Radiographic determination of trabecular bone change in 2- and 4-implant−supported overdenture prostheses

Begüm Ünlü Kurşun,[a] and Ender Akan[b]

Objective. The aim of this study was to compare the fractal dimensions (FDs) of peri-implant trabecular bone around 2-implant−supported overdentures with the FDs around 4-implant−supported overdentures at the time of implant placement (T0) and 1 year after placement (T1).

Study Design. Standardized regions of interest were chosen at sites mesial and distal to 60 mandibular implants: 20 in 2-implant−supported prostheses (group 1) and 40 in 4-implant−supported prostheses (group 2), for a total of 120 measurements. FD values were calculated by using ImageJ software with the box-counting method.

Results. The mean FD values of peri-implant bone were significantly lower at T1 than at T0 in both groups ($P \leq .001$). Differences between the groups in the decrease in FD between T0 and T1 were mostly insignificant.

Conclusions. Within the limitations of this study, 2-implant and 4-implant−supported overdentures exhibited the same degree of reduction in peri-implant FD over time, suggesting similar risk of failure because FD is related to implant stability. Depending on the patient's residual ridge status and other factors, the 2-implant−supported overdenture may be preferred because it requires less surgery and is less costly. (Oral Surg Oral Med Oral Pathol Oral Radiol 2021;131:364−370)

Reduced chewing ability caused by retention and stability deficiencies is a common complaint of patients with complete denture prostheses, especially mandibular complete dentures. For this reason, implant-supported overdenture prostheses are often used instead of complete dentures.[1] Implant-supported fixed prostheses are another option when it is possible to place an adequate number of implants followed by successful osseointegration. A general level of satisfaction for both implant-supported overdenture prostheses and implant-supported fixed prostheses has been reported.[2] According to a prospective study, 50% of the patients preferred mandibular overdenture prostheses over fixed prostheses, and the authors reported only minor differences in chewing ability.[3]

Implant-supported mandibular overdenture prostheses are generally supported by 2 or 4 implants.[4] The 4-implant−supported prosthesis provides better retention and chewing capability and, thus, improves intraoral comfort and reduces the risk of food getting trapped under the prosthesis. It is recommended especially in patients who require increased retention and stability, such as those with high muscle attachments.[5-7] Two-implant−supported designs have several advantages, such as low cost, acceptable occlusal stability, and reduced surgical risk in patients with systemic discomfort and are sufficient for adequate functional and psychological outcomes.[5,8] However, disadvantages include rotation of the prosthesis during function, continued resorption of the bone in the posterior region, and transfer of a large portion of the applied force to the implants.[8]

Peri-implant bone loss is one of the most important complications of implant treatment and has a significant impact on long-term stabilization of the implant.[9,10] Surgical trauma, incorrect positioning of implants, and excessive occlusal and nonaxial loading may lead to peri-implant bone resorption, which can be associated with the adaptation of bone to the applied force.[11] Marginal bone loss should be less than 1 to 1.5 mm during the first year and less than 0.2 mm in the following period.[12] In a study by Adell et al., bone structure was found to be subjected to the functional loading of the prosthesis during the first year after prosthetic treatment, and more bone resorption occurred around the implant as a result of remodeling.[13] The argument that 4 implants produce less bone resorption compared with 2 implants has not yet been scientifically proven.[7]

Fractal analysis (FA) is a noninvasive mathematical technique that uses radiographs to measure the self-similarity of such structures as trabecular bone.[14-16] Because of its more active turnover rate compared with that of compact bone, trabecular bone is often evaluated.[17] FA can help assess trabecular bone change with

Statement of Clinical Relevance

In this study, when 2- and 4-implant−supported overdenture prostheses were compared by using fractal analysis, it was noted that both designs are clinically available and that there was no statistically significant difference between them in terms of peri-implant bone exchange.

[a]Research Assistant, Department of Prosthetic Dentistry, University of Katip Çelebi, Izmir, Turkey.
[b]Associate Professor, Department of Prosthetic Dentistry, University of Katip Çelebi, Izmir, Turkey.
Received for publication Mar 3, 2020; returned for revision Jul 18, 2020; accepted for publication Aug 2, 2020.

2212-4403/$-see front matter
https://doi.org/10.1016/j.oooo.2020.08.002

retrospective radiographs in a variety of conditions, including endodontic treatment, periodontitis, osteoporosis, and implant stability.[14,15,18] In the FA process, the number calculated with a computer algorithm and expressed as fractal dimension (FD) indicates the complexity of the structure.[18]

In general, higher FD values represent more dense and complex bone. There are several methods to calculate FD, but the most commonly used is the box-counting method.[19] FA has been carried out on nonstandardized radiographs for the evaluation of the peri-implant region in dentistry.[18] The objectives of this study were to (1) retrospectively compare the change in the FDs of peri-implant trabecular bone between T0 and T1 in 2-implant and 4-implant−supported overdenture prostheses and (2) compare the differences in FD changes over time between the 2-implant and 4-implant−supported prostheses. The null hypotheses stated that there would be no significant differences in FDs between the time of implant placement (T0) and 1 year after placement (T1) for either the 2-implant or 4-implant−supported bone and no significant differences in the changes in FD over the 1 year time period when comparing the implant sites in the 2-implant and 4-implant−supported prostheses.

MATERIALS AND METHODS

This study was conducted by reviewing the archives of the Department of Prosthodontics, Dentistry Faculty, at the University of Izmir Katip Celebi. The study was approved by the Non-Interventional Clinical Research Ethics Committee of Izmir Katip Çelebi University (Decision No.: 2019/290) and followed the tenets of the Helsinki Declaration of 1964 and later versions.

Patient selection

In total, 60 implants in the mandibles of 20 patients were chosen for the investigation. The 20 edentulous patients (9 males, 11 females; age 42 to 80 years), who had 2- or 4-implant−supported overdenture prostheses, were selected according to the inclusion and exclusion criteria. The inclusion criteria were (1) the presence of 2- or 4-implant−supported mandibular overdenture prostheses; (2) availability of at least 1 year follow-up panoramic radiographs of the prostheses; and (3) acceptable image quality.

The exclusion criteria were (1) presence of any systemic disorder affecting bone metabolism; (2) use of any drug affecting bone metabolism; (3) unacceptable image quality because of artifacts or distortion; and (4) history of radiotherapy of the head and neck region.

All panoramic radiographs were acquired with an Orthopantomograph OP 300 unit (Instrumentarium, Helsinki, Finland) with the same exposure parameters: 66 kVp, 10 mA, and 16 s exposure time. To perform FA, all images were saved to a personal computer.

The 20 study patients were assigned to 2 groups. Group 1 included 10 patients, each with a 2-implant−supported overdenture. The implants on the right and left sides were designated "R" and "L", respectively (Figure 1A). Group 2 consisted of 10 patients, each with a 4-implant−supported overdenture. The implants were designated "RP" (right posterior), "RA" (right anterior), "LA" (left anterior), and "LP" (left posterior) (Figure 1B). Panoramic radiographs acquired at the time of implant placement (T0) and approximately 1 year after placement (T1) were used for FA.

Fractal analysis

FA was performed on the same personal computer by the same researcher who had been trained in the procedure by using ImageJ Software version 1.52 a (National Institutes of Health, Bethesda, MD). In the first step, standardized regions of interest (ROIs) of 60 × 90 pixels were selected from the mesial and distal aspects of the neck region of each implant (see Figure 1). This resulted in 40 ROIs in group 1 (2 ROIs per implant in the 2-implant−supported prostheses [n = 10]) and 80 ROIs in group 2 (2 ROIs per implant in the 4-implant−supported prostheses [n = 10]), for a total of 120 ROIs from the 2 groups on both the T0 and T1 radiographs. The ROIs did not include the lamina dura, periodontal ligament, or any other anatomic structures with abnormalities.

Each ROI was then duplicated for image processing (Figure 2A). The duplicated image was blurred by 35 pixel diameter Gaussian filters (Figure 2B). The blurred image was subtracted from the original image (Figure 2C). Then, 128 gray values were added (Figure 2D). The areas with different brightness in the image with an average value of 128 gray values helped distinguish bone marrow and trabecular structure. The image was then converted to a 2-color binary black and white image (Figure 2E) so that the outline of bone marrow and trabecular structure could be distinguished. To reduce unwanted fluctuations in the image, it was first eroded with the "Erode" option (Figure 2F) and then dilated with the "Dilate" option, in which the existing areas were expanded and made more visible (Figure 2G). After this process, the white areas were transformed into black, and the black areas were converted to white by inverting the gray scale (Figure 2H). With the "Skeletonize" option, the outline of the trabecular structure was determined and made ready for fractal analysis (Figure 2I).

FDs were calculated by using software with the fractal box counting method, as described by White and Rudolph.[20] When calculating the fractal size, the

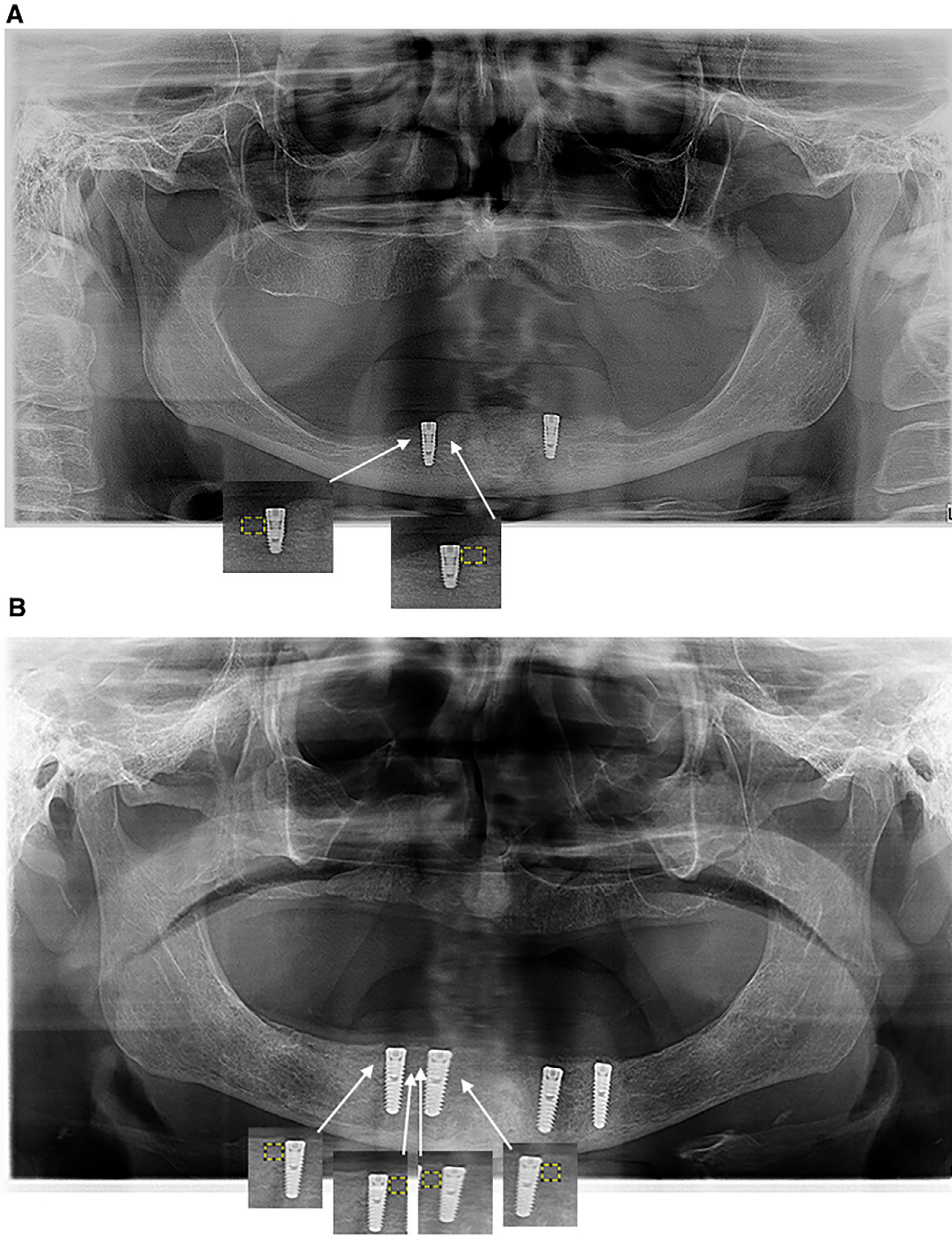

Fig. 1. Panoramic radiographs of 2-implant **(A)** and 4-implant **(B)**−supported overdenture prostheses. The inserts demonstrate the 2 regions of interest (ROIs), on the mesial and distal sides of each implant examined for fractal analysis.

program divides the image into frames with dimensions of 2, 3, 4, 6, 8, 12, 16, 32, and 64 pixels. The total number of boxes whose size ranged between 2 and 64 pixels was calculated. These values were plotted on a logarithmic scale to generate a line that best matched the points. The slope of the line is the FD value, which

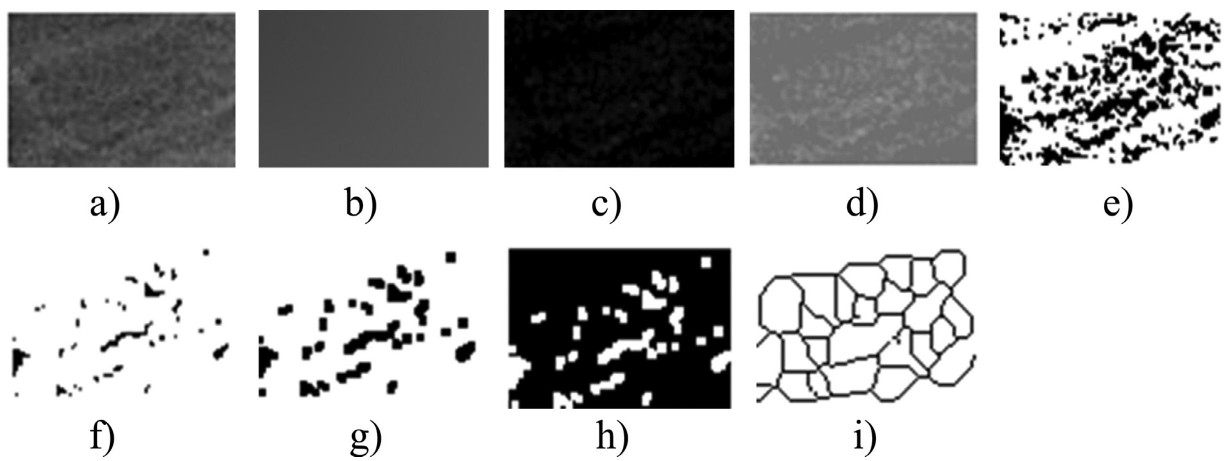

Fig. 2. Fractal analysis process, according to White and Rudolph (1999). **A,** Duplicated image. **B,** 35 pixel Gaussian filtered image. **C,** Subtraction from the original image. **D,** Image of 128 grey values were added. **E,** Binary image. **F,** Eroded image. **G,** Dilated image. **H,** Inverted image. **I,** Skeletonized image.

indicates the degree of complexity of the structure. The mean values and standard deviations of the calculated FDs were saved for statistical analysis.

Statistical analysis

The study variables were analyzed with the use of SPSS software version 22.0 (SPSS Inc., Chicago, IL). The measurements were performed again on 10 randomly selected radiographs by the same examiner after 2 weeks to allow calculation of intraexaminer reliability. The intraclass correlation coefficient ranged from 0.90 to 1.00, indicating excellent reliability.[21] The Shapiro-Wilk test confirmed the normal distribution of data. The paired *t* test was used to compare the mean FDs at T0 and T1 at each ROI to evaluate the change in FD over time in both group 1 and group 2. The paired *t* test was also used to compare the changes in FDs over time (by subtracting the mean values at T0 from the mean values at T1) at each ROI to evaluate the differences in FD change between group 1 and group 2. A value of $P < .05$ was considered statistically significant.

RESULTS

After comparison of the results of FA of group 1 before (T0) and after (T1) treatment, the FD values in both mesial and distal regions of the 2 implants were found to be significantly lower at T1 ($P \leq .001$) (Table I). In group 2, the FDs in all sites around all 4 implants were also found to be significantly lower at T1 ($P \leq .001$) (Table II). When the changes in FD over time (calculated by subtracting the mean FD values at T0 from T1) for the R and L implants in group 1 were compared with the changes for the posterior implants (RP and LP, respectively) in group 2, the differences between the FD changes on the distal side of the R and RP implants were statistically significant, with greater reductions in FD around the implants in group 1 ($P = .003$). The differences on the distal aspects of the L and LP implants approached significance, with greater reductions in

Table I. Comparison of fractal dimensions in group 1 at the time of implant placement (T0) and 1 year after placement (T1) to evaluate changes in FD over time

		T0		*T1*		
		Mean	*SD*	*Mean*	*SD*	*P*
R	Mesial	1.3975	0.08518	1.3139	0.07991	.001
	Distal	1.3958	0.06224	1.2541	0.09254	< .001
L	Mesial	1.4237	0.05566	1.3552	0.07434	< .001
	Distal	1.3980	0.07141	1.3179	0.08421	< .001

L, implant in the left side; *Mean,* average of FD values at each region of interest; *R,* Implant in the right side; *SD,* standard deviation

Table II. Comparison of fractal dimensions in group 2 at the time of implant placement (T0) and 1 year after placement (T1) to evaluate changes in FD over time

		T0		*T1*		
		Mean	*SD*	*Mean*	*SD*	*P*
RP	Mesial	1.4186	0.06508	1.3513	0.05122	< .001
	Distal	1.3998	0.05800	1.3471	0.04216	<.001
RA	Mesial	1.4016	0.05742	1.3485	0.04240	.001
	Distal	1.4094	0.06245	1.3469	0.05698	< .001
LA	Mesial	1.4221	0.06457	1.3760	0.06182	< .001
	Distal	1.3789	0.06907	1.3321	0.07922	.001
LP	Mesial	1.4006	0.07342	1.3571	0.07575	.001
	Distal	1.3713	0.05713	1.3318	0.06137	.001

LA, implant in the left anterior; *LP,* implant in the left posterior; *Mean,* average of FD values at each region of interest; *RA,* implant in the right anterior; *RP,* implant in the right posterior; *SD,* standard deviation.

Table III. Comparison of changes in fractal dimensions over time (by subtracting the mean values at T0 from T1) to evaluate the implants in group 1 versus the posterior implants in group 2

			Mean	*SD*	*P*
Group 1	R	Mesial	−0.0840	0.05562	.067
Group 2	RP		−0.0463	0.01685	
Group 1	R	Distal	−0.1420	0.07345	.003
Group 2	RP		−0.0450	0.02330	
Group 1	L	Mesial	−0.0690	0.03635	.126
Group 2	LP		−0.0450	0.02330	
Group 1	L	Distal	−0.0800	0.02867	.054
Group 2	LP		−0.0413	0.02031	

L, implant in the left side; *LP,* implant in the left posterior; *Mean,* average of the changes in FD between T1 and T0 (by subtracting T0 from T1) at each region of interest; *R,* implant in the right side; *RP,* implant in the right posterior.

group 1 ($P = .054$) (Table III). As a result of comparing the changes in FD over time for the R and L implants in group 1 with the changes for the anterior implants (RA and LA, respectively) in group 2, only the differences at the distal sites of the R and RA implants were statistically significant, with greater reduction in FD values detected in group 1 ($P = .005$) (Table IV). No significant differences were found when comparing FD values between the mesial and distal surfaces of the 2 posterior implants or of the 2 anterior implants in group 2 ($P \geq .086$).

DISCUSSION

The results of our study allowed us to reject the null hypothesis that there would be no significant differences in mean FD values when comparing measurements at T0 with T1 in either group 1 or group 2. At 1 year after insertion of the overdenture prostheses, the FD values of the trabecular bone, calculated with sections taken from mesial and distal regions from implants, were found to be significantly lower than the initial values in all sites in both groups ($P \leq .001$). The null hypothesis that the 2 groups would not be significantly different from each other when comparing changes in FDs between T0 and T1 can be rejected for the distal ROI of the R implant in group 1 compared with the RP implant in group 2 ($P = .003$) and with the RA implant in group 2 ($P = .005$). However, comparisons between groups in all other ROIs yielded no significant differences between the groups in decreases in FDs over time ($P \geq .054$).

Research indicates that marginal bone loss in the peri-implant region is influenced by various patient factors, implant-related neck design, placement depth and torque, location of the implant site, and the properties of the prosthesis.[11] Other factors contributing to bone loss include surgical trauma, biomechanical factors, and bacterial infections. Overloading of implants may also increase bone resorption and even lead to failure of osseointegration.[7] According to a study to evaluate implant survival by Albrektsson et al., marginal bone loss should be less than 1 to 1.5 mm during the first year and less than 0.2 mm in the following period.[12] There is an assumption that overdenture prostheses with 4-implant supports result in less peri-implant bone loss compared with 2-implant−supported prostheses. However, this is based on anecdotal clinical experience, and there are not enough studies to support this theory.[7]

Bone resorption has also been studied in the mandibular peri-implant area according to type of prosthesis in the maxillary arch. Carlsson et al. reported the effect of opposite jaw prosthesis in 47 patients. Thirteen patients with mandibular implant-supported fixed partial dentures were also treated with implant-assisted prostheses in the maxillae, whereas the remaining 34 patients had standard maxillary complete dentures. After 10 years, the mean bone resorption around the mandibular implants was less than 1 mm, and no significant difference was observed in bone loss in the mandibular peri-implant region between patients with implant-supported overdentures and those with standard complete maxillary dentures.[22]

Generally, high FD values signify a more complex structure.[23] Southard et al. reported that the density of the alveolar bone had a positive correlation with FD.[24] Similarly, Heo et al. reported that FD values increased after orthognathic surgery, at the time of the bone healing process.[25] Ergün et al. reported that the FD value of the mandibular alveolar bone of patients who had hyperparathyroidism also increased after surgery during the healing process.[26] However, Yu et al. found

Table IV. Comparison of changes in fractal dimensions over time (by subtracting the mean values at T0 from T1) to evaluate the implants in group 1 versus the anterior implants in group 2

			Mean	*SD*	*P*
Group 1	R	Mesial	−0.0840	0.05562	.346
Group 2	RA		−0.0650	0.02330	
Group 1	R	Distal	−0.1420	0.07345	.005
Group 2	RA		−0.0525	0.02493	
Group 1	L	Mesial	−0.0690	0.03635	.278
Group 2	LA		−0.0513	0.02900	
Group 1	L	Distal	−0.0800	0.02867	.093
Group 2	LA		−0.0588	0.01959	

L, implant in the left side; *LA,* implant in the left anterior; *Mean,* average of the changes in FD between T1 and T0 (by subtracting T0 from T1) at each region of interest; *R,* implant in the right side; *RA,* implant in the right anterior.

decreased FD values in the reactive bone areas after clinically effective endodontic treatment.[27]

When the studies are evaluated in terms of the methods for obtaining the radiographs used in FD calculations, it was observed that some researchers used panoramic radiographs, some preferred to use periapical radiographs with higher resolution, and some used both periapical and panoramic radiographs.[28] Wilding et al. reported that bone remodeling can be evaluated by performing FA with the use of panoramic radiography after implant placement, as was done in our study.[29]

Lee et al. identified 52 related areas of 60 × 90 pixel size before and after implant treatment by using panoramic radiographs of 22 patients. Primary stability of the implant was represented by the implant stability quotient, which is calculated from resonance frequency analysis. The results showed that there was a statistically significant positive relationship between the FD values and the implant stability coefficient of the resonance frequency analysis and that the mandibular implants showed a higher correlation between these 2 measures than maxillary implants.[30]

Treatment with 2 versus 4 implants to support overdenture prostheses is a highly controversial issue. The German Maxillofacial Surgery Association proposes the use of 4 implants for support.[31] Posterior implants that provide stress distribution and a quadrilateral support between anterior and posterior implants may result in less peri-implant vertical bone loss.[32] Petrie et al. reported that the use of 4-implant−supported overdentures leads to a decrease in damaging strain on implants.[33] However, Cune et al. found that the survival rate of implants in patients with 2-implant−supported mandibular overdenture prostheses was 93.9% after the 1-year follow-up period and reported high patient satisfaction and few prosthetic complications.[34] Visser et al. observed no significant differences in the 5-year success rates of 2- and 4-implant−supported mandibular overdentures in terms of clinical and radiologic parameters.[1]

In the present investigation, we found that both 2- and 4-implant−supported prostheses suffered significant decreases in FD over 1 year of function. Because the FD is correlated with implant stability coefficient, both designs might have equal rates of success or failure as measured in implant stability. No significant difference was observed in the decreased FDs between group 1 and group 2 except for the distal sites of the right implants in group 1 compared with the right anterior and right posterior implants in group 2. This implies that, all else being equal, 2-implant−supported overdentures have no significantly greater risk of failure compared with 4-implant−supported overdentures.

General health, morphologic conditions, and functional and economic factors must be considered when determining the design of implant-supported prostheses. Placement of 2 implants is less challenging and less costly in the edentulous mandible compared with the use of 4 implants to support overdentures. The disadvantages are increased movement and reduced of stability of the prosthesis on the distal side of the implants. The advantages of treatment using 4 implants include increased intraoral comfort and stability.[7]

One of the important limitations of this study is the restricted clinical information because of the small number of patients included. Bone loss resulting from occlusal forces around the implants, influence of positioning during panoramic radiography, and lack of overall quality in comparison of the T0 and T1 radiographs are other limitations. Further clinical research with appropriate sample sizes is necessary.

CONCLUSIONS

In this study, the FD values in both groups significantly decreased between T0 and T1 ($P \leq .001$). Comparison of group 1 with group 2 with regard to the peri-implant decrease in FDs between T0 and T1 revealed significant differences in some ROIs ($P \leq .005$), but most of the compared sites were not significantly different ($P \geq .054$).

Within the limitations of this study, the findings indicate that 2-implant and 4-implant−supported overdentures result in similar degrees of adverse bone change around the implants. Both designs are clinically available, and depending on the patient's residual ridge status, the 2-implant−supported overdenture could be preferred because it requires less surgery and is more economical.

REFERENCES

1. Visser A, Raghoebar GM, Meijer HJA, Batenburg RHK, Vissink A. Mandibular overdentures supported by two or four endosseous implants: a 5-year prospective study. *Clin Oral Impl Res*. 2005;16:19-25.
2. Brennan M, Houston F, O'Sullivan M, O'Connel B. Patient satisfaction and oral health-related quality of life outcomes of implant overdentures and fixed complete dentures. *Int J Oral Maxillofac Implants*. 2010;25:791-800.
3. Feine JS, Dufresne E, Boudrias P, Lund J. Outcome assessment of implant-supported prostheses. *J Prosthet Dent*. 1998;79: 575-579.
4. Batenburg RHK, Raghoebar GM, Van Oort RP, Heijdenrijk K, Boering G. Mandibular overdentures supported by two or four endosteal implants. *Int J Oral Maxillofac Surg*. 1998;27:435-439.
5. Karbach J, Hartmann S, Jahn-Eimermacher A, Wagner W. Oral health−related quality of life in edentulous patients with two- vs four-locator-retained mandibular overdentures: a prospective, randomized, crossover study. *Int J Oral Maxillofac Implants*. 2015;30:1143-1148.
6. Mericske-Stern RD, Taylor TD, Belser U. Management of the edentulous patient. *Clin Oral Implants Res*. 2000;11:108-125.
7. Ketabi AR, Bornemann G, Ketabi S, Lauer HC. Hybrid prosthetic treatment of the edentulous mandible with two or four implants—a literature review. *Dentistry*. 2014;S2:1.
8. Elsyad MA, Alokda MM, Gebreel AA, Hammouda NI, Habib AA. Effect of two designs of implant supported overdentures on

peri-implant and posterior mandibular bone resorptions: a 5-year prospective radiographic study. *Clin Oral Implants Res*. 2017;18:e184-e192.
9. Chen Z, Lin CY, Li J, Wang HL, Yu H. Influence of abutment height on peri-implant marginal bone loss: a systematic review and meta-analysis. *J Prosthet Dent*. 2019;122:14-21.
10. Liu Y, Wang J. Influences of microgap and micromotion of implant−abutment interface on marginal bone loss around implant neck. *Arch Oral Biol*. 2017;83:153-160.
11. Hof M, Pommer B, Zukic N, Vasak C, Lorenzoni M, Zechner W. Influence of prosthetic parameters on peri-implant bone resorption in the first year of loading: a multi-factorial analysis. *Clin Implant Dent Relat Res*. 2015;17:183-191.
12. Albrektsson T, Zarb G, Worthington P, Eriksson RA. The long−term efficacy of currently used dental implants: a review and proposed criteria for success. *Int J Oral Maxillofac Implants*. 1986;1:11-25.
13. Adell R, Lekholm U, Rockler B, Brånemark PI. A 15-year study of osseointegrated implants in the treatment of the edentulous jaw. *Int J Oral Surg*. 1981;10:387-416.
14. Demiralp KÖ, Kurşun-Çakmak EŞ, Bayrak S, Akbulut N, Atakan C, Orhan K. Trabecular structure designation using fractal analysis technique on panoramic radiographs of patients with bisphosphonate intake: a preliminary study. *Oral Radiol*. 2018;35:23-28.
15. Abdulhameed EA, Al-Rawi NH, Uthman AT, Samsudin AR. Bone texture fractal dimension analysis of ultrasound-treated bone around implant site: a double-blind clinical trial. *Int J Dent*. 2018;2018:2672659.
16. Updike SX, Nowzari H. Fractal analysis of dental radiographs to detect periodontitis-induced trabecular changes. *J Periodontal Res*. 2008;43:658-664.
17. Magat G, Ozcan SS. Evaluation of trabecular pattern of mandible using fractal dimension, bone area fraction, and gray scale value: comparison of cone-beam computed tomography and panoramic radiography. *Oral Radiol*. 2018;35:35-42.
18. Jolley L, Majumdar S, Kapila S. Technical factors in fractal analysis of periapical radiographs. *Dentomaxillofac Radiol*. 2006;35:393-397.
19. Arsan B, Kose TE, Cene E, Ozcan I. Assessment of the trabecular structure of mandibular condyles in patients with temporomandibular disorders using fractal analysis. *Oral Surg Oral Med Oral Pathol Oral Radiol*. 2017;123:382-391.
20. White SC, Rudolph DJ. Alterations of the trabecular pattern of the jaws in patients with osteoporosis. *Oral Surg Oral Med Oral Pathol*. 1999;88:628-635.
21. Portney LG, Watkins MP. *Foundations of Clinical Research: Applications to Practice*. Upper Saddle River, NJ: Prentice Hall; 2000.
22. Carlsson GE, Lindquist LW, Jemt T. Long-term marginal peri-implant bone loss in edentulous patients. *Int J Prosthodont*. 2000;13:295-302.
23. Yaşar F, Akgünlü F. The differences in panoramic mandibular indices and fractal dimension between patients with and without spinal osteoporosis. *Dentomaxillofac Radiol*. 2006;35:1-9.
24. Southard TE, Southard KA, Lee A. Alveolar process fractal dimension and postcranial bone density. *Oral Surg Oral Med Oral Pathol Oral Radiol Endod*. 2001;91:486-491.
25. Heo MS, Park KS, Lee SS, et al. Fractal analysis of mandibular bony healing after orthognathic surgery. *Oral Surg Oral Med Oral Pathol Oral Radiol Endod*. 2002;94:763-767.
26. Ergün S, Saraçoglu A, Guneri P, Ozpinar B. Application of fractal analysis in hyperparathyroidism. *Dentomaxillofac Radiol*. 2009;38:281-288.
27. Yu YY, Chen H, Lin CH, et al. Fractal dimension analysis of periapical reactive bone in response to root canal treatment. *Oral Surg Oral Med Oral Pathol Oral Radiol Endod*. 2009;107:283-288.
28. Sener E, Baksı BG. Fractal dimension and mandibular cortical bone index evaluations in normal and osteoporotic patients. *J Ege Univ School Dent*. 2016;37:159-167. [in Turkish].
29. Wilding RJC, Slabbert JCG, 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.
30. Lee DH, Ku Y, Rhyu IC, et al. A clinical study of alveolar bone quality using the fractal dimension and the implant stability quotient. *J Periodontal Implant Sci*. 2010;40:19-24.
31. German Maxillofacial Surgery Association (DGZMK). *Stellungnahme der. Implantologie in der Zahnheilkunde*. Düsseldorf, Germany: DGZMK; 2005 https://www.dgzmk.de/implantologie-in-der-zahnheilkunde.
32. Misch CE. *Treatment options for mandibular implant overdentures*. Dental Implant Prosthetics. 3rd ed. St. Louis, MO: Elsevier; 2005:218-235.
33. Petrie CS, Walker MP, Lu Y, Thiagarajan G. A preliminary three-dimensional finite element analysis of mandibular implant overdentures. *Int J Prosthodont*. 2014;27:70-72.
34. Cune MS, Verhoeven JW, Meijer GJ. A prospective evaluation of Rialoc implants with ball-abutments in the edentulous mandible: 1-year results. *Clin Oral Implants Res*. 2004;15:167-173.

Reprint requests:
Begum Ünlü Kurşun
Department of Prosthetic Dentistry
University of Katip Celebi
Cigli Izmir
Turkey 35640
beguumunlu@gmail.com