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Evaluation of long-term trabecular changes around dental implants using fractal analysis

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Abstract

Aim: The aim of this study was to evaluate the long-term bone formation around functioning dental implants with prosthetic loading using the fractal analysis (FA) method.

Methodology: The bone around four different brands of dental implants placed on maxillary and mandibular bone was evaluated by fractal analysis using panoramic radiographs taken before the dental implant was placed and after it had been functioning for at least 12 months. Fractal analysis was performed using the box-counting method. According to the conformity of the data to the normal distribution, the significance of the difference between the groups was interpreted by independent samples t-test and the Mann-Whitney U test.

Results: No significant difference was observed in the fractal dimension of the bone surrounding the dental implant in the pre- and post-treatment radiographs ($p>0.05$). No significant difference was observed when comparing patient gender and implant brands ($p>0.05$).

Conclusion: Regardless of the implant brand, patient gender, and the jaw in which the treatment was performed, there may be no significant difference between radiographs in the trabecular bone around the dental implants before implant treatment and after at least 12 months of function. Further and large-scale clinical studies on the subject are needed.

Keywords: Fractal analysis, dental implant, osseointegration, implant-supported dental prosthesis, orthopantomograph

Introduction

Dental implants have been used for many years to repair full or partial edentulous jaws (1). The success of dental implants is closely related to uncomplicated surgery and the quality of the bone tissue (1). While the mechanical performance of bone is one of the critical factors of a successful dental implant surgery, the most important factor in a prosthetic procedure is effective osseointegration (2). In cases where there are doubts about bone quality, osseointegration protocols indicate that the implants should not be loaded during this period, typically three to four months in the mandible and six to eight months in the maxilla (3-5).

Fractal analysis is a mathematical method that is used to calculate the complexity of irregular and complex structures. A self-similar geometrical structure is represented by fractal dimension (FD), which is the result of processing an object or image after fractioning it into various sections. Methods such as mandibular cortical index, resonance frequency analysis, implant stability quotient (ISQ), and fractal analysis (FA) have been described in the literature as effective methods for assessing bone quality and and primary stability before surgical intervention (1, 5).

Fractal analysis is a method first described by Mandelbrot, who used the term "fractal" to describe complex geometric structures. It is used to delineate and quantify the morphology of the natural world (6). For example, FA has been used to identify dripping faucets, stock prices, cell lines, lung branches, heartbeats, and temporomandibular joint sounds (7, 8). It is also used in medicine to mathematically evaluate irregular and complex body structures. The biological structure studied by FA is characterized by a single number calculated using a computer algorithm, which is defined as the fractal dimension (FD) (9). Thus, FA allows both qualitative and quantitative evaluation of the structure under investigation.

In dental implantology, FA has been used in studies on issues such as measuring stability following implant placement (8) and evaluating angiogenesis in bone at variable inter-implant distances (10, 11). Existing literature indicates that FA can be used as an objective diagnostic method for the characterization of alveolar bone (1, 12). Many studies have used FA to evaluate bone density around dental implants (5, 13), although there are no studies that assess this bone density in the long term.

The aim of this study was to evaluate the long-term changes in bone quality in the alveolar bone around implants of different brands placed in the maxilla and mandible using the fractal analysis method on panoramic radiographs. The quantitative values will be useful for designing strategies to control possible undesirable effects on bone after dental implant placement. The null hypothesis was that there would be no long-term difference in the fractal dimension of the supporting bone before and after panoramic radiographs.

Materials and Methods

Sample size calculation

The sample size was calculated by using the G*Power software (Version 3.1.9.2, Heinrich Heine University, Dusseldorf, Germany). The following parameters were considered: a) test power of 0.9; b) 0.05 significance level; c) effect size of 0.4. Considering these standards, 55 samples would be sufficient to detect statistically significant differences. A total of 67 implants were included in the study, with 32 in the mandible and 35 in the maxilla, applied to 19 patients (5 males and 14 females; age range, 27 to 70 years; mean age 49 years). The mean follow-up was 35 months, ranging from 13 to 80 months.

Sample characteristics and data collection

This study was designed as a retrospective cross-sectional analytical survey to evaluate the long-term changes in bone quality in the alveolar bone around implants of different brands placed in the upper and Mandibula bones. This research was conducted on patients who underwent dental implant surgery at the Department of Prosthodontics and the Department of Maxillofacial Surgery at the University of Health Sciences. The principles of Helsinki Declaration were adhered to in the present research. Ethical approval was obtained from the University of Health Sciences Hamidiye Scientific Research Ethics Board with registration number 2023/20.

In this study, a retrospective analysis was performed by one researcher on the files of all patients between the ages of 18 and 65 who underwent implant-supported fixed dental restoration due to single or multiple missing teeth in the maxilla or mandible and and who had preoperative and postoperative panoramic radiographs. All implants selected for this study had been in functional use for more than 12 months. Exclusion criteria included the presence of systemic diseases or use of medications that affect bone metabolism, bone grafting at the time of implant placement, and incomplete radiographic records.

Fractal analysis

The evaluation of the changes in bone quality in the alveolar bone around implants was performed using the FA method on panoramic radiographs (PR).

The data collected from the radiographic records were divided into two groups:

1) T0: Preoperative PR
2) T1: Postoperative PR

The trabecular bone microstructure at region of interest (ROI) points on panoramic (orthopantomograph) radiographs was evaluated by the fractal analysis method. Comparative quantitative determination of bone density changes between the two groups (T0 and T1) time periods were measured by calculating the fractal dimension. ROI areas were determined on PRs for FD calculation using FA (16). The fractal dimension was calculated using the rates of change in the selected ROIs.

Statistical analysis

The data obtained from the CBCT images were analyzed using SPSS software (IBM SPSS Statistics version 21, IBM Inc., Armonk, NY, USA).

The Kolmogorov-Smirnov normality test was used to determine the suitability of the data for normal distribution. According to the data's suitability to normal distribution, the significance of the difference between groups was determined. It was interpreted with the t-test or Mann-Whitney U test in independent groups. In comparing data obtained at different times in the same group, the t-test or Wilcoxon sign test was used independent groups. Significance was evaluated at an alpha level of 0.05.

Results

Pre- and post-measurement comparison

The comparison of mesial, distal, and periapical measurements was analyzed using a dependent t-test. Accordingly, there was no significant difference between the mesial, distal, and periapical measurements obtained before and after implantation (Table 1) (*p*>0.05).

Table 1. Pre and post measurement comparison

		N	Mean	SD	t	p
Mesial	Pre	80	0.847	0.215	0.004	0.997
	Post	80	0.847	0.202		
Distal	Pre	80	0.816	0.220	0.621	0.536
	Post	80	0.790	0.274		
Periapical	Pre	80	0.777	0.232	0.457	0.656
	Post	80	0.808	0.152		

SD: Standart Deviation

Comparison of changes pre- and post-changes compared to reference value

Changes between pre- and post-measurements were calculated as percentages. A one-sample t-test was used to determine whether these changes were significantly different from the change at baseline (Table 2). Accordingly, the mean change in the reference value was 9.22%, and the changes in the mesial, distal, and periapical measurements were not significantly different from the change in the reference value. The level of change in the reference value and in the measurements was at the same level (Table 3). When the absolute changes in the measurements were compared with the absolute change in the reference value, it was found that these changes were not significantly different (33.2%).

Table 2. Comparison of changes pre and post changes compared to reference value

	N	Mean	SD	t	p
Mesial change (%)	80	12.8	73.2	0.378	0.707
Distal change (%)	80	13.7	93.7	0.384	0.702
Periapical change (%)	80	42.9	150.0	0.778	0.453

SD: Standart Deviation

Table 3. Comparison of absolute changes in measurements with absolute changes at the reference changes

	N	Mean	SD	t	p
Mesial change (%) (Absolute)	80	32.72	66.61	-0.057	0.955
Distal change (%) (Absolute)	80	41.68	84.86	0.805	0.424
Periapical change (%) (Absolute)	80	57.19	144.70	0.574	0.577

SD: Standart Deviation

Analysis of changes in measurements by gender

The independent samples t-test was used to determine the means of the change in measurements and absolute changes according to gender and the difference between these means (Table 4). According to the results, the change in measurements and absolute changes did not differ significantly by gender (*p*>0.05). In other words, the changes in measurements were at the same level in males and females.

Table 4. Analysis of changes in measurements by gender

Gender		N	Mean	SD	t	p
Mesial Change (%)	Female	43	18.44	81.30	0.935	0.353
	Male	18	-0.80	48.05		
Distal Change (%)	Female	47	20.95	107.21	1.011	0.316
	Male	18	-5.29	37.53		
Periapical Change (%)	Female	10	49.41	164.86	0.322	0.754
	Male	2	10.36	17.75		
Mesial Change (%) (Absolute)	Female	43	34.41	75.81	0.304	0.762
	Male	18	28.68	37.93		
Distal Change (%) (Absolute)	Female	47	47.65	98.09	0.915	0.364
	Male	18	26.09	26.78		
Periapical Change (%) (Absolute)	Female	10	66.12	158.23	0.460	0.655
	Male	2	12.55	14.65		

SD: Standart Deviation

Analyzing the changes in measurements according to the jaw

The means of the changes in measurements and absolute changes according to the jaw and the difference between these averages were examined by t-test in independent groups (Table 5). Accordingly, the changes in measurements and absolute changes did not differ significantly according to the jaw ($p>0.05$). In other words, the measurement changes in the upper and Mandibulas were at the same level.

Analysis of changes in measurements by brand

The averages of the change in measurements and absolute changes according to the brand and the difference between these averages were analyzed by one-way analysis of variance (Table 6). According to the results, the measurements did not differ significantly according to the brand and were found to be at the same level.

Table 5. Analyzing the changes in measurements according to the jaw

Jaw		N	Mean	SD	t	p
Mesial Change (%)	Maxilla	28	1.1	38.7	-1.151	0.254
	Mandibula	33	22.7	92.5		
Distal Change (%)	Maxilla	30	13.3	109.5	-0.029	0.977
	Mandibula	35	14.0	79.3		
Periapical Change (%)	Maxilla	0[a]	-	-	-	-
	Mandibula	12	42.9	150.0		
Mesial Change (%) (Absolute)	Maxilla	28	21.7	31.8	-1.191	0.238
	Mandibula	33	42.0	85.3		
Distal Change (%) (Absolute)	Maxilla	30	48.4	98.7	0.591	0.557
	Mandibula	35	35.9	71.9		
Periapical Change (%) (Absolute)	Maxilla	0[a]	-	-	-	-
	Mandibula	12	57.2	144.7		

Table 6. Analysis of changes in measurements by brand

Implant brand		N	Mean	SD	F	p
Mesial Change	ITI	18	7.261	48.210	1.082	0.368
	Camlog	6	42.518	51.235		
	XIVE	12	46.147	122.720		
	Mis	6	-7.717	12.115		
	Total	42	21.268	76.148		
Distal Change	ITI	18	-10.210	45.520	1.671	0.189
	Camlog	6	4.424	24.781		
	XIVE	13	74.302	188.761		
	Mis	6	-8.898	41.134		
	Total	43	17.565	112.894		
Periapical Change	ITI	18	-3.009	21.574	2.011	0.129
	Camlog	6	88.984	209.644		
	XIVE	12	21.220	42.454		
	Mis	6	3.987	15.338		
	Total	42	18.055	83.833		
Mesial Change (Absolute)	ITI	18	28.133	39.268	0.818	0.492
	Camlog	6	48.972	43.778		
	XIVE	12	58.545	116.808		
	Mis	6	10.593	9.141		
	Total	42	37.293	69.550		
Distal Change (Absolute)	ITI	18	35.450	29.185	1.340	0.275
	Camlog	6	19.208	13.960		
	XIVE	13	96.388	177.614		
	Mis	6	25.308	31.913		
	Total	43	50.192	102.381		
Periapical Change (Absolute)	ITI	18	17.233	12.672	2.146	0.110
	Camlog	6	104.073	201.134		
	XIVE	12	30.136	36.094		
	Mis	6	13.326	6.420		
	Total	42	32.767	79.133		

SD: Standart Deviation

Discussion

Our hypothesis was accepted. No significant difference was observed between baseline and follow-up in the mesial, distal, and periapical measurements of the bone around the dental implants (*p*>0.05). In addition, there was no significant difference between the measurements in the gender and implant brand comparisons (*p*>0.05).

Fractal analysis is a mathematical method used in radiograph analysis that describes and analyzes complex shapes and structural patterns, such as bone tissue. FA has been shown to be useful for measuring and studying mandibular and maxillary regeneration and trabecular changes in the phases after implant placement (17). The main application of FA in dentistry is the assessment of the morphologic characteristics of the jaw bones and its possible change over time (19). Many studies in medicine and dentistry have examined the trabecular bone using the fractal analysis method (13,19). In dental implants, it is accepted that fractal analysis can be an early indicator of osseointegration. Reports indicate that the FA method is a promising, non-invasive method for predicting osseointegration of dental implants based on dental radiographs, and it may also help to shorten the total treatment time (13).

It is important to use the appropriate image format, such as TIFF, for accurate fractal dimensioning on radiographs (20, 21). A study evaluating the ability of TIFF and JPEG image formats to preserve grayscale values in images reported that TIFF was more successful (22). Another study evaluating the effect of panoramic radiographs in TIFF and JPEG formats on image density and fractal dimension values, it was reported that the loss of detail was higher in JPEG format images, and FA measurements obtained from TIFF format images were more reliable (23). Based on this information, in our study, radiographs of all groups were saved in TIFF format to prevent data loss, and FA measurements were performed. The box-counting method, which is the most widely used method in the literature, was used to evaluate the trabecular structure of the bone (13, 24, 25). All images were analyzed by an expert maxillofacial surgeon.

Koh et al. showed that the mental foramen was the most reliable area to use as a reference for FA measurement using panoramic radiographs, because the trabecular pattern is clearly visible in dense bone (26). In the present study, the mental foramen region was used as the reference area. In addition, standard ROIs were used to determine the FD.

Osseointegration was defined by Brånemark as a successful and functional direct connection between bone and implant (3). The osseointegration process depends on several factors, including the macro- and microstructure of the implant, the surgical technique used, bone quality, and loading protocols. Primary stability of the dental implant during placement is a prerequisite for implant survival (1, 27). A positive correlation was found between the ISQ measured after implant placement and the FD value measured before placement (1). Sansare et al. showed that the FD value increased significantly after implant placement due to the increase in bone microstructure and the amount of bone trabeculae around the implant (14). Jung found no significant change in fractal dimension change in the first six months after implant placement (15).

Farsiani et al. evaluated the bone structure around photofunctionalized implants using the fractal analysis method for a period of 12 to 16 months and found no significant difference between the initial and final radiographs taken at the end of the study (25). They reported that the implants they evaluated during the study were osteointegrated at three or four months. Soylu et al. showed that osseointegration and bone healing processes can be completed in two months by evaluating fractal dimensions (13). They also observed that after dental implant placement, the FD value decreased in the first week and subsequently increased; furthermore, in the second month, the bone was almost close to its condition before dental implant placement.

Similar to these results, in a study evaluating bone healing after orthognathic surgery with FD, it was observed that FD decreased after surgery and gradually increased during the healing process (28). This can be explained by the healing pattern of the bone. Therefore, it can be said that after the bone healing process of FD, there is an increase in bone formation and trabecular pattern, reaching the same bone density as before implant placement. In this study, X-rays after implant placement were not taken into account; therefore, the decrease in FD was not observed. However, in support of the aforementioned studies, FD values of radiographic images taken before implant placement and at least 12 months after implant placement, where bone healing was completed and prosthetic loading was performed around dental implants, were found to be similar and no significant difference was observed between them.

Jung evaluated radiographs taken immediately after prosthetic rehabilitation of dental implants and at the end of the first year of loading and reported that the FD value increased (24). Wilding et al. in their study of dental implants in 18 patients, found that FD increased after prosthetic loading in fractal analysis of radiographs after fixed restoration and two years later (29). In this study, the relationship between FD and prosthetic loading was not evaluated because radiographs taken after prosthetic loading were not included in the evaluation.

Bone metabolism is one of the patient-related factors affecting ostreointegration. Bone metabolism differs between males and females in terms of bone-regulating hormones. Chen et al. showed that implants in women a had lower ISQ compared than in men, but the difference was not statistically significant (30). In similar studies evaluating the osteointegration of dental implants, no significant difference was observed between male and female patients (13, 24). The current study is consistent with previous studies in which no significant gender difference was observed.

Some of the studies that performed fractal analysis on dental implant radiographs (24, 25) evaluated implants of the same brand, while others (13) evaluated implants of different brands. In this study, four different brands of implants were evaluated. When comparing the fractal analyses according to implant brands, it was reported that no significant difference was observed according to brand. In our research, no significant difference was observed between maxillary and mandibular bone in terms of FD change around the placed dental implant. There are no studies in the literature that compare the effect of implant brands and maxillary mandibular bone on post-treatment bone structure with FA on radiographs, so we could not compare our results.

The study had some limitations. ROI selection was based on pre-implant and post-implant radiographs. The effect of ROI location and size on FD measurements is unclear. It has been shown that precise specification of ROI location and size may not make a significant difference, but there is no consensus on this. Furthermore, due to the retrospective design of the study, the total number of implants included was low, and no additional measurements were performed.

Conclusion

Within the limitations of the study, it can be concluded that in dental implant treatments with complete bone healing and prosthetic rehabilitation, radiographs of the bone tissue at least 12 months later show a trabecular structure similar to the pre-treatment radiographs. This situation was not influenced by implant brand, gender, or jaw bone differences.

Future clinical studies are needed to consider a larger number of implants and different methods.

Disclosures

Ethical Approval: Ethics committee approval was received for this study from the University of Health Sciences, Hamidiye Scientific Research Ethics Committee, in accordance the World Medical Association Declaration of Helsinki, with the approval number: 2023-20.

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Author Contributions: Conception – E.G.S.; Design – E.G.S., A.Ç.Ş.; Supervision – A.Ç.Ş.; Materials – E.G.S., K.E.Ü, A.Ç.Ş.; Data Collection and/or Processing – E.G.S., B.M.K., M.Ö.; Analysis and/or Interpretation – E.G.S., B.M.K.; Literature Review – E.G.S.; Writer –E.G.S.; Critical Review – A.Ç.Ş, M.Ö.

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References

1. Lee DH, Ku Y, Rhyu IC, Hong JU, Lee CW, Heo MS, et al. A clinical study of alve-olar bone quality using the fractal dimension and the implant stability quotient. J Periodontal Implan. 2010;40:19-24. https://doi.org/10.5051/jpis.2010.40.1.19
2. Tözüm TF, Bal BT, Turkyilmaz I, Gülay G, Tulunoglu I. Which device is more ac-curate to determine the stability/mobility of dental implants? A human cadaver study. J Oral Rehabil. 2010;37:217-24. https://doi.org/10.1111/j.1365-2842.2009.02038.x
3. Branemark PI. Osseointegration and its experimental background. J Prosthet Dent. 1983;50:399-410. https://doi.org/10.1016/S0022-3913(83)80101-2
4. Albrektsson T, Branemark PI, Hansson HA, Lindstrom J. Osseointegrated titanium implants. Requirements for ensuring a long lasting, direct bone to implant anchorage in man. Acta Orthop Scand. 1981;52:155-70., https://doi.org/10.3109/17453678108991776
5. Mililllo L, Fiandaca C, Giannoulis F, Ottria L, Lucchese A, Silvestre F, et al. Immedi-ate vs non-immediate loading post-extractive implants: A comparative study of Im-plant Stability Quotient (ISQ). ORAL & implantology. 2016;9:123-31.
6. Mandelbrot BB. The fractal geometry of nature. 3rd ed. New York: W.H. Freeman; 1983. https://doi.org/10.1119/1.13295
7. Przemysław LeszczyńskiB-D F, Jerzy SokalskiA EF. The use of fractal analysis in medicine: A literature review Zastosowanie analizy fraktalnej w medycynie - prze-gląd piśmiennictwa- Dental and Medical Problems. Dent Med Probl. 2017;54:79-83. https://doi.org/10.17219/dmp/67501
8. Mishra S, Kumar M, Mishra L, Mohanty R, Nayak R, Das AC, et al. Fractal Dimension as a Tool for Assessment of Dental Implant Stability-A Scoping Review. J Clin Med. 2022;11:4051. https://doi.org/10.3390/jcm11144051
9. Jeong KI, Kim SG, Oh JS, Jeong MA. Consideration of various bone quality evalu-ation methods. Implant Dent. 2013;22:55-9. https://doi.org/10.1097/ID.0b013e31827778d9
10. Sánchez I, Uzcátegui G. Fractals in dentistry. J Dent. 2011;39(4):273-92. https://doi.org/10.1016/j.jdent.2011.01.010
11. Huh KH, Baik JS, Yi WJ, Heo MS, Lee SS, Choi SC, Lee SB, Lee SP. Fractal analysis of mandibular trabecular bone: optimal tile sizes for the tile counting method. Imaging Sci Dent. 2011;41:71-8. https://doi.org/10.5624/isd.2011.41.2.71
12. Khosrovi PM, Kahn AJ, Majumdar S, Genant HK, Izu C. Fractal analysis of dental radiographs to assess trabecular bone structure. J Dent Res. 1995;74:173.
13. Soylu E, Coşgunarslan A, Çelebi S, Soydan D, Demirbaş AE, Demir O. Fractal analysis as a useful predictor for determining osseointegration of dental implant? A retrospective study. Int J Implant Dent. 2021 25;7:14. https://doi.org/10.1186/s40729-021-00296-0
14. Sansare K, Singh D, Karjodkar F. Changes in the fractal dimension on pre-and post-implant panoramic radiographs. Oral Radiol. 2012;28:15-23. https://doi.org/10.1007/s11282-011-0075-8
15. Jung YH. Evaluation of peri-implant bone using fractal analysis. Korean J Oral Maxillofac Radiol 2005;35:121-5.
16. Güleç M, Taşsöker M, Özcan S. Mandibular trabeküler kemiğin fraktal boyutu: Yaş, cinsiyet ve ilgi alani seçiminin önemi nedir?. Selcuk Dental Journal , ODMFR 2019 Kongre Kitapçığı Özel Sayısı, 2019;15-19. Retrieved from https://dergipark.org.tr/en/pub/selcukdentj/issue/50164/640657
17. Shalu B, Nageshwar I. 2017, Textbook of Periodontics, Chapter-47 Surgical Anatomy. https://doi.org/10.5005/jp/books/13037_48
18. Perrotti V, Aprile G, Degidi M, Piattelli A, Lezzi G. Fractal analysis: a novel method to assess roughness organization of implant surface topography. Int J Periodontics Restorative Dent. 2011;31:633-9.
19. Camila NAO Kato, Sâmila G Barra, Núbia PK Tavares, Tânia MP Amaral, Cláudia B Brasileiro, Ricardo A Mesquita, Lucas G Abreu, Use of fractal analysis in dental images: a systematic review. Dentomaxillofacial Radiology. 2020;2(1):20180457. https://doi.org/10.1259/dmfr.20180457
20. Küçükkaraca E, Sarıçam E. Evaluation of the effect of class II fixed orthodontic treatment on the periradicular bone structure of endodontically treated mandibular molar teeth using fractal dimension analysis. Int Dent Res 2023;13(S1):38-43. https://doi.org/10.5577/idr.2023.vol13.s1.6

21. Yüzbaşıoğlu Ertuğrul B. Effects of removable functional orthodontic apparatus on mandibular condyle bone quality. Int Dent Res 2021;11(Suppl.1):7-11. https://doi.org/10.5577/intdentres.2021.vol11.suppl1.2
22. Gürdal P, Hildebolt C, Akdeniz, B. The effects of different image file formats and imageanalysis software programs on dental radiometric digital evalua-tions. Dentomaxillofacial Radiology 2001;30:1-63. https://doi.org/10.1038/sj/dmfr/4600570
23. Yasar F, Apaydin B, Yilmaz HH. The effects of image compression on quantitative measurements of digital panoramic radiographs. Med Oral Patol Oral Cir Bucal. 2012;17:e1074-81.https://doi.org/10.4317/medoral.17912
24. Jung YH. Evaluation of peri-implant bone using fractal analysis. Korean J Oral Maxillofac Radiol 2005;35:121-5.
25. Farsiani H. 'Fotofonksiyonalize edilerek uygulanmış implantların çevresindeki kemik yapısının fraktal analiz yöntemi ile değerlendirilmesi' 2024. Phd Thesis
26. Koh KJ, Park HN, Kim, KA. Prediction of age-related osteoporosis using fractal analysis on panoramic radiographs. Imaging Sci Dent., 2012;42:231-5. https://doi.org/10.5624/isd.2012.42.4.231
27. Elias JJ, Brunski JB, Scarton HA. A dynamic modal testing technique for noninvasive assessment of bone-dental implant interfaces. Int J Oral Maxillofac Implants. 1996;11:728-34.
28. Heo MS, Park KS, Lee SS, Choi SC, Koak JY, Heo SJ, et al. Fractal analysis of mandibular bony healing after orthognathic surgery. Oral Surg Oral Med Oral Pathol. 2002;94:763-7. https://doi.org/10.1067/moe.2002.128972
29. Wilding RJ, Slabbert JC, Kathree H, Owen CP, Crombie K, Delport P. The use of fractal analysis to reveal remodelling in human alveolar bone following the placement of dental implants. Arch Oral Biol 1995;40:61-72. https://doi.org/10.1016/0003-9969(94)00138-2
30. Chen MH, Lyons K, Tawse-Smith A, Ma S. Resonance Frequency Analysis in Assessing Implant Stability: A Retrospective Analysis. Int J Prosthodont. 2019 Jul/Aug;32(4):317-326. https://doi.org/10.11607/ijp.6057