

RESEARCH

Open Access



Investigation of the effects of two- and three-implant supported overdenture prostheses on peri-implant bone and mandibular trabecular bone using fractal analysis and radiomorphometric methods on panoramic radiographs

Furkan Özgür¹ , Meltem Zihni Korkmaz^{1*} , Semih Alperen Bostan¹ and Taha Emre Köse²

Abstract

Background To compare the average values of fractal and radiomorphometric analysis measurements in patients using overdenture prostheses supported by two or three implants.

Methods This retrospective study analyzed panoramic radiographs of 40 patients (aged 40–90 years) treated with overdentures supported by either two or three implants ($n = 20$ per group). Baseline and 1–2-year follow-up radiographs were evaluated. Fractal dimension was assessed in mesial, distal, and apical peri-implant regions and averaged at the patient level to avoid clustering of implant-level observations. Radiomorphometric indices, including mandibular cortical width (MCW), mandibular cortical index (MCI), panoramic mandibular index (PMI), antegonial index (AI), and gonial index (GI), were measured bilaterally. Multiple linear regression analyses were performed to determine independent predictors of fractal dimension changes (T1–T0).

Results Fractal analysis showed no significant intergroup differences in overall trabecular bone structure. A significant increase over time was observed only in distal fractal measurements in the two-implant group, with higher follow-up values compared with the three-implant group ($p < 0.05$). At follow-up (T1), mandibular cortical width (MCW) and antegonial index (AI) values were significantly higher in the three-implant group ($p < 0.05$), whereas no differences were detected for PMI or MCI. Regression analysis demonstrated that baseline fractal values were significant predictors of fractal dimension changes in all regions, whereas implant configuration was significantly associated only with distal fractal change.

Conclusion Fractal analysis showed no significant difference in overall trabecular bone adaptation between two- and three-implant-supported overdenture groups. Radiomorphometric findings suggest a potential association

*Correspondence:
Meltem Zihni Korkmaz
meltem.zihni@erdogan.edu.tr

Full list of author information is available at the end of the article



© The Author(s) 2026. **Open Access** This article is licensed under a Creative Commons Attribution-NonCommercial-NoDerivatives 4.0 International License, which permits any non-commercial use, sharing, distribution and reproduction in any medium or format, as long as you give appropriate credit to the original author(s) and the source, provide a link to the Creative Commons licence, and indicate if you modified the licensed material. You do not have permission under this licence to share adapted material derived from this article or parts of it. The images or other third party material in this article are included in the article's Creative Commons licence, unless indicated otherwise in a credit line to the material. If material is not included in the article's Creative Commons licence and your intended use is not permitted by statutory regulation or exceeds the permitted use, you will need to obtain permission directly from the copyright holder. To view a copy of this licence, visit <http://creativecommons.org/licenses/by-nc-nd/4.0/>.

between implant configuration and cortical bone characteristics; however, these findings should be interpreted with caution. Regression analysis indicated that baseline fractal values were the strongest predictors of subsequent changes, while the effect of implant configuration was limited to the distal region. These findings should be interpreted cautiously and considered hypothesis-generating rather than confirmatory.

Keywords Fractal analysis, Implant, Overdenture prosthesis, Panoramic Radiography, Implant overdenture

Background

Complete edentulism refers to the condition in which an individual loses all natural teeth. This condition affects more than 10% of adults aged over 50 years worldwide and is recognized as a major public health problem because of its functional, esthetic, and psychosocial limitations [1]. Although traditional complete dentures are still commonly used to manage complete edentulism, several other treatment options have emerged due to ongoing difficulties with retention, stability, and chewing efficiency [2]. Dental implant therapy has emerged as an effective option for addressing the limitations associated with conventional complete dentures. Both fixed and removable implant-supported prostheses are widely preferred treatment modalities for patients with complete edentulism. A prospective study reported that mandibular implant-supported overdentures exhibited only minimal differences in masticatory efficiency compared with implant-supported fixed prostheses [2]. Overdenture prostheses are generally planned with support from two or four implants. However, in cases where the fulcrum line in two-implant-supported designs adversely affects the biomechanics of the prosthesis, an additional implant may be placed to minimize this effect, resulting in three-implant-supported configurations [3].

Two and three-implant-supported overdenture prostheses each have their own advantages and limitations. Compared with conventional complete dentures, the two-implant design is advantageous because of its lower cost, reduced surgical intervention requirements, and improved stability. However, these designs tend to exhibit rotational movement under occlusal loading, which may lead to loss of stability and food entrapment beneath the prosthesis. In contrast, three-implant-supported overdentures provide three-point support by eliminating the fulcrum line, thereby offering the potential to enhance biomechanical stability. Nevertheless, although implant-supported overdentures can withstand greater occlusal forces than conventional complete dentures, this biomechanical advantage may also result in increased hydrostatic pressure on mucosal tissues, potentially contributing to underlying bone resorption [4].

Fractal analysis is a quantitative method used to evaluate the micromorphologic complexity of bone tissue on the basis of images obtained from periapical or panoramic radiographs [5]. This technique provides an objective means of monitoring physiologic bone remodeling

processes as well as resorptive changes within the bone structure [6, 7].

Radiomorphometric analyses are noninvasive methods that enable the evaluation of bone structure through radiographic imaging. Radiomorphometric indices are important parameters used in dentistry to assess the structural characteristics of the jawbone on the basis of measurements obtained from panoramic radiographs [7]. These indices provide valuable information for the early detection of conditions associated with decreased bone mineral density (BMD), such as osteoporosis. Among the most commonly used measurements for this purpose are the mandibular cortical index (MCI), panoramic mandibular index (PMI), gonial index (GI), and antegonial index (AI) [8]. The MCI classifies the appearance of the mandibular cortical bone to determine the risk of osteoporosis [9]. The GI measures cortical thickness in the gonial region and determines systemic bone density and age-related changes. The AI evaluates cortical thickness in the antegonial region and is used for osteoporosis screening and assessing morphologic changes in the mandible [9].

Despite the clinical relevance of implant number and distribution, studies simultaneously combining fractal analysis and radiomorphometric indices to compare two- and three-implant-supported mandibular overdentures remain limited.

In the present study, the biomechanical effects of two- and three-implant-supported removable overdentures on bone tissue were compared using radiologic parameters. The aim of this study was to compare peri-implant trabecular bone structure and mandibular radiomorphometric indices in patients treated with two-implant and three-implant supported mandibular overdentures using panoramic radiographs.

The null hypothesis (H0) was that there would be no statistically significant differences in fractal dimension (FD) values or radiomorphometric indices between the two implant configurations over time.

Methods

Ethical approval

The study protocol was conducted in full accordance with the principles of the Declaration of Helsinki. Written informed consent was obtained from all participants for both the implant surgery and radiographic imaging procedures. Access to the collected data was restricted to

the responsible investigators only. The study was initiated after approval was obtained from the Non-Interventional Clinical Research Ethics Committee of Recep Tayyip Erdoğan University (Approval No: 2024/267).

Sample size calculation

According to the power analysis, the sample size for this retrospective study was calculated using the G*Power statistical software (version 3.1.9.7). The study consisted of two groups. On the basis of an independent samples t-test design, with a test power of 0.80, an effect size of 0.8 (large effect according to t-test conventions), and a Type I error (α) of 0.05, the minimum required sample size was determined as 20 subjects per group, resulting in a total of 40 participants. Therefore, 40 patients were included in the study. The effect size was selected based on previously published radiographic studies evaluating peri-implant bone changes using fractal analysis [10].

Inclusion criteria

The study included patients who had been admitted to the Faculty of Dentistry at Recep Tayyip Erdoğan University since 2015, presented with complete edentulism in the mandible, and were treated with either two- or three-implant-supported overdenture prostheses. All the implant surgeries and prosthetic treatments were performed at the Faculty of Dentistry, Recep Tayyip Erdoğan University.

Exclusion criteria

The exclusion criteria were the presence of systemic diseases or the use of medications that could affect bone metabolism, panoramic radiographs that were diagnostically inadequate or exhibited reduced image quality due to technical errors during acquisition, and a history of radiotherapy in the head and neck region.

Panoramic radiographs

For this study, panoramic radiographs of patients were obtained at the Department of Oral and Maxillofacial Radiology, Faculty of Dentistry, Recep Tayyip Erdoğan University, using a panoramic X-ray unit (Planmeca ProMax 2D S2, Planmeca Oy; Helsinki, Finland). All images were acquired under identical exposure parameters (66 kVp, 8 mA, 16.6 s). Two panoramic radiographs were used for each patient: The first radiograph (T0) represents the immediate postoperative control radiograph obtained before functional loading. Therefore, T0 measurements reflect baseline bone morphology prior to prosthetic loading and the second radiograph (T1) was taken 1–2 years later during routine follow-up evaluations.

Fractal analysis

To ensure image standardization, all radiographs were saved in TIFF format with a high-resolution setting of 2945×1435 pixels. Fractal analysis for each sample was performed using the box-counting method as proposed by White and Rudolph [11].

Fractal analysis was performed on panoramic radiographs using the freely available ImageJ software (National Institutes of Health, Bethesda, MD, USA; <https://imagej.nih.gov/ij/>).

The region of interest (ROI) size and localization were determined based on previously published protocols for fractal dimension (FD) analysis on panoramic radiographs [12].

Rectangular ROIs were selected in the mesial and distal cervical regions and in the apical region to represent different peri-implant trabecular bone areas. Care was taken to exclude implant structures, adjacent roots, radiopaque artifacts, and resorptive areas to ensure that the selected ROIs accurately reflected trabecular bone architecture and improved the reproducibility of the measurements [12].

Rectangular regions of interest (ROIs) were used for fractal dimension analysis. In the mesial and distal peri-implant regions, ROIs measuring 60×90 pixels (width $\times$ height) were selected. In the apical region, the orientation of the ROI was rotated to align with the long axis of the implant, resulting in a 90×60 pixel (width $\times$ height) ROI. The total area of the ROI was kept constant across all regions to maintain measurement consistency [12].

Figure 1. Representative panoramic radiograph illustrating standardized ROI placement for both fractal and radiomorphometric analyses in the peri-implant region of the anterior mandible. Distal (g), mesial (h), and apical (i) regions were used for fractal analysis. For radiomorphometric evaluation, GI was measured at the gonial angle (a), AI at the antegonial region (d), and PMI at the superior (b/e) and inferior (c/f) borders of the mental foramen.

Fractal dimension (FD) analysis was performed using the box-counting method according to the protocol described by Stuart C. White and Michael J. Rudolph. The analysis was conducted using ImageJ software (National Institutes of Health, Bethesda, MD, USA). For each region of interest (ROI), images were processed following a standardized workflow. First, the selected ROI was converted to an 8-bit grayscale image. A Gaussian blur filter (sigma = 35 pixels) was then applied to remove large-scale brightness variations. The blurred image was subsequently subtracted from the original image to enhance trabecular bone structures. The resulting image was converted into a binary format using an automatic thresholding procedure. Morphological operations, including erosion and dilation, were applied to reduce

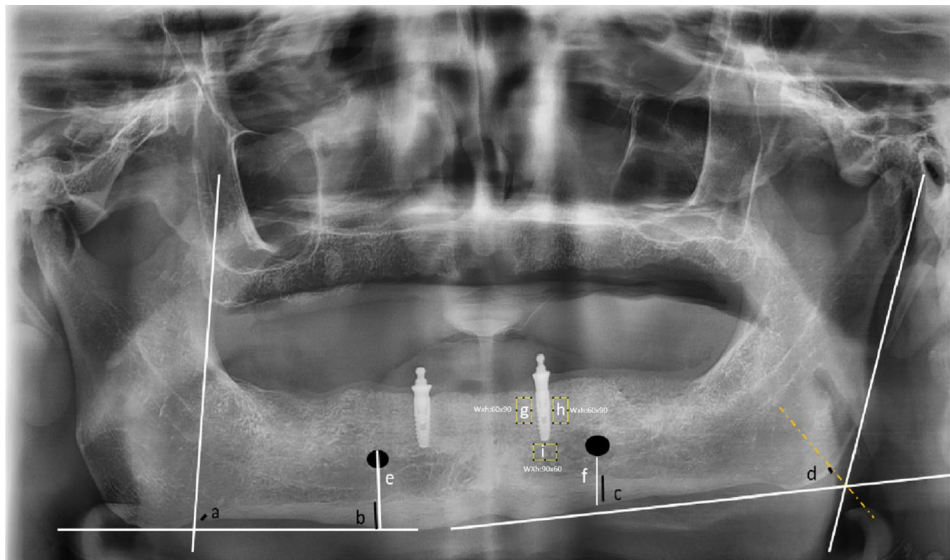


Fig. 1 GI was measured at the gonial angle (a). SPMI and IPMI were calculated as b/e and c/f based on cortical thickness and mandibular height measured at the superior and inferior borders of the mental foramen, respectively (b, c, e, f). AI was measured at the antegonial region (d). For fractal analysis, peri-implant trabecular ROIs were defined as distal (g), mesial (h), and apical (i)

noise and refine the trabecular pattern. The processed image was then skeletonized to obtain a one-pixel-wide representation of the trabecular network. Finally, fractal dimension values were calculated using the box-counting algorithm with box sizes ranging from 2 to 64 pixels.

The numerical FD values ranged between 1 and 2, and these values were compared between the two study groups to evaluate the density and complexity of the mandibular trabecular bone structure [11].

Intra-observer agreement

All radiographic measurements were performed by a single oral and maxillofacial radiologist with more than 14 years of clinical experience. To evaluate measurement reproducibility, 15 randomly selected panoramic radiographs (approximately 30% of the total sample) were re-evaluated by the same examiner after a 15-day interval. For continuous variables, including fractal dimension (FD), mandibular cortical width (MCW), panoramic mandibular index (PMI), antegonial index (AI), and gonial index (GI), intra-observer agreement was assessed using the intraclass correlation coefficient (ICC) with absolute agreement. The ICC values ranged from 0.89 to 0.95, indicating excellent measurement reliability. For the categorical variable mandibular cortical index (MCI), weighted Cohen's kappa statistics were calculated ($\kappa = 0.84$), indicating strong agreement.

Radiomorphometric index measurements

In this study, radiomorphometric analysis was performed on panoramic radiographs to evaluate the cortical

structure of the jawbone and to assess potential changes in bone density noninvasively.

Mandibular cortical width (MCW/Mental Index): The thickness (in millimeters) of the cortical bone was measured along a line drawn perpendicular to the lower border of the mandible at the level of the mental foramen [9]. **PMI:** The ratio of the MCW to the distance between the lower border of the mandible and the inferior margin of the mental foramen [9]. **AI:** The thickness of the cortical bone in the antegonial region, measured along a line drawn perpendicular to the lower border of the mandible [13]. **GI:** Measurement of cortical bone thickness along the bisector of the gonial angle region [13]. (Fig. 1)

GI was measured as cortical thickness at the gonial angle (a). SPMI and IPMI were calculated as ratios of cortical thickness to mandibular height at the superior (b/e) and inferior (c/f) borders of the mental foramen, respectively. AI was measured as cortical thickness at the antegonial region (d). (Fig. 1)

All measurements were performed on digital panoramic radiographs following a standardized protocol and were recorded in millimeters. These parameters were used to quantitatively evaluate the mandibular BMD and structural integrity.

All implants were placed in the interforaminal region of the mandible. In the two-implant group, implants were positioned in the bilateral canine regions. In the three-implant group, two implants were placed in the canine regions and an additional implant was positioned in the midline.

All implants belonged to the same implant system and were placed according to the manufacturer's surgical

protocol. Implant diameters ranged between 4.1 and 4.7 mm, and implant lengths ranged between 10 and 12 mm.

A delayed loading protocol was used for all patients. The overdenture prostheses were delivered after completion of the osseointegration period. Locator attachment systems were used for prosthesis retention.

Statistical analysis

Descriptive statistics (number, percentage, mean, standard deviation, median, minimum, and maximum values) are presented. The assumption of a normal distribution was evaluated using the Shapiro–Wilk test, and the homogeneity of variance was verified using Levene’s test. If there was an assumption of normality, comparisons between two independent groups were performed using the independent samples t-test, and comparisons between dependent variables were made using the paired samples t-test. When the assumption of normality was not met, the Mann–Whitney U test and the Wilcoxon signed-rank test were used. For categorical variables, relationships were analyzed using the Chi-square test, and when the expected cell count assumption (expected value > 5) was not satisfied, Fisher’s exact test was used. The McNemar test was used to evaluate relationships between dependent categorical variables.

To analyze the relationships between implant groups and sex, Pearson’s Chi-square test was used. For fractal measurements, implant-level observations were first converted into patient-level regional values by averaging measurements obtained from different implant positions within the same patient. Thereafter, intergroup comparisons were performed using the Mann–Whitney U test and intragroup temporal comparisons were performed using the Wilcoxon signed-rank test. Multiple linear regression analyses were additionally used to identify independent predictors of fractal dimension changes. Similarly, comparisons of radiomorphometric measurements between implant groups and across time points were performed using the same statistical procedures. Finally, Fisher’s exact test was used to assess the relationship between the implant groups and the distribution of MCI measurements.

Because multiple implants could be present within the same patient, implant-level fractal measurements were not considered independent observations. To reduce

clustering bias caused by multiple implants within the same individual, fractal measurements obtained from different implant positions were averaged to obtain a single patient-level value for each region (distal, mesial, and apical).

However, implant positions were not identical across groups. In the two-implant group, implants were placed in the bilateral canine regions, whereas in the three-implant group, an additional implant was present in the midline. Therefore, regional averages may not represent anatomically or biomechanically equivalent locations across groups.

While patient-level averaging reduces within-subject dependence, it may also introduce positional heterogeneity by combining measurements derived from structurally non-equivalent implant sites. Because the sample size was relatively small, a patient-level analysis approach was preferred instead of mixed-effects modeling to ensure model stability.

In addition, multiple linear regression analyses were performed to identify independent predictors of fractal dimension changes over time. The dependent variable was defined as the change in fractal dimension between baseline (T0) and follow-up (T1). Baseline fractal value, implant configuration (two implants vs. three implants), and sex were included as predictor variables in the regression models. Separate models were constructed for distal, mesial, and apical regions. Multicollinearity was assessed using variance inflation factor values.

Intra-observer reliability was assessed using the intra-class correlation coefficient (ICC) with absolute agreement for continuous measurements, including fractal dimension (FD), mandibular cortical width (MCW), panoramic mandibular index (PMI), antegonial index (AI), and gonial index (GI). For the categorical variable mandibular cortical index (MCI), weighted Cohen’s kappa statistics were calculated to determine intra-observer agreement.

All the statistical analyses were conducted using the IBM SPSS Statistics version 27 software package (IBM Corp., Armonk, NY, USA).

Results

Sex distributions according to implant groups

The distributions of sex according to implant groups are presented in Table 1. When the distribution by

Table 1 Distribution of sex according to implant group and relationship

	Group 1 (Two Implants)			Group 2 (Three Implants)			Test Statistic	p
	n	%	% Within Group	n	%	% Within Group		
Female	10	47.6	50.0	11	52.4	55.0	0.100	0.752
Male	10	52.6	50.0	9	47.4	45.0		

%: column percentage
% within Group: Percentage within study groups

implant number was examined, females and males each accounted for 50.0% of the two-implant group, whereas in the three-implant group, females represented 55.0% and males 45.0% of the sample. The analysis revealed no statistically significant relationships between the study groups and sex ($p > 0.05$) (Table 1). Therefore, the sex distribution across implant groups was considered homogeneous.

Distribution and comparison of fractal measurements according to implant groups and time point

Table 2 presents the distribution and comparisons of fractal measurements according to implant groups and time points. In the intergroup comparisons, a statistically significant difference was observed between the two-implant and three-implant groups for distal measurements at T1 ($Z = -2.408$, $p = 0.016$). Accordingly, the mean fractal value at T1 in the two-implant group was higher than that in the three-implant group. However, no statistically significant differences were found between the groups for distal measurements at T0 or for mesial and apical measurements at both T0 and T1 ($p > 0.05$).

In the intragroup comparisons, distal fractal measurements in the two-implant group showed a statistically significant increase from T0 to T1 ($Z = -2.576$, $p = 0.010$). In contrast, no significant change was observed over time in the three-implant group for distal measurements ($Z = -0.765$, $p = 0.444$). Furthermore, no statistically significant differences were detected between T0 and T1 measurements in the mesial region in either implant group ($p > 0.05$). Similarly, apical measurements did not show significant changes over time in either the two-implant group ($Z = -0.653$, $p = 0.514$) or the three-implant group ($Z = -0.877$, $p = 0.380$). Overall, these findings indicate that a significant change in fractal measurements occurred only in the distal region of the two-implant

group, while mesial and apical regions remained stable over time.

Distribution and comparison of radiomorphometric measurements

The distributions of radiomorphometric measurements according to implant groups and time points are presented in Table 3. The analyses revealed statistically significant differences between the two-implant and three-implant groups in the superior PMI measurements at both T0 and T1, as well as in the mandibular cortical width and antegonial index measurements at T1 ($p < 0.05$) (Table 3). The values obtained from the three-implant group were greater than those obtained from the two-implant group. No statistically significant differences were found among the remaining measurement regions or time points ($p > 0.05$) (Table 3).

When the analyses at T0 and T1 were compared, a statistically significant difference was found only in the AI measurements within the two-implant group ($p < 0.05$). The T0 values were higher than the T1 values. No statistically significant differences were detected in any of the remaining measurement regions or time points ($p > 0.05$) (Table 3).

The distribution of MCI measurements according to implant group is presented in Table 4. The analyses revealed no statistically significant relationships between the implant groups and MCI measurements at either the T0 or T1 time points ($p > 0.05$) (Table 4).

Multiple linear regression analysis for predictors of fractal dimension change (T1–T0)

Multiple linear regression analyses were conducted to identify independent predictors of fractal changes in distal, mesial, and apical regions. The regression models were statistically significant for all three regions (distal: $F(3,36) = 15.03$, $p < 0.001$; mesial: $F(3,36) = 6.38$, $p = 0.001$;

Table 2 Distribution and comparison of fractal measurements according to implant groups and time points

Measurement Region – Time Point	Group 1 (Two Implants)		Group 2 (Three Implants)		U†	p
	Min–Max	Mean ± SD (Median)	Min–Max	Mean ± SD (Median)		
Distal						
T0	1.38–1.57	1.49 ± 0.05 (1.49)	1.41–1.59	1.50 ± 0.05 (1.50)	-0.649	0.516
T1	1.44–1.60	1.53 ± 0.05 (1.53)	1.40–1.57	1.49 ± 0.04 (1.49)	-2.408	0.016*
Z ^Φ /p	-2.576 / 0.010*		-0.765 / 0.444			
Mesial						
T0	1.36–1.59	1.48 ± 0.05 (1.48)	1.41–1.59	1.49 ± 0.05 (1.49)	-0.622	0.534
T1	1.38–1.55	1.48 ± 0.04 (1.47)	1.37–1.59	1.49 ± 0.05 (1.48)	-0.933	0.351
Z/p	-0.392 / 0.695		-0.149 / 0.881			
Apical						
T0	1.39–1.57	1.47 ± 0.06 (1.46)	1.40–1.61	1.48 ± 0.05 (1.48)	-0.122	0.904
T1	1.39–1.57	1.47 ± 0.05 (1.46)	1.40–1.61	1.48 ± 0.05 (1.48)	-1.353	0.176
Z/p	-0.653 / 0.514		-0.877 / 0.380			

* $p < 0.05$ indicates statistical significance. †Mann–Whitney U test; Φ: Wilcoxon signed-rank test

Table 3 Distribution and comparison of radiomorphometric measurements according to implant groups and time points

Intragroup comparison (T0 vs. T1)		Group 1 (Two Implants)		Group 2 (Three Implants)		Intergroup	
		Min.-Max.	Mean ± SD (Median)	Min.-Max.	Mean ± SD (Median)	Test Statistic	P value
Superior PMI (SPMI)	T0	0.14–0.39	0.25 ± 0.06 (0.24)	0.2–0.4	0.29 ± 0.06 (0.27)	-2.041	0.048*
	T1	0.14–0.42	0.26 ± 0.06 (0.25)	0.21–0.47	0.3 ± 0.07 (0.27)	-2.031	0.049*
	Test Statistic/p	-1.795/0.089		-1.045/0.309			
Inferior PMI (IPMI)	T0	0.21–0.5	0.32 ± 0.08 (0.32)	0.24–0.5	0.37 ± 0.07 (0.34)	-1.996	0.053
	T1	0.21–0.55	0.34 ± 0.08 (0.32)	0.26–0.46	0.43 ± 0.26 (0.35)	-1.461†	0.149
	Test Statistic/p	-1.926/0.069		-0.161‡/0.872			
Mandibular Cortical Width (MCW)	T0	0.19–0.48	0.32 ± 0.07 (0.31)	0.23–0.47	0.36 ± 0.06 (0.35)	-1.962	0.057
	T1	0.21–0.51	0.31 ± 0.07 (0.32)	0.28–0.48	0.36 ± 0.06 (0.35)	-2.237	0.031*
	Test Statistic/p	0.428/0.673		-0.180/0.859			
Antegonial Index (AI)	T0	0.2–0.35	0.25 ± 0.04 (0.25)	0.17–0.35	0.27 ± 0.06 (0.28)	-0.964	0.341
	T1	0.19–0.31	0.23 ± 0.03 (0.23)	0.11–0.36	0.26 ± 0.06 (0.28)	-2.342	0.026*
	Test Statistic/p	2.373/0.028*		0.298/0.769			
Gonial Index (GI)	T0	0.06–0.18	0.1 ± 0.03 (0.09)	0.01–0.15	0.09 ± 0.03 (0.1)	-0.041†	0.968
	T1	0.06–0.15	0.09 ± 0.03 (0.08)	0.04–0.14	0.08 ± 0.03 (0.08)	0.820	0.417
	Test Statistic/p	-1.298‡/0.194		0.703/0.491			

* $p < 0.05$ indicates statistical significance † Mann–Whitney U test; ‡ Wilcoxon Signed-rank test

Abbreviations: SPMI Superior Panoramic Mandibular Index, IPMI Inferior Panoramic Mandibular Index

Table 4 Distributions and relationships between mandibular cortical index measurements according to implant groups

		Group 1 (Two Implants)			Group 2 (Three Implants)			Intergroup	
		n	%	% within group	n	%	% within group	Test Statistic	P value
T0 mandibular cortical index	Type 1	3	37.5	15.0	5	62.5	25.0	1.059	0.701
	Type 2	12	57.1	60.0	9	42.9	45.0		
	Type 3	5	45.5	25.0	6	54.5	30.0		
T1 mandibular cortical index	Type 1	3	50.0	15.0	3	50.0	15.0		
	Type 2	12	54.5	60.0	10	45.5	50.0		
	Type 3	5	41.7	25.0	7	58.3	35.0		

* $p < 0.05$ indicates statistical significance %: Column percentage % within Group: Percentage within study groups

Table 5 Multiple Linear Regression Analysis for Predictors of Fractal Dimension Change (T1–T0)

Variable	Distal (B ± SE)	β	p	Mesial (B ± SE)	β	p	Apical (B ± SE)	β	p
Constant	1.080 ± 0.198	—	< 0.001	0.890 ± 0.205	—	< 0.001	0.769 ± 0.189	—	< 0.001
Baseline value	-0.719 ± 0.130	-0.641	< 0.001**	-0.590 ± 0.136	-0.598	< 0.001**	-0.517 ± 0.127	-0.549	< 0.001**
Sex (female)	-0.016 ± 0.013	-0.143	0.223	-0.017 ± 0.013	-0.178	0.202	0.007 ± 0.013	0.071	0.601
Implant group (two implants)	0.039 ± 0.013	0.342	0.004*	-0.011 ± 0.013	-0.114	0.405	-0.020 ± 0.013	-0.205	0.138
Model statistics	R² = 0.556			R² = 0.347			R² = 0.347		
	F(3, 36) = 15.03, $p < 0.001$			F(3, 36) = 6.38, $p = 0.001$			F(3, 36) = 6.37, $p = 0.001$		

* $p < 0.05$, ** $p < 0.001$, Multicollinearity diagnostics indicated no significant collinearity among the independent variables (all VIF values < 5)

apical: $F(3,36) = 6.37$, $p = 0.001$). The models explained 55.6% of the variance in distal fractal change and 34.7% of the variance in both mesial and apical fractal changes (Table 5).

Baseline fractal values were significant predictors of changes in all regions ($p < 0.001$), indicating that higher baseline measurements were associated with smaller changes over time. Implant group was significantly associated only with distal fractal change ($\beta = 0.342$, $p = 0.004$), suggesting that patients with two implants exhibited greater distal changes compared with those with three implants. However, implant group was not significantly associated with mesial or apical fractal changes (p

> 0.05). Sex was not a significant predictor in any of the regression models.

Overall, these findings suggest that baseline fractal measurements were the strongest determinants of subsequent changes, while implant configuration influenced only distal fractal alterations.

Discussion

This study evaluates the biomechanical and radiologic outcomes of two- and three-implant-supported mandibular overdenture prostheses using fractal and radiomorphometric analyses. The findings of this study did not demonstrate overall statistically significant differences

in fractal dimension values between the two-implant and three-implant overdenture groups. A statistically significant difference was observed only in the distal peri-implant region. Therefore, these findings should be interpreted with caution, as this localized result may reflect regional variability rather than a consistent influence of implant number on mandibular trabecular bone structure. Within the limitations of the present study, the results do not provide clear evidence that implant number has a generalized effect on peri-implant trabecular bone morphology.

Fractal analysis is a mathematical method used to quantify complex structures and their degree of irregularity through a numerical value known as the FD. This technique has been employed by radiologists as a tool for assessing bone quality and BMD [7].

In our study, the distal fractal measurement in the peri-implant region in the two-implant group was greater than that in the three-implant group, and within the same group, the T1 measurement was greater than the T0 measurement.

Trabecular bone has been evaluated through different clinical methods in many studies because it is a better indicator of bone metabolic activity and is found to be more useful in monitoring changes in the bone [7, 14]. Several studies demonstrated a strong correlation between trabecular bone mineralization and an increase in FD values, suggesting that greater mineral density was associated with greater structural complexity of the bone trabecular [7, 15].

In the studies by Kurşun and Akan [10], the peri-implant trabecular bone structure was evaluated using FD in individuals treated with two- and four-implant-supported mandibular overdentures. The authors reported a significant decrease in FD values in both groups after a 1-year follow-up period. They associated this reduction with the physiologic bone remodeling process occurring around implants over time and concluded that the number of implants did not significantly influence the degree of micromorphologic adaptation in trabecular bone. Similarly, in the present study, no statistically significant differences were found in the overall fractal measurement values between the two- and three-implant-supported groups. However, the increase in FD observed at the distal aspect of the peri-implant region in the two-implant group may reflect a regional variation in fractal changes associated with functional loading patterns. This finding suggests that the trabecular microarchitecture surrounding dental implants may be influenced by the number of supporting implants and by factors such as loading direction, masticatory side preference, and occlusal force intensity.

Yurtoglu et al. [5] reported a time-dependent increase in peri-implant FD values, which was attributed to bone

remodeling induced by functional loading around dental implants. In contrast, the present study revealed no generalized differences in fractal measurements between two- and three-implant-supported overdenture groups. Instead, a localized increase in FD was observed only at the distal aspect of the peri-implant region in the two-implant group. This finding may reflect a potential association between peri-implant trabecular adaptation and prosthesis-related biomechanical factors, and may be related to variables such as implant number and potentially asymmetric occlusal load distribution.

Yilmaz et al. [16] reported that in individuals without tooth loss, chewing hard-form gum typically began on the right side, and as the gum softened, masticatory movements became more evenly distributed between both sides. Similarly, Nissan et al. [17] demonstrated that the majority of individuals (78%) preferred the right side during mastication, and that this preference was independent of the presence of implant-supported restorations. In light of these findings, the increased trabeculation observed at the distal aspect of the peri-implant region in the present study may potentially be related to chewing-side preference. However, chewing preference was not assessed in the present study; therefore, this explanation should be interpreted as speculative. Future studies that systematically evaluate chewing-side preference and incorporate this variable into analyses may provide a more comprehensive understanding of peri-implant bone adaptation.

In addition to the group-based comparisons, multiple linear regression analyses were performed to identify independent predictors of fractal dimension changes. The results demonstrated that baseline fractal values were the strongest determinants of subsequent changes in all regions, whereas implant configuration was significantly associated only with distal fractal change. These findings suggest that baseline trabecular structure may play an important role in peri-implant bone adaptation, while the effect of implant number may be more localized.

However, it should be noted that multivariable regression analyses were limited to fractal dimension outcomes. Radiomorphometric parameters were not adjusted for potential confounding variables using similar models, and therefore these findings should be interpreted cautiously.

Şimşek et al. [18] reported an increase in FD values in the trabecular bone of completely edentulous individuals following implant-supported overdenture treatment and associated this finding with micromorphologic bone adaptation. In our study, the increased FD observed at the distal aspect of the peri-implant region in the two-implant group may reflect trabecular remodeling related to functional loading. However, the fact that this increase was detected only in a specific region suggests that it

could be associated with localized adaptation related to asymmetric occlusal loading and chewing-side preference. In addition, long-term use of implant-supported overdentures may contribute to increased organization of trabecular bone and peri-implant bone adaptation.

According to the radiomorphometric analysis results, compared with the two-implant group, the three-implant group presented higher values of superior PMI at both the baseline (T0) and follow-up (T1) periods, as well as higher MCW and AI values at T1. When temporal changes within each group were evaluated, it was observed that in the two-implant group, the superior PMI, inferior PMI, and AI values decreased at T1, whereas in the three-implant group, a reduction was detected only in the superior PMI compared with T0.

In a three-dimensional finite element analysis study conducted by Jingyin Liu et al. [19] the effect of implant number on the biomechanical behavior of mandibular overdenture prostheses was evaluated. The authors reported that increasing the number of implants might contribute to a more balanced distribution of occlusal loads on the bone and, consequently, could reduce stress accumulation in the cortical bone. They also noted that in two-implant systems, rotational tendencies of the prosthesis along the fulcrum line and stress accumulation in attachment components might be more pronounced, whereas three-implant systems could provide a more homogeneous load transfer, thereby limiting stress accumulation in the surrounding bone. These findings are consistent with the higher MCW and AI values observed in the three-implant group compared with the two-implant group in our study.

Saribal et al. [20] investigated long-term bone changes in individuals using conventional complete dentures and implant-supported overdentures and reported that although alveolar bone resorption occurred in both groups, the amount of bone loss was less pronounced in the implant-supported group. However, no significant differences were observed in radiomorphometric parameters such as the MCW, PMI, AI, and GI. These findings are consistent with those of the present study, in which the MCW and AI values were greater in the three-implant group than in the two-implant group. Additionally, the decrease in AI values within the two-implant group suggests that an increased number of implants may provide a biomechanical advantage in maintaining cortical bone integrity.

Oda et al. [21] investigated the effect of implant number on prosthesis movement in mandibular overdentures and reported that two-implant-supported overdentures might exhibit greater rotational and vertical displacement, particularly under anterior loading, whereas three-implant systems could reduce these movements. In this context, rotational forces acting along the fulcrum line in

two-implant systems may be associated with structural changes in the cortical bone over time. It should be noted that certain radiomorphometric parameters, particularly superior PMI, differed between groups already at baseline. Therefore, differences observed at follow-up may partly reflect pre-existing variations rather than changes attributable solely to implant configuration.

Although higher MCW and AI values were observed in the three-implant group at follow-up, these findings do not necessarily indicate a definitive advantage in cortical bone preservation. Instead, they may reflect a potential association that should be interpreted cautiously.

The findings of the present study may provide insight into clinical decision-making in mandibular overdenture treatment. Although no consistent differences were observed in trabecular bone adaptation between two- and three-implant configurations, the higher radiomorphometric values observed in the three-implant group may reflect a potential association rather than a definitive advantage in cortical bone preservation. Because all patients were treated with Locator attachments, the present findings cannot be used to draw conclusions regarding attachment selection between different systems.

From a clinical perspective, two-implant-supported overdentures may remain a cost-effective and minimally invasive treatment option with acceptable outcomes. However, in cases where long-term biomechanical stability or cortical bone preservation is of greater concern, the use of an additional implant could be considered. These findings also highlight the importance of long-term prosthetic maintenance and regular radiographic follow-up in patients with implant-supported overdentures.

Nevertheless, these findings should be interpreted with caution due to the limitations of the study design. Further prospective studies with larger sample sizes and advanced statistical modeling are needed to confirm these observations and to better define their clinical implications.

The findings of this study should be interpreted in light of several methodological limitations. First, the retrospective design limits the ability to control for potential confounding variables and restricts the strength of causal inferences. In addition, the two-dimensional nature of panoramic radiographs and their susceptibility to magnification and geometric distortion, particularly in the anterior mandible, may have influenced the accuracy of radiographic measurements.

The follow-up period ranged between 1 and 2 years, and this variability was not incorporated into the statistical models. Because peri-implant bone remodeling is a time-dependent process, differences in follow-up duration may have affected the observed radiographic outcomes.

Although all patients were treated using Locator attachment systems, and therefore attachment type was

standardized and did not represent a confounding factor, detailed information regarding prosthetic maintenance procedures—such as attachment wear, replacement frequency, relining, and management of technical complications—was not consistently available in the retrospective records. Because these factors may influence load distribution and peri-implant bone adaptation, they should be considered when interpreting the results.

Furthermore, potentially influential variables such as arch form, prosthetic design characteristics, occlusal loading patterns, and chewing-side preference could not be controlled in this study. In addition, although patient-level averaging was used to reduce clustering of implant-level measurements, the anatomical positions of implants differed between groups, which may have introduced positional heterogeneity into regional comparisons.

Therefore, the results of this study should be interpreted with caution, and future prospective studies with standardized follow-up periods and controlled biomechanical variables are needed to confirm these findings.

Conclusions

Within the limitations of the present study, no consistent differences were observed in overall trabecular bone structure between two- and three-implant-supported overdenture groups.

The observed differences in radiomorphometric parameters may suggest a potential association between implant configuration and mandibular cortical characteristics; however, these findings should be interpreted with caution due to baseline differences between groups and the absence of direct measurements of cortical bone preservation.

Overall, the results of this study should be considered exploratory and hypothesis-generating rather than confirmatory. Further prospective studies with larger sample sizes and advanced statistical approaches are required to better clarify these relationships.

Abbreviations

AI	Antegonial index
BMD	Bone mineral density
FD	Fractal dimension
GI	Gonial index
MCI	Mandibular cortical index
MCW	Mandibular cortical width
PMI	Panoramic mandibular index
TIFF	Tagged Image File Format

Acknowledgements

The authors thank the Recep Tayyip Erdoğan University Development Foundation for their support.

Authors' contributions

The study was conceptualized and designed by F.Ö. and M.Z.K. The radiological measurements were performed by T.E.K. The manuscript was written by F.Ö. and critically revised and edited by M.Z.K. and S.A.B. All the authors have read and approved the final manuscript.

Funding

This study was supported by the Recep Tayyip Erdoğan University Development Foundation (Grant number: 02026002013111).

Data availability

The data that support the findings of this study are available from the corresponding author upon reasonable request.

Declarations

Ethics approval and consent to participate

Ethical approval was obtained from Recep Tayyip Erdoğan University Non-Invasive Clinical Research Ethics Committee for this study (Approval No: 2024/267). The study was conducted in accordance with the ethical principles outlined in the Declaration of Helsinki (1964). Due to the retrospective nature of the study, patient data were obtained from archived panoramic radiographs, and informed consent was obtained from all participants for the use of their clinical and radiographic records.

Consent for publication

Not applicable.

Competing interests

The authors declare no competing interests.

Author details

¹Faculty of Dentistry, Department of Periodontology, Recep Tayyip Erdoğan University, Rize 53100, Turkey

²Faculty of Dentistry, Department of Oral and Maxillofacial Radiology, Recep Tayyip Erdoğan University, Rize, Turkey

Received: 17 October 2025 / Accepted: 5 May 2026

Published online: 14 May 2026

References

1. Tyrovolas S, et al. Population prevalence of edentulism and its association with depression and self-rated health. *Sci Rep*. 2016;6:37083.
2. Elawady D, et al. Single Implant-Retained Mandibular Overdentures: A Literature Review. *Cureus*. 2024;16(1):e52486.
3. Kurian N. Treatment options before and after edentulism: tooth supported overdentures. Nature Publishing Group UK London; 2024.
4. Sokolowski A, et al. The influence of prosthetic treatments and implant-supported prostheses on posterior mandibular ridge atrophy: a retrospective cohort study. *BMC Oral Health*. 2025;25(1):100.
5. Yurtoglu N, Tozum TF, Uysal S. Evaluation of Peri-Implant Bone Changes with Fractal Analysis. *J Clin Med*. 2025. 14(11).
6. Zihni Korkmaz M, et al. The effects of vitamin D deficiency on mandibular bone structure: a retrospective radiological study. *Oral Radiol*. 2023;39(1):67–74.
7. Yemenoglu H, Beder M, Cüre O, Günaçar DN. Effects of Different Treatment Methods Used in Patients with Rheumatoid Arthritis on the Trabecular and Cortical Structure of the Mandible. *Diagnostics (Basel)*. 2025. 15(3).
8. Heuchert J, Koziel S, Spinek AE. Radiomorphometric indices of the mandible as indicators of decreased bone mineral density and osteoporosis - meta-analysis and systematic review. *Osteoporos Int*. 2024;35(3):401–12.
9. Bangar BR, et al. Radiomorphometric Indices and their Relation to Alveolar Bone Loss: A Panoramic Radiographic Study. *Int J Prev Med*. 2022;13:25.
10. Ünlü Kurşun B, Akan E. Radiographic determination of trabecular bone change in 2- and 4-implant-supported overdenture prostheses. *Oral Surg Oral Med Oral Pathol Oral Radiol*. 2021;131(3):364–70.
11. Kato CN, et al. Use of fractal analysis in dental images: a systematic review. *Dentomaxillofac Radiol*. 2020;49(2):20180457.
12. Karadag I, Yilmaz HG. Evaluation of change in trabecular bone structure surrounding dental implants by fractal dimension analysis and comparison with radiomorphometric indicators: a retrospective study. *PeerJ*. 2022;10:e13145.
13. Asha V, Kaimal VG. Detection of osteoporosis using orthopantomography: An analytical study. *Int J Appl Dent Sci*. 2023;9:106–9.

14. Hind K, Davies M, Gonzalez-Rodriguez E, Hans D. Trabecular Bone Score: From Over a Decade of Evidence to a Connected Bone Health Ecosystem. *Osteologie*. 2025;34(03):213–22.
15. Bostan SA, et al. Direct-Acting Oral Anticoagulant/Vitamin K Antagonists: Do They Affect the Trabecular and Cortical Structure of the Mandible? *J Clin Dent-sitom*. 2024;27(3):101495.
16. Yılmaz C, Yaluğ S, Kocabalkan E, Doğan A. Çiğnemece taraf tercihi ve elektromyografik değerlendirilmesi. *Gazi Üniversitesi Diş Hekimliği Fakültesi Dergisi*. 1995;12(2):11–5.
17. Nissan J, et al. The influence of partial implant-supported restorations on chewing side preference. *J Oral Rehabil*. 2011;38(3):165–9.
18. Şimşek MS, Alan H, Dedeoğlu N. A fractal evaluation study of implant-supported overdentures. *Oral Surg Oral Med Oral Pathol Oral Radiol*. 2025;140(3):264–70.
19. Liu J, et al. Influence of implant number on the biomechanical behaviour of mandibular implant-retained/supported overdentures: a three-dimensional finite element analysis. *J Dent*. 2013;41(3):241–9.
20. Şirin Sarıbal G, Ersu N, Canger EM. Effects of conventional complete dentures and implant-supported overdentures on alveolar ridge height and mandibular bone structure: 2-year and 6-year follow-up study. *Clin Oral Investig*. 2022;26(9):5643–52.
21. Oda K, Kanazawa M, Takeshita S, Minakuchi S. Influence of implant number on the movement of mandibular implant overdentures. *J Prosthet Dent*. 2017;117(3):380–5.

Publisher's note

Springer Nature remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.