ASSESSMENT OF ACCURACY OF 2D CEPHALOGRAMS RECONSTRUCTED FROM 3D CBCT IN LABIAL ALVEOLAR BONE THICKNESS MEASUREMENTS OVER THE MOST FORWARD MAXILLARY INCISOR

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Abstract

Objectives: *Assess the accuracy of 2D cephalograms reconstructed from 3D CBCT by comparing labial alveolar bone thickness over the most forward maxillary incisor (MFMI) in 2 dimensions vs 3 dimensions.* ***Materials and Methods:*** *Sixty cone-beam computed tomography (CBCT) images were coded, and 2-dimensional (2D) cephalograms were constructed using ray sum technique by using the entire volumetric data in the On demand 3DAPP software (version1.0.10.7s10;cybermed, korea). The 2D CBCT reconstructed images were analyzed using audax ceph 2d analysis software. The 2D and 3D MFMI crowns were located using (FH)-A-point line as the vertical reference line and alveolar bone labial to 3 points on the MFMI roots, using Frankfort horizontal FH line as a horizontal reference line, were measured. The 2D and 3D measurements were compared using paired t tests. A 5% significance level was used for all tests.* ***Results:*** *labial alveolar bone thickness over the 3 root points of MFMI and the MFMI distance to (FH)-A-point line were significantly greater in 2 dimensions than in 3 dimensions.* ***Conclusions:*** *Labial alveolar bone thickness over MFMI roots can be overestimated when evaluated using 2D reconstructed cephalograms compared with 3D evaluation. Alveolar bone measurements over maxillary incisors were interfered by ANS in two dimensions.*

Key words: *CBCT, alveolar bone, reconstructed cephalogram*

Introduction

Orthodontic tooth movement is achieved through remodeling of the alveolar process, so understanding the hard and soft tissue limits of the orthodontic tooth movement is of great importance prior to the start of the treatment for positioning the teeth in an ideal position which is necessary to achieve better esthetics and occlusion and also protecting the patients from iatrogenic problems including root resorption, dehiscence, fenestrations and mucogingival changes so, maintaining healthy periodontal condition and long lasting stability [1,2].

Baumrind and Frantz; and Mandelaris had reported that two-dimensional (2D) radiographic analyses are not accurate when used for treatment planning decisions and determining the risk assessment specific to alveolar bone of the natural dentition prior to orthodontic tooth movement especially for treatment approaches in patients where buccal root torque or buccal tooth movement (expansion) is planned since identification errors of the actual root of the most forward maxillary incisor (MFMI) due to the overlying structures

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such as the roots of the other incisors and canines, and even the canine eminence can obscure the root outline of the MFMI results in problem in measuring bone thickness [3,4].

Since a substantial database of traditional lateral cephalometric analyses had been developed for orthodontic treatment planning decisions and had been related to orthodontic treatment outcomes, it seems to be illogical to discard this valuable information from the past due to the drifting of orthodontic specialty to the use of 3D imaging modalities. So, reconstruction of traditional lateral cephalograms from the 3D CBCT data is of great value for the traditional lateral cephalometric analyses to be done without the need to expose the patient to further radiation for the traditional lateral cephalograms to be done [5-8].

Three dimensional cone beam computed tomography (CBCT) was used in the present study for precise alveolar bone thickness evaluation over the MFMI root due to its high accuracy in diagnosis and analysis, since it overcomes the problems of superimpositions, magnification and provides high definition of image. So, clinicians can use 3D CBCT for better determination of risk assessment and develop preventative or plan interceptive periodontal augmentation (bone augmentation and/or soft tissue) therapies for patients undergoing orthodontic tooth movement [9-11].

The purpose of this study was to assess the accuracy of 2D cephalograms reconstructed from 3D CBCT by comparing labial alveolar bone thickness over the most forward maxillary incisor (MFMI) in 2 dimensions vs 3dimentions after determining the MFMI two and three dimensionally.

Materials and Methods:

This cross-sectional study was approved by the Research Ethics committee of Faculty of Dentistry, Tanta University, Egypt. After a sample size calculation, 60 CBCT images of both sexes with age range between (16-35) years old were randomly selected before orthodontic treatment from the records of the Egyptian patients admitted for treatment of different types of malocclusions at the clinic of the Orthodontic Department.

The 3D CBCT images were taken with the same machine (iCAT; next generation Imaging Sciences International, Hatfield, PA, USA), set for 13 cm field of view, 8.9 seconds scanning time for a resolution of 0.3voxel size and 14.7 seconds scanning time for a resolution of 0.25 voxel size. Inclusion criteria were eruption of all permanent teeth anterior to the first molar. All malocclusions (Class I, Class II, Class III) based on Angle classifications were accepted where the exclusion criteria were, previous orthodontic treatment, impacted maxillary anterior teeth, obvious root resorption, craniofacial abnormalities and noticeable periodontal diseases based on vertical bone defects or alveolar bone loss greater than 3 mm from the cement-enamel junction (CEJ). The 3D images exported as digital imaging and communications in medicine (DICOM) format files before importing them into the On demand 3DAPP software. The ray sum technique was used for reconstruction of 2D images by using the entire volumetric CBCT data in the On demand software. The 2D reconstructed images were analyzed using audax ceph 2d analysis software.

Three dimensionally, the radiograph was oriented frontally with the FH parallel to the floor, the mid-sagittal plane was constructed with the skeletal midline through nasion perpendicular passing through A point. FH horizontal plane was constructed using the patient's right porion and right and left orbitals as the horizontal reference line as shown in figure (1). A perpendicular line was drawn from FH passing through A-point (FH–A-point line) as the vertical reference line for tooth and bone measures to be standardized and to relate A-point to all incisors.

On the 3D images, the MFMI crown was located by determining the most convex part of the labial surface of each maxillary incisor tooth from the sagittal view and the distance from this part to FH-A line was measured for each incisor tooth and compared for determination of the large distance which represent the distance of the MFMI tooth as shown in figure (2,3). The mid-sagittal line was transferred to the side from the axial view keeping the same axial inclination (FH plane) so that this reconstructed sagittal line pass through the center of the MFMI root canal along its whole long axis exposing the entire root length from the sagittal view and expressing the real bone thickness. The MFMI root length measured from the labial CEJ to the apex. Three points along the root (3 mm apical to the CEJ, half the length of the root, and root apex) were determined and acorresponding points to the root surface points were determined on the alveolar bone edge along a parallel line to FH plane. Alveolar bone thickness was measured as the distance from the root surface points to their corresponding points on the alveolar bone edge as shown in figure (4).

On the 2D reconstructed cephalograms, Frankfort Horizontal [FH] line was constructed using the patient's right porion and right orbitale. Perpendicular line was drawn from FH through A-point (FH–A-point line) as a vertical reference line. The MFMI was determined and the same measurements were done as 3D images as shown in figure (5).

Before data collection, intra-examiner reliability test was performed by performing all the measurements twice by the same investigator after one month from the first estimation.

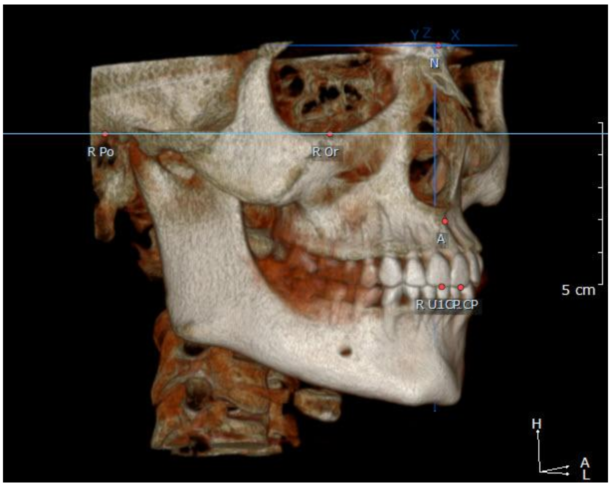
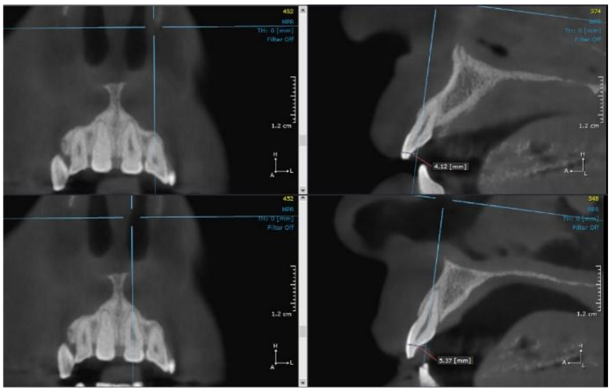


Fig (1): Three-dimensional volumetric image showing skull orientation along the FH plane and midsagittal orientation along the skeletal midline and nasion.



Fig(2): 3D image showing measuring the MFMI distance of left central and lateral incisors to FH.A.line.

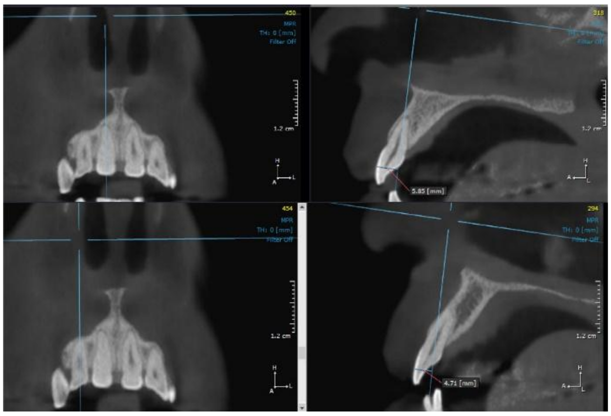


Fig (3): 3D image showing measuring the MFMI distance of right central and lateral incisors to FH.A.line.

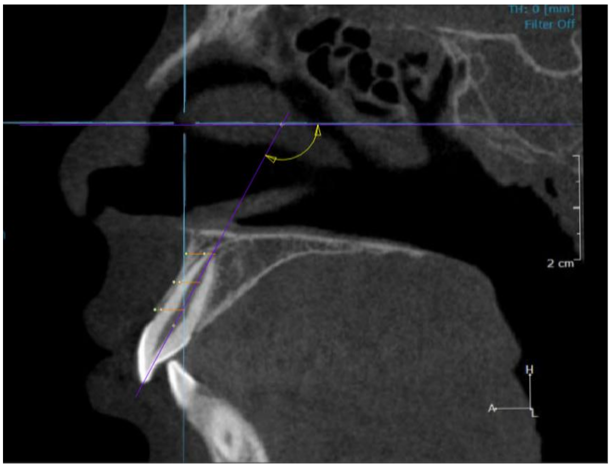
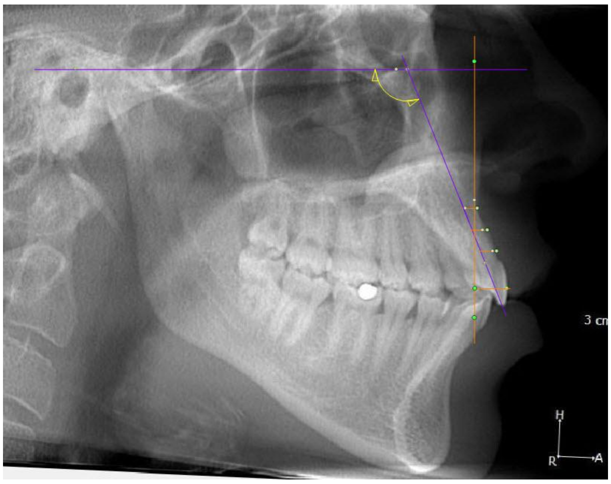


Fig (4): 3D image showing reference lines, points and labial alveolar bone measurements that were used for the MFMI tooth.



Fig(5): Reconstructed 2D image showing reference lines, points and labial alveolar bone measurements that were used for the MFMI tooth.

STATISTICAL ANALYSIS

Statistical analyses were performed using Statistical Package for the Social Sciences SPSS version (26). Numerical variables are expressed by descriptive statistics as mean and standard deviation. A one-way analysis of variance (ANOVA) test was used for comparing the mean differences between the 3D measurements. Independent t-test was performed to compare 2D and 3D measurements. All statistical tests were interpreted at the 5% significance level.

Results

The results of one-way ANOVA showed no statistically significant difference in the MFMI distance to FH.A line among maxillary incisor teeth. In addition, the right centrals were found to be the MFMI which showed the greatest mean (**5.39±2.34)** as presented in table (1) and figure (6).

As illustrated in table (2) and figure (7), there was statistically significant difference in the root length between the 3D and 2D MFMI teeth where the 2D MFMI root lengths were greater. Also, the results revealed that there was statistically highly significant difference (P <0.001) in the labial alveolar bone thickness between the 3D and 2D MFMI teeth at the three root points (E1, E2, E3) where the 2D MFMI incisor tooth had greater labial alveolar bone thickness at the three root points with the bone thickness increasing toward root apices of both of them. Furthermore, the 2D MFMI distance was significantly greater than that of the 3D MFMI distance.

Table (1): Comparison among maxillary incisor teeth for determination of MFMI tooth.

3D measurements				
MFMI distance	**Mean±S.D**	**Min –Max**	**F**	**p-value**
R 1	**5.39±2.34**	**0.22—11.28**	**1.400**	**0.243**
R2	**4.61±2.42**	**0.27—10.13**		
L1	**5.09±2.47**	**0.10—10.89**		
L2	**4.68±2.38**	**0.54—9.83**		

***R1** (Right central incisor); **R2** (Right lateral incisor)*
***L1** (Left central incisor); **L2** (Left lateral incisor)*
***MFMI distance** (distance from the most convex part of the labial crown surface to FH-A line)*
P>0.05 (Non-significant)

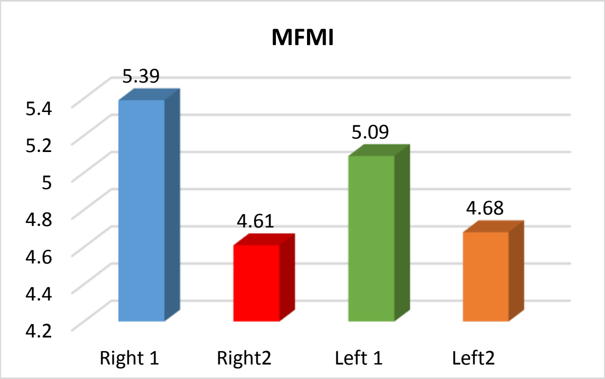


Fig (6): Bar chart representing the MFMI tooth among maxillary incisor teeth.

Table (2): Comparison between 2D and 3D alveolar bone thickness measurements for the MFMI tooth.

2D versus 3D CBCT measurements						
Measurements	**2D**		**3D**		**T**	**p-value**
	Mean	**S.D**	**Mean**	**S.D**		
Root Length	**14.03**	**1.90**	**13.17**	**1.75**	**2.549**	**0.012***
E1-Thickness	0.97	0.47	0.59	0.37	4.921	0.000**
E2-Thickness	**1.74**	**0.64**	**1.14**	**0.37**	**6.287**	**0.000****
E3-Thickness	3.35	1.33	2.04	1.01	6.076	0.000**
MFMI distance	**6.78**	**2.30**	**5.39**	**2.34**	**3.270**	**0.001***

P>0.05 (Non-significant); **P* $\leq$ *0.05 (Significant)*
***P* $\leq$ *0.001 (Highly significant)* ; ***E1-Thickness** (Root 3 mm from CEJ to bone)*
***E2-Thickness** (1/2 root to bone)* ; ***E3-Thickness** (Root apex to bone)*
***MFMI distance** (distance from the most convex part of the labial crown surface to FH/A line)*

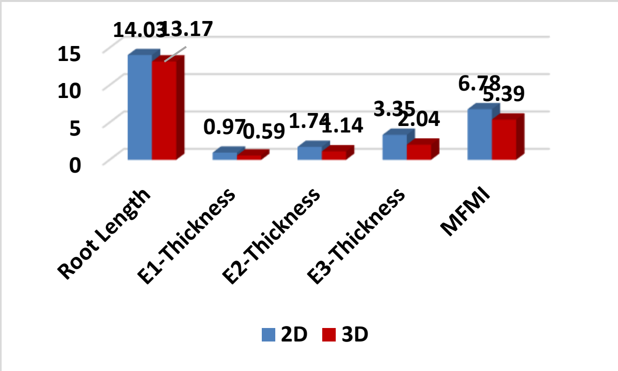


Fig (7): Bar chart representing 2D versus 3D MFMI tooth measurements.

Discussion

Evaluation of labial alveolar bone thickness over maxillary incisors prior to the start of orthodontic treatment is of great significance as it help in providing safe treatment by detecting the limits of orthodontic tooth movement, achieve better facial esthetics and maintain healthy periodontal condition by preventing iatrogenic bone loss and also may be useful for clinicians who are in need of accurate data about alveolar bone to perform root torque movements during orthodontic treatment [1,2].

Alveolar bone thickness evaluation using traditional 2D cephalometric radiographs may be overestimated since they are mid-sagittal projections and the presence of anterior nasal spine projecting from the midline of the maxilla obscures in 2 dimensions the amount of labial bone present. Also, expressing alveolar bone which is a three-dimensional anatomical structure as a two dimensional may mask the real alveolar bone thickness. In addition, magnification of image, distortion on lateral structures, head rotation and measuring-points identification errors made 2D cephalometric radiographs inaccurate in evaluation of alveolar bone measurements. Furthermore, superimposition of four incisors and canines on one another on traditional lateral cephalometric radiographs lead to large digitizing errors which can totally obliterate root definition of incisors resulting in difficulty in pairing the incisal and apical points of the incisors which obligates the observer to measure the most prominent incisor [3, 4].

Three dimensional imaging has the advantage of providing accurate measurements of alveolar bone over traditional 2D imaging. CBCT scanning is considered one of the three dimensional imaging modalities which provide accurate alveolar bone measurements since it overcomes the problems of image magnification, provides high definition of image which eliminates measuring point identification errors, eliminates superimposition of midline structures and superimposition of the roots of incisors and canines on one another which make it difficult to assess alveolar bone on each incisor tooth individually. These features give the clinicians the opportunity to use CBCT in evaluation of alveolar bone for precise diagnosis and treatment planning decisions [6, 10, 12, 13].

The current study was conducted to evaluate the labial alveolar bone thickness over the MFMI tooth three dimensionally after allocating it using CBCT and compare the measurements of the MFMI tooth detected on 3D CBCT with the measurements of the MFMI tooth on 2D CBCT constructed cephalogram to assess the accuracy of 2D CBCT reconstructed cephalograms from 3D CBCT. The decision of measuring alveolar bone at a distance of 3 mm from the CEJ was based on reports that buccal bone generally is 3 mm from the CEJ [14, 15].

The patient's ages whose CBCT records were used in the present study, were ranged between 16 to 35 years old. This age group above 16 years was selected to be sure that all permanent teeth had been fully erupted and below 35 years to decrease the opportunity of occurrence of alveolar bone loss due to periodontal diseases [16,17].

There was no significant difference in the forward distance of incisor's crowns in relation to FH.A line among maxillary incisor teeth when assessed three dimensionally. However, the right centrals were found to be the MFMI tooth where the forward distance from the most convex part of their labial crown surface to FH.A line was the greatest.

In the present study, instead of exposing patients, already subjected to CBCT scanning, to further exposure to radiation for obtaining a traditional lateral cephalograms (LCR), 2D LCRs were reconstructed from the 3D CBCT data which can be used as an alternative to traditional LCRs for analysis. Several studies had reported that reconstruction of conventional lateral cephalometric radiographs from CBCT can be done with similar accuracy and precision. Furthermore, reconstructed cephalograms were more accurate than traditional LCRs [5, 6, 8, 18-20].

On comparing 2D & 3D measurements, the MFMI distance to FH-A point line was greater in 2D than in 3D and this might be due to projection of ANS obscuring the position of A point in two dimensions.

Furthermore, the labial alveolar bone thickness over the MFMI at the three root points were overestimated when measured using 2D reconstructed cephalograms in comparison with the 3D CBCT measurements. This difference is probably related to projection of ANS from the midline of the maxilla and obscuring in 2 dimensions the bone labial to the apices of roots. kula et al [21] reported similar findings for the MFMI tooth. The bone near the CEJ frequently bulged compared with the bone over the middle of the root. Baumrind and Frantz [3] reported that landmark identification on a curve in 2D conventional cephalograms was not reliable. Fenestrations or dehiscence of the buccal bony plate could occur as iatrogenic consequence based on tracing of 2D lateral cephalograms. This suggests that clinicians who are concerned with the amount of bone at incisor root apices if performing labial root torque should be cautious when analyzing the 2D rendition of a CBCT image.

The MFMI root length was significantly longer when assessed in 2 dimensions than in 3 dimensions and this might be due to overlying of the roots of the four incisors over each other producing identification problems in two dimensions. Also, this might be due to evaluation of only one 0.25/0.3 mm section of the root by the 3D image whereas the 2D derivation of the CBCT image was a combination of multiple sections. Furthermore, slight distal tipping of incisor's root tips might allow them to be identified as left or right and a midline section through the long axis of the tooth might not include a small amount of root apex. Although magnification is considered a factor in conventional 2D radiographs causing an increase in root length measures in comparison with CBCT images, the 2D radiographs in this study were extracted from CBCT data and were not digital or conventional 2D radiographs. In spite of the small difference in root length reported in the present study, a greater difference was reported by Sherrard et al [22] when repeated measures were taken at the same day versus two time intervals.

However, parameters showed greater differences between 2D and 3D measurements than the reliability measurements. None of the authors reporting the labial bone thickness over the MFMI included intra-investigator reliability studies in their published articles so that it is difficult to compare reliabilities [14, 23-25]. Although the reliability of alveolar bone thickness measures using CBCT images was reported by Timock et al [26] to be excellent, it was not as good as alveolar bone height measures. Sun et al [27] showed that the similarity between the radio-density of bone and cementum can negatively influence identification of landmarks more for bone thickness than for bone height when comparing bone with soft tissue.

A prospective study using CBCT image and additional conventional films of the same patient could result in positioning problems and would increase exposure to radiation. Some clinicians take only 3D CBCT images and derive the 2D information usually from cephalometric, panoramic and periapical radiographs reconstructed from the CBCT image. In spite of better resolution provided by conventional 2D cephalograms, this study displayed that using 3D images was more beneficial as they allow isolation of various areas such as non-midline structures and maxillary incisors besides magnification with a conventional 2D radiograph compared with a 3D image would be an issue.

Conclusions

Based on the results obtained from the current study, the following conclusions were noted:

- On comparing measurements of 2D cephalograms reconstructed from 3D CBCT images with 3D images measurements, the thickness of alveolar bone overlying the most forward maxillary incisor roots seems to be overestimated in 2D cephalograms.
- Alveolar bone measurements over the MFMI roots were interfered by ANS in two dimensions.

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