Quantitative Evaluation of Bone-Related Factors at the Implant Site by Cone-Beam Computed Tomography

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ABSTRACT: Objectives: Dental implant is a commonly used treatment modality for replacement of the missing teeth. The aim of the present study was to evaluate a number of bone-related factors at the implant site preoperatively by cone-beam computed tomography (CBCT).

Materials and Methods: A total of 400 implant sites were evaluated on CBCT images. The height, width, angle of residual ridge, thickness of cortical bone crest, and the ridge concavity were evaluated on cross sectional images at four regions: the anterior maxilla, anterior mandible, posterior maxilla, and posterior mandible.

Results: The highest thickness of cortical bone was observed in posterior mandible followed by anterior mandible, anterior maxilla, and posterior maxilla. In the mandible, the mean buccal concavity was higher in the anterior than in the posterior region ($P = 0.0094$). The measurements indicated that in both the maxilla ($P = 0.0256$) and mandible ($P < 0.0001$), the residual ridge width was lower in the anterior than in the posterior region; while the height of the residual ridge was higher in the anterior than in the posterior region in the mandible ($P < 0.0001$). In the maxilla, the remaining ridge angle in the anterior region was greater than that in the posterior region ($P < 0.0001$).

Conclusion: Anatomical variations detected on CBCT results in personalized treatment planning considering best site and the best fixture in terms of size and position prior to implant fixture insertion.

KEY WORDS: cone-beam computed tomography, dental implants, anatomy

I. INTRODUCTION

Tooth loss has an adverse effect on smile esthetics and efficiency of mastication.[1] It also results in a reduction in bone width and height, followed by adverse facial changes, overeruption of the opposing tooth, orthodontic problems, and eventually negative psychosocial effects.[2,3]

Dental implant treatment is widely used to replace the missing teeth.[4–6] Successful implant osseointegration and optimal long-term stability depend on adequate management of decreased bone volume.[7] Cone-beam computed tomography (CBCT) has become highly popular as a reliable imaging modality for maxillofacial imaging. It offers beneficial information for selection of the final implant size and location, and allows the clinicians to assess the amount, density and quality of bone, ultimately enabling optimal implant placement without traumatizing the vital structures such as the mandibular canal, the inferior alveolar nerve, the mandibular posterior lingual undercut, and the maxillary sinuses.[8] Accurate assessment of bone volume and shape, along with clinical evaluations and palpation

of the bone ridge at the implant placement site, are essential prior to implant insertion.[9,10] In oral implantology, the most serious and frequent complications described in the literature occur during surgery, and may result from inadequate preoperative assessment, poor implant orientation, or the surgical procedure itself.[11]

The aim of the present study was to evaluate a number of bone-related factors including the bone height, width, angle of residual ridge, thickness of cortical bone of the alveolar crest, and ridge concavity at the implant site before surgery by CBCT.

II. MATERIALS AND METHODS

This study was approved by research committee of Shahid Beheshti University of Medical Sciences, Tehran, Iran (IR.SBMU.RIDS.REC.1396.493).

A. Sample Size

This descriptive cross-sectional study was performed on data from CBCT examinations of 38 patients referred to a private oral and maxillofacial radiology clinic, Tehran, Iran from January 2018 to January 2019.

B. Evaluation of CT Scans

CBCT scans were taken with NewTom VGi (Verona, Italy), with the exposure settings of 110 kVp, 3.3–20 mA, 12 × 8 cm field of view, and 0.3 mm voxel size. Images were evaluated using NNT 3D software (Version No. 8, Verona, Italy) in a standardized position for each site of assessment in which the long axis of the ridge is parallelized to axis of implant insertion. Demographic information including age and gender were recorded. All measurements taken from the CBCT scans were completed by one experienced oral and maxillofacial radiologist.

C. Inclusion Criteria

– CBCT scans must contain at least one edentulous site in maxilla or mandible in adult patients above 18 years old.

– Scans must have been full volume containing proximal anatomic landmarks.

– Images must have been of adequate resolution/diagnostic quality.

D. Exclusion Criteria

– Any scan that did not satisfy any of the requirements listed in the inclusion criteria.

– Any scan with "radiographic noise" or patient movements that did not allow measurements to be recorded in the planning software.

– Any scan that included maxillofacial trauma, orthognathic surgery, congenital anomalies, or pathology at the site of evaluation.

– Patients with previous dental implant or bone graft.

– Patients with previous history of bisphosphonate drug consumption.

One hundred (100) dental implant sites were required at each of the four regions namely the anterior maxilla, anterior mandible, posterior maxilla, and posterior mandible. Therefore, a total of 400 implant sites were evaluated. The anterior region was defined from canine to canine, and the posterior region was defined from the first premolar to the second molar. At each edentulous area, cross-sectional images with 2-mm thickness were reconstructed. In single-tooth edentulous areas, the central cross-sectional slice was evaluated as the desired section. In areas where more than one tooth was missing, the mesiodistal width of the tooth crown as shown in Table 1 was used to select the desired cross-section.[12] In this way, from the distal of the existing tooth, cross-sectional slices were

TABLE 1: Mean mesiodistal width of permanent teeth[12]

Tooth	Mandibular (mm)	Maxillary (mm)
Central incisor	5.3	8.6
Lateral incisor	5.7	6.6
Canine	6.8	7.6
First premolar	7.0	7.1
Second premolar	7.1	6.6
First molar	11.4	10.4
Second molar	10.8	9.8

counted as the width of the missing tooth crown, and the closest section to the center of the tooth crown was selected as the desired section.

On the selected cross-sectional image, the following measurements were performed according to Nickenig et al.[13]

1. Height of the Residual Alveolar Ridge

From the crest of the ridge to the proximity of the existing anatomical landmark; the mandibular canal, mental foramen, and anterior loop in the posterior mandible, up to the floor of the maxillary sinus in the posterior maxilla, up to the floor of the nasal cavity and the incisive canal in the anterior maxilla, and up to the inferior border of the mandible in the anterior mandible (Fig. 1A–1E).

2. Width of the Residual Ridge

One millimeter apical to the crest of the ridge as a transverse line connecting the buccal and lingual plates (Fig. 2).

3. Bucco-Lingual Width

Bucco-lingual width of cortical bone at 2 mm, 4 mm, and 6 mm distance apical to the alveolar crest (Fig. 3).

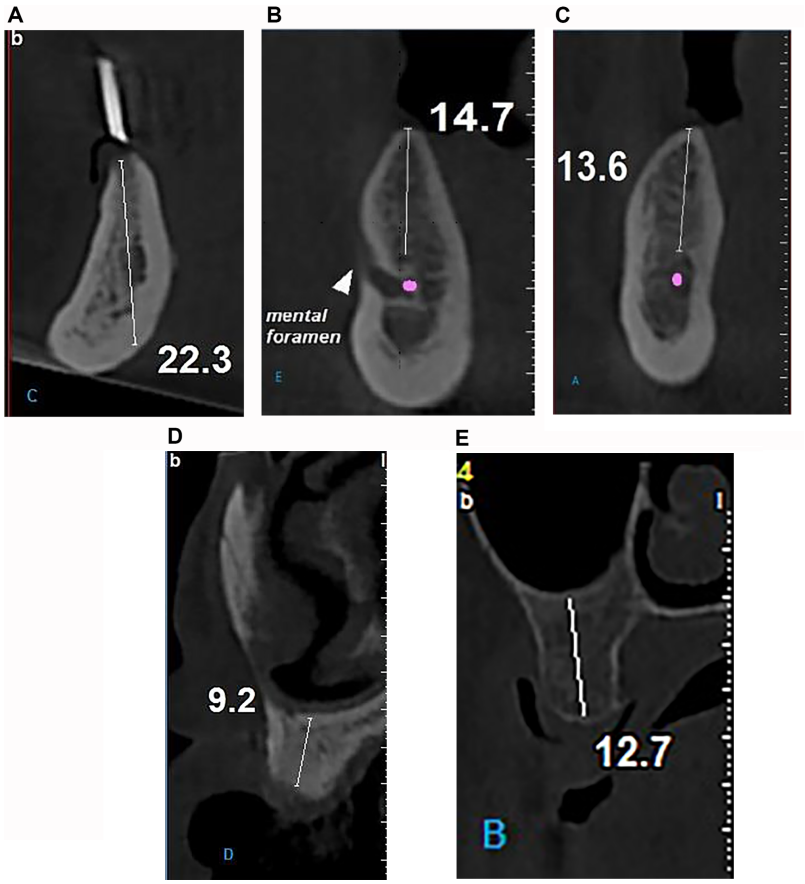

FIG. 1: Quantitative assessment of ridge height using cross-sectional CBCT images. Measurements of the height. (A) ridge height in anterior mandible, (B) ridge height considering mental foramen, (C) ridge height in posterior mandible considering inferior alveolar nerve canal, (D) ridge height in anterior maxilla considering nasal floor, (E) ridge height in posterior maxilla considering sinus floor.

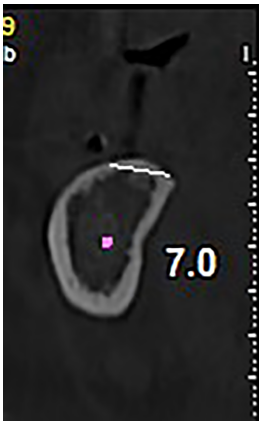

FIG. 2: Assessment of ridge width at 1 mm distance to ridge crest

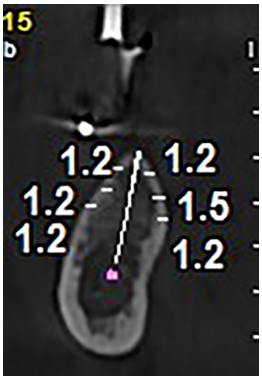

FIG. 3: Assessment of cortical bone thickness on buccal and lingual site at 2, 4, and 6 mm from the crest

4. Crestal Cortical Bone Thickness

From the top edge of the crest to where the cancellous bone was observed (Fig. 4).

5. Buccal and Lingual Concavity

Ridge undercut depth from the deepest point of the concavity, to the most prominent point of the lingual overhang (Fig. 5).

6. Ridge Angle in Degrees

The angle between the longitudinal axis of the ridge and a line perpendicular to the base from the crest (Fig. 6).

E. Statistical Analysis

All data were entered into a database system and evaluated using SPSS® for Windows version 21 (SPSS Inc., Chicago, IL, USA). Patients' data were analyzed anonymously. Every case was assigned a registration number before evaluation to allow explicit and anonymous attribution of necessary information. The intra-examiner agreement was determined by comparing two repeated measurements at 10 randomly chosen cross-sectional images at 1 month apart, using the intraclass coefficient (ICC) test. Data analysis was performed with descriptive statistics. The level of significance was set at $p = 0.05$.

III. RESULTS

A. Intra-Operator Reliability

Measures for the first and second replicates of 15 patients were recorded and intra-class correlation coefficients (ICC) were established for all measurements. Most measures demonstrated a high degree of reliability between the first and second replicates with ICC values exceeding from 0.63 to 0.97.

B. Demographic Data

Within the 38 assessed CBCT scans, the gender distribution was 18 (47.3%) female and 20 (52.6%) male. The age range of subjects in this study varied from 42 to 75 years old with mean of 64.33 ± 10.61 for females and 65.16 ± 10.88 for males.

C. Quantitative Assessments (Tables 2–4)

1. Ridge Height

The mean ridge height in the anterior maxilla and mandible was 14.07 ± 3.61 and 19.32 ± 6.02 mm, respectively. These values were 9.26 ± 4.70 and 12.12 ± 4.81 mm in the posterior maxilla and mandible, respectively. The height of the residual ridge was significantly higher in the anterior than in the posterior region in the mandible ($P < 0.0001$).

FIG. 4: Assessment of crestal cortical bone thickness

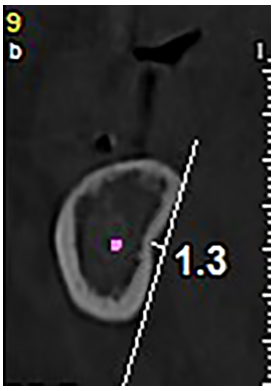

FIG. 5: Assessment of lingual concavity

FIG. 6: Assessment of ridge angle in degrees

2. Cortical Crest Height

The mean cortical crest height in anterior and posterior maxilla were 1.28 ± 0. 44 and 0.95 ± 0.37 mm, respectively. The mean cortical crest height in anterior and posterior mandible were 1.11 ± 0.43 and 1.47 ± 0.58 mm, respectively. The maximum crestal cortical bone thickness was related to the posterior mandible with 4-mm thickness and the minimum crestal cortical bone thickness was related to the anterior and posterior maxilla with 0.5-mm thickness. The thickness of the cortical crest was significantly higher in the anterior maxilla than in the posterior region and in posterior mandible than anterior segment ($P < 0.0001$).

3. Ridge Width

The mean ridge width in the anterior maxilla and mandible was 4.21 ± 1.14 and 4.48 ± 1.11 mm, respectively; these values were 4.68 ± 1.77 and 5.23 ± 1.17 mm, in the posterior maxilla and mandible, respectively. The measurements indicated that in both the maxilla ($P = 0.0256$) and mandible ($P < 0.0001$), the residual ridge width was significantly lower in the anterior than in the posterior regions.

4. Buccal Lingual Cortex

Buccal and lingual cortex width at 2, 4, and 6 mm distance from the crest.

TABLE 2: Quantitative data, ridge height, width, cortical crest thickness, and angle, assessed using CBCT measurements

	Jaw	Region	Min	Max	Mean (mm)	SD	*P* value
Height	Maxilla	Anterior	4.49	19.79	14.076	3.615	0.1723
		Posterior	2.21	22	9.263	4.708	
	Mandible	Anterior	3.59	34.21	19.329	6.026	< 0.0001
		Posterior	3.20	25.76	12.123	4.815	
Width	Maxilla	Anterior	1.76	7.29	4.210	1.140	0.0256
		Posterior	1.52	9.71	4.684	1.773	
	Mandible	Anterior	1.43	7.22	4.489	1.113	< 0.0001
		Posterior	2.21	25.76	5.230	1.177	
Cortical crest thickness	Maxilla	Anterior	0.50	2.51	1.280	± 0.440	< 0.0001
		Posterior	0.50	2.50	0.958	± 0.371	
		Total	0.50	2.51	1.117	± 0.436	
	Mandible	Anterior	0.60	3.50	1.473	± 0.582	< 0.0001
		Posterior	0.60	4.00	1.711	± 0.608	
		Total	0.60	4.00	1.59	± 0.605	
Angle	Maxilla	Anterior	0.60	4.00	18.28	± 7.197	< 0.0001
		Posterior	0.60	4.00	11.165	± 9.263	
	Mandible	Anterior	0	25	10.200	± 5.340	0.5670
		Posterior	0	25	10.659	± 5.964	

TABLE 2: (*continued*)

Region	Jaw		Height	Width	Cortical crest thickness	Buccal cortex thickness at 2	Buccal cortex at 4	Buccal cortex at 6	Angulation	Length	Width
Anterior	Maxilla	Mean							18.280	14.076	4.210
		N							100	100	100
		Std. deviation							± 7.197	± 3.615	± 1.140
		Minimum							0	4.49	1.76
		Maximum							5	19.79	7.29
	Mandible	Mean							10.200	19.329	4.489
		N							100	100	100
		Std. deviation							± 5.340	± 6.026	± 1.113
		Minimum							0	3.59	1.43
		Maximum							25	34.21	7.22
Posterior	Maxilla	Mean							11.165	9.263	4.684
		N							100	100	100
		Std. deviation							± 6.262	± 4.708	± 1.773
		Minimum							5	2.21	1.52
		Maximum							28	22	9.71
	Mandible	Mean							10.659	12.123	5.230
		N							100	100	100
		Std. deviation							± 5.964	± 4.815	± 1.177
		Minimum							0	3.20	2.21
		Maximum							25	25.76	10.87

Max, maximum; Min, minimum; SD, standard deviation.

TABLE 3: Quantitative data, frequency and depth of buccal and lingual concavity, assessed using CBCT measurements

Concavity	Jaw	Region	*N*	Minimum	Maximum	Mean (mm)	Std. deviation	*P* value
Buccal concavity	Maxilla	Anterior	62	0.5	3	1.432	0.915	0.4594
		Posterior	12	1.2	3	1.225	0.673	
	Mandible	Anterior	57	1.1	3	1.735	0.673	0.0094
		Posterior	13	1	1.5	1.207	0.477	
Lingual concavity	Maxilla	Anterior	13	1	2	1.361	0.379	0.1697
		Posterior	20	1	25	1.611	0.562	
	Mandible	Anterior	4	1	2.5	2.125	0.478	0.0520
		Posterior	63	0.7	3	1.565	0.552	

Max, maximum; Min, minimum; SD, standard deviation.

5. Ridge Angle

The mean ridge angle in anterior and posterior maxilla was 18.28 ± 7.197 and 11.16 ± 9.26 degrees, respectively. In the maxilla, ridge angle in the anterior region was significantly greater than that in the posterior region ($P < 0.0001$). The mean ridge angle in anterior and posterior mandible was 10.2 ± 5.34 and 10.65 ± 5.964 degrees, respectively.

6. Ridge Concavity

Regarding the buccal concavity of the maxilla, 62% of the anterior regions and 12% of the posterior regions had concavity. In the mandible, 57% of the anterior and 13% of the posterior regions had buccal concavity. In the mandible, the mean buccal concavity was significantly higher in the anterior regions than in the posterior region ($P = 0.0094$). In the palatal region of the maxilla, 13% of the anterior and 20% of the posterior regions had undercuts. In the lingual region of the mandible, lingual concavity was present in the anterior region in 4%, and in the posterior region in 63%.

7. Buccal and Lingual Cortical Bone Thickness

The mean thickness of cortical bone increased as the distance from the crest increased, both in maxilla and mandible. In all sites, the thickness of cortical bone was significantly higher in lingual than buccal ($p = 0.00$).

IV. DISCUSSION

The aim of this study was to evaluate CBCT scans consisting of at least one edentulous site in patients in need of dental implant in order to present quantitative descriptions of ridge anatomy. Accurate radiographic evaluation is important to prevent implant complications and increase the success rate of treatment and patient satisfaction. Detecting ridge height, width, undercuts, and angulation will prevent cortical bone perforation for placement of dental implants. A 3D imaging modality such as CBCT is the imaging modality of choice prior to implant placement especially in patients with long-term edentulism.[14,15]

Cortical crest thickness has a major role in implant stability. In this study, the crestal cortical bone thickness at the implant sites in various regions was as follows: 1.71 ± 0.60 mm in the posterior mandible, 1.47 ± 0.58 mm in the anterior mandible, 1.28 ± 0.44 mm in the anterior maxilla, and 0.95 ± 0.37 mm in the posterior maxilla. The thinnest bone was found in the posterior maxillary implant site, owing to the presence of the maxillary sinus. Thus, placement of implants in the posterior maxilla should be done with care because of less cancellous bone density in this region and proximity of the floor of the maxillary sinus.[16] In the study of Safi et al.,[17] the

TABLE 4: Quantitative data, cortical bone thickness at 2, 4, and 6 mm distance form ridge crest, assessed using CBCT measurements

Jaw	Region	Position	Distance from crest (mm)	Std. Deviation	Mean
Maxilla	Anterior	Buccal	2	± 0.031	0.87
			4	± 0.031	0.88
			6	± 0.031	0.936
		lingual	2	± 0.035	1.075
			4	± 0.039	1.182
			6	± 0.043	1.228
	Posterior	Buccal	2	± 0.206	0.686
			4	± 0.028	0.642
			6	± 0.037	0.549
		Lingual	2	± 0.335	0.945
			4	± 0.519	0.916
			6	± 0.644	0.841
Mandible	Anterior	Buccal	2	± 0.206	0.966
			4	± 0.285	1.105
			6	± 0.644	1.123
		Lingual	2	± 0.407	1.161
			4	± 0.570	1.844
			6	± 0.565	2.024
	Posterior	Buccal	2	± 0.407	1.330
			4	± 0.448	1.499
			6	± 0.479	1.678
		Lingual	2	± 0.514	1.689
			4	± 0.478	1.979
			6	± 0.529	2.159

Max, maximum; Min, minimum; SD, standard deviation.

mean cortical crest bone thickness was 1.28 ± 0.49 mm in the right side and 1.24 ± 0.43 mm in the left side anterior edentulous mandible. Ko et al.[18] evaluated the crestal cortical bone thickness at 661 implant sites in the anterior and posterior maxilla, and in the anterior and posterior mandible. The crestal cortical bone was the thickest in the posterior mandible and the thinnest in the posterior maxilla. The crestal cortical bone thickness in the anterior maxilla was higher than that in the posterior maxilla, but it was not the case in the mandible. Our study results were consistent with those of Ko et al.,[18] except that, in our study, the mean values obtained in all four areas were slightly higher. The possible reasons for this difference include the small number of sites examined in the present study, which can affect the mean values, as well as the difference in the number of edentulous years that can affect bone thickness in different cases.

In a study by Gerlach et al.,[19] the thickness of the cortical bone of the mandible was reported to be 2 ± 0.15 mm, which was higher than the total value of the thickness of the crestal bone in our study. The reason for this difference may be that they evaluated fewer sites (8 sites) and obtained images from the corpses. Miyamato et al.[20] reported that the crestal

bone thickness was 2.22 ± 0.47 mm at 127 edentulous sites in the mandible and 0.98 ± 0.34 mm at 98 edentulous sites in the maxilla. In their study, the thickness of the cortical crestal bone in the mandible was greater than that in the maxilla, which was consistent with our study results. But, the mean crestal bone thickness in our study was lower in the mandible. The reason for this difference may be the imaging modalities, which was CBCT in the present study and CT in their study or type of edentulism, which was partial in our study and partial and complete in theirs.

The depth of lingual concavity in the posterior mandibular region was reported to be 2.3 ± 4.5 mm in a study by Herranz-Aparicio et al.,[21] which was higher than the value in our study. This difference may be due to the fact that our study was conducted on an Iranian population while Herranz-Aparicio et al.[21] evaluated a Spanish population. The type of imaging modality may also explain this difference, which was CBCT in our study and CT in their study. A previous study[22] examined the width and height of the ridge in the posterior mandible at the site of first premolars, second premolars, first molars, and second molars. The mean ridge width in our study in the posterior mandible was higher than that in all areas studied in the aforementioned study, which may be due to racial differences of patients. The height of the ridge was almost the same in the two studies in all areas except at the site of the first molar.

In a study by Acharya et al.,[23] the average width of the ridge in the posterior maxilla at the site of first molar was 6.31 mm at 1 mm distance apical to the crest. The mean height from the crest to the floor of the maxillary sinus was 7.05 mm. The ridge width was lower in our study, which may be due to the fact that in the aforementioned study, only the first molar site was examined. The average height was also higher in our study. This difference may be due to the ethnic diversity, difference in duration of edentulism, or assessment of one single dental site.

The mean ridge angle in the posterior mandible in a study by Panjnoush et al.[24] was 10.13 ± 6.10°, which was consistent with our study result.

In the study of Safi et al.,[17] the prevalence of ridge undercut in the buccal cortex was 10% in the right side and 7.2% in the left side with mean of 1.52 ± 0.62 mm and 1.61 ± 0.42 mm in anterior mandible respectively and male demonstrated more ridge undercut ($P < 0.05$). In the study of Quirynen et al., 210 mandibles were assessed in interforaminal region and a lingual concavity, with a depth of 6 ± 2.6 mm, was observed in 2.4% of the jaws.

A. Study Limitations

Due to the cross-sectional nature of this study, the cause and exact length time of tooth loss could not be assessed. Further studies may include these factors and can explore potential anatomic changes with systemic diseases and drug consumption on quantitative assessment of the ridge.

V. CONCLUSION

CBCT provides useful quantitative information regarding edentulous ridge prior to insertion of dental implants. Individualized treatment plan is necessary based on anatomical variations.

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