

Assessments of jaw bone density at implant sites using 3D cone-beam computed tomography

Y. HAO, W. ZHAO, Y. WANG, J. YU, D. ZOU

Department of Stomatology, Shanghai Jiao Tong University Affiliated Sixth People's Hospital, Shanghai, People's Republic of China

Abstract. – OBJECTIVE: To assess the bone density of dental implant sites using CBCT and Simplant software, and establish a quantitative ranges for each bone quality classification according to the classification of bone quality proposed by Lekholm and Zarb.

PATIENTS AND METHODS: 128 patients' jaw bone were scanned by CBCT, the images were reconstructed by the Simplant software. The bone density of 236 potential implant sites was measured and the results were recorded using Hounsfield units (HU) The data was analyzed with SPSS 19.0 software package for Mann-Whitney U test.

RESULTS: The anterior mandible mean bone density was (679.6 ± 141.67) HU > anterior maxilla, (460.25 ± 136.42) HU and posterior mandible, (394.4 ± 128.37) HU > posterior maxilla, (229.62 ± 144.48) HU. Quantitative parameters ranged of the bone density according to CBCT as follows: Lekholm and Zarb classification Type D4 was less than 200 HU, Type D2 and Type D3 were more than 200HU and less than 600 HU, and Type D1 was more than 600 HU.

CONCLUSIONS: Anterior mandible has the highest mean bone density and posterior maxilla has the lowest mean bone density It is, therefore, proposed that an objective classification which confirms the importance of a site-specific bone tissue evaluation prior to implant installation.

Key Words:

CBCT, Bone density, Implant, Bone classification.

Introduction

Dental implants are gaining popularity and wide acceptance. The successful treatment of dental implants is considered to be influenced by both the quality and the quantity of available bone for implant placement. Bone quality is an important factor affecting the success of dental implants. Lekholm and Zarb¹ classified bone quality as Q1 to Q4 according to the ratio of cortical bone to spongy bone. Misch² classified bone

as D1 to D4 according to differing resistance during drilling procedures. In addition, Misch suggested that computed tomography (CT) can be used for the objective quantification of direct density measurements of bone, expressed in Hounsfield units (HU). HU represent the relative density of body tissues according to a calibrated gray-level scale. Previous studies have investigated the use of HU to evaluate the relative bone density of the jaws³⁻⁵.

Suitable craniofacial cone beam computed tomography (CBCT) scanners were developed in the late 1990s and had gradually increased over the past few years. CBCT have advantages in terms of cost, time, image resolution, and radiation dose over CT⁶⁻⁹.

The purposes of this study were to evaluate the bone density of dental implant sites using CBCT and Simplant software, and establish a quantitative ranges for each bone quality classification according to the classification of bone quality proposed by Lekholm and Zarb.

Patients and Methods

A total of 128 patients (74 men, 54 women; mean age, 45.48 years; SD, 13.04 years), who had 236 implant sites were included in this study. The patients with no diseases affecting bone density were either fully or partially edentulous.

Pre-Operative Radiological Evaluation

A total of 128 scans taken using the ProMax 3D cone-beam computed tomography (PLAN-MECA, Helsinki, Finland) for patients undergoing assessment for implant treatment were adopted for use. A Larger volume CBCT scan was performed in each mode with a rotation of 360 degrees for data acquisition. The size of imaging volume is dependent on the mode selected: The height and diameter are 160 mm and 160 mm.

The voxel size was 0.2 mm and the exposure factors were 90 kV, 14.0 mA, 13.779 s exposure time. A series of axially sliced image data were exported to a personal computer in DICOM 3.0 format. All CBCT images were utilized to allow classification of edentulous spans within the four regions: anterior mandible (AMd), anterior maxilla (AMx), posterior mandible (PMd), and posterior maxilla (PMx).

Measurements of Bone Density and Classification of Bone Quality

Using the interactive setting on the S implant software, the 10 mm × 3.5 mm implant was then placed in each edentulous span of the anterior jaws (Figure 1). Meanwhile, the diameters of the proper implants selected were 4.1 mm while the lengths of the implants selected were 10 mm in the regions of the posterior jaws. The computer was then asked to map the density of the bone around the entire circumference of each implant, with a surrounding thickness of 1 mm bone, which is the default setting (Figure 2). The bone density measurements were given in Hounsfield units (HU).

Surgical template was fabricated according to the position of the implants, which was simulated in alveolar bone by the Simplant software based on the obtained CBCT data. Surgery was then done using surgical template fabricated by CAD/CAM technique.

A comparative study¹⁰ between bone classification and the bone density as measured histomorphometrically, demonstrated a strong correlation for densities classified as D1 or D4. However, there was a high degree of variation for bone classified as D2 or D3. Hence, an implant specialist classified the bone quality as Group 1 to Group 3 according to differing resistance during drilling procedures.

- Group 1 = D1
- Group 2 = D2/3
- Group 3 = D4

Statistical Analysis

Comparative analysis of the raw data was performed with SPSS 19.0 statistical software (SPSS Inc., IL, USA). The data of recorded bone density (HU) were subjected to statistical analysis in the different regions within the mouth, by using Mann-Whitney U-test. A value of $p < 0.01$ was considered significant.

Results

128 patients (74 male, 54 female), whose mean age was 45.48 ± 13.04 were adopted for this study. The 128 CBCT scans yielded a total of 236 implant sites. There were 14 anterior

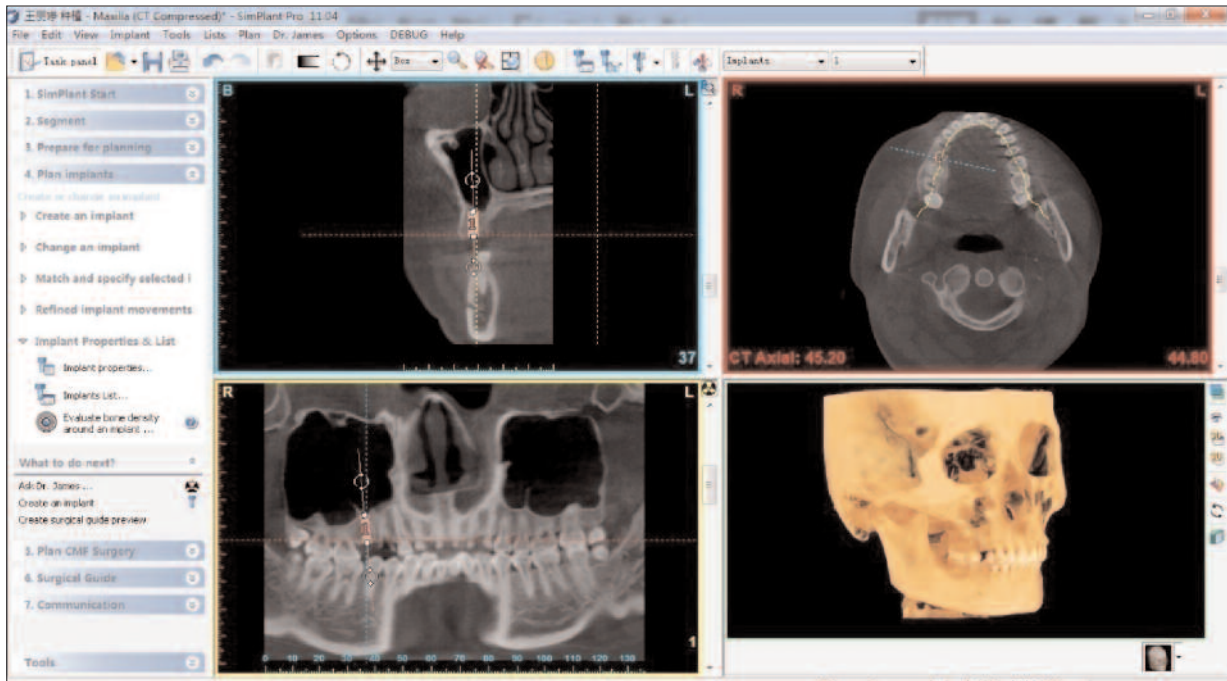


Figure 1. A 10 mm × 4.1 mm implant has been placed into the edentulous span of this anterior mandible.

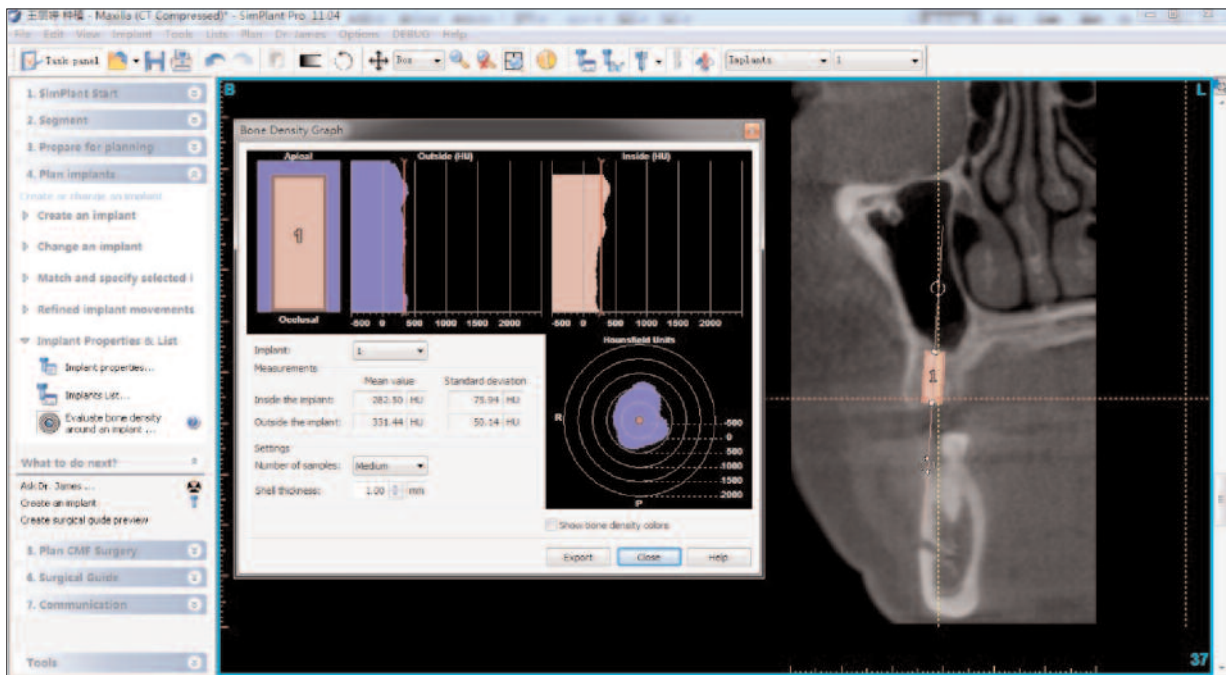


Figure 2. The bone map around the implant in Figure 1 reveals a mean bone density of 331.44 HU.

mandibular sites, 29 anterior maxillary sites, 115 posterior mandibular sites and 78 posterior maxillary sites. It has been observed that the bone density in all patients ranged from 42.4 to 895.6 HU with a mean value of 364.95 ± 178 HU.

It can be seen that the anterior mandible yield a mean density value of (679.6 ± 141.67) HU > anterior maxilla, (460.25 ± 136.42) HU and posterior mandible, (394.41 ± 128.37) HU > posterior maxilla (Figure 3).

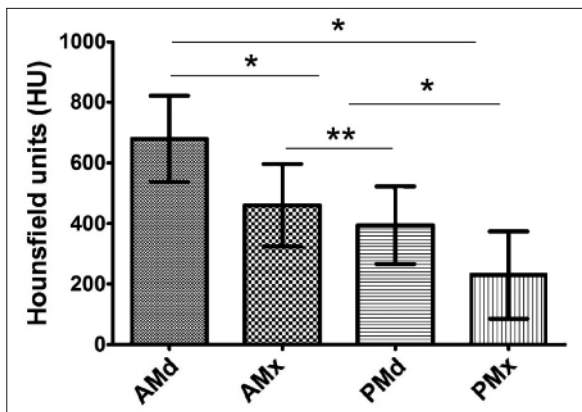


Figure 3. The mean bone densities in the different regions are shown ($*p < 0.001$; $**p > 0.01$). AMd: anterior mandible; AMx: anterior maxilla; PMd: posterior mandible; PMx: posterior maxilla.

The statistically significant differences in the mean bone density of the implant sites were observed between the regions of the jaws (AMd and AMx; AMd and PMd; AMd and PMx; AMx and PMx; PMd and PMX) ($p < 0.001$). The difference in the mean bone density of the implant sites was not statistically significant between the AMx and PMd ($p > 0.01$).

The bone in all implant sites was classified as D2 and D3 (74.15%), D1 (8.9%) and D4 (16.95%), respectively (Table I).

Reference parameters for predicting bone quality from known values of bone density are defined in Table II. Actual values were rounded off for clinical purposes (Table III).

Discussion

Precise and quantitative pre-operative evaluation of bone density is essential to help provide the clinician an indicator of planning implant therapy. Numerous studies¹¹⁻¹³ reported cluster failures that could be associated with poorer bone quality in Q4 bone. Therefore, a quantitative reliable scale, rather than absolute values, would be more flexible and accurate in helping the clinician categorize bone quality, so that clinicians

Table I. Distribution of subjective classifications of bone type.





Region	Implant sites	Subjective classification			D4 (%) in each region
		D1	D2/3	D4	
AMd	14	12	2	0	0%
AMx	29	3	24	2	6.90%
PMd	115	6	101	8	6.96%
PMx	78	0	48	30	38.46%
Total	236	21 (8.90%)	175 (74.15%)	40 (16.95%)	

AMd: anterior mandible; AMx: anterior maxilla; PMd: posterior mandible; PMx: posterior maxilla.

Table II. Bone densities of 3 groups.

Bone type	Implant sites	Minimum (HU)	Maximum (HU)	Mean (HU)	SD	95% CI	p value
Group 1 (D1)	21	598.51	895.6	712.62	87.79	672.66-752.58	< 0.01
Group 2 (D2/3)	175	118.23	714.06	374.89	120.64	356.89-392.89	< 0.01
Group 3 (D4)	40	42.4	285.7	138.96	64.11	118.45-159.46	< 0.01

Table III. Reference values of bone density for each bone type.

Bone quality according to Lekholm and Zarb*		Norton and Gamble bone density scale (HU)	Bone density according to CBCT in this study(HU)
Bone type 1		> +850	> +600
Bone type 2		+500~+850 (Bone type 2 and type 3)	+200~+600 (Bone type 2 and type 3)
Bone type 3			
Bone type 4		0~+500	< +200

HU: Hounsfield units. *According to the classification of Lekholm and Zarb.

can more easily determine when to load an implant: immediately, earlier, or later.

CBCT scanners are 3D in their acquisition of images and offer usable images from systems that are sufficiently compact and inexpensive to be installed in clinics and private dental¹⁴⁻¹⁶. In-

deed, CBCT has some advantages^{16,17} when compared with computed tomography (CT), such as lower radiation dose, shorter acquisition time, and reduced costs. HU should be better understood as “relative” density rather than “true” density. This relative density is determined by CT

numbers, which represent the total X-ray attenuation of different body tissues¹⁸. That is why the present research analyzed the density of bone by using CBCT in intro.

In this study, differences in the bone densities of the 4 regions in the mouth were significant, with the anterior mandible yielding a higher mean bone density value, followed by the anterior maxilla, the posterior mandible, and the posterior maxilla. These differences have also been observed by other authors^{1,4,5,19}. However, when considering all implant sites in this study, the mean bone density was 364.95 ± 178 HU, which is lower than that reported by Norton and Gamble⁵. The mean bone density value in the anterior mandible (AMd), anterior maxilla (AMx), posterior mandible (PMd), and posterior maxilla (PMx) are lower than those reported previously^{4,5}. The bone densities reported in this study were lower than that found in those studies^{4,5}, the difference might result from the differences between CBCT and CT scanners. The results of some studies indicated the HU is significant differences between CBCT and CT values^{7,20,21}. The other reasons might have been the variations in the age and the gender of the patients. Agreeing with an opinion reported earlier^{4,5}. The results of this study also indicated a strong correlation between the four regions of the mouth and the bone density.

In the previous study of Trisi and Rao¹⁰ a strong correlation was reported between bone, subjectively classified as D1 or D4 (based on drilling resistance), and the bone density as measured histomorphometrically. On the contrary, it was not possible to distinguish the subtle differences between D2 and D3 by this way. A close relationship was shown between the poor bone density and increased implant failures, Jaffin and Berman¹² reported that it was 3% for types 1, 2, and 3 bone, but 35% for type 4 bone, according to bone quality as defined by Lekholm and Zarb. In this study (Table I), D1 to D4 were found in all examined regions, except for D1 in the posterior maxilla and D4 in anterior mandible. The bone density in the posterior maxilla, approximately 38.5% of the bone quality was classified as D4. This type 4 bone requires a meticulous surgical technique¹. So clinicians require careful planning for implant design, implant number, and progressive loading in the posterior maxilla. In addition, the majority of the bone in all implant sites was classified as D2 and D3 (74.15%), which is adequate for implantation.

Differences in the bone densities of the 3 groups (D1, D2/3, D4) were significant (Table II), this will accommodate the “gray zones” between groups which exist as a result of the standard deviations. The bone density of D4 (mean and standard deviation) was (138.96 ± 64.11) HU, this type of bone requires a careful surgical technique due to the failure of implant. Therefore, quantitative density values for D4 were below +200 HU according to the tolerance upper limit of D4. The type of D1, which bone density was (712.62 ± 87.79) HU, has a greater risk of overheating during implant installation. According to the tolerance lower limit of D1, the values above +600 HU indicate denser bone. D2 and D3 have been combined into one group, the difficulty in differentiating between D2 and D3 based on a subjective visual evaluation or quantitative bone density measurements was found previously in other studies¹⁰. Intermediary values (D2/3) between +200 and +600 HU represent conditions favorable for osseointegration.

Some previous studies²² claimed that the use of intensity values in CBCT images is not reliable, because the values are influenced by device, imaging parameters and positioning. However, results from this study also suggest a high degree of concordance between the different regions of the mouth and the differing bone densities, with a strong correlation between the four bone qualities.

Conclusions

The relationship between density value and bone quality was studied by means of PLAN-MECA ProMax 3D CBCT. A density scale could also help clinicians to avoid placement of implants into the very poorest qualities of bone, where failure is more likely.

Acknowledgements

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Conflict of Interest

The Authors declare that there are no conflicts of interest.

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