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Radiographic changes of trabecular bone density after loading of implant-supported complete dentures: A 3-year prospective study

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Abstract

Background: Bone tissues may undergo remodeling under functional mechanical stimuli.

Purpose: This prospective study on implant-supported fixed complete dentures (IFCDs) evaluated the radiographic trabecular bone changes in density by means of gray levels and texture analysis variables after up to 3-year loading.

Materials and Methods: The sample consisted of digital periapical radiographs of 63 distal implants of hybrid IFCDs installed in 30 patients (22 women, mean age of 62 ± 7.8 years). Digital periapical radiographs were taken after prosthesis installation, and 1 and 3 years after IFCD loading. Longitudinal images of each implant were superimposed, and the same regions of interest were selected for measurement of gray levels statistics (mean gray levels, SD, and coefficient of variation [CV]) and texture parameters (correlation, contrast, entropy, and angular second moment). Data were analyzed by mixed regression models.

Results: Mean gray levels increased for 1 year ($P < .05$), for 3 years ($P < .01$) and for maximum bite force ($P < .01$). The interaction between bruxism and time in 1 year was significant ($P < .01$) for a decrease in CV. No significant effect of texture analysis variables was found ($P > .05$).

Conclusions: The results suggest an increase of radiographic bone density as measured by an increase in mean gray levels and a decrease in CV in IFCD distal implants up to 3 years of loading.

KEYWORDS
bone density, bruxism, dental implants, occlusal force, radiology, texture analysis

1 | INTRODUCTION

Intraoral regions with sparse trabecular bone and thin cortical bone layer have potential high risk for implant failure because of low primary stability and limited bone-to-implant contact.[1-6] Nevertheless, the constant remodeling caused by dynamic cycles of microdamage and bone repair under occlusal functional loading may change peri-implant bone characteristics, leading to a reactional osseodensification in metabolically favorable bone.[7-9]

Radiographic changes of trabecular bone microstructure have been evaluated by quantitative methods to measure the variation of gray levels.[10-14] Gray levels are generally assessed by means of first-order statistics (mean, SD, and coefficient of variation [CV]), which describe the occurrence of gray levels without considering the spatial relation between pixels. Second-order statistics, which describe the properties of two related pixels in specific locations, can be used to analyze gray levels in medical imaging.[10,12-14] Second-order statistics are also called texture parameters, such as contrast, angular second moment, entropy, and correlation, which represent measures of uniformity, density, sharpness, regularity, and intensity.[11] A recent study quantified peri-implant bone changes under prosthetic loading for long periods of time.[13]However, it still is not clear if changes in peri-implant bone microstructure are affected by clinical factors such as occlusal force, bruxism, and use of provisional dentures. This could add important information to clinicians when planning implant-supported fixed prosthesis over sparse trabecular bone.

This prospective study evaluated radiographic changes in trabecular bone density, by means of gray levels and texture analysis variables, in distal implants of implant fixed complete dentures (IFCDs) under function up to 3 years. We also tested the possible effects of some clinical factors, such as use of provisional denture, maximum occlusal force, presence of bruxism, dental arch, and time of function, on gray levels and texture analysis variables in periapical radiographs.

2 | MATERIALS AND METHODS

This clinical study was conducted in accordance with the Declaration of Helsinki (Amendment 2009), and this report followed the STROBE guidelines. This study is part of a long-term prospective project, and the overall clinical protocol was previously described.[15,16] This study was approved by the University Ethics Committee (CAAE: 69742517.8.0000.5336), and all patients signed an informed consent form.

The sample consisted of digital periapical radiographs of 63 distal implants of hybrid IFCDs installed in 30 patients (22 women, mean age of 62 ± 7.8 years). Participants were recruited among consecutive patients treated at the outpatient dental clinics of the Pontifical Catholic University of Rio Grande do Sul, in Porto Alegre, Brazil, between 2010 and 2015. The eligibility criteria were:

1. Inclusion criteria: IFCD rehabilitation of edentulous maxilla and/or mandible, with metallic framework, acrylic resin veneering, and artificial teeth.
2. Exclusion criteria: Immediate loading, bone augmentation or grafting with biomaterials, previous osseointegration failure in the ROI, heavy smoking habit (over 10 cigarettes per day), non-compensated type 2 diabetes, cemented IFCD, poor oral hygiene.

2.1 | Maximum occlusal force and presence of bruxism

Maximum occlusal force was recorded using a cross-arch compressive force transducer,[17] while the patient was seated in an upright position with no head support. After orientation and training of the research procedure, patients were asked to bite the transducer with their maximum force. The maximum value out of five recordings was assigned as the maximum occlusal force.

A self-report questionnaire[18] was used to record the presence of possible nocturnal bruxism (yes/no). Possible bruxism was considered when the patient answered “yes” for questions 1 and/or 2 (Question 1: Are you aware, or has anyone heard your grinding your teeth frequently during sleep? and Question 2: “Are you aware that your dentition is worn down more than it should be?”), and matched at least one positive symptom listed in Question 3 (Question 3: “Are you aware of any of the following symptoms upon awakening?—to each of the six described symptoms: tiredness, tightness, or pain in jaw? Are your teeth clenched or is your mouth hurt when waking up? Pain in temple? Difficult opening your mouth? A sensation of tension in the temporomandibular joint when waking up and a feeling of having to move your jaw to get it relaxed? Have you ever heard or felt a “click” in the temporomandibular joint when waking up that disappears later?”).

2.2 | Digital periapical radiographs

Radiographic exams were performed after IFCD installation (baseline—BL), and at 1- and 3-year follow-up sessions (T1 and T3, respectively). Digital periapical radiographs were obtained using the parallel technique, with individualized film holders (Rinn XCP, Dentsply) with putty silicon to standardize the positioning overtime.[16] The X-ray images were obtained by using a photostimulable phosphor plate (Digora digital system, Optime, Soredex) an X-ray equipment (SOMMO, Gnatus), with 70 kVp, 7 mA, total aluminum filtration of 3.22 mm, and focus distance of 40 cm. The exposure times were 0.63 seconds for maxilla and 0.56 seconds for mandible. The Scanora 5.1 software (Soredex, Tuusula, Finland) was used for image processing.

2.3 | Gray levels and texture analysis

The radiographic images were standardized at 8-bit with pixels in the range from 0 (black) to 255 (white). All images of a given implant were superimposed using the free software GIMP (v.2.8, GIMP). The free software ImageJ (v.1.50i, National Institutes of Health) was used to collect data on both gray levels and texture analysis by means of the GLCM Texture Tool plugin.

The first author drew two region of interests (ROIs) of 20×20 pixels at two pixels away of the mesial and distal sides of each distal implant, in a 200× magnification for better identification of the pixels, next to the third thread inside the bone, considering the first bone/implant contact. The pixel size of all radiographs was 64-μm height by 64-μm width, which resulted in a ROI area of 1.28 mm^2 (Figure 1).

The following image data were collected: (a) first-order statistics: mean gray levels, SD, and CV; and (b) second-order statistics or texture analysis: angular second moment, contrast, entropy, and correlation (Table 1).

2.4 | Statistical analysis

The variables were tested as follows:

- Outcomes: gray levels or first-order statistics (mean gray levels, SD, and CV) and texture analysis or second-order statistics (angular second moment, contrast, entropy, and correlation).
- Predictors: maximum occlusal force, presence of bruxism, dental arch, use of provisional denture, and time of function (observation time).

A linear regression of mixed effects model for correlated data (for more than one implant installed in one patient) was used to analyze the relation between the changes in gray levels and texture parameters and the effect of factors over time (Figure 2). This multilevel model with random effects estimates the variation in the baseline data over time, considering the correlation between measures.[19,20] The models were adjusted separately for each parameter and also tested the interaction between time and factors. The significance level was set at 0.05.

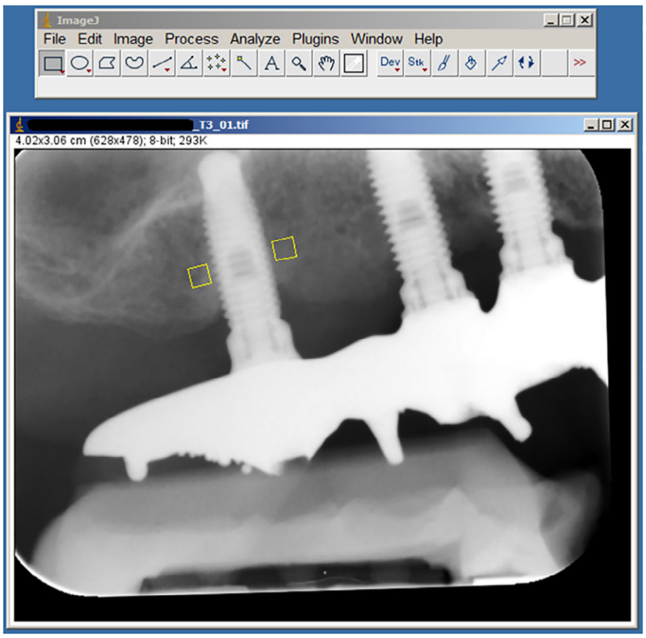

FIGURE 1 ROIs positioned in the mesial and distal sides of the distal implant for collection of gray levels data. ROI, region of interest

3 | RESULTS

A flowchart of sample size for different observation times is shown in Figure 3. Table 2 shows the descriptive analysis of the baseline sample. Table 3 shows the descriptive statistics of outcomes in different observation times.

Table 4 shows the results of the mixed regression models for the first-order parameters. Time and maximum occlusal force were significant for "Mean of gray levels" ($P < .05$), with an estimated increase of 4.19 and 9.15 in mean gray levels for 1 and 3 years, respectively, when adjusted by occlusal force. An increase of 0.1 in mean gray levels was estimated for each addition of unit of force (1 N).

The interaction between time and bruxism was significant ($P < .05$) for "Coefficient of Variation." A decrease of 0.0028 and 0.0129 after 1 and 3 years was estimated for patients without bruxism, and it was statistically significant at 3 years ($P < .01$). For patients with bruxism, the CV decreased 0.0302 after 1 year ($P < .01$). For each addition of unit of occlusal force (1 N), the CV decreased 0.000062 ($P < .05$).

Second-order parameters showed no effect from time, age, sex, maximum occlusal force, bruxism, use of provisional denture, or dental arch (Table 5).

4 | DISCUSSION

This study showed that bone density changes in periapical radiographs could be objectively measured as an increase of mean gray levels and a decrease of CV. In radiographic images, an increase in bone trabeculae should increase brightness, while the SD and the CV should decrease.[12-14] Models tested in this sample suggest that clinical factors such as time of functional loading, maximum bite force, and bruxism increase the bone density around IFCD distal implants. Those

TABLE 1 Study image variables, description and interpretation

Category	Parameter	Description	Interpretation
First order	Mean	Average value of gray levels inside a given region of interest (ROI)	The higher the mean, the denser the bone
	SD	Measure of the dispersion of pixel values around the mean of the ROI	The lower the SD, less dispersion of gray values. A uniformity representation
	Coefficient of Variation	The ratio between SD and mean	The lower the ratio, the less variation among the gray levels. A uniformity representation
Second order	Angular Second Moment	Measure of the image homogeneity	Value tends to 1 when the image is homogeneous
	Contrast	Measure of the local variation in gray levels	Low values represent more homogeneity
	Entropy	Measure of gray levels randomness	The more random the gray levels, the greater the entropy value
	Correlation	Measure of the linear dependency between pixel pairs	Value tends to 1 when pixels are more similar

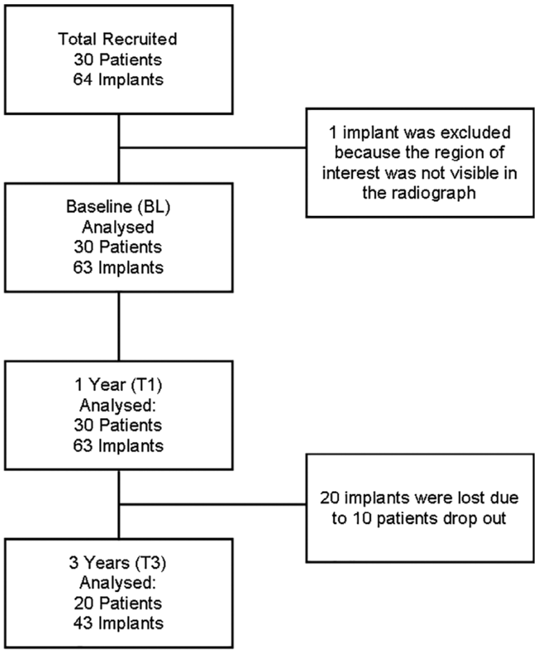

FIGURE 2 Hierarchy of dental implant data in the statistical multilevel model (linear regression of mixed random effects model)

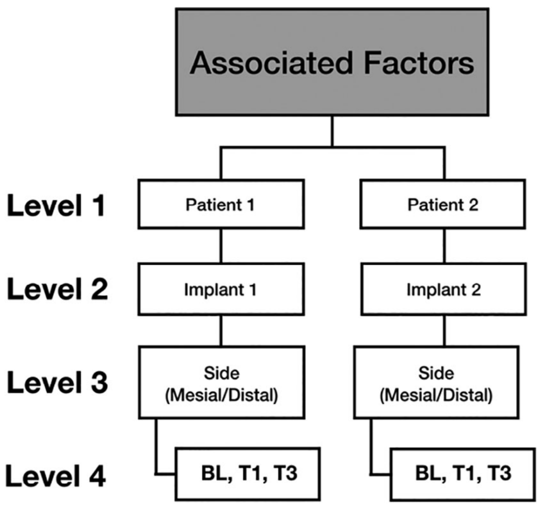

FIGURE 3 Flowchart of the sample in different times

TABLE 2 Descriptive statistics of the sample

Variable	Frequency	Mean	SD
Patients	30		
Sex—female	22		
Age (years)		62	7.8
Distal implants	63		
Maxilla	27		
Mandible	36		
Presence of possible bruxism			
Yes	22		
No	8		
Use of provisional dentures			
Yes	22		
No	41		
Maximum bite force (N)	30	471	142

TABLE 3 Mean and SD of parameters analyzed in mesial and distal and combined at baseline, T1 and T3

Category	Parameter	Baseline	T1	T3
First order	Mean gray levels	96.2 (32.7)	100 (31.8)	106 (35.1)
	SD	7.52 (3.24)	7.32 (3.22)	7.04 (2.89)
	Coefficient of variation	0.09 (0.05)	0.08 (0.04)	0.07 (0.03)
Second order	Angular second moment	0.02 (0.01)	0.02 (0.01)	0.02 (0.01)
	Contrast	6.15 (3.97)	5.57 (3.62)	5.45 (3.83)
	Entropy	4.53 (0.41)	4.51 (0.43)	4.49 (0.43)
	Correlation	0.03 (0.03)	0.03 (0.03)	0.03 (0.03)

mixed effects regression models were appropriate for multiple longitudinal observations, as well as for two distal implants in the same patient.[19,20]

Regarding texture analysis, the descriptive data showed a trend for bone densification overtime, but the results were not statistically significant in the regression models. A possible explanation may be the small size of ROIs used in the present investigation, which was determined by technical measurement reasons after a pilot study that indicated the best size of ROIs to obtain as much sample as possible. Mundim et al[14] found a relation between some texture parameters with bone types and primary stability using larger ROIs in the apical area and on each side of the implant (mesial and distal). A finite elements study by Yoon et al[21] showed that most stress transmitted to the peri-implant bone is concentrated in the upper region of the implant body in contact with bone. Thus, the ROIs were positioned at the third implant thread level, considering the first bone/implant contact, based on the last radiographic image. We avoided sites of marginal bone loss because any black pixel would lead to an erroneous interpretation of decrease in bone density. Appleton et al[22] and Carneiro et al[23] analyzed nine ROI's around dental implants, measuring 1 mm^2 (63 μm × 63 μm) each, positioned in mesial and distal implant sides, from crestal to apical regions. Appleton et al[22] showed no statistical difference in bone density for both conventional and progressive loading groups at subcrestal level, which is similar to the ROI position in our study. Conversely, Carneiro et al[23] reported a statistically significant increase in bone density at subcrestal level, with larger effect on bone around implants immediately loaded.

Regarding the effect of loading time, the period of 3 years was a significant factor for an increase in mean gray levels and a decrease in CV. These findings differ from Appleton et al,[22] who reported a tendency for increasing bone density in 1-year follow-up. Ramachandran et al[24] found an initial decrease in bone density at crestal level in

TABLE 4 Variation in first-order parameters as a function of time, age, sex, maximum bite force, bruxism, provisional, and arch

	Model		
Factor	**Mean gray level**	**SD**	**Coefficient of variation**
Time 1 year	4.190** (0.364-8.016)	−0.249 (−0.824 to 0.327)	−0.003 (−0.011 to 0.005)
Time 3 years	9.155*** (4.789-13.521)	−0.553* (−1.207 to 0.101)	−0.013*** (−0.022 to −0.003)
Age		−0.047 (−0.149 to 0.055)	
Sex: female		0.064 (−1.842 to 1.970)	
Maximum bite force	0.096*** (0.041-0.150)	0.0001 (−0.007 to 0.007)	−0.0001** (−0.0001 to −0.00000)
Bruxism: yes		0.914 (−0.715 to 2.544)	0.033*** (0.013-0.053)
Provisional: yes		0.179 (−1.342 to 1.701)	
Arch: mandible		0.863 (−0.478 to 2.204)	
Time 1 year × bruxism			−0.027*** (−0.043 to −0.012)
Time 3 years × bruxism			−0.016 (−0.033 to 0.002)
Constant	51.023*** (24.326-77.721)	9.560** (0.710-18.410)	0.108*** (0.079-0.138)

**$P < .05$; ***$P < .01$.

immediately loaded and nonloaded implants, followed by an increase in bone density from 3 to 6 months, but with no statistical significance. Aköğlan et al[25] evaluated different loading protocols and observed a significant increase in bone density at the cervical region for immediate, early, and delayed loading implants. These previous studies used different methods to quantify radiographic changes and acknowledged several limitations because of lack of protocol standardization, lengthy image digitalization and analysis, small sample sizes, and short follow-up.

The CV decreased when bruxism was associated with time, which represents bone densification. CV is the ratio between standard deviation (*sd*) and mean gray levels (*m*): CV = sd/m. A decrease in CV means either a decrease in *sd* and/or an increase in *m*. Our results showed no significant factor effect on *sd*, but time and maximum bite force had a significant effect on mean gray levels. Thus, patients with bruxism may have higher occlusal force, which would possibly increase the load over implants and bone density overtime.

Other clinical factors such as age, sex, use of provisional dentures, and dental arch had no significant effect on trabecular bone density. A larger change in bone density was expected for both gray levels and texture analysis in the maxilla because of thinner cortical layer than in the mandible. Turkyilmaz and colleagues[26,27] reported differences in bone density between maxilla and mandible before the implant installation. On the other hand, others found some bone changes in radiographs, but they did not compare maxilla and mandible.[22,24,25,28]

Some limitations of this study affect the generalization of results. The sample size dropped from 63 to 43 implants in the 3-year follow-up, which decreased the statistical power. However, the main alterations in bone density are expected to occur during the first year of clinical function. Additionally, the present findings are only applicable to the distal implants of IFCDs, and all implants in this sample had external hexagon. Other results are possible for different implant and prosthesis systems. Periapical radiographs are a routine exam in dental practice, but some limitations are inherent to the technique such as superimposition of anatomic structures and bone tissue visualization only in the mesial and distal implant sides. It would be interesting to evaluate a possible relation between clinical factors and bone microstructure in tridimensional exams such as computed tomography, without cortical and trabecular bone superimposition. Additionally, computed tomography also allows the visualization of cross-sectional cuts, which are essential in the planning phase of the treatment. To provide circumferential information of the process around the implants, it would be important to add the buccal and lingual/palatal sites to the analysis.

TABLE 5 Variation in second-order parameters as a function of time, age, sex, maximum bite force, bruxism, provisional, and arch

	Model			
Factor	Contrast	Entropy	Angular second moment	Correlation
Time 1 year	−0.648 (−1.474 to 0.179)	−0.026 (−0.102 to 0.050)	0.001 (−0.001 to 0.002)	0.002 (−0.003 to 0.007)
Time 3 years	−0.486 (−1.419 to 0.447)	−0.046 (−0.132 to 0.041)	0.001 (−0.001 to 0.002)	0.002 (−0.004 to 0.008)
Age	0.036 (−0.078 to 0.149)	−0.008 (−0.023 to 0.006)	0.0002 (−0.0001 to 0.0004)	0.0005 (−0.0003 to 0.001)
Sex: Female	0.598 (−1.536 to 2.732)	0.030 (−0.237 to 0.296)	−0.0005 (−0.005 to 0.004)	−0.001 (−0.015 to 0.014)
Maximum bite force	0.003 (−0.004 to 0.011)	0.0003 (−0.001 to 0.001)	−0.00001 (−0.00002 to 0.00001)	−0.00001 (−0.0001 to 0.00004)
Bruxism: Yes	1.362 (−0.472 to 3.197)	0.112 (−0.116 to 0.341)	−0.002 (−0.006 to 0.002)	−0.007 (−0.019 to 0.006)
Provisional: Yes	−0.946 (−2.594 to 0.703)	0.002 (−0.208 to 0.211)	−0.0001 (−0.004 to 0.004)	0.0005 (−0.011 to 0.012)
Arch: Mandible	−0.204 (−1.621 to 1.214)	0.024 (0.157-0.206)	−0.001 (−0.004 to 0.003)	−0.008 (−0.019 to 0.002)
Constant	2.013 (−7.930 to 11.957)	4.858* (3.621-6.095)	0.009 (−0.013 to 0.031)	0.010 (0.057-0.077)

*$P < .01$.

In summary, based on our findings and within the study limitations, it is possible to conclude that:

- There was an increase in radiographic trabecular bone density around distal implants of IFCDs.
- Three-year loading and maximum bite force had a significant effect on the increase in mean gray levels.
- Maximum bite force and the interaction between 1-year loading and bruxism had a significant effect on the decrease in CV.

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CONFLICT OF INTEREST

The authors declare no conflict of interest.

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