Karabağ *et al. BMC Oral Health (2025) 25:740*
https://doi.org/10.1186/s12903-025-06122-y

RESEARCH

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Evaluation of the effects of geometric design and surface properties of dental implants on marginal bone loss and bone quality by fractal analysis

Mert Karabağ[1], Zeynep Gümrükçü[1*] and Seval Bayrak[2]

Abstract

Background The aim of this study is to investigate the effects of surface properties and geometric design on marginal bone loss in dental implants and to compare the parallelism of bone loss and fractal analysis results.

Methods A total of 378 implants from 114 patients were evaluated in this study using panoramic and periapical radiographs. Implants were categorized into 19 subgroups according to the jaw where they were placed, length, diameter, surface preparation, type of prosthetic superstructure, and neck design. Radiological evaluations were conducted based on radiographs obtained at the time of implant placement and 3 months after prosthetic loading. After obtaining measurements of marginal bone loss and fractal analysis data, the significance of differences between groups was statistically evaluated.

Results Marginal bone loss was significantly higher in the maxilla compared to the mandible when considering the changes between jaws ($p < 0.05$). Analysis of variations among prosthetic superstructures revealed that implant-supported removable prostheses had the highest marginal bone loss ($p < 0.05$). Additionally, marginal bone loss was significantly lower in implants with coronal microthreads not exceeding 1 mm compared to those exceeding 1 mm ($p < 0.05$). Also the increase in fractal values was significantly higher in implants with coronal microthreads 1 mm compared to 3 mm.

Conslusion This study demonstrates that the geometric design of dental implants may have an impact on marginal bone loss, which is a determinant of long-term success. However, considering that marginal bone loss has a multifactorial etiology, further studies are needed to identify other potential factors contributing to marginal bone loss.

Keywords MBL, Dental implant geometry, Fractal analysis, Microthreads

Introductıon

In recent years, dental implants have emerged as a popular therapeutic choice for addressing tooth loss [1]. However, the success of dental implants is influenced by numerous factors related to both the patient and the practitioner [2]. Among these factors are surgical trauma, improper prosthetic loading, microleakage, poor oral hygiene, and implant neck design [3]. It is well-established that macro design, surface properties, and implant diameter also play crucial roles in implant success [4]. Criteria for success in dental implants were defined during the Italy Consensus Conference of the International Congress of Oral Implantologists in 2007, including absence of pain during function, lack of mobility, less than 2 mm bone loss in the first year, and absence

*Correspondence:
Zeynep Gümrükçü
zeynep.gumrukcu@erdogan.edu.tr
Full list of author information is available at the end of the article

of exudate history. The same conference designated pain, mobility, exudate, and bone loss exceeding half the implant length during function as definite failure criteria for dental implants [5].

Various clinical and radiological examination methods are used to determine the long-term success of dental implants. Although cone beam computed tomography (CBCT) provides a three-dimensional and detailed examination of the bone surrounding the implant, the most reliable and frequently used method for examining bone loss around the implant is intraoral radiographs [6, 7]. Marginal bone loss (MBL) detected through radiographs is an early indicator of long-term implant success [8]. Monitoring and treating MBL prevent functional and aesthetic complications, ensuring the implant's survival [8].

Currently, different macro and micro-level treatments are applied to the surfaces of dental implants to enhance treatment success [9]. Surface treatments, although varying by manufacturer, share the common goal of facilitating implant application and improving long-term success [10]. Wennerberg and Albrektsson showed in their study that surface topography affects bone response at the micron level and that surface topography affects bone response at the nanometer level [9]. Similarly, it has been shown that implants with high surface roughness at the nano level can provide stronger bone cell proliferation and stronger tissue integration [10, 11]. However, factors influencing dental implant success are also dependent on the patient and the practitioner [2].

Fractal analysis is a method used in various fields, such as calculating stock prices, determining cell boundaries, examining pulmonary branching, and listening to heart and temporomandibular joint (TMJ) sounds [12]. Studies in the literature indicate a correlation between trabecular bone architecture and fractal dimension (FD) [13]. There are studies in the literature examining the relationship between FD and conditions that affect alveolar bone metabolism, such as periodontitis and dental implant applications [14, 15]. Similarly, Soylu et al. reported in their study that FD reached its highest value on the 90 th day in successful implants, suggesting that FD could be a precursor to implant success [16]. However, there is no study in the literature that directly examines the relationship between MBL and fractal analysis.

The aim of this study is to determine the amounts of MBL and bone quality through panoramic radiographs (OPG) and periapical radiographs for implants with different surface properties, geometric designs, prosthetic superstructures, and sizes. The study also aims to examine the impact of surface properties, geometric design, prosthetic superstructure type, and implant sizes on MBL using fractal analysis.

Methods

Our study was conducted at the Department of Oral and Maxillofacial Surgery at Recep Tayyip Erdoğan University Faculty of Dentistry between January 2018 and March 2023, involving patients who applied for implant treatment and underwent implant procedures. The 378 implants included in the study were categorized based on recorded parameters. Ethics approval and consent to participate This study was approved by the Ethics Committee of Rece Tayyip Erdogan University (Grant No. E-40465587-050.01.04–656/2023/83). The actual participation of the participants in the study indicated their informed consent. The participants were aware of the study's purpose, risks, and benefits. Confdentiality and data protection measures were upheld throughout the study. All collected data was anonymized and stored securely to ensure the privacy and confdentiality of the participants.

Patient selection

Inclusion criteria for the study were:

- Implants with a minimum length of 8 mm
- Implants with a minimum diameter of 3.5 mm
- Availability of panoramic and periapical radiographs at T0 (immediately after surgery) and T1 (3 months after prosthetic loading).

Exclusion criteria for the study were:

- Presence of a systemic condition hindering dental implant treatment and routine check-ups
- History of regular alcohol/tobacco use
- Presence of severe parafunctional habits (bruxism, etc.)
- Prior grafting procedures before dental implant placement
- Implant failure

Through retrospective screening, data from 156 patients were examined, and 42 patients not meeting the inclusion criteria were excluded from the study. The study included a total of 378 implants from 114 patients.

The 378 implants included in the study were categorized based on recorded parameters. During grouping by manufacturer, implants with the same surface properties and neck designs from Bredent® and Bego® were evaluated in the same group. These groups were (Fig. 1):

– Manufacturer-based:

  - Group NB (Nobel Biocare® Zurich/Switzerland)
  - Group NC (Nucleoss® Izmir/Türkiye)

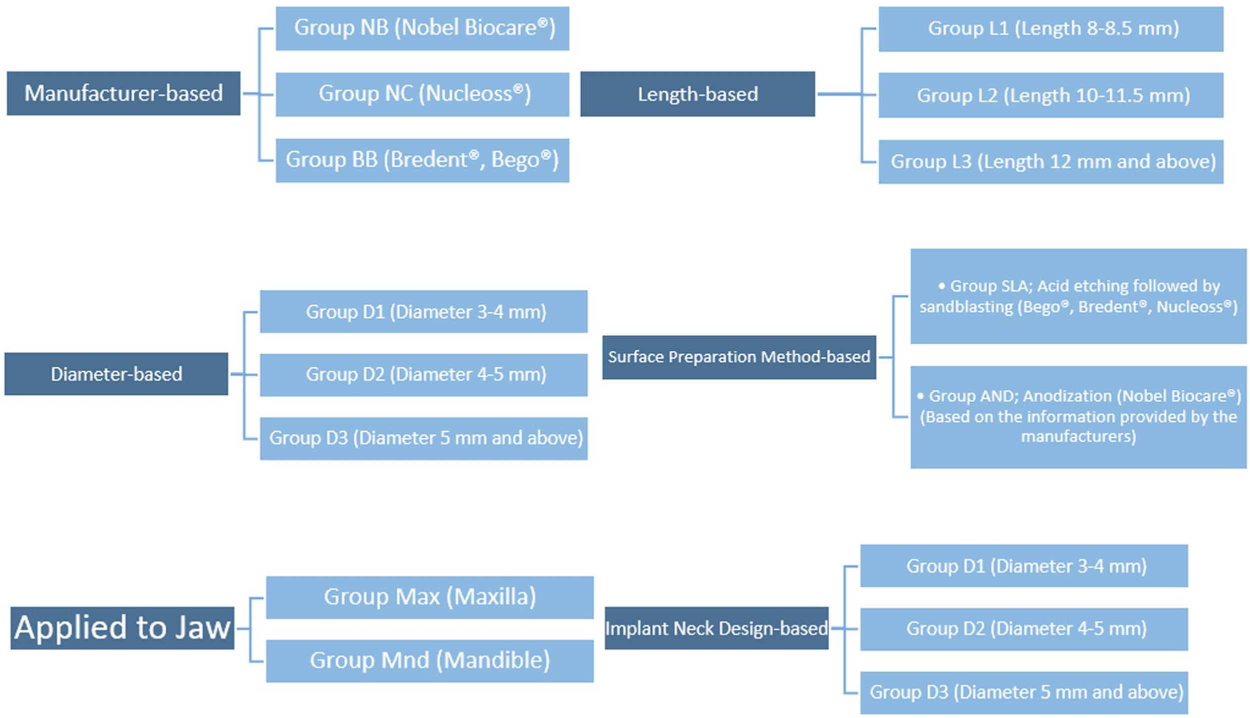

Fig. 1 Schematic representation of groups

- Group BB (Bredent® Senden/Germany -, Bego® Bremen/Germany)

– Length-based:

- Group L1 (Length 8–8.5 mm)
- Group L2 (Length 10–11.5 mm)
- Group L3 (Length 12 mm and above)

– Diameter-based:

- Group D1 (Diameter 3–4 mm)
- Group D2 (Diameter 4–5 mm)
- Group D3 (Diameter 5 mm and above)

– Surface Preparation Method-based:

- Group SLA; Acid etching followed by sandblasting (Bego® Bremen/Germany, Bredent® Senden/Germany, Nucleoss® Izmir/Türkiye)
- Group AND; Anodization (Nobel Biocare® Zurich/Switzerland) (Values provided by manufacturers were taken into account)

– Applied to Jaw:

- Group Max (Maxilla)
- Group Mnd (Mandible)

– Neck Design-based:

- Group MT 1 (Coronal Microgrooves 1 mm; Nobel Biocare® Zurich/Switzerland, Nucleoss®)
- Group MT 2 (Coronal Microgrooves 3 mm; Bredent®, Bego®) (Values provided by manufacturers were taken into account) (Fig. 2)

– Prosthetic Restoration Type-based:

- Group 1 (Single Crown)
- Group 2 (Crown-Bridge)
- Group 3 (Full-Arch Fixed Prosthesis)
- Group 4 (Removable Prosthesis/Overdenture)

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Fig. 2 Types of implants included in the study. **a** Implant with microthreads 1 mm along on the implant neck (Group MT 1). **b** Implant with microthreads 3 mm along on the implant neck (Group MT 2)

Demographic information of included patients, such as age, gender, systemic conditions, periodontal history, and tobacco/alcohol use, along with details about implant placement location, brand, length, diameter, implant success, and type of prosthetic restoration, was recorded. Implants from four different manufacturers were applied to the 114 patients in the study: Nobel Biocare/Active® (Zurich/Switzerland), Bego/Semados SCX® (Bremen/Germany), Bredent/Blue Sky® (Senden/Germany), and Nucleoss T6® (Izmir/Turkiye). The study was conducted on radiographs taken during routine control sessions at times T0 and T1.

Measurement of Marginal Bone Loss (MBL) from radiographs

Digital panoramic (Planmeca Oy; Helsinki, Finland/66 kVp, 8 mA, 16.6 s) and periapical (Acteon XMIND UNITY; Merignac, France) radiographs taken during the patients'treatment periods (T0, T1) were used in the study. Measurements of marginal bone levels on radiographs were performed using the ImageJ 1.52 (Wisconsin, USA) software. The distance between the most coronal part of the implant neck and the most apical part of the defect caused by marginal bone loss was measured. To secure parallelism and standardization of all radiographs, an occlusal jig was prepared for each patient. All radiographs were performed by the same radiologist with the same device. The magnification ratio was calculated by comparing the previously recorded implant length with the length measured on the software, allowing the determination of the actual value of MBL (Fig. 3).

Fractal analysis

Fractal analysis (FA) was conducted on OPG with a size of 2952x1435 pixels and a depth of 32 bits. FA on these radiographs at T0 and T1 times was performed using the box counting method determined by White and Rudolp with the ImageJ program [17].

Initially, a region of interest (ROI) of 30x90 pixels was defined on T0 and T1 OPG images using this method.

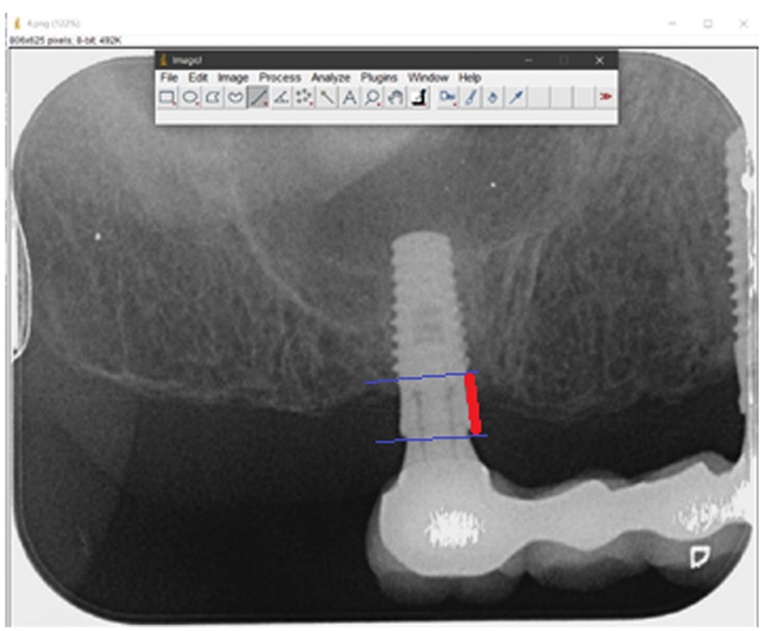

Fig. 3 MBL measurement with periapical radiography

During FA, the ROI was first determined on the mesial and distal surfaces of the implant starting from the apical level of the implant on the T1 image, and then the same-sized ROI was determined on the T0 image at the same location (Fig. 4)

After selecting the ROI, it was duplicated. Subsequently, a'gaussian blur 2'filter was applied, and the resulting image was subtracted from the real image. In the existing image, 128 gray tones were added to each pixel to separate bone trabeculae from trabecular interspace. After converting the image to black and white with a threshold value of 128, noise was reduced using the'erode'and'dilate'options, and the image was inverted. With the'skeletonize'option, trabecular structures were revealed, and the fractal dimension was calculated (Fig. 5). This process was carried out for each implant on mesial and distal surfaces on T0 and T1 images, and the results obtained were recorded. The analyses were conducted based on the changes in fractal values (FD) obtained from the mesial and distal surfaces of the implants at T0 and T1 times.

In determining the sample size for the study, a Power (Test Power) of at least 80% and a Type-1 error of 5% were considered for each variable. Normal distribution of continuous measurements was assessed using Kolmogorov-Smirnov (n>50) and Skewness-Kurtosis tests, and since the measurements followed a normal distribution, parametric tests were applied. Descriptive statistics for

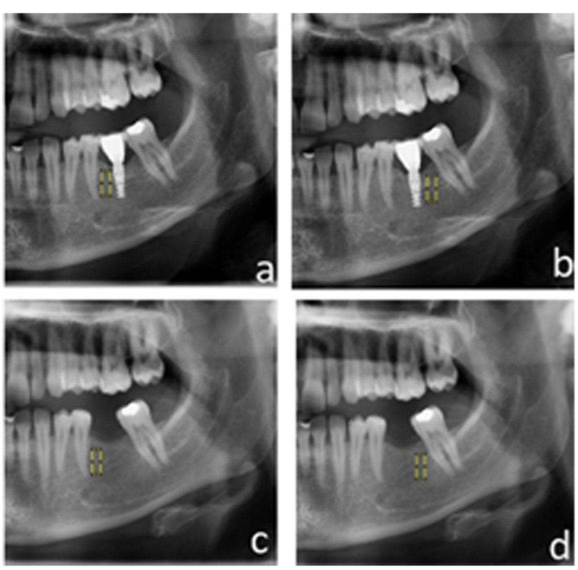

Fig. 4 Selection of ROI. **a** T0 selected ROI on the cropped OPG with a size of 30 × 90 pixels on the mesial surface of the implant. **b** Selected ROI of 30 × 90 pixel size on the distal surface of the implant in the T0 cropped image. **c** Selected ROI of 30 × 90 pixel size on the mesial surface of the implant in the same location as the T1 image in the T1 cropped image. **d** ROI selected in the T1 cropped image with a size of 30 × 90 pixels on the distal surface of the implant in the same location as the T1 image

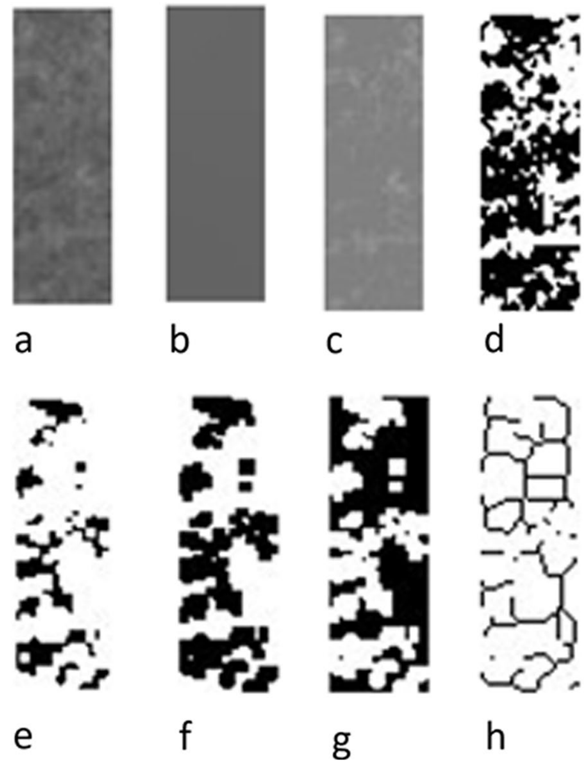

Fig. 5 Calculation Of fractal dimension. **a** Selected and duplicated ROI. **b** ROI with Gaussian blurr filter applied. **c** ROI subtracted from the original image and added 128 shades of gray. **d** ROI converted to black and white with a threshold value of 128. **e** Noise reduced ROI with erode. **f** Reduce noise with dilate reduced ROI. **g** Inverted ROI. **h** ROI with Sketlonize option applied

continuous variables were expressed as mean (Mean) and Standard Deviation (Std. Deviation). Independent T-test and One-Way Analysis of Variance (ANOVA) were performed to compare measurement values between groups. Following variance analysis, the"Duncan test"was used to determine different groups. In statistical calculations related to FA, the"Paired T-test"was specifically used for comparing changes between T0 and T1 measurement periods. Pearson correlation coefficients were calculated to determine the relationship between MBL measurements. A significance level of $p < 0.05$ was considered in calculations, and the SPSS (IBM SPSS for Windows, ver.26, SPSS Inc., Chicago, IL, USA) statistical package program was used for analyses.

All persons involved had provided their informed consent prior to inclusion in the study.

Results

Descriptive statistics for the implants included in the study are given in Table 1. A total of 114 patients within the age range of 22–80 were included in the study (±13.2). Among these patients, 64 were female (56.2%),

Table 1 Descriptive statistics of the implants included in the study

			MMBL		DMBL	
		Mean	**Ort**	**Std. Dev***	**Mean**	**Std. Dev***
Applied Jaw	Mandible	171	1,04	0,77	0,86	0,71
	Maxilla	207	1,10	0,77	1,05	0,73
Diameter	3–4 mm	138	1,14	0,75	1,10	0,75
	4–5 mm	235	1,04	0,78	0,90	0,70
	5 + mm	5	,77	0,41	0,51	0,67
Length	8/8,5 mm	52	1,03	0,82	0,86	0,73
	10/11,5 mm	223	1,00	0,70	0,94	0,70
	12 + mm	103	1,26	0,85	1,07	0,77
Prosthesis Type	Single Crown	39	,77	0,60	0,68	0,53
	Crown-Bridge	168	1,06	0,72	1,02	0,72
	Full-Arch Fixed Prosthesis	108	1,04	0,66	0,90	0,62
	Overdenture	63	1,36	1,03	1,11	0,94
Manufacturer	Group NC	159	1,02	0,80	0,89	0,74
	Group NB	131	1,04	0,78	0,97	0,76
	Group BB	88	1,23	0,67	1,10	0,64
Surface Preparation Method	Group AND	131	1,04	0,78	0,97	0,76
	Group SLA	247	1,09	0,76	0,96	0,71
Neck Design	Group MT 1	290	1,03	0,79	0,93	0,75
	Group MT 2	88	1,23	0,67	1,10	0,64

* Std. Dev: Standart Deviation

and 50 were male (43.8%). The total number of implants included in the study was 378. The mean Mesial Marginal Bone Loss (MMBL) was found to be 1.13 mm, and the mean Distal Marginal Bone Loss (DMBL) was 1.02 mm for all applied implants. The average length of the implants was 10.63 mm.

Findings regarding MBL

Table 2 shows the relationship between MBL and the applied jaw (maxilla/mandible), the"Distal Marginal Bone Loss (DMBL)"value was found to be statistically significantly higher in Group Max compared to Group Mnd (p=0.011).

When examining MBL based on implant diameters, the DMBL value in Group D3 was found to be statistically significantly higher compared to other groups as shown on Table 3 (p=0.038).

Table 4 describes the relationship between MMBL and implant length, MMBL was found to be statistically significantly higher in Group L3 (p=0.047).

In the examination based on the applied prosthetic superstructure, MMBL was found to be statistically significantly higher in Group 4, while implant-supported

Table 2 MBL (mm) and FD according to the applied jaw

	MBL (mm)				
	Group Mnd (n:171)		Group Max (n:207)		*p
	Mean	Std. Deviation**	Mean	Std. Deviation**	
MMBL	1.04	0.77	1.10	0.77	0.483
DMBL	0.86	0.71	1.05	0.73	*0.011*
	Fractal Dimension				
	Group Mnd(n:171)		Group Max(n:207)		*p
	Mean	Std. Deviation**	Mean	Std. Deviation**	
T1-T0 MESİAL	29.51	111.56	−2.26	97.05	0.002
T1-T0 DİSTAL	45.59	111.01	13.29	100.01	0.003

* Significance levels according to Independent T-test results

** Std Standart

Table 3 MBL-Implant diameter relationship

	Group D1 (n:138)		Group D2 (n:235)		Group D3 (n:5)		*p
	Mean	**Std. Deviation****	**Mean**	**Std. Deviation****	**Mean**	**Std. Deviation****	
MMBL	1.14	0.75	1.04	0.78	0.77	0.41	0.346
DMBL	1.10[a]	0.75	0.90[a]	0.70	0.51[c]	0.67	***0.038***

[*] Significance levels according to one-way ANOVA test results; a. b. c: Shows the difference between groups (Bonferroni post-hoc test)

[**] Std Standart

Table 4 MBL-ımplant length relationship

	Group L1 (n:52)		Group L2 (n:223)		Group L3 (n:103)		*p
	Mean	**Std. Deviation****	**Mean**	**Std. Deviation****	**Mean**	**Std. Deviation****	
MMBL	1.03[b]	0.82	1.00[b]	0.70	1.26[a]	0.85	***0.047***
DMBL	0.86	0.73	0.94	0.70	1.07	0.77	0.198

[*] Significance levels according to one-way ANOVA test results; [a, b]: Shows the difference between groups (Bonferroni post-hoc test)

[**] Std Standart

Table 5 MBL-Prosthesis type relationship

	Group 1 (n:39)		Group 2 (n:168)		Group 3 (n:108)		Group 4 (n:63)		*p
	Mean	**Std. Deviation****	**Mean**	**Std. Deviation****	**Mean**	**Std. Deviation****	**Mean**	**Std. Deviation****	
MMBL	0.77[c]	0.60	1.06[b]	0.72	1.04[b]	0.66	1.36[a]	1.03	***0.025***
DMBL	0.68[b]	0.53	1.02[a]	0.72	0.90[a]	0.62	1.11[a]	0.94	***0.038***

[*] Significance levels according to one-way ANOVA test results; [a, b, c]: Shows the difference between groups (Bonferroni post-hoc test)

[**] Std Standart

Table 6 MBL and FD—neck design relationship

	MBL				
	Group MT 1 (n:290)		Group MT 2 (n:88)		*p
	Mean	Std. Deviation**	Mean	Std. Deviation**	
MMBL	1.03	0.79	1.23	0.67	*0.034*
DMBL	0.93	0.75	1.10	0.64	*0.049*
	Fractal Dimension				
	Group MT 1(n:290)		Group MT 2(n:88)		*p
	Mean	Std. Deviation**	Mean	Std. Deviation**	
T1-T0 MESİAL	15.93	104.89	−0.25	104.75	0.206
T1-T0 DİSTAL	35.02	104.43	4.43	109.22	0.018

[*] Significance levels according to Independent T-test results

[**] Std Standart

Group 2 and Group 3 showed similar results. In Group 1, MMBL is significantly lower (p=0.025). Similarly, when examining the relationship between DMBL and the type of applied prosthesis, DMBL in Group 1 is statistically significantly lower than in other groups as shown on Table 5 (p=0.038).

Tables 6 describes the MBL changes according to microthreads; Group MT 1, MMBL is statistically significantly lower than in Group MT 2 (p=0.034). Similarly, in Group MT 1, DMBL is statistically significantly lower than in Group MT 2 (p=0.049).

Overall, when examining the correlation between MMBL and DMBL, a statistically significant positive relationship of 72.2% is observed (p=0.01).

Fractal analysis findings

Table 7 shows the intergroup significance of changes in fractal values (FD) obtained from the mesial and distal aspects of implants at T0 and T1 times was evaluated. When examining the changes between T0 and T1 without grouping in FD measurements taken from OPG, both mesial (p=0.025) and distal (p=0.001) regions showed a statistically significant increase.

"When examining the change in FD based on the applied jaw (maxilla/mandible), the increase in Group Mnd was found to be statistically significant compared to Group Max (Table 2).

When examining the relationship between neck design and FD in the distal aspect, FD in Group MT 1 has significantly increased compared to Group MT 2 (p=0.018). Conversely, no statistically significant difference was observed in FD in the mesial aspect between the groups (p>0.05) (Table 6).

When evaluating the correlation between changes in FD on the mesial and distal surfaces, a positive correlation of 41.3% was observed between the values (p=0.001).

Discussion

Following the acknowledgment of the concept of MBL as an early indicator for failed implants, numerous studies have explored factors affecting MBL [18]. However, existing literature often focuses on changes in MBL based on one or a few parameters. In this study, considering the multifactorial etiology of MBL, we aimed to evaluate changes in MBL and fractal analysis (FA) based on factors such as height, diameter, surface preparation method, applied jaw, and neck design.

In a study encompassing 4591 implants, French et al. evaluated MBL between jaws (maxilla/mandible) and reported a significantly higher MBL in the upper jaw compared to the lower jaw [19]. Similarly, Nitzan et al. found a significant excess of MBL in the upper jaw compared to the lower jaw in their study [20]. In our study, MBL in implants applied to the upper jaw (DMBL) was found to be significantly higher than those applied to the lower jaw. Our study results align with the literature, particularly in terms of DMBL. The higher presence of MBL in the upper jaw may be explained by the spongy structure of the maxilla, leading to greater compression under functional forces and a decrease in micro-level intraosseous vascularization.

Table 7 FD at T0 -T1 times

	Mean	Std. Deviation**	*p
T1 Distal – T0 Distal	27.8995	106.2126	***0.001***
T1 Mesial – T0 Mesial	12.1512	104.9439	***0.025***

[*] Significance levels according to paired T-test results

[**] Std Standart

Zimmermann et al. conducted a systematic review, examining 22 articles on MBL in implants restored with fixed and removable prosthetics. They reported no statistically significant relationship between prosthetic superstructure and MBL [21]. Saravi et al. conducted a systematic review focusing on studies of MBL in fixed and removable prosthetics and reported no statistically significant difference in MBL between groups using fixed and removable prosthetics [22]. Similarly, Pauletto et al., in their systematic review and meta-analysis, found no statistically significant difference in MBL between patients using fixed or removable prosthetics on implants [23]. Dorj et al. attributed the significantly higher MMBL in implant-supported removable prosthetics to the multifaceted forces exerted on the bone due to removable prosthetics [24]. These findings are consistent with our study results. In our study, MMBL was significantly higher in patients using implant-supported removable prosthetics (with locator attachments).

Geng et al., in their review, reported that stress distribution in implant-supported bridge restorations was higher and more variable than in single crown restorations [25]. In our study, MMBL and DMBL were significantly lower in patients using single crowns on implants than in other groups. In line with these findings, the significantly lower MBL in implant-supported single crowns in our study can be explained by the lower and unidirectional stress on implants in single crowns.

Abrahamsson et al., in their review covering publications examining the relationship between MBL and implant surface properties, reported that the implant surface preparation method did not significantly affect MBL [26]. Similarly, Donati et al. examining MBL on 149 implants with different surface features, reported no statistically significant difference in MBL between groups during a 20-year follow-up [27]. Our study also yielded similar results to the literature. The 378 implants examined were divided into two groups (SLA Group and AND Group) based on surface preparation methods, and there was no significant difference in MMBL/DMBL values between the groups.

Spies et al. conducted a randomized controlled study comparing marginal bone levels in implants with and without microgrooves in the neck portion. They reported no statistically significant difference in MBL between the groups [28]. In contrast, Bratu et al. examined MBL in two different implants with microgrooves in the neck region and reported significantly lower MBL in implants with microgrooves [29]. Bratu et al. also reported the presence of premature soft tissue around the cover screw and implant neck in polished neck implants after a 4-month osseointegration period. The researchers attributed this to better osteoblast proliferation on rough surfaces (implants with microgrooves). Most studies have compared situations with and without microgrooves on dental implants. All implants included in our study had microgrooves. Therefore, a more specific and dimensional grouping was made based on the coronal length of microgrooves. According to our results, both MMBL and DMBL were significantly lower in implants with coronal microgrooves of 1 mm.

Chowdhary et al., in their study, suggested that microgrooves convert cutting stress, which is less resistant in bone after implant placement, into compressive stress, which is more resistant in bone, potentially reducing MBL [30]. Hermann et al. evaluated MBL in implants with a rough neck region and a polished surface and reported lower MBL in implants with a polished neck [31]. They attributed this to the lower plaque accumulation seen on polished surfaces. In light of this information, although microgrooves in the neck region may provide mechanical benefits by converting cutting stress into compressive stress, the lower MMBL in Group MT 1 may be associated with increased surface area susceptible to bacterial adhesion in implants included in Group MT 2.

Fractal analysis is an advantageous method because it is a non-invasive and mathematical method that can be carried out on routine control radiographs [32, 33]. Therefore, in addition to radiographic MBL measurements, FA was also preferred for the examination of peri-implant bone tissue. Mu et al. took OPGs of dental implants in 48 patients immediately before prosthetic loading and at the 12 th month after loading and compared them in terms of FD [34]. They reported a significant increase in FD after functional loading. Julius Wolff reported in his study in 1893 that bone tissue responds differently (building or resorption) to different intensities of stimuli [35]. This phenomenon became known as Wolff's Law. Stanford et al. reported in their study that positive remodeling leading to increased trabeculation could develop in the bone tissue surrounding dental implants under occlusal loading [36]. In our study, similarly, FD significantly increased in both mesial and distal surfaces between T0 and T1, i.e., after prosthetic loading. Considering the increased microtrauma during the osteointegration process and prosthetic loading, the increase in bone remodeling is expected. In this regard, the increase in FD can be explained by the increase in trabeculation.

There is no study in the literature evaluating the effects of dental implant design on MBL and bone quality through fractal analysis. In this aspect, our study is an original contribution that could provide new insights. Our fractal analysis revealed no significant relationship between FD and factors such as the jaw where the implant was applied, implant diameter, implant length, prosthetic type, and surface characteristics. However, when looking at the relationship between FD and implant neck design, an increase in FD in implants with coronal microgrooves of 1 mm was significantly higher than in implants with coronal microgrooves of 3 mm. This indicates that the increase in trabeculation after 3 months of loading is greater in implants with coronal microgrooves of 1 mm.

Fractal analysis is an easily applicable, non-invasive and quantitative analysis that enables the examination of bone trabeculation on radiographs [37]. Mishra et al. evaluated the trabeculation loss due to periodontitis with fractal analysis in their study and showed that there is a negative correlation between the progression of periodontitis stages and FD [14]. In addition, studies indicate that fractal analysis can be used to examine conditions such as grafting procedures and peri-implantitis [37, 38]. In our study, MBL was examined and a correlation between the amount of MBL and FD was shown. The results of our study show that fractal analysis can be an alternative in the evaluation of MBL or peri-implantitis.

However, when looking at the correlation of the mentioned data with MBL, the MBL in implants with coronal microgrooves of 1 mm is significantly lower than in implants with coronal microgrooves of 3 mm. It is known that microgrooves regulate stress distribution. However, while the increase in FD in our study group with more microgrooves in the coronal direction is not statistically significant, on the contrary, FD has significantly increased in the group with fewer microgrooves. Implants with rough surfaces in the neck region are known to be more prone to plaque accumulation and bacterial adhesion. Therefore, implants with coronal microgrooves of 3 mm provide a larger surface area that allows bacterial colonization in case of attachment loss due to peri-implantitis. This may explain the increased MBL in implants with coronal microgrooves of 3 mm. Our data suggest that the coverage of microgrooves in dental implants with a coronal 1 mm is sufficient to regulate stress transmission and minimize MBL.

Our findings suggest that fractal analysis is a valuable, non-invasive method for evaluating peri-implant bone changes. While no significant relationship was found between FD and most implant characteristics, a notable increase in trabeculation was observed in implants with 1 mm coronal microgrooves. Additionally, implants with 1 mm microgrooves exhibited significantly lower MBL compared to those with 3 mm, likely due to reduced bacterial adhesion. These results highlight the potential of fractal analysis in implant assessment and suggest that a 1 mm microgroove design may be optimal for minimizing MBL and regulating stress distribution.

Limitations of this study as follow;

- Since our study was conducted retrospectively, specific data related to the surgeries where dental implants were placed (insertion torque, complications, etc.) were not included in the study.
- As our study was conducted retrospectively, clinical data related to patients at T1 time (pocket depth, bleeding on probing, hyperemia, etc.) were not included in the study.
- Our study aimed to maintain a high number of participants in each group since it was a multi-group study. Therefore, in grouping the data according to implant localization, only upper and lower jaw categorization was performed based on the available data, and the anterior-posterior region differentiation could not be made due to insufficient archives.
- This study was designed as a precursor to a study with a larger sample and longer follow-up periods. Therefore, the follow-up periods of our study cover the 3-month period following prosthetic loading. It is planned to include longer-term data in subsequent studies.

Conclusıons

When planning in patients with low bone quality, especially in the upper jaw, considering the increased MBL ratio in planning, it may be recommended to increase the number of implants in planning.

Our results indicate that the most at-risk group in terms of MBL is the group with implant-supported removable prostheses. In light of these results, in planning removable prosthesis, when deemed necessary, increasing the number of implants in removable prosthesis planning can reduce stress and ensure homogeneous distribution.

Among the implants used, only implants with a length of 14 mm and above were found to have significantly higher MBL, but when the regional distribution of these implants was examined, it was observed that the majority were applied to the maxilla. In the grouping according to diameter, only implants with a diameter of 5 mm showed significantly higher MBL, while no significant difference was observed between other diameter groups. These results suggest that implant prognosis is independent of both the length and diameter factors.

In the grouping and analysis based on surface characteristics, no significant difference was found between groups, and it is predicted that implants with both surface characteristics will show similar survival rates in clinical practice.

In terms of neck microgrooves, implants with coronal 1 mm were found to have lower MBL. Although the presence of microgrooves in dental implants converts cutting stress into compressive stress, ensuring more homogeneous distribution of stresses in the neck region, the rough surfaces of microgrooves, on the other hand, lead to plaque accumulation and increased bacterial adhesion. Therefore, the fact that microgrooves in the neck should not exceed 1 mm in the coronal direction may be sufficient to regulate stress and may result in more positive outcomes for implant prognosis compared to designs with longer grooves.

Three months after prosthetic loading, FD increased for each group. This increase is parallel to the expected remodeling and increased trabeculation in jaw bones under functional forces (Wolff's Law).

The results of our study revealed FD changes in the bone surrounding dental implants after prosthetic loading. These results are in correlation with the amount of MBL. Although these results need to be supported by further studies, they suggest that fractal analysis can be used as a method to examine changes in the bone surrounding dental implants.

Acknowledgements

This study has been supported by the Recep Tayyip Erdoğan University Development Foundation (Grant number: 020250010130246).

Clinical trial registration number

NCT06148012.

Authors' contributions

MK: Concept/Design, Data analysis/interpretation, Drafting article, SB: Data collection, Data analysis/interpretation, ZG: Critical revision of article. All authors have approved the fnal manuscript and agreed to be accountable for all aspects of the work.

Funding

None.

Data availability

The datasets generated and analyzed during the current study are available from the corresponding author on reasonable request.

Declarations

Ethics approval and consent to participate

Ethics approval and consent to participate This study was approved by the Ethics Committee of Rece Tayyip Erdogan University (Grant No. E-40465587–050.01.04–656/2023/83). The actual participation of the participants in the study indicated their informed consent. The participants were aware of the study's purpose, risks, and benefts. Confdentiality and data protection measures were upheld throughout the study. All collected data was anonymized and stored securely to ensure the privacy and confdentiality of the participants. Throughout the study, the Declaration of Helsinki on Human Rights was adhered to approval and consent to participate.

Consent for publication
Not applicable.

Competing interests
The authors declare no competing interests.

Author details
[1]Department of Oral and Maxillofacial Surgery, Faculty of Dentistry, Recep Tayyip Erdoğan University, Rize, Turkey. [2]Department of Oral Radiology, Faculty of Dentistry, Bolu Abant İzzet Baysal University, Bolu, Turkey.

Received: 31 December 2024 Accepted: 6 May 2025
Published online: 20 May 2025

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