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Relationship between the bone density estimated by cone-beam computed tomography and the primary stability of dental implants

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***Abstract*---**It enables more accurate three-dimensional evaluation of anatomic structures and directly measures the bone density. The density of the bone is usually expressed in Hounsfield units (HU)1 which is a parameter that provide the most important details about the available bone. A total of 18 fresh femoral heads of swine were taken for the study. The adjacent soft tissues have been removed completely and the surfaces of the bone blocks were made flat using a carbide bur. The thickness of each block was cross-checked using precision vernier calipers and maintained at more than 10 mm. Using the ISQ values as the independent variable, the standardized partial regression coefficients of the thickness of the cortical bone, the voxel value, and the length of the implant were 0.328, 0.306, and 0.422 respectively, all of them are significant variables. It has been observed

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that there was a correlation between the thickness of the cortical bone or the voxel values obtained from the CBCT scanning images prior to the implant placement and the implant stabilities.

***Keywords*---**cone beam, bone density, primary stability.

Introduction

The clinical success rate of a dental implant can be determined by the quantity and the quality (density) of available bone influence the clinical success of dental implants. Computed tomography (CT) is a well predicted method for acquiring bone images prior to perform the surgery for dental implants. It enables more accurate three-dimensional evaluation of anatomic structures and directly measures the bone density. The density of the bone is usually expressed in Hounsfield units (HU)[1] which is a parameter that provide the most important details about the available bone. Hounsfield units (HU) are usually a standard number which basically originates from CT imaging methods. HU represent the relative density of body tissues according to a calibrated gray-level scale, based on values for air (−1000 HU), water (0 HU), and bone density (+1000 HU).[2] Various studies have assessed the relative bone density of the jaws in CT, and their HU seem to be a valuable method to analyse bone density, despite the high radiation doses associated with CT imaging.[3,4]

Nowadays, cone-beam computed tomography (CBCT) is greatly replacing multi slice CT (MSCT) in dentistry for evaluating mineralized tissues in the oral cavity, since it provides adequate image quality associated with a lower exposure dose. Other advantages of CBCT are low cost, as compared with CT, rapid scanning time and reduced image artifacts.[5] Many authors have reported the use of CBCT intensity values as a measure to assess bone density.[1,6-10] However, other studies revealed that the HU derived from CBCT and from MSCT is not identical.[2] Moreover, there are many noticeable differences in the methodology used in these studies with respect to the sample and the CBCT device. *Isoda* et al[9] concluded that it is not clear whether the density values obtained by a CBCT device could rather be applied to another device. *Nackaerts* et al[2] observed that when five CBCT scanners were verified, the intensity values obtained would rather be varied depending on each device. We also believe that projection data discontinuity, image artifacts and the scattering levels produced by CBCT scanners can vary depending on the device and can affect the accuracy of CBCT intensity values. This has the capacity to make the CBCT images unreliable for estimating the bone densities. As far as concerned, only one study evaluated the images of i-CAT-10 therefore they can be compared them with micro-CT. This evaluation provides accurate bone density measurements but it also cannot be applied clinically. This indicates that further researches are required in order to conclude the proposition that CBCT images obtained by the CBCT scanner can successfully substitute the MSCT scanner in evaluating the bone density. Therefore, given the importance of the subject, the lack of consensus of other studies and the lack of studies on the i-CAT scanner, the aim of this study was to assess the bone density value of the potential implant sites in HU obtained by a specific CBCT device and to determine the primary implant stability. In this study, the HU values obtained using a MSCT scanner were used as the gold standard value.

Materials and Methodology

A total of 18 fresh femoral heads of swine were taken for the study. The adjacent soft tissues have been removed completely and the surfaces of the bone blocks were made flat using a carbide bur. The thickness of each block was cross-checked using precision vernier calipers and maintained at more than 10 mm. The specimens were then examined macroscopically; a wide variety of bone types were included in the study. Eighteen titanium screw-type implants with a large-grid sandblasted and acid-etched surface (Straumann Standard implants, Straumann AG, Basel, Switzerland) with a diameter of 4.1 mm and an intrabony length of more than 10 mm were used.

All implant sockets were prepared according to the manufacturer's instructions using a surgical micromotor (Implanteos , Anthogyr, Sallanches, France). Briefly, a pilot drill of 2.2-mm was used first, followed by 2.8- and 3.5-mm twist drills and a 4.1-mm tap for the preparation of the implant socket. Radiological evaluation was then performed by one observer. CBCT scanning (GXCB-500s, Gendex, Des Plaines, IL, USA) of the specimens, which were then placed in containers of water, was performed under the following criterion: 120 kV, 5 mA, a voxel size of 0.2 mm and a scan volume 8.5 cm in diameter and 8.5 cm in height. The bone density of the implant recipient sites, which was expressed in density values, was preoperatively evaluated using CBCT data. The density value obtained from the CBCT device used in this study was already made to coincide with that values of helical CT. (Sogo 2009) The average density values of the surrounding bone to a distance of 1 mm from the surfaces of the implant sockets were analysed and measured using a specially modified software (LANDmarker Ver5, iLAND Solutions Inc., Osaka, Japan). All implants were then inserted by one operator. During the implant placement, the maximum insertion torque value of each implant was weighed using a digital torquemeter (STC400CN, Tohnichi, Tokyo, Japan).

Resonance frequency measurements were performed using the Osstells Mentor (Integration Diagnostics, Go¨teborg, Sweden). The SmartPegs were mounted on the implants and tightened by hand with a screw. The RF value was measured four times in four directions (every 90^{o}) for each implant. RF values were usually represented by a quantitative unit called the implant stability quotient (ISQ) on a scale from 1 to 100. The results were expressed in ISQ and the average been calculated for each implant. All the data were collected and the statistical analyses were performed using SPSS Statistics 17.0J software (SPSS Inc., Tokyo, Japan). Spearman's correlation coefficient (rs) was calculated to assess the correlations among density values, insertion torques and ISQ at implant placement. A value of $P<0.05$ was considered to be statistically significant.

Results

A positive relation was found to be present between the thickness of the cortical bone and ITVs or ISQ values in all kinds of implants used in the study. Moreover, a significant positive correlation was also found between the voxel values and ITVs. On the other hand, in the relationship between the voxel values and ISQ values, it was insignificant to correlate the association of the implant of 5.0 mm in width and 12.0 mm in length (Table 1).

Multiple regression analysis was then performed using the ITVs or the ISQ values as the dependent variable and using the cortical bone thickness, the voxel value and the length of the implant taken as the independent variables. The standardized partial regression coefficients of the thickness of the cortical bone and the voxel value were 0.404 and 0.461 respectively, which turned out to be significant. However, length of the implant did not become an explanatory variable. When using the ISQ values as the independent variable, the standardized partial regression coefficients of the thickness of the cortical bone, the voxel value, and the length of the implant were 0.328, 0.306, and 0.422 respectively, all of them are significant variables. From these data, it was confirmed that the thickness of the cortical bone and the voxel values had a positive value on ITV while the thickness of the cortical bone, the voxel value, and the length of the implant had a positive influence on the ISQ values as shown in table 2.

Table 1
Correlation between bone factors and stability factors

Stability factors	Diameter (mm)	Length (mm)	R	P - value
Thickness of cortical bone (ITV)	3.8	7	0.746	<0.001
		12	0.565	0.004
	5	7	0.813	<0.001
		12	0.772	<0.001
Thickness of cortical bone (ISQ)	3.8	7	0.839	<0.001
		12	0.412	0.054
	5	7	0.709	<0.001
		12	0.429	0.039
Voxel values (ITV)	3.8	7	0.605	0.002
		12	0.746	<0.001
	5	7	0.852	<0.001
		12	0.669	<0.001
Voxel values (ISQ)	3.8	7	0.686	<0.001
		12	0.449	0.034
	5	7	0.695	<0.001
		12	0.282	0.205

ITV – Insertion Torque Values, $P<0.01$, $p<0.05$

Table 2
Statistical analysis of the results of the multiple regression analysis of the 3.8-mm-width implant

Dependent variable (ITV)	n=48
Independent variables	P - value
Thickness of the cortical bone	0.404

Voxel value	0.461
Length of the implant	0.005
	R^2 = 0.635

Dependent variable (ISQ)	n=48
Independent variables	P - value
Thickness of the cortical bone	0.328
Voxel value	0.306
Length of the implant	0.422
	R^2 = 0.597

Table 3
Statistical analysis of the results of the multiple regression analysis of the 5.0-mm-width implant

Dependent variable (ITV)	n=48
Independent variables	P - value
Thickness of the cortical bone	0.411
Voxel value	0.368
Length of the implant	0.531 (<0.01)
	R^2 = 0.641

Dependent variable (ISQ)	n=48
Independent variables	P – value
Thickness of the cortical bone	0.445
Voxel value	-0.066
Length of the implant	0.755 (<0.01)
	R^2 = 0.841

Discussion

Preoperative evaluation of bone quality is mandatory for the clinician/implantologist to establish a treatment plan for implant restoration. Precise information on bone density will enable the dentist to identify suitable implant sites and determine implant design and surgical procedures. The femoral heads of swine used in this study were considered to be a good representation of a reality clinical situation regarding variances in bone density and volume. Various studies have reported the relation between reports of bone density of actual patients[11,12] or dry bones[13,14] and primary implant stability. Therefore, clinical studies in actual patients could not be performed a unified surgical procedure with a single type of implant design. Since the dry bone used in the earlier study was not fresh and the bone density values might be lower than those observed from actual patient.[14] Thus, experimental studies have extensively used femoral heads as the experimental model on which implants are inserted.[15,16,17]

Considering the bone condition, femoral heads used in this study were relatively similar to that of actual patients because they were fresh when compared with the dry bone. In the present study, the implant socket which was created by the tap drill was almost similar to that of the implant dimensions, as per the manufacturer's instructions. Hence, it was considered that the implant did not condense the surrounding bone during insertion. Under this condition, preoperatively determined implant recipient sites using CBCT precisely reflected the recommended sites after insertion. When helical CT is used, bone density can be obtained in Hounsfield Units (HU). For CBCT, however, there is no standard unit such as HU because there is no calibration has been set as yet. In this study, bone density obtained by CBCT was expressed in density values for easy understanding. The density values obtained by the CBCT device were confirmed to relate the values with those estimated using helical CT (Activiont, Toshiba Co., Tokyo, Japan).

Various studies also reported a higher-level of correlation between the density values of CBCT and HU using multi-slice CT.[18,19,20] The bone density could be estimated by the density values obtained by these specific CBCT devices. However, it should be noted that the density values obtained from the present study should not be applied to other CBCT devices till the confirmatory studies are conducted on them. Numerous studies have reported that structures outside the scan volume usually affected the density values of hard and soft tissue structures within the scan volume in limited-volume CBCT.[21,22] However, an in vitro study observed fewer changes in CBCT scans of larger (more than 10 cm) volumes.[23] In this study, it has been considered that the density value of the specimen was affected least because the object was smaller than the scan volume. Hence, further research is needed in this aspect whether the density values obtained by the CBCT device used in the present study could be applied to other clinical situations.

The earlier study examined 32 helical CT scans of patients and the recorded mean bone density value ranged from 77 to 1421.[24] The bone density values from 20 patients evaluated by CBCT reportedly ranged from 238 to 777.[12] However, the bone density values in their study were not calibrated by standard values. Moreover, the bone density values of three human mandibles (dry bone) varied between 267 and 553 HU, with a mean of 113 HU.[14] The density values recorded in the present study were similar to those of the bone density values obtained and can be considered to relate with HU evaluated by helical CT.

Conclusion

In this present study, it has been observed that there was a correlation between the thickness of the cortical bone or the voxel values obtained from the CBCT scanning images prior to the implant placement and the implant stabilities. Besides, it was confirmed that the thickness of the cortical bone, the voxel value and the length of the implant had positive correlations with the ITVs and that the thickness and length had positive correlations with the ISQ values.

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