a question about routine use of CBCT in daily clinical practice.

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