RESEARCH

The Effect of Single-Tooth Implant Restorations on Prognosis of Adjacent Teeth and on Fractal Dimension of Peri-Implant Trabecular Bone: A Retrospective Study

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ABSTRACT

The Effect of Single-Tooth Implant Restorations on Prognosis of Adjacent Teeth and on Fractal Dimension of Peri-Implant Trabecular Bone: A Retrospective Study

Background: To investigate the effect of single posterior mandibular implants on the survival, restorative status, pulpal, periapical and periodontal health of the adjacent teeth and surrounding trabecular bone structure.

Methods: A total of 174 teeth adjacent to single-tooth implants and 174 teeth on the contralateral side were assessed. Survival and restorative, pulpal, periapical, and periodontal status of the teeth were recorded using numerical definitions. Fractal dimension (FD) of the trabecular bone on the mesial and distal sides of the implant and control teeth were measured on panoramic radiographs obtained after implant placement and 1 year after occlusal loading.

Results: FD values measured around the teeth adjacent to the implants were increased compared to the baseline ($p < 0.001$); a decrease was observed in the control group ($p < 0.001$). There was no difference between the FD values in the mesial and distal regions of the control teeth ($p = 0.982$), and the teeth adjacent to the implants ($p = 0.666$). Change in the number of minimally restored teeth showed no difference between regions ($p = 0.082$), while the number of heavily restored teeth was higher in the control region compared to the implant side ($p = 0.032$).

Conclusions: The fractal dimension of the trabecular bone around the teeth adjacent to the implants increased after occlusal loading of the implants while decreased on the contralateral side. The survival, restorative, periapical, and periodontal conditions of the teeth adjacent to the implants changed minimally after occlusal loading.

KEYWORDS

Bone Remodeling, Fractal, Panoramic Radiography, Single-Tooth Dental Implant, Trabecular Bone

ÖZ

Tek Diş İmplant Restorasyonlarının Komşu Dişlerin Prognozu ve Peri-İmplant Trabeküler Kemiğin Fraktal Boyutuna Etkisi: Retrospektif Bir Çalışma

Amaç: Tek diş posterior mandibula implantlarının komşu dişlerin sağkalımı, restoratif durumu, pulpa, periapikal ve periodontal sağlığı ve çevreleyen trabeküler kemik yapısı üzerindeki etkisini araştırmaktır.

Gereç ve Yöntemler: Tek diş implantlarına komşu 174 diş ve karşı tarafta 174 diş değerlendirildi. Dişlerin sağkalım ve restoratif, pulpal, periapikal ve periodontal durumları sayısal tanımlarla kaydedildi. İmplantın ve kontrol dişlerin mezial ve distal taraflarındaki trabeküler kemiğin fraktal boyutu (FD), implant yerleştirildikten sonra ve okluzal yüklemeden 1 yıl sonra elde edilen panoramik radyografilerde ölçüldü.

Bulgular: İmplantlara komşu dişlerin çevresinde ölçülen FD değerleri başlangıca göre anlamlı olarak arttı ($p <0,001$); kontrol grubunda azalma gözlendi ($p <0.001$). Kontrol dişlerinin mezial ve distal bölgelerinde ($p = 0,982$) ve implantlara komşu dişlerde ($p = 0,666$) FD değerleri arasında istatistiksel olarak anlamlı bir fark yoktu. Minimal olarak restore edilmiş diş sayısındaki değişiklik bölgeler arasında fark göstermezken ($p = 0.082$), kontrol bölgesinde yoğun şekilde restore edilmiş diş sayısı implant tarafına göre anlamlı olarak daha yüksekti ($p = 0.032$).

Sonuç: İmplantlara komşu dişler etrafındaki trabeküler kemiğin fraktal boyutu, implantların oklüzal yüklenmesinden sonra artarken, kontralateral tarafta azaldı. İmplantlara komşu dişlerin hayatta kalma, restoratif, periapikal ve periodontal koşulları oklüzal yüklemeden sonra minimal olarak değişti.

ANAHTAR KELİMELER

Kemik Yeniden Şekillenmesi, Fraktal, Panoramik Radyografi, Tek Diş Implantı, Trabeküler Kemik.

Considering the patient's good oral hygiene, healthy periodontal tissues and adequate bone volume, implant-supported restoration was preferred instead of traditional fixed prosthetic restorations. Thus, the preparation of healthy teeth adjacent to space was prevented and at the same time, the bone in the toothless region was protected. Successful results regarding single-tooth implant restorations in posterior jaws have been reported to be between 94.6% and 100% .[1-5]

The success of dental implant treatment depends on multiple factors related to patients and procedures such as bone quality and implant stability.[6,7] Complications

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such as loss of implants, abutment screw loosening or fracture, crown restoration fracture, bone loss, loss of osseointegration, soft tissue inflammation, and negative changes in the pulpal and periapical conditions of the adjacent teeth have been reported following dental implant treatment.[8-10] For these reasons, an appropriately planned implant treatment is needed to protect the health of pulp, periapical tissues, and alveolar bone of adjacent teeth and to minimize further treatment needs.[11,12]

Alveolar bone loss due to various surgical procedures has been observed in the teeth adjacent to the implants. The most important reason for this bone loss is that the horizontal distance between the implant and natural tooth is not maintained.[13] Mismeasurement of the horizontal distance between a tooth and an implant during radiological evaluation may cause complications as the use of wide fixtures and direct damage to the neighboring teeth because of the low residual bone height and overheating during osteotomy.[14,15] Thus, blood flow may be impaired, which can cause the loss of vitality in the tooth and increase the incidence of the development of periapical lesions.[16] Therefore, the teeth adjacent to the implant may need root canal treatment or may even require extraction.[17]

A number of biological events occur in the periapical bone during the osseointegration process after implants have been inserted.[18] The alveolar bone tissue is subjected to continuous resorption and formation cycles, and this combination of restructuring is critical to maintaining the balance of the bone-implant interface.[19,20] In these cycles, the shape of the crestal bone around the implants changes both horizontally and vertically.[21]

Image analysis methods developed with digital technology allow the measurement of changes in alveolar bone, but methods that can quantitatively evaluate changes in trabecular bone are limited. For this purpose, fractal analysis has been developed on radiographs as a method for mathematical analysis of trabecular bone. The numerical value obtained as a result of the fractal analysis is defined as the 'fractal dimension' (FD).[22] In dentistry, FD values are mostly used in osteoporotic patients to examine bone quality in order to determine the effect of periodontal disease on involved alveolar bone and peri-implant bone trabecular structure.[23-26]

Some studies have evaluated FD of the trabecular bone around the implants in the literature.[26-29] There is insufficient data that has evaluated the effect of change in the bone trabecular structure on the prognosis of adjacent teeth to implants. The purpose of the present study was to investigate the effect of single posterior mandibular implants on the survival and pulpal, periapical and periodontal health of the adjacent teeth and FD of related trabecular bone.

MATERİALS AND METHODS

This retrospective study was approved by the Clinical Research Ethics Committee of the University (number 2021/67). Eighty-seven subjects (43 men, 44 women; age range, 33 to 77 years; mean age, 56 years) were selected from among patients who received dental implants to replace a missing single tooth in the mandibular premolar and molar regions at the Department of Periodontology, between July 2016 and December 2017. The exclusion criteria included: (1) patients who had conditions or were under medications affecting bone metabolism or bone turnover; (2) patients who had bruxism/parafunctional habits; (3) patients who had undergone bone grafting procedures in conjunction with implant placement; and (4) patients whose panoramic radiographs had poor diagnostic quality including digital artifacts. Patients with natural teeth in the adjacent implant and contralateral regions were included.

Eighty-seven two-stage dental implants (Roxolid, Straumann, Switzerland) were used to replace missing mandibular premolar or molar teeth. The implants were inserted by one experienced periodontist (G.U.) using a conventional two-step surgical protocol. The first control panoramic radiographs were taken after the surgery procedure. Three months after surgical placement, all submerged implants were uncovered, and 3 weeks after the uncovering stage (second-stage), the porcelain fused to metal (PFM) crowns were temporarily cemented over the prefabricated titanium abutments with a temporary dental cement (TempBond NE, Kerr, West Collins, CA, USA). In protrusive and lateral movements, the excursive contacts on the implant prosthesis were also eliminated before cementation. Following the cementation of the provisional crown, periapical radiograph was taken to ensure that no cement was left at the crown surface that could cause periodontal/bone loss problems. The restorations were intraorally validated regarding the marginal fit and proximal contact. Patients were recalled every 3 months for professional plaque control and oral hygiene evaluations. Twelve months after temporary cementation of the implant crowns, the PFM crowns were permanently cemented over the prefabricated titanium abutments with zinc polycarboxylate cement (Adhesor Carbofine, Germany) and the second control panoramic radiographs were taken.

The same panoramic Soredex machine (Cranex Novus, Tuusula, Finland at 70 kVp, 10 mA for 8 s exposure time) was used to obtain the first and second panoramic radiographs in the same radiology department. The radiographs were taken according to the device manufacturer's instructions, and the patients were positioned according to these instructions.

All radiographs were examined by 2 calibrated observers (G.U., Z.U.A). The survival and coronal, root

All radiographs were examined by 2 calibrated observers (G.U., Z.U.A). The survival and coronal, root canal treatment, periapical, and periodontal status of the teeth adjacent to the implants as well as the contralateral teeth were recorded using numerical definitions as follows.

- The survival condition of teeth was scored as 0 if present and as 1 if missing.
- The coronal restorative condition was recorded as 0 if not restored, 1 if minimally restored (1-2 surfaces), or 2 if highly restored (3 or more surfaces).
- To evaluate periodontal changes in the teeth, the distance between the cemento-enamel junctions and the alveolar crest were measured on both radiographs.[30] The cases where there was no change were recorded as 0, and the cases where there was change were recorded as 1.
- Root canal treatment status was recorded as 0 if no state of presence and as 1 if endodontic treatment was performed.
- The periapical status was recorded as 0 if there was no change or as 1 if there was a radiolucent change in the periapical region.

Restorative state changes were calculated by subtracting the last condition from the initial state. When the value was greater than 1, it was interpreted as more heavily restored; values of 0 were interpreted to mean the status did not change 10. The same method was used for the pulpal, periapical, and periodontal conditions. If the obtained value was 1, it was interpreted as the root canal treatment was performed, periapical pathology or periodontal bone loss developed in the follow-up period. It was noted that there was no change in the neighboring teeth if the value obtained was 0.

FD analysis was carried out by one observer (D.G.B) using the box-counting method proposed by White and Rudolph.[31] The intra-observer reliability of fractal analysis was assessed by re-evaluating randomly selected 15 panoramic images at a 2-weeks interval by using the intra-class correlation coefficient (ICC) with a confidence interval (CI) of 95%. All high-resolution JPEG format panoramic radiographs were converted to the tagged image file format (TIFF). Each region of interest (ROI) was set to a width of 20 pixels and a height of 90 pixels (2.0 mm×9.0 mm). For the implant site, a corono-apical region was selected from the alveolar bone between the implant and the adjacent tooth root (Figure 1), ROI was selected from the mesial and distal sides of the same number of teeth in the contralateral region (Figure 1) and then clipped and replicated.

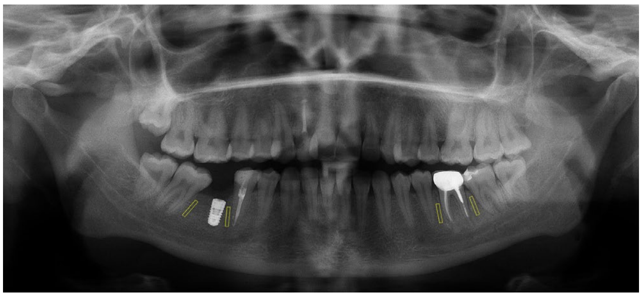

Figure 1

Panoramic radiograph with selected ROI on the implant and contralateral regions.

Gaussian blur was used to eliminate the changes in brightness due to soft tissues and variable bone thickness. The resulting image was then removed from the original image. Bone marrow cavities and trabeculae were separated by adding 128 gray values to each pixel position. FD was calculated after performing double, etching, dilated, inverting and skeletal processes (Figure 2).

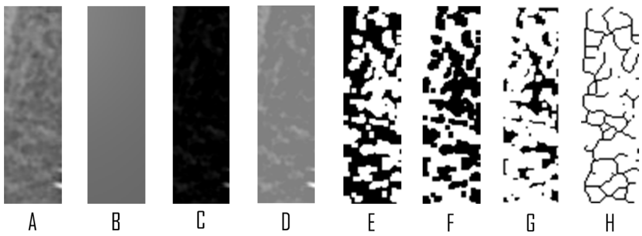

Figure 2

(A). Blurred image of the cropped and duplicated ROI; (B). The duplicated image
was blurred with a Gaussian filter; (C). The blurred image was then subtracted from the original image; (D). Addition of 128 gray value to each pixel location; (E). Binarization; (F). Dilatation; (G). Inversion; (H). Skeletonization.

STATISTICAL ANALYSIS

SPSS version 21.0 (IBM Statistical Package for the Social Sciences Statistics; New York, USA) was used for the statistical analysis of the findings. Paired sample t-test was used to compare the FD values of the groups before and after the implants. Independent t-test was used to compare time-dependent changes of FD between groups. A significance level of $p < 0.05$ was considered.

RESULTS

In the mandibular posterior region, a total of 87 single-tooth implant regions and 87 control regions were evaluated. We evaluated the mesial and distal teeth of the implants as a control group, and thus a total of 348 teeth were evaluated. Table 1 shows the fractal values and descriptive data of the mesial and distal regions of the teeth adjacent to the implants and the control teeth. FD values measured at the mesial and distal regions of the teeth adjacent to the implants were implants were significantly increased compared to the baseline, and a decrease was observed in the control group ($p < 0.001$).

Table 1.

FD values obtained in T0 and T1 time periods according to regions

	Mesial region of the implant	Distal region of the implant	Mesial region of natural teeth	Distal region of natural teeth
T0 FD value	1.41 ± 0.09	1.42 ± 0.09	1.42 ± 0.10	0.41 ± 0.09
T1 FD value	1.44 ± 0.09	1.44 ± 0.01	1.42 ± 0.01	1.41 ± 0.10
P value	p < 0.001	p < 0.001	p < 0.001	p < 0.001

TO: Immediately after implant placement, T1: One year after occlusal loading
The significance level of p < 0.05 was considered.

There was no statistically significant difference between the FD values of the mesial and distal regions in the control teeth (p=0.982) and the teeth adjacent to the implants (p=0.666) (Table 2).

Table 2.

Changes in FD values of the adjacent bone to the mesial and distal regions of the natural tooth and implant

	The mesial region of the implant	The distal region of the implant	The mesial region of natural teeth	The distal region of natural teeth	P value
FD changes (mean ± SD)	0.029 ± 0.05[a]	0.022 ± 0.044[a]	-0.003 ± 0.031[b]	-0.002 ± 0.035[b]	p < 0.001

Table 3 shows the changes in survival, coronal restorative status, and pulpal, periapical and periodontal status in teeth adjacent to implants versus those on the contralateral side. There was no statistically significant difference in survival: 2 out of 174 (1.13%) teeth adjacent to the implant site were missing, and no teeth adjacent to the control side were missing ($p = 0.071$). When evaluated the coronal restorative status, the change in the number of minimally restored teeth showed no difference between regions ($p = 0.082$), while the number of heavily restored teeth was significantly higher in the control region than on the implant side ($p = 0.032$). 3.4% of the teeth adjacent to the implant site had root canal treatment, and no teeth adjacent to the control side had root canal treatment. No significant differences were observed in the changes in the pulpal and periapical conditions of teeth adjacent to the implant and the contralateral region ($p = 0.063$ and $p = 0.071$, respectively).

There was no change in the periodontal status of the adjacent teeth in the contralateral region, while five of the teeth adjacent to the implants showed crestal bone loss ($p = 0.045$).

Table 3.

Changes of survival, restorations, and pulpal, periapical and periodontal status in teeth adjacent to implants versus the contralateral teeth

Status Changes		Implant	Control	P value
Survival	Missing	2 (1.13%)	0 (0%)	0.071
Coronal restorative status	minimally restored (1–2 surfaces)	5 (2.84%)	6 (3.4%)	0.082
	heavily restored (3+ surfaces)	7 (3.97%)	20 (11.36%)	0.032*
Root canal treatment	state of presence	6 (3.4%)	3 (1.70%)	0.063
Periapical status	Changes in bone structures	2 (1.13%)	0 (%)	0.071
Periodontal status	Crestal bone loss	5 (2.84%)	0 (%)	0.045*

**Significance level of p < 0.05 was considered.*

DISCUSSION

In the present study, we aimed to investigate the changes in restorative and pulpal conditions, crestal bone levels, and changes in the trabeculae in the bone after implantation of a single tooth implant. According to the results of the study, pulpal and restorative changes were observed in the teeth adjacent to the implants. In addition, the alveolar bone trabecular structure increased in the first year compared to baseline.

Although there are clinical, radiographic, and histological studies evaluating the health status of the implant and adjacent teeth in different time periods and protocols, further studies are needed in the literature.[10,26-29,32,33]

FD analysis of the bone tissue has been introduced as a useful predictor of the initial dental implant's stability and bony healing process.[34,35] Many studies have reported that the reliability of fractal size calculations is not affected by parameters such as overdose sub-exposure when evaluating them with radiographs. Furthermore, it has been found that the location of the ROI is more critical than its size.[36,37] Bollen et al.[38] performed a fractal analysis using both periapical and panoramic radiographic images and obtained similar results in both images. In this study, we used standardized panoramic radiographs similar to Mu et al.[29] We performed measurements in the mandibular premolar and molar regions and carefully placed the ROI to minimize the potential unknown effects of factors such as magnification and artifact. Although panoramic radiography has been reported to have limitations when compared to periapical radiography, accurate results can be obtained if the ROI is well established and placed under controlled conditions in fractal analysis using panoramic radiography.[28]

The response of the alveolar bone around a loaded dental implant is affected by mechanical influence, implant design, and implant surface.[39] In this study, factors related to implant material were excluded factors related to implant material were excluded because we used the implant and abutment connections with the same characteristics produced by the same manufacturer. Following the implant loading, increased occlusal forces are transmitted to the bone through the implant. In response to these forces in the bone, remodeling begins and increases the amount of microstructure in the bone around the implant. Bone trabecular density changes result in changes in fractal size.[36] In this study, FD values measured around the implant 12 months after implant loading were significantly higher than baseline. Similarly in the literature, the fractal size found to be increased significantly 12 months [29] and 24 [40] months after implantation. In contrast, in a study performed by panoramic radiography, fractal size was not change significantly in the first 6 months after implantation.[41] However, data on implant loading time were not included in that study. Zeytinoğlu et al.[26] reported a significant decrease in FD values after implantation. It has been reported that the same amount of stress can result in different amounts of strain in bones with different mechanical features. These factors may explain why fractal dimensional values decreased after loading.

Some studies reported lower FD at the dentulous areas due to differences in occlusal forces produced during mastication in edentulous and dentulous areas.[42,43] In this study, FD values of the alveolar bone surrounding the contralateral teeth were lower than the baseline. The periodontal ligament fibers around natural teeth provide resistance to mechanical forces to the tooth, act as shock absorbers, and reduce stress to the alveolar bone. Since there is no periodontal ligament around the implant, the force tolerance is less and the occlusal forces are transmitted directly to the bone, which exposes the alveolar bone to more stress.[44] The decrease of FD values in the control-side region can be explained in this way.

For the success of the implant, the preservation of the pulpal, periapical and periodontal health of the teeth adjacent to the implant is also important. Krennmair et al.[11] reported the need for a 3% restoration of the adjacent teeth following the insertion of 78 single-tooth implants and 3 of them were small restorations. Duqum et al.[10] found that 12% of the teeth adjacent to the single tooth implants in the follow-up period needed some type of restorative treatment. Priest reported this rate as 1.02%.[45] In our study, 2.84% of the teeth adjacent to the implants needed to be minimally restored, and 3.97% were heavily restored during the follow-up period. Differences in study results can be attributed to changing factors such as follow-up time, sample size, and oral hygiene habits.

Krennmair et al.[11] did not observe endodontic treatment and extraction need in any of the teeth adjacent to the implants in their study after 58 months of follow-up. Misch et al.[46] reported that only 0.3% of the adjacent teeth in their study needed root canal treatment. In our study, 3.4% of the teeth adjacent to the implants had root canal treatment, and two of the teeth had a radiolucent change in the periapical status needed root canal treatment. The reason this study has a higher rate of root canal treatment than previous studies is because of the need for root canal treatment during the prosthetic restoration of the adjacent teeth.

In contrast to Duqum et al.[10], we observed higher levels of restorative treatment in control teeth than in implant-adjacent teeth. There are several potential reasons for this result. In this study, neighboring teeth in the control group were significantly more heavily restored than the teeth adjacent to the implants. This could be because of the application of crown restoration to adjust the interproximal and the inter-occlusal distance during the prosthetic restoration phase and, recondition of restorations due to secondary caries.

The most important limitation of this study is the retrospective design. Because of this design, we did not have any knowledge about oral hygiene status and dietary habits of the patients, the pulpal vitality of the teeth, or proximal and inter-occlusion of existing restorations. However, since we evaluated the implants and control regions in all patients, we believe that the effect of these factors on statistical analysis was reduced.

The results of this study are limited to the population evaluated. Therefore, examination of more cases and long-term follow-up longitudinal clinical studies are needed.

CONCLUSION

In the present study, FD of trabecular bone increased in the region of the teeth adjacent to the implants and decreased in the contralateral regions. Minimal status changes were observed in the teeth adjacent to the implants and the neighboring teeth in the control regions. Fractal analysis holds promise as an economical and easily available method to assess the changes in peri-implant alveolar trabecular bone patterns.

Authors' contributions

Categories of authors' contribution are as follows: concept/ design (GU and DGB), data collection (GU, DGB and ZUA), data analysis/interpretation (ZUA), drafting of the article (GU, DGB and ZUA), critical revision of the article (GU, DGB and ZUA), and approval of the article (GU, DGB and ZUA).

Availability of data and materials

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

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Ethics approval

Approval was obtained for this cross-sectional study from the Clinical Research Ethics Committee of the Bolu Abant Izzet Baysal University (protocol no: 2021/67).

Consent for publication

Not applicable.

Competing interests

All authors declare that they have no competing interests.

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