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Accuracy of Crestal Buccal Bone Height Measurements in the Anterior Maxilla Using Cone-Beam Computed Tomography

Daryoush Goodarzipour[1], Sona Ghahramani[2], Negar Kiani[3], Zahra Madani[4]*

1. Department of Dentomaxillofacial Radiology, School of Dentistry, Tehran University of Medical Sciences, Tehran, Iran
2. Private Practice, Tehran, Iran
3. Department of Dentomaxillofacial Radiology, Faculty of Dentistry, Semnan University of Medical Sciences, Semnan, Iran
4. Department of Dentomaxillofacial Radiology, Faculty of Dentistry, Arak University of Medical Sciences, Arak, Iran

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**** Corresponding author:***
Department of Dentomaxillofacial Radiology, Faculty of Dentistry, Arak University of Medical Sciences, Arak, Iran

Email: zahramdn93@gmail.com

A B S T R A C T

Objectives: Linear measurements play a pivotal role in determining bone quantity. This study aimed to assess the accuracy of cone-beam computed tomography (CBCT) in measuring the height of buccal bone in the maxillary anterior teeth, relative to the cementoenamel junction (CEJ).

Materials and Methods: This Original Research study evaluated 33 maxillary anterior teeth (11 central incisors, 11 lateral incisors, and 11 canines) of 20 patients. Following surgical exposure, the distance between the CEJ and the buccal alveolar bone crest was measured with a digital caliper. Measurements were made by an oral radiologist twice with a 3-week interval on CBCT images. Data were analyzed using SPSS, and P≤0.05 was considered statistically significant.

Results: The mean difference in buccal bone height between CBCT and clinical measurements was 0.45±0.38mm for central incisors, 0.26±0.29mm for lateral incisors, 0.52±0.42 mm for canines, and 0.41±0.37mm overall. No significant difference was detected between the CBCT and direct measurements (P>0.05). The frequency of inaccurate measurements (defined as differences greater than 0.5mm) was 36.4% for central incisors, 9.1% for lateral incisors, and 36.4% for canines. The intraclass correlation coefficient (ICC) between the twice-taken CBCT measurements (with a 3-week interval) was 0.972; while the ICC was 0.824 between the CBCT and direct measurements.

Conclusion: CBCT may not be accurate enough to assess the position and height of thin buccal bone relative to the CEJ in the anterior maxilla. However, CBCT demonstrated sufficient accuracy in assessing the position of buccal bone crest for lateral incisors.

Keywords: Cone-Beam Computed Tomography; Dental Implants; Dimensional Measurement Accuracy; Tooth Cervix

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INTRODUCTION

Recently, the success criteria in implant dentistry were expanded to include parameters such as the soft tissue around the implants, implant surfaces and prosthesis, and rehabilitation of anterior maxilla by dental implants. Placement of an implant in the anterior region of the maxilla is often considered a challenging procedure due to its significant impact on patient's esthetic appearance and delicate anatomy of the site. Typically, a thin buccal bone plate covers prominent roots in this area [1,2]. Before placing an implant, it is important to conduct a thorough evaluation of the orofacial anatomy, taking into consideration factors such as crown

width and facial bone atrophy. By performing meticulous evaluations [3], it becomes possible to accurately place dental implants in correct position. Furthermore, preserving the buccal bone in the esthetic zone is crucial as it enables the preservation of soft tissue contour after tooth extraction, and promotes bone regeneration around dental implants [4].

Imaging techniques are essential for assessing bone quality and quantity, and alveolar bone height to provide a suitable treatment plan for implant placement. This can ultimately lead to the long-term success of implant treatment [5]. Panoramic radiography, intraoral radiography, computed tomography, and cone-beam computed tomography (CBCT) are the commonly used imaging techniques for treatment planning [6]. Among these techniques, panoramic radiography is the most frequently utilized two-dimensional dental radiographic modality that provides a comprehensive single view of the jaws and teeth [7].

Conventional radiographic techniques, such as intraoral and panoramic radiographs, are commonly recommended for assessing bone height at the implant site. However, these techniques often fall short in accurately detecting bone width, determining the extent of bone resorption, and providing three-dimensional (3D) information critical to achieve the best preoperative treatment plan [7]. Additionally, determining the bone height with high precision is not always feasible due to various technical and processing errors as well as magnification-induced distortions. Blurred and artifact-ridden images of structures outside the focal trough are unavoidable in panoramic radiography [7]. Linear measurements hold great significance in implant surgery, making it imperative for surgeons and radiologists to recommend alternative radiographic methods. Other clinical radiographic techniques like computed tomography can be employed to diagnose defects in all three dimensions. CBCT, with its high-resolution, low-dose radiation, and full 3D identification of alveolar bone, offers several advantages over conventional radiographs when assessing bone structure around teeth [8].

CBCT is a relatively modern imaging modality that was developed after the advent of digital radiography systems. These systems offer 3D images of maxillofacial structures, without causing overexposure or blurring of structures. CBCT finds extensive use in dentistry, including implantology and orthodontics. It is also used for detection of temporomandibular disorders, and diagnosis and treatment of cysts and tumors in the oral and maxillofacial region [9]. Recent research indicates that linear measurements made on CBCT images are precise and dependable [10]. However, the accuracy of CBCT images can be influenced by various factors such as radiation exposure, scanner characteristics, software used for measurements, interpretation limitations of clinicians, and motion artifacts [8,11]. Based on a study by Tanaka et al, [12] on dry skulls, CBCT imaging used to measure buccal bone thickness demonstrated a sensitivity of 75.4% and a specificity of 65.5%. The burnout of bone makes it challenging to diagnose conditions in the anterior region through imaging. Therefore, given these factors, CBCT imaging may have certain limitations [12]. Hence, it becomes crucial to ascertain the accuracy of linear measurements in the presence of soft tissue - something that surgeons encounter in the clinical setting.

Linear measurements made on CBCT images with caliper or conventional computed tomography measurements taken at the same points have been compared to assess the CBCT accuracy in dry skulls [10]. However, due to the lack of soft tissue around the dry alveolar bone [13], the measurements made on dry skulls may not be precise enough. In fact, the contrast between bone and air during imaging is typically higher than the contrast between bone and soft tissue, as is the case with a dry skull versus a human. Presence of soft tissue around bone can decrease image contrast, increase scattered radiation, and consequently affect both image quality and measurement accuracy. Moreover, metal and motion artifacts can also impact the accuracy of CBCT measurements, along with the soft tissue surrounding and within the bone [14].

As CBCT imaging is primarily used to obtain linear measurements for various dental applications, it is essential to clearly define

the limitations of measurements made on CBCT images. The objective of this study was to assess the accuracy of CBCT measurements in determining the position of the buccal bone crest of maxillary anterior teeth relative to the cementoenamel junction (CEJ) in implant candidates.

MATERIALS AND METHODS

Subject selection and data collection:

This Original Research study included evaluation of 33 maxillary anterior teeth, comprising 11 central incisors, 11 lateral incisors, and 11 canines in 20 patients who underwent preoperative CBCT for dental implant placement at the Implant Department of the Faculty of Dentistry, Tehran University of Medical Sciences. Written informed consent was obtained from each participant, and the Clinical Research Ethics Committee of Tehran University of Medical Sciences approved the study (reference number: IR.TUMS.VCR.REC.1395.146). Age and sex were not relevant to this evaluation as the goal of the study was to measure linear distances using relevant techniques and compare the results across different teeth. Subjects were excluded from the study if it was not possible to clearly visualize the CEJ of their teeth during surgery or had veneered teeth or crowns that hindered accurate examination of the CEJ area.

Direct measurements:

During surgical exposure, the distance from the CEJ to the mid-buccal point of the buccal bone crest was measured twice using a digital caliper with an accuracy of 0.01mm by the surgeon (Fig. 1).

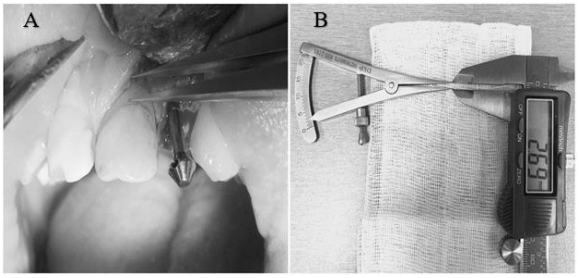

Fig 1. (A) Measuring the distance from the CEJ to the buccal bone crest in the mid-buccal region of maxillary left central incisor during the surgical exposure; (B) To be more precise, a digital caliper with 0.01mm accuracy was used.

The mean value of these repeated measurements was considered as the gold standard and used for comparison with CBCT measurements.

CBCT measurements:

All CBCT images were obtained at the Radiology Department of the Dentistry Faculty of Tehran University of Medical Sciences using an Alphard Vega Dental CT system (Asahi Roentgen Ind. Co., Ltd, Kyoto, Japan). The CBCT exposure settings included a current of 4mA, an exposure time of 17sec, a voxel size of 0.2mm, and a voltage of 80kVp. Neo 3D software (Asahi Roentgen) was employed to analyze the images, and measurements of the distance between the CEJ and the buccal bone crest were made at the mid-buccal section on the cross-sectional view of the CBCT images (Fig. 2). Each measurement was performed twice by the same oral and maxillofacial radiologist with a 3-week interval between assessments. The intraclass correlation coefficient (ICC) was calculated to assess intraobserver reliability between the first and second CBCT measurements of the distance between the buccal alveolar crest and the cementoenamel junction (CEJ) of anterior maxillary teeth.

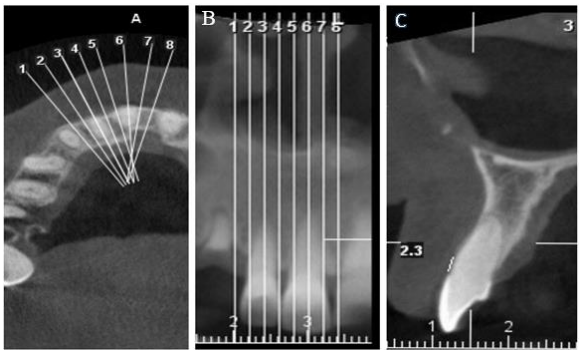

Fig 2. (A) Axial view;(B) Mesiodistal dimension was bisected on panoramic view to find the mid-buccal point; (C) Cross-sectional view of the CBCT image used to measure the distance from the CEJ to the buccal bone crest.

Statistical analysis:

Data analysis was performed using SPSS statistical software version 26 (IBM Corp., Armonk, NY, USA). Quantitative variables

were presented as mean and standard deviation values; while, qualitative variables were reported as number and percentage. One-way ANOVA was used to perform a quantitative comparison of the measurement differences (for both absolute and actual values). Additionally, to qualitatively assess the observed measurement differences, the Chi-square test was used. Furthermore, to compare the mean absolute error of CBCT measurements with direct measurements, one-sample t-test was employed for each tooth, using a constant value of 0.5mm. A P value less than 0.05 was considered statistically significant. Fisher's exact test was used to compare the frequency of measurement differences greater than 0.5mm among the examined tooth groups.

RESULTS

The mean difference in buccal bone level between the CBCT and direct measurements was 0.35mm for central incisors, 0.23mm for lateral incisors, and 0.07mm for canines. Nonetheless, the mean absolute errors indicated that the difference was greater in canines (0.52mm) than in central (0.45mm) and lateral (0.26mm) incisors (Table 1). The results of one-sample t-test revealed that the difference between direct and CBCT measurements in lateral incisors was significantly smaller than 0.5mm (P=0.02); whereas, this difference did not reach statistical significance in central incisors (P=0.69) or canines (P=0.87). Additionally, one-way ANOVA demonstrated no significant difference among tooth types (central incisors, lateral incisors, canines) in this regard (P= 0.45). Also, there was no significant difference between the absolute value of direct and CBCT measurement differences within the tooth groups (P=0.24).

This study also compared the frequency of inaccuracies in measuring the position of the buccal bone crest of maxillary anterior teeth relative to the CEJ using both CBCT and direct clinical measurements, with results presented in Table 2. The difference between the CBCT and direct measurements in 9 out of 33 studied teeth (4 central incisors, 4 canines, and 1 lateral incisor) was greater than 0.5 mm, resulting in a total of 27.3% CBCT inaccuracy rate. According to Table 2, the difference ratio (>0.5mm) between the CBCT and direct clinical measurements of the position of the buccal bone in central incisor and canine teeth was similar (36.4%); while, this ratio for lateral incisors was low (9.1%).

Fisher's statistical test was utilized to evaluate the accuracy of CBCT in determining the anterior maxillary buccal bone crest position in central incisors, lateral incisors, and canines. Although the difference ratio of more than 0.5mm was equal to 36.4% in central incisor and canine teeth and only 9.1% in lateral incisors, this difference was not statistically significant (P=0.30). The ICC between the twice-taken CBCT measurements (with a 3-week interval) was 0.972; while the ICC was 0.824 between the CBCT and direct measurements (Table 3).

Table 1. Mean difference of distances from cementoenamel junction (CEJ) to buccal bone crest (BBC) in cone-beam computed tomography (CBCT) measurements compared to direct measurements in maxillary anterior region

Variables	Teeth	N	Mean difference of distances	SD	CI
CEJ-BBC distance difference between CBCT and direct measurement	Central incisors	11	0.35	0.48	0.02–0.67
	Lateral incisors	11	0.23	0.31	0.02–0.44
	Canines	11	0.07	0.69	0.39–0.53
	Total	33	0.22	0.52	0.03–0.40
Absolute value of CEJ-BBC distance difference between CBCT and direct measurement	Central incisors	11	0.45	0.38	0.20–0.71
	Lateral incisors	11	0.26	0.29	0.07–0.45
	Canines	11	0.52	0.42	0.24–0.80
	Total	33	0.41	0.37	0.28–0.54

SD: standard deviation; CI: confidence interval; N: number.

Table 2. Frequency of inaccuracies (differences >0.5mm) in measuring the position of the buccal bone crest in the anterior maxilla relative to the CEJ between CBCT and clinical measurements

Teeth	Difference					
	<0.5mm		>0.5mm		Total	
	N	%	N	%	N	%
Central incisors	7	63.6	4	36.4	11	100
Lateral incisors	10	90.9	1	9.1	11	100
Canines	7	63.6	4	36.4	11	100
Total	24	72.7	9	27.3	33	100

Table 3. Validity and reliability of measuring the distance between the anterior maxilla buccal bone crest and CEJ on CBCT images using ICC

Measurements	ICC	P value
Clinical and CBCT measurements	0.82	<0.001
CBCT measurements repeated after a 3-week interval	0.97	<0.001

ICC: Intraclass correlation coefficient

DISCUSSION

For many years, dental implants have been the preferred choice for achieving optimal results in dental esthetics [3]. Recently, there has been a growing demand for prosthetic and cosmetic treatments that involve implant placement. Successful implant placement requires comprehensive information about the quality and quantity of bone, a precise 3D view of the implant position, and an understanding of vital anatomical structures surrounding the implants—such as the mandibular canal, nasal cavity, alveolar crest, and maxillofacial regions—as well as adjacent teeth, all of which can be obtained through appropriate radiographic imaging systems. Additionally, a careful surgical treatment plan is essential to ensure long-term stability of dental implants [8,15].

Numerous studies have pointed out the limitations of 2D imaging, which has now been largely replaced by 3D imaging. The shortcomings of 2D images include the inability to diagnose issues such as lack of osseointegration, undesirable marginal bone levels due to image superimposition, and the difficulty in visualizing the surfaces of interproximal alveolar bone. These limitations can contribute to implant failure [7, 16-18]. Several studies have explored the accuracy, validity, and reliability of CBCT in measuring bone height and thickness, as well as diagnosing and treating marginal bone deformities in the maxillofacial region, particularly around implants. Early detection of bone loss is vital for effective treatment planning and for predicting the outcomes for teeth and implants [19-21]. Researchers have also proposed using CBCT as a paraclinical tool to enhance accuracy and shorten clinical procedural times, eliminating the need for extensive bone mapping [5, 18]. The American Academy of Oral and Maxillofacial Radiology recommends the use of 3D CBCT images for evaluation and treatment planning in fields such as periodontology, implantology, maxillofacial surgery, and orthodontics [21]. Today, there is a growing trend towards utilizing CBCT for 3D and cross-sectional imaging in oral and maxillofacial areas [22].

The present results indicated that the absolute value difference in CBCT and direct measurements of the buccal crest of central and lateral incisors, and canine teeth compared to CEJ were not significantly different from each other. The CEJ-buccal bone crest distance in central incisors was greater than that in canine and lateral incisors, but the absolute value of the CEJ-buccal bone crest distance in canine teeth was greater than that in others; nonetheless, the differences were not statistically significant. In terms of the difference in CEJ-buccal bone crest distance between the CBCT and clinical measurements, it was significantly less than 0.5mm (90.9%) for lateral incisors, but not for central incisors and canines. This may be due to the low thickness of the buccal bone in the anterior region of the maxilla (averagely 1mm) [23, 12], which was not detectable on some CBCT images in this study and increased measurement error. The difference in measuring the position of the buccal crest using CBCT versus clinical measurements was more than 0.5mm in one-third of both central incisors and canine teeth (36.4% in both groups), but in only one lateral

incisor. Although this difference was not statistically significant, it was clinically significant, and CBCT inaccuracy was estimated at 27.3% of the total samples. The lack of statistical significance may be due to the small sample size. These differences appear to be related to anatomical variations between the evaluated tooth types. The buccal bone is generally thinner in the lateral incisor region compared to central incisors and canines, which may influence the accuracy of CBCT measurements across these areas. Based on our study and some previous research, CBCT has good accuracy and reliability for measuring bone dimensions when bone thickness is greater than 1mm, but it may become burnt out in the anterior maxilla due to the thickness of bone [12].

Behnia et al. [13] compared the thickness of the labial and palatal bone plates in the maxillary anterior region using both clinical and CBCT measurements. They found that CBCT was more accurate when the alveolar bone thickness was greater than 1mm, but in most cases, it was less than 1mm, which caused many measurement errors. In another study, there was no significant difference between clinical and CBCT measurements, and CBCT was able to reconstruct clinical measurements with sufficient accuracy. This study attributed the better detection and accurate measurements of CBCT images in posterior teeth to the greater thickness of buccal bone [24]. Shiratori et al. [25] evaluated the accuracy of CBCT for measuring the volume of the buccal bone in implant candidates and found no statistically significant difference between the measurements made on CBCT scans and clinical measurements. However, CBCT did not have the same accuracy at all implant points, and measurements with bone thickness less than 2mm were less accurate. These results align with the findings of our study. In dentistry, measurements are a fundamental part of orthodontics and dental implant procedures, so it is crucial to ensure that the evaluation methods for teeth and bone are highly reliable. In the present study, the validity and reliability of measurements between the two groups (CBCT and clinical measurements, with CBCT measurements repeated twice with a 3-week interval) were assessed using ICC. The results showed a high level of agreement between the groups, with an ICC close to 1, indicating good reproducibility of this measurement method. In a study by Timock et al, [26] CBCT was used with 0.3mm voxel size for buccal bone thickness and height measurements in comparison with direct measurements on 12 dry skulls. They found that CBCT was more reliable and accurate in buccal bone height measurements compared to buccal bone thickness measurements, with agreement between the results of direct and CBCT measurements.

The reliability and accuracy of CBCT have been compared to other conventional methods, including multi-slice computed tomography (MSCT). In a study by Dings et al, [27] after the imaging procedure, measurements were carried out at various implant positions in the orbital, nasal, and temporal regions on five human skulls. The mean measurement bias of 0.39 to 0.53mm with a significant overestimation of bony dimensions was shown for CBCT, exceeding the used voxel size of 0.3mm. It was also noted that contrast adjustments could statistically affect linear bone width measurements for CBCT images. Both clinical and CBCT methods had sufficient validity and reliability for dental measurements.

Other studies have also assessed the accuracy of CBCT and MSCT for diagnosing mandibular bone defects in sheep. They found that the specificity and sensitivity of CBCT were higher than MSCT, indicating that CBCT had greater accuracy compared to MSCT in detecting bone defects [28, 29]. The high accuracy of CBCT images has also been emphasized in diagnosing and examining the dimensions and location of accessory mental foramen, which is important for preventing complications during and after surgery [30,31]. These studies focused on measuring maxillofacial distances more extensively than our study and measuring larger distances will likely yield even greater accuracy and reliability of CBCT measurements.

Several factors can influence the accuracy of CBCT imaging measurements, including the presence of soft tissue surrounding the bone, which can reduce image contrast and also

produce scattered radiation. Additionally, presence of metal and patient movement-induced artifacts, as well as voxel sizes, can affect measurements [32, 33]. Therefore, it appears that the accuracy of measurements performed on human skulls is lower compared to those calculated on dry skulls. Due to these limitations, recent research has been conducted in vitro using dry skulls; while, clinical trials are limited in this regard [34].

Given the high inaccuracy of CBCT (more than 1.5mm difference in CEJ-buccal bone crest distance between CBCT and clinical measurements) observed in central incisor and canine teeth, it appears that CBCT may not have sufficient accuracy to estimate the position of the thin buccal bone crest relative to the CEJ in the anterior maxilla. However, CBCT measurements were not significantly different from direct clinical measurements in lateral incisors, and had optimal accuracy in measuring the position of the buccal bone crest relative to the CEJ in lateral incisors.

Careful consideration of the aim of CBCT evaluation can optimize image features to reach maximum levels. Smaller volumes (field of view) of CBCT are associated with lower radiation dose and better image resolution; while, larger volumes of CBCT scans achieve more consistent density [35]. To observe periodontal structures, cortical bone, alveolar crest, and alveolar cortical plate, high-resolution images and smaller voxel sizes are needed in CBCT [36]. Mukhia et al. [33] found no significant difference in measurement reliability between the CBCT scans with 0.2mm and 0.4mm voxel sizes, indicating that larger voxels may only be used to minimize radiation exposure. In the present study, 0.2mm voxel size was used in Alphard Vega Dental CT system to obtain images. In general, when conducting imaging evaluations of each patient before implant surgery, two important factors should be assessed: the accuracy and efficiency of the method used to estimate the quantity, quality, and position of bone [37, 38].

One limitation of the present study was the challenge of identifying patients with bone resorption in the anterior maxilla, since imaging is typically not recommended for periodontal patients. As a result, we had to select patients who, despite having bone resorption in the anterior region, were still in need of dental implant placement.

CONCLUSION

In conclusion, based on the limitations of this study, the CBCT imaging technique is not accurate enough to estimate the position and height of the thin buccal bone relative to the CEJ in the anterior maxilla due to its low accuracy in central incisor and canine regions. However, in lateral incisors, there was no significant difference between the CBCT and direct measurements, indicating sufficient accuracy of CBCT in measuring the position of the buccal bone crest relative to the CEJ in this area. Nonetheless, further CBCT evaluations may be required to confirm these findings.

CONFLICT OF INTEREST STATEMENT

None declared.

GENERATIVE AI IN SCIENTIFIC WRITING

Artificial intelligence (AI) tools were used only for language editing and improvement of grammar and readability. No AI tool was used for data analysis, image interpretation, or generation of scientific conclusions

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