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A Computerized Tomographic Data Analysis System to Evaluate the Dental Implant Surface Roughness

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Abstract

Dental implants have been progressively used in the recent years to support and retain dental prosthesis. Implant surface roughness has been suggested as a crucial factor in implant osseointegration and long term survival of the implant and prosthesis, where a key factor for the success or failure of dental implants is the manner in which stresses are transferred to surrounding bone. In this study completely edentulous patients were rehabilitated by implant retained over denture in which two implant systems with different surface roughness were used. Peri implant bone density in Hounsfield Units (HU) was evaluated by analyze Computerized Tomographic (CT) images to judge the behavior of an implant system under functional loading, where DICOM raw data was imported into the analysis proposed system to correlate the bone density regarding to the HU values. Results are compared with clinical readings and previous findings, which it showed that there is a difference in peri implant bone density around regularly patterned and randomly patterned implant surfaces.

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Keywords: Dental Implants; Surface Roughness; Bone Density; Laser Microgroove Implants; RBT Implants; HU

1. Introduction

The increased need and reported success of dental implants, encouraged promoting multidiscipline research to enhance clinical outcome passing by the evolution in biomaterials[1-3], to the advances in tissue engineering that led to

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significant progress in tissue repair and regeneration, and allowed simulating the natural healing process thus enhancing rapid and reliable integration of load bearing implants. In addition implant research field was even enriched by getting advance of engineering technology and computational sciences to monitor and simulate peri implant tissues.[4]

Lindh et. al., [5] emphasized that bone density Bone Mineral Density (BMD) and bone quality are not synonymous. Bone quality encompasses factors other than bone density such as skeletal size, the architecture and 3-dimensional (3-D) orientation of the trabeculae, and matrix properties. Bone quality is not only a matter of mineral content, but also of structure. Lekholm and Zarb[6] suggested a bone classification system based on macrostructure, where the morphology and distribution of cortical and trabecular bones determine bone quality. Following the introduction of multi slice computed tomography (MSCT) for preoperative evaluation of bone density in Hounsfield units (HU) as a parameter of bone quality[7], Norton and Gamble[8], proposed a new classification system based on bone HU and related this new classification to that of Lekholm and Zarb.

In 1987 Schwartz et al, [9] introduced the concept of using computed tomography scans (CT) for pre-operative assessment of dental implant candidates. CT scanning technology allowed quantifying bone density in Hounsfield units. As a nondestructive mean, CT seemed highly promising to plan implant surgery, to monitor osseointegration and the ongoing bone remodeling induced by implants. Raw CT data is converted into Hounsfield Units (HU) by an equation: [10]

$$HU = \frac{CT - CTw}{CTw - CTa}, \qquad \text{eq.1}$$

, where CTw and CTa are the CT grey levels (intensity values) of the references (water and air) respectively

The Hounsfield index is a standardized and accepted scale for reporting and displaying reconstructed CT values. It is the measure of x-ray attenuation and varies according to the density of the tissues. The denser tissues higher CT number which ranges from -1000 HU (air) to 1000 HU (dense bone). Since the values are directly related to the tissue attenuation coefficients, a correction element was built in to make the comparison of CT values obtained from different CT scanners feasible.[11]

Alternatively, the use of cone-beam computed tomography (CBCT) was suggested associated with benefits such as increased patient comfort, lower radiation doses, and lower operation costs compared to conventional CT [12].The ideal imaging technique for dental implant should offer the ability to visualize the implant in mesiodistal, buccolingual and super ioinferior dimensions; the ability to allow reliable, accurate measurements; a capacity to evaluate trabecular bone density and cortical thickness; reasonable access and cost to the patient and minimal radiation risk.[13] Nackaerts et al[14] demonstrated that density profiles of conventional CT showed stable HU values whereas intensity values in CBCT images are not reliable.

The aim of the present work is to test the null hypothesis that bone density measured as HU in CT scans at different zones along bone implant interface of implants of different surface roughness is not affected by location on implant surface as it is affected by the orientation and degree of roughness. Bone density values were evaluated along different surfaces of the implant which were further subdivided into three horizontal regions to facilitate understanding of bone response to loading and to compare the reliability of rectangular region of interest to profile lines.

2. Materials and Methods

The study was designed to test the null hypothesis that pattern of surface roughness has no effect on peri-implant bone density. Each patient received two implants an implant with Laser micro-grooved surface LMG (manufactured at Princeton University-USA), characterized by regular pattern of surface roughness.[15] The other implant with Resorbable Blast Texturing surface (RBT) (BiohorizonsInc, 2300 Riverchase Center, Birmingham) characterized by randomly oriented surface roughness produced by blasting the surface with resorbable particles of tri-calcium phosphate. A total of 18 implants were inserted in the mandibular anterior region. Implants were allocated randomly to the right or left sides of the mandible.

Nine completely edentulous male patients were selected who were free from any systemic disease and of age range 50-65 years. Each patient was rehabilitated by conventional maxillary complete denture and mandibular implant retained over denture as shown in figure 1.

Figure 1: mandibular over denture retained by two implants

The effect of surface roughness on peri-implant bone density was evaluated radio-graphically by assessment of changes of peri-implant bone density in CT images made immediately after loading (0 month) and after 3, and 6months of loading. CT scanning was carried out by high speed multi slice three dimensional computer tomographic examination 3D CT (GE Medical Systems/Bright Speed S, GE Healthcare 3000 North Grandview Waukesha, WI 53188 U.S.A.). Transaxial scans of the mandible were obtained by making slices 0.4mm, 512x512 pixels through the bone and a total of 400 axial slices were obtained. Data were saved as DICOM (digital imaging and communication in medicine) file format. DICOM data was then imported into software package namely Mimics 8.1 (Materialise, Leuven, Belgium).

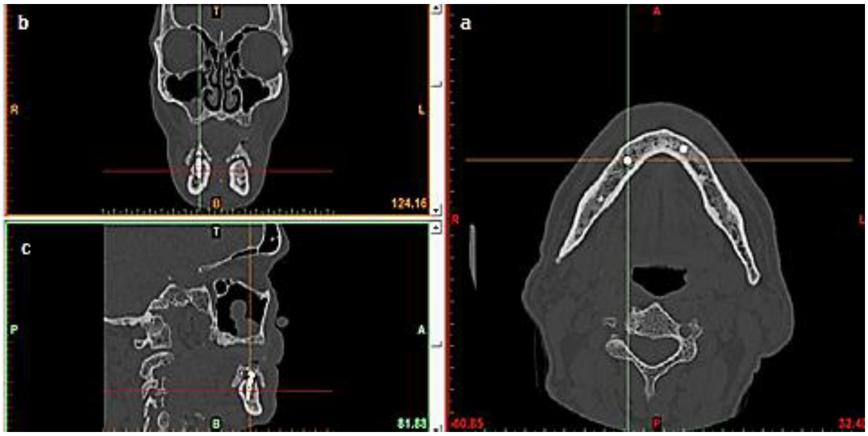


Figure 2: reformatted images of the mandible with two implants showing: a, axial view, b, coronal, c sagittal view

Peri-implant bone density was evaluated in sagittal and coronal reformatted sections of 3-D CT radiographic images on buccal, lingual, mesial, distal surfaces of each implant based on HU at 0, 3 and 6 months. Images were magnified and implant surface was divided into three vertical regions: Coronal (C), Middle (M) and Apical (A) on each axial surface of the implant (Buccal, Lingual, Mesial and Distal) as represented in figure 3. Bone density was measured in rectangular areas in all three zones along all implant surfaces; buccal and lingual surfaces in the sagittal plane, and on mesial and distal surfaces in the coronal plane. Bone density in the selected regions was displayed automatically through the software program used, in terms of mean value and standard deviation of HU. The examiner measured the bone density of each region three times on three successive slices through the center of each implant and in a plane anterior and a plane posterior to the central plane. The mean peri-implant bone density value at the coronal zone of buccal, lingual, mesial, and distal surfaces of the two implants, was calculated at 0, 3, and 6 months and compared with the corresponding values of the middle and apical zones. The average of such a density profile represents a line integral, which is an indicator for the degree of osseointegration.

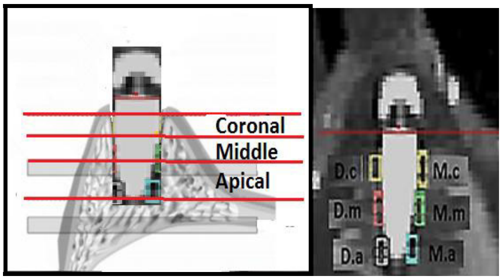


Figure 3: for the purpose of studying bone density, the implant surface was divided into three horizontal sections along the long axis of the implant, (i) coronal C, (ii) middle M, (iii) apical A.

3. Results

Comparison of mean peri implant bone density of LMG and RBT implants in reformatted CT images at base line (0-month), 3, and 6 months is shown in table 1 and figure 4. Comparison between different zones of LMG and their corresponding surfaces of RBT was carried out by paired t-test where 5% was considered as the significant level.

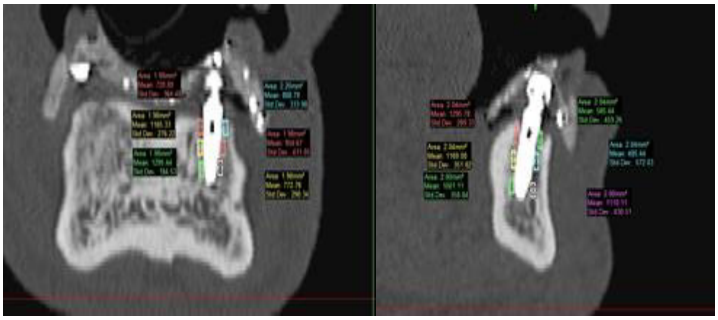
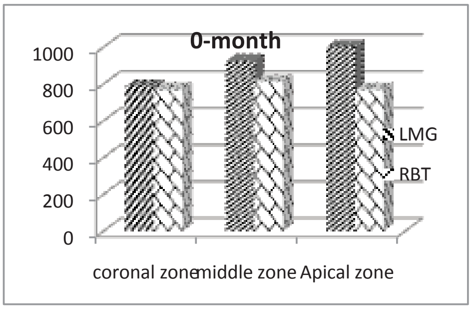


Figure 4: bone density shows automatically in the selected regions of interest as mean value and standard deviation of HU, right image bone density measured in coronal plane, left bone density measured in sagittal plane

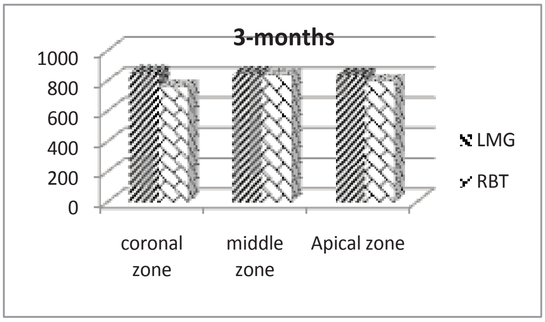
	Implant	0-month	3-month	6-months
coronal zone	LMG implant	784.3 ± 76.6	852.2 ± 258.3	978.4 ± 195.9
	RBT implant	768.9 ± 124.5	758.7 ± 229.4	739.3 ± 211.3
	P	0.755	0.429	0.024*
middle zone	LMG implant	923.9 ± 86.3	846.4 ± 183.3	872.2 ± 217.0
	RBT implant	811.5 ± 117.8	836.6 ± 174.4	819.8 ± 222.7
	P	0.035*	0.909	0.62
Apical zone	LMG implant	1055.3 ± 133.3	833.2 ± 263.6	918.5 ± 202.3
	RBT implant	767.2 ± 110.8	792.9 ± 168.3	797.2 ± 217.8
	P	0.001*	0.704	0.238

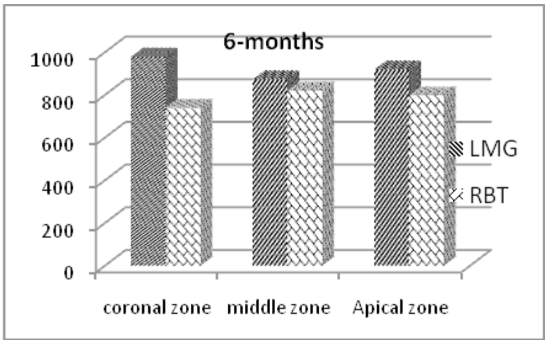
Data are represented as mean value± standard deviation of peri implant bone density in HU. P: Adjusted P value of independent samples t-test *P<0.05(significant)

mean peri-implant bone density of LMG implant was higher than RBT implant at all zones and at all intervals of the follow-up period as shown in graphs 1,2,3.Significant difference in mean peri-implant bone density was noticed at the coronal zone after 6-months (P= 0,024). While significant difference in mean peri-implant bone density values at the middle and apical zones was noticed at the initial phase with P equal 0.035 and 0.001 respectively.



Graph (1) Comparison between LMG (first series) and RBT (second series) implants regarding per-implant bone density at 0-month





Graph (2) Comparison between LMG and RBT implants regarding per-implant bone density at 3-month Comparison between LMG and RBT implants regarding per-implant bone density at 3-month

4. Discussion

According to Wolff's law of transformation, bone responses to its mechanical environment by bone remodeling which is described as changes in the structure of bone both internally (changes in density) and externally (changes in shape). 16 After implant insertion, the initial bone response is the same as wound healing process which allows new bone to form around the implant and osseointegration to occur. During functional loading of implants physiological bone adaptation to mechanical loading, via modeling and remodeling mechanisms takes place at bone implant interface. Remodeling comprises the process of bone resorption followed by bone formation and provides a mechanism for self-repair and adaptation to stress. The remodeled bone can extend up to 1 mm from the implant surface and for this reason the region of interest for measuring bone density was selected as a rectangular form of area 2mm2. Norton and Gamble used reformatted CTs of either completely or partially edentate patients and assessed bone quality by measuring HU densitometric readings of an area 1 mm wide around the implant body at the proposal implant site. Implant surface characteristics have crucial effect on directing osseointegration. The combination of macroscopic levels of implant design in the form of threaded root shaped implants, with microscopic architecture of titanium surface diminishes the effect of shear strains acting on the implant-bone interface. Increased surface roughness enhances bone apposition and remodeling. This may be due to the increased surface area used to transfer occlusal forces to bone. Bone responds to load by adjusting its mass density, when its mechanical loading conditions deviate from homeostatic levels, by a series of bone remodeling processes. A remodeling algorithm suggested by Chou et al, predicted a non-homogeneous density/elastic modulus distribution around four different implant systems. Bone density was predicted to increase on the tips of the threads of the implants, but to decrease inside the grooves while for unthreaded implants softer bone was suggested around their periphery.

In this study mean HU values around LMG implant was higher than HU around RBT implants which may be attributed to the fact of regularly patterned surface roughness and its influence on osteoblast and bone deposition. Contact guidance was found to promote cell adhesion due to the increase in interactions between the focal adhesions and the patterned extra-cellular matrix (ECM) proteins on the laser micro-grooved surfaces.[18-20] Lahori et al, compared bone density changes around dental implants in coronal, middle and apical regions and reported insignificant changes at the coronal level at all intervals of follow up but significant at middle and apical regions after 12 months. In this study, a comparison between different regions revealed a significant different between coronal, middle and apical regions of RBT implant and insignificant difference between different regions on LMG implants, which might suggest a smoother transfer of stress along bone implant interface of the LMG which requires further stress analysis in future studies.

5. Conclusion

Bone density monitoring is a useful diagnostic tool to judge the behavior of an implant system under functional loading. Many clinicians find that the benefits of using CT in implant follow up outweighs the risks of increased radiation doses especially with modified scanners of lower radiation doses. Implant surface characteristics affect bone remodeling at bone implant interface which suggests that not only the degree of roughness is effective but its orientation as well.

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