Erbil Dental Jurnal

EDJ

Radiographic Evaluation of The Bone Density Around Tooth-Anchored One-Piece Immediate-Loading Dental Implant

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ABSTRACT

Introduction: Immediate loading of dental implants has gained attention for its potential to enhance patient satisfaction and reduce treatment time. However, limited data exists on its effects on bone density around tooth-anchored, one-piece compressive implants. This study evaluates the impact of immediate functional loading on bone density changes using radiographic grayscale and texture analysis over one year.

Materials and Methods: A total of 68 patients (mean age: 56 ±8.2 years) received 89 distal implants in free-end partial edentulous sites. Cone beam computed tomography (CBCT) was used for treatment planning, and intra-oral digital radiographs were taken at baseline (T0), six months (T1), and one year (T2). Functional loading began seven days post-implantation using fixed porcelain-fused-to-metal (PFM) prostheses. Grayscale values and texture parameters, including mean, standard deviation (SD), and coefficient of variation (CV), were analyzed in regions of interest (ROIs) around the implants.

Results: Significant increases in bone density were observed across all ROIs between T0 and T1 and T0 and T2 ($P<0.05$). Between T1 and T2, differences were less pronounced but still indicated stabilization.

Upper ROIs: Significant changes ($P<0.05$) were observed across all time intervals except CV between T1 and T2 ($P>0.05$).

Lower ROIs: Consistently significant improvements ($P<0.05$) at all time intervals.

Mesial ROIs: Significant differences in SD and CV across all intervals ($P<0.05$), with notable mean changes between T0 and T2.

Distal ROIs: Early significant changes (T0-T1, $P<0.05$) in SD and CV, with stabilization by T2 ($P>0.05$).

Conclusion: Immediate functional loading enhances bone density, particularly within the first six months, with continued stability over one year, demonstrating its effectiveness for tooth-anchored one-piece compressive dental implants.

Keywords: Bone density, immediate loading, dental implants, one-piece design, radiographic analysis.

Article Information

Submission Date: 19/11/2023
Revision date: 5/12/2023
Acceptance date:24/12/2023
Publishing date: Dec 2024

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DOI: doi.org/10.15218/edj.2024.17

INTRODUCTION

Dental implants are utilized as a method modality for missing teeth owing to the fact that they function as artificial roots onto which a prosthesis may be anchored .[1] The layout of the one-piece dental implant has a more powerful concept as implant-abutment connection is absent. Crestal bone loss around the dental implant may be due to the lack of a microgap. Fewer complications of the mechanical load have been reported such as loosening of the screw and fracture of the abutment. One -piece dental implants, due to the high cortical stabilization, can be placed immediately and loaded promptly. Compared to two-stage implant installation, the advantages of the immediate loading protocol represent in lesser surgical appointments, lesser treatment times and minimal trauma.[2] Connecting osseointegrated implants with the teeth offers a biomechanical challenge. This is because of that the tooth is adhered to the bone with a periodontal membrane and the dental implants are rigidly fixed to the bone. However, this connection is possible under certain circumstances among them using the teeth that have healthy non-reduced periodontium with dense bone, cantilever extensions should be precluded and the distribution of the occlusal forces have to apply equally as possible.[3] Bone tissue answers emphatically and adversely to mechanical burdens; changes as far as the mass of skeletal bone and mineral thickness are related with mechanical improvements and recorded in the literature .[4] Jaws are continually exposed to the useful and parafunctional powers while rumination, crushing, gulping, banging and tapping: those conditions could impact adversely and decidedly on jaws' status.[5] Prompt loading of dental implants has turned into a broadly revealed practice with progress rates going from 70.8% to 100%.[6] The steady bone remodeling brought about by unique patterns of microdamage and bone fix under occlusal utilitarian stacking might change peri-embed bone qualities, prompting an incitement of osseodensification in a metabolically ideal bone.[7] The changes in trabecular bone microstructure radiographically have been assessed by quantitative methods of the gray level variations .[9] The radiographic progressions in trabecular bone microstructure have been surveyed by quantitative techniques for the gray level varieties.

Nevertheless, due to each unique factor, several important questions remain unresolved. According to Gerhardt et al., occlusal improvements may have an effect on the remodeling of the peri-implant bone around stable dental implants .[9] Persistent patterns of microdamage and bone recovery under utilitarian loading may alter the quantitative and subjective characteristics of peri-implant bone.[7] The stack on the dental implant is addressed by even and vertical parts; the stack applying inappropriately can pressure the periapical bone and the burdens are normally centered around the coronal third of the implant's collar, prompting peri- implant bone renovating. In cortical bone, scattering is generally confined to the implant's encompassing region, while in trabecular bone, dispersal happens at a more extensive distance.[10] The sum and the nature of the encompassing bone can impact the substance of the heap move from inserts to bone,[5] load move can likewise be impacted by the implant geometry.[11] The available research shows mixed outcomes on how a one-piece implant system impacts the adjacent hard and soft tissues.[12]

MATERIALS AND METHODS

This randomized clinical trial (RCT) study was conducted on 89 distal one-piece compressive dental implants (OPCDIs), 22 distal implants for the maxilla and 67 distal implants for the mandible. The study sample consisted of 68 patients (mean age of 56 ±8.2 years) having free-end partial edentulous upper and/or lower sites with the presence of healthy natural teeth or fixed prosthesis opposing the free-end partial edentulous areas. Those patients attended the Periodontics Department, College of Dentistry, University of Duhok, Iraq and private dental practice seeking for replacement of missing teeth. All patients had signed informed consent sheets and the study was approved by the Research Ethics Committee, Duhok, Iraq (Ref. No. 3008202-7-7).

CBCTs have been taken for all cases for proper treatment planning, monitoring bone conditions and measuring bone width and height for proper selection of distal implant sizes. Besides, the teeth neighboring the edentulous areas were probed and examined clinically and radiographically for evaluation of their eligibility to be anchored by (OPCDIs). The eligibility was represented in that these teeth have to possess healthy non-reduced

DOI: doi.org/10.15218/edj.2024.17

periodontium with dense bone[3] so as to be anchored with (OPCDIs) through the fabrication of fixed prosthesis which was porcelain fused to metal(PFM).

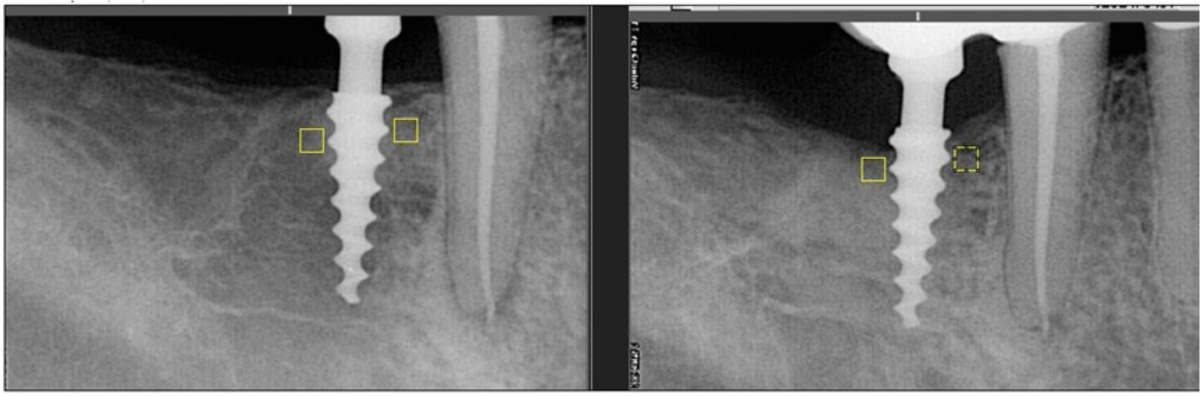
Digital periapical radiographs

Radiographs with high resolution were taken by using intra-oral digital periapical radiographs with parallel techniques immediately at the time of implant installation (baseline T_0), six months (T_1) and one year (T_2) after immediate functional loading.

The intra-oral x-ray sensor brand used was Villa Italy Videograph RVG Regular-size 1 (38.6*24.7*5.5mm) with pixel size equal to 1500*1000 pixels. The x-ray machine manufacturer company (Villa Endos ACP / Italy made) was used for this purpose. Radiation exposure conditions were: the tube voltage was 70 KV, the tube current was 80 mA and the exposure time ranged from 0.10 - 0.16 seconds coinciding with the tooth site, the arch (mandible or maxilla) and the patient weight in accordance to the manufacturer instructions.

Gray levels and texture analysis

All radiographic pictures have been standardized at 8-bit with the pixels within the range from 0 (black) to 255 (white). 2 regions of interest (ROIs), 1 for mesial and 1 for distal of every single or distal implant (Figures 1 and 2) were taken into account at the coronal half of the implant body at the level of the second implant thread excluding the first thread expecting crestal bone resorption. Because the force applied to the implant is focused in the upper part of the implant body where it makes contact with the bone, the (ROIs) were chosen.[14] Every single (ROI) was drawn with an area equal to (20 × 20) pixels and magnified to (×200) for better identification of the pixels. The pixel size of all radiographs was (64-µm) in height and (64-µm) in width, which resulted in an (ROI) equal to (4.096 mm^2). Gray Level Correlation Matrices (GLCM, version 0.4) were used to gather information about gray levels and texture analysis using the ImageJ free program (version 1.54f, National Institutes of



A B

Figure 1: Regions of interest were set in the mesial and distal sites of a single implant which was placed in the lower first molar area. A, The time of implant installation. B, One year of functional loading.

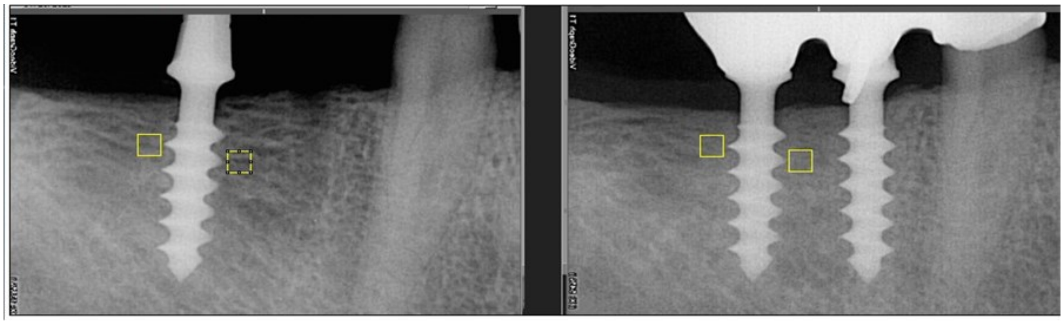


Figure 2: Regions of interest were set in the mesial and distal sites of a distal implant which was placed in the lower second molar area. A, The time of implant installation. B, One year of functional loading.

Health, USA). Plugin for Texture Tool.[9]

The parameters of both the gray levels and the texture analysis have been described and interpreted according to Maurício N. Gerhardt, et al.[9]

The parameters of both the gray levels and the texture analysis have been described and interpreted according to Maurício N. Gerhardt, et al.[9]

Gray level parameters include; **Mean gray levels** represent the average value of gray levels within a specified region of interest (ROI); higher mean values indicate greater bone density. **Standard deviation (SD)** measures the spread of pixel values indicating less gray level dispersion and a more uniform representation. The **Coefficient of variation (CV)** is a ratio of (SD) to the mean, where a lower (CV) signifies less variation in gray level greater uniformity. The texture analysis parameters include; **Contrast,** which measures local variation in gray levels, with Low values indicating greater homogeneity. **Correlation** assesses the linear relationship between pixel pairs, with value approaching 1 when pixels are more similar. **Angular second moment** quantifies image homogeneity. **Entropy** refers to the estimation of the arbitrariness of the gray levels. The more arbitrary the gray levels, the more prominent the entropy value.

Surgical technique

After proper selection of the implant sizes for the defined arch sites, all (OPCDIs) were placed without flap (flapless) surgery. The number of implants placed in the edentulous free-end areas depended on the bite conditions, presence of the opposite teeth and availability of sufficient bone height and width. Among all placed (OPCDIs) only the mesial and distal areas of the distal implants were taken into consideration for data collection. As the head of the (OPCDI) was exposed to the oral cavity, oral microflora might adhere to the implant surface and reside in the interface between the implant head and the soft tissue surrounding it. This might result in soft tissue infection and retarding soft tissue healing around the neck of the implant with subsequent retardation in the fixation of the fixed prosthesis and retardation of immediate functional loading. So antibiotics have been prescribed such as amoxicillin capsules (500mg tid) and metronidazole tablets (500mg tid) for 7 days. Tetracycline powder contained in capsules (250mg) was prescribed to be used as a mouthwash for 1 min/twice a day for 7 days as it could inhibit the growth of bacteria in the soft tissue-implant head interface (infection control) for accelerating soft tissue recovery from inflammatory processes.

Prosthetic stage

Functional load has started after 7 days of implant installation through fabrication of fixed prosthesis (PFM) connecting all implants together with healthy non-reduced periodontium neighbor teeth. (PFM) were cemented by using resin-reinforced glass ionomer cement (GC Fuji PLUS). The connection of the non-reduced periodontally healthy neighbored teeth with the (OPCDIs) aimed to provide more support for the (OPCDI) against lateral masticatory forces during stages of bone remodeling, so that the concept of ligualized occlusion was utilized to maximize cutting efficiency with minimized lateral forces.[15] All patients were motivated, educated and trained for correct brushing techniques for good oral hygiene and informed of recall visits for the maintenance phase every 3 months.

Inclusion criteria

Free-end edentulous site(s) per patient those having missing molars teeth in the maxilla and/or mandible with sufficient bone height and width and cases with bone densities (D_2, D_3 and D_4) were enrolled.

Exclusion criteria

Exclusion criteria included (D_1) bone as (D_1) bone quality was poorly evident through radiographic evaluation, the remaining teeth showed signs of aggressive periodontitis, teeth to be anchored neighboring the free-end edentulous areas had reduced periodontium or signs of periodontitis, sinus lift and bone grafting or augmentation with biomaterials previously treated, systemic illnesses that might compromise osseointegration, smokers, those having a history of previous irradiation, history of antibiotic sensitivity, bruxism cases, pregnant or lactating, lack of opposite dentition/ prosthesis were excluded from the study.

Statistical analysis

The data were analyzed using Statistical Package for Social Science (SPSS, IBM, Chicago, USA, version 28). For every single patient, despite the maximum bite force has been recorded, the bite measurement was not included in the statistical tests because it was taken into account as a constant non-continuous measurement over time and as the data were normally distributed, paired-samples T-tests were employed for intra-groups comparisons between different time intervals [(T_0-T_1), (T_0-T_2) and (T_1-T_2)]. Conversely, independent-samples T-tests were used for inter-groups comparisons at different time intervals [baseline (T_0), 6 months (T_1), and 1 year (T_2)] of functional loading (Figures 3 and 4).

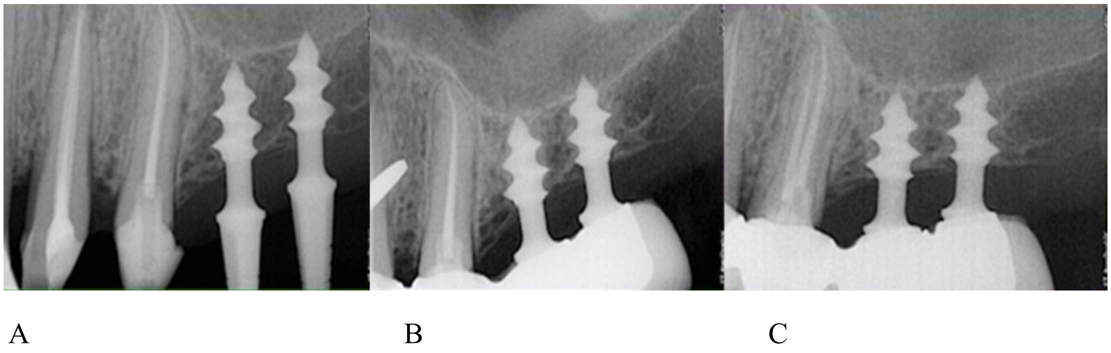


Figure 3: Gray level changes around an upper distal implant. A, The time of implant installation. B, Six months of functional loading. C, One year of functional loading.

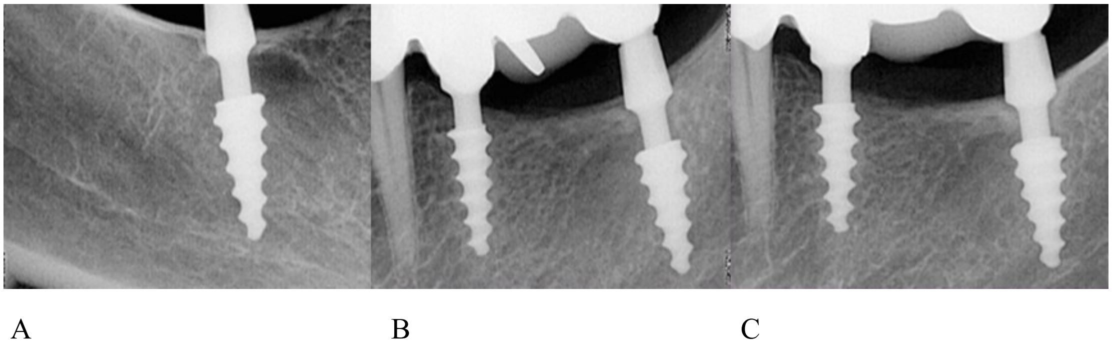


Figure 4: Figures 4 Gray level changes around a lower distal implant. A, The time of implant installation. B, Six months of functional loading. C, One year of functional loading.

RESULTS

The mean and standard deviation (SD) of the gray level and texture analysis parameters for the (ROIs) of the distal implants at baseline (T_0), 6 months (T_1) and 1 year (T_2) were illustrated in (Table 1). The differences in the gray level parameters for the (ROIs) of the distal implants were taken into account for evaluating bone densities. The differences were significant ($P<0.05$) at (T_0-T_1), (T_0-T_2) and (T_1-T_2) time intervals except for the mean which was not significant ($P>0.05$) at (T_1 -T_2) time interval (Table 1).

Table 1: Mean and (SD) for the (ROIs) of the distal implants at different time intervals and the

Parameters	Time Intervals (Mean±SD)			Time Intervals (p-value)		
	Baseline (T_0)	Six months (T_1)	One year (T_2)	Baseline-Six months (T_0-T_1)	Baseline-One year (T_0-T_2)	Six months-One year (T_1-T_2)
Mean	107.4 (17.6)	117.4(16.6)	120.06 (14.5)	0.002^{*}	0.001^{**}	0.117
SD	10.59 (3.59)	8.88(2.42)	7.86(2.46)	0.002^{*}	0.0001^{**}	0.02^{*}
CV	0.10 (0.038)	0.07(0.034)	0.06(0.029)	0.001^{**}	0.0001^{**}	0.01^{*}
Angular second moment	0.03 (0.002)	0.03(0.001)	0.03(0.002)			
Contrast	14.84 (6.87)	11.64(7.33)	9.19(6.73)			
Correlation	0.01(0.01)	0.01(0.007)	0.01(0.005)			
Entropy	6.06(0.21)	5.95(0.29)	5.76(0.41)			

*Significant difference; **: Highly significant difference using Paired-samples T-test; SD: Standard deviation; CV: Coefficient of variation

The mean and standard deviation (SD) of the gray level and texture analysis parameters for the (ROIs) of the upper and lower distal implants at baseline (T_0), 6 months (T_1) and 1 year (T_2) were illustrated in (Table 2). The differences (P-value) of the gray level variables at (T_0-T_1), (T_0-T_2) and (T_1-T_2) time intervals of the upper (ROIs) were significant ($P<0.05$) except for the mean and (SD) at (T_1-T_2) time interval the differences were not significant ($P>0.05$), while for the lower (ROIs) the differences for the gray level parameters were significant ($P<0.05$) (Table 2).

differences (P-value) for the gray level variables between different time intervals.

Table 2: Mean and (SD) for the upper and lower (ROIs) of the distal implants at different

(ROIs)	Parameters	Time Intervals (Mean±SD)			Time Intervals (p-value)		
		Baseline (T_0)	Six months (T_1)	One year (T_2)	Baseline-Six months (T_0-T_1)	Baseline-One year (T_0-T_2)	Six months-One year (T_1-T_2)
Upper	Mean	102.02(17.8)	109.8(13.3)	112(13.6)	0.03^*	0.02^*	0.62
	SD	14.02(3.4)	11.10(2.06)	8.6(2.6)	0.009^*	0.001^{**}	0.28
	CV	0.14(0.03)	0.10(0.02)	0.07(0.02)	0.002^*	0.001^{**}	0.037^*
	Angular second moment	0.03(0.001)	0.02(0.005)	0.02(0.005)			
	Contrast	13.5(5.39)	10.56(2.9)	8.9(2.9)			
	Correlation	0.018(0.05)	0.017(0.03)	0.016(0.02)			
	Entropy	6.28(0.10)	6.2(0.12)	5.9(0.2)			
Lower	Mean	109.21(17.6)	119.9(17.05)	122.5(14.2)	0.012^*	0.002^*	0.04^*
	SD	9.4(2.9)	8.14(2.08)	7.6(2.39)	0.046^*	0.009^*	0.021^*
	CV	0.08(0.03)	0.07(0.03)	0.06(0.03)	0.025^*	0.001^{**}	0.009^*
	Angular second moment	0.04(0.002)	0.04(0.001)	0.04(0.002)			
	Contrast	11.94(4.4)	8.0(6.37)	6.94(7.5)			
	Correlation	0.017(0.01)	0.012(0.07)	0.012(0.04)			
	Entropy	5.98(0.19)	5.87(0.28)	5.72(0.45)			

*Significant difference; **: Highly significant difference using Paired-samples T-test; ROIs: Regions of interest; SD: Standard deviation; CV: Coefficient of variation

time intervals and the difference (P-value) for the gray level variables between different time intervals.

The mean and standard deviation (SD) of the gray level and texture analysis parameters for the mesial and distal (ROIs) of the distal implants at different time intervals were illustrated in (Table 3). The differences (P-value) of the gray level variables of the mesial (ROIs) at different time intervals were significant ($P<0.05$) except for the mean which was observed significant ($P<0.05$) only at (T_0-T_2) time interval. For the distal (ROIs), the

Table 3: Mean and (SD) for the mesial and distal (ROIs) of the distal implants at different times and the differences (P-value) for the gray level variables between different time intervals.

(ROIs)	Parameters	Time Intervals (Mean±SD)			Time Intervals (p-value)		
		Baseline (T_0)	Six months (T_1)	One year (T_2)	Baseline-Six months (T_0-T_1)	Baseline-One year (T_0-T_2)	Six months-One year (T_1-T_2)
Mesial	Mean	98.26(16.14)	106.64(13.45)	108.18(11.55)	0.079	0.005^*	0.094
	SD	15.73(3.97)	12.01(2.26)	9.23(3.4)	0.010^*	0.002^*	0.022^*
	CV	0.15(0.016)	0.11(0.014)	0.08(0.023)	0.025^*	0.001^{**}	0.005^*
	Angular second moment	0.04(0.01)	0.02(0.01)	0.02(0.02)			
	Contrast	15.17(2.51)	14.56(3.08)	10.95(3.17)			
	Correlation	0.09(0.07)	0.05(0.04)	0.04(0.02)			
	Entropy	6.33(0.07)	6.25(0.11)	5.89(0.29)			
Distal	Mean	108.63(20.3)	122.3(16.1)	124.02(13.8)	0.015^*	0.009^*	0.048^*
	SD	9.69(3.37)	8.46(1.78)	7.57(1.6)	0.017^*	0.011^*	0.045^*
	CV	0.09(0.037)	0.07(0.02)	0.06(0.02)	0.010^*	0.004^*	0.012^*
	Angular second moment	0.03(0.02)	0.03(0.01)	0.02(0.01)			
	Contrast	13.6(4.74)	11.1(3.9)	9.07(2.8)			
	Correlation	0.015(0.07)	0.012(0.08)	0.01(0.05)			
	Entropy	6.02(0.19)	5.88(0.3)	5.78(0.31)			

*Significant difference; **: Highly significant difference using Paired-samples T-test; ROIs: Regions of interest; SD: Standard deviation; CV: Coefficient of variation

DOI: doi.org/10.15218/edj.2024.17

differences were significant ($P<0.05$) for the gray level variables (Table 3).

Regarding the differences of the gray level variables between upper and lower (ROIs) at baseline (T_0), 6 months (T_1) and 1 year (T_2), the differences for the mean were not significant ($P>0.05$) while for the (SD) and (CV), the differences were significant ($P<0.05$) at (T_0) and (T_1) and not significant ($P>0.05$) at (T_2). Concerning the comparisons in the gray level variables between the mesial and distal (ROIs) of the distal implants, the differences were observed no significant ($P>0.05$) (Table 4).

ROIs	Parameters	Time Intervals (Mean±SD)			Time Intervals (p-value)		
		Baseline (T0)	Six months (T1)	One year (T2)	Baseline-Six months (T0-T1)	Baseline-One year (T0-T2)	Six months-One year (T1-T2)
Mesial	**Mean**	98.26(16.14)	106.64(13.45)	108.18(11.55)	0.079	0.005^{*}	0.094
	SD	15.73(3.97)	12.01(2.26)	9.23(3.4)	0.010^{*}	0.002^{*}	0.022^{*}
	CV	0.15(0.016)	0.11(0.014)	0.08(0.023)	0.025^{*}	0.001^{**}	0.005^{*}
	Angular second moment	0.04(0.01)	0.02(0.01)	0.02(0.02)			
	Contrast	15.17(2.51)	14.56(3.08)	10.95(3.17)			
	Correlation	0.09(0.07)	0.05(0.04)	0.04(0.02)			
	Entropy	6.33(0.07)	6.25(0.11)	5.89(0.29)			
Distal	**Mean**	108.63(20.3)	122.3(16.1)	124.02(13.8)	0.015^{*}	0.009^{*}	0.048^{*}
	SD	9.69(3.37)	8.46(1.78)	7.57(1.6)	0.017^{*}	0.011^{*}	0.045^{*}
	CV	0.09(0.037)	0.07(0.02)	0.06(0.02)	0.010^{*}	0.004^{*}	0.012^{*}
	Angular second moment	0.03(0.02)	0.03(0.01)	0.02(0.01)			
	Contrast	13.6(4.74)	11.1(3.9)	9.07(2.8)			
	Correlation	0.015(0.07)	0.012(0.08)	0.01(0.05)			
	Entropy	6.02(0.19)	5.88(0.3)	5.78(0.31)			

*Significant difference; **: Highly significant difference using Independent-samples T-test; ROIs: Regions of interest; SD: Standard deviation; CV: Coefficient of variation

Table 4: Differences (P-value) between upper and lower (ROIs) and mesial and distal (ROIs) of the distal implants at different time intervals.

DISCUSSION

22 distal implants in the maxilla and 67 in the mandible were among the 89 distal OPCDIs investigated in this study. The results showed a decrease in the standard deviation (Sd) and the coefficient variation (CV) for gray levels, as well as an increase in mean gray levels, indicating an improvement in radiographic bone density around the OPCDIs for up to a year. Greater homogeneity in the radiography image, which reflects less fluctuation among the grey levels, is indicated by a lower CV.[8] In orthopaedics, bone quality is assessed by structural evaluations rather than just mineral deposition in the bone. These evaluations are difficult to perform in dental implants because there are currently no innovative tools for accurately measuring bone structure.[16] (D_1) bone is primarily cortical, resulting in increased radiopacity with narrow gray levels (entropy) and pixel values that exhibit low deviation from the mean (SD), according to Lekholm and Zarb's classification of jawbones. This study did not include (D_1) bone because of its low coefficient of variation (the ratio of standard deviation to mean gray levels). Conversely, D_2, D_3, and D_4 bone have increasingly reduced gray levels as a result of their higher radiolucency, which is attributed to a larger percentage of medullary gaps in these kinds.[16] Consequently, these bone types exhibit a higher coefficient of variation from D2 to D4 bone, with a progressively lower mean gray level and increased pixel value variability.[18] The upper portion of the implant body in touch with the bone is where the majority of the stress imparted to the peri-implant bone is concentrated, accord-

ing to a finite elements study by Yoon et al.[14] Thus, the regions of interest (ROIs) were drawn at the level between the first and the second implant thread. The advantages of a one-piece implant include rapid functional restoration, shorter procedure time, reduced instrumentation requirements, minimized risk of damage to surrounding tissues, and efficient use within limited space. Compared to two-stage implants, one-piece implants also enhance patient compliance, as they are associated with reduced inflammation, pain, and stress due to fewer prosthetic appointments. Additional benefits include improved osseointegration, reduced micromovements, and favorable soft tissue healing.[19]

In the past and the present, the connection of dental implants with natural teeth has been a big controversy among dental practitioners and presents a biomechanical challenge. This is due to the implant being rigidly fixed to the bone and the tooth being attached to the bone with a periodontal ligament. However, this connection is applicable under certain situations as reported and concluded by Serhat Ramoglu et al.[3] The current study has proved that this connection could provide many advantages. Among them; the anchored teeth had the ability to provide support for the dental implants against occlusal force, particularly the lateral masticatory load during stages of bone remodeling as implant installation into the bone results in the provocation of the inflammatory process in the bone which consequently followed by bone remodeling (resorption and formation). Since it may jeopardize the integrity of the implants during the masticatory stresses, causing the implant to fail, the remodeling process during inflammatory stimulation surrounding the dental implant has been considered a significant stage in the success of the dental implant. Osteoclasts around dental implants under functional loading have demonstrated bone remodeling, and there has also been increased bone-implant contact in these areas.[20,21] Connection of the dental implants with non-reduced periodontally healthy neighbored teeth could promote immediate functional loading on the dental implants. It has seemed that immediate functional loading on the dental implants during inflammatory provocation has modified bone remodeling pathways thereby over stimulation of the regenerative cells during bone formation stage which consequently account for improvement of bone quality, i.e., deposition of more bone minerals around the dental implants, thus mechanical loading increases trabecular content and thickness, increases bone volume fraction and changes bone trabecular morphology.[22] Literature reported that biomechanical stability and micromovement at dental implant-bone interface proved to be strongly related to the quality, i.e. formation of mineralized tissue, and organization of the tissues, particularly if this micromovement immediately after the implant installation.[20]

In the current study, (D_4) bones have been included and improvement of bone quality was revealed after a period of time while widely in the dental population they excluded placement of dental implants in the poor bone quality (i.e, (D_4) or osteoporotic bone) as the prognosis of the implant success is unclear.[23] Ramachandran et al, found an initial decrease in bone density at the crestal level in immediately loaded and non-loaded implants, followed by an increase in bone density from 3 to 6 months, but with no statistical significance.[24] In their study, Appleton et al, demonstrated that there was no statistically significant difference at the subcrestal level, when comparing conventional loading protocols with progressive loading protocols. This finding aligns closet with the position of the regions of interest (ROIs) examined in our study, supporting the consistency of subccrestal bone density outcomes across different loading approach.[25] Similarly, Akög!lan et al. showed an evaluation of various loading protocols, including immediate, early, and delayed loading, to measure their impact on peri-implant bone density. Their results showed a significant increase in bone density specifically at the cervical region of the implants across all loading protocols. This suggests that the timing of implant loading, whether immediate or delayed, can positively influence bone variation and density at the cervical region, which is omportant for implant stability and long-term success.[26] Conversely, Carneiro et al. showed a statistically significant increase in bone density at the subcrestal level after a one-year follow-up, with the most distinct effects observed around immediately-loaded implants. This finding suggests that immediate loading may have a stronger positive impact on bone density at the subcrestal level compared to other loading protocols, highlighting its potential aids for increasing peri-implant bone support over time.[27] Maurício N. Gerhardt et al. detected an increase in radiographic trabecular bone density around distal implants over a three-year follow-up period.[13] Turkyilmaz and coworker stated differences in bone density between the maxilla and mandible prior to implant placement. However, other studies noted radiographic bone changes but did not specifically compare these two regions.[18,28] It is important to highlight that the studies referenced primarily focused on conventional, non-tooth-anchored, two-piece dental implants. These implants lack the integration with natural teeth, which distinguishes them from one-piece or tooth-anchored implant designs that may interact differently with surrounding bone and soft tissue.

RECOMMENDATIONS

Based on the results, future studies should focus on measuring bone density changes around immediate-loading one-piece implants, definitely across different jawbone types and locations (mandible vs. maxilla). Long-term follow-up beyond one year is optional to assess the stability of these density improvements. Investigating the biological mechanisms of bone remodeling in immediate loading, and comparation one-piece with two-piece implant systems, particularly in low-density bone, would offer valuable insights for improving implant protocols.

CONCLUSION

The study suggests that direct functional loading on tooth-anchored one-piece compressive implants significantly improves bone quality around distal implants, with main density changes occurring within the first six months. These results indicate that one-piece implants may be effective even in low-density bone and support the requirement for modified protocols that consider bone type, implant location, and patient-specific responses to loading.

CONFLICT OF INTEREST

The authors declare that there are no conflicts of interest.

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