Original Research

Fractal Analysis of Trabecular Alveolar Bone with Intrabony and Furcation Defects Using Periapical Dental Radiographs

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ABSTRACT

Objective: Fractal analysis (FA) is a non-invasive method that quantitatively measures complex patterned geometric structures present throughout the image. Trabecular morphology of the alveolar bone and the changes occurring in the trabeculae in case of periodontitis can be detected with this method. To examine the periodontal defects in human skull bones using the FA, to compare them with healthy alveolar bone regions.

Methods: Furcation and intrabony defects were artificially created in the mandible alveolar bones (n:24). Periapical X-ray images of alveolar bone regions containing teeth with defects were taken using the parallel technique. Fractal analysis was performed by box-counting method using Image J software on images from areas containing healthy and defective trabecular bone.

Results: No statistically significant difference was found between the fractal values of healthy tissue and bifurcation defetcs and between the healthy tissue and intrabony defects (p>0.05).

Conclusion: Many factors may have affected the outcomes; patient selection, imaging methods, sample size, Region of interest (ROI) selection-location and size, individual and anatomical variations. These variables need to be standardized as much as possible and the limitations of the method need to be improved.

Keywords: fractal analysis, fractal dimension, periodontal defect, periodontitis, periapical radiograph, trabecular bone.

INTRODUCTION

Chronic inflammation in periodontitis causes bone loss and the formation of bone defects [1]. Untreated alveolar bone destruction around the teeth eventually leads to tooth loss. It was determined that when the destruction in the alveolar bone reached 30-50%, it could be detected with conventional radiographs [2]. In this case, the initial stages of periodontitis may not be noticed. Additionally, radiographic analyzes are completely subjective and do not provide quantitative data. Nowadays, as technology is developing, efforts are being made to develop non-invasive diagnostic methods that include objective and quantitative data in radiographic analysis [3].

It has been proven that trabecular bone has fractal properties, and with the fractal analysis (FA) method, details in its structure that cannot be distinguished by the human eye can be evaluated [4]. One of the two important characteristics that represent fractal geometry is self-similarity, that is, any part resembles the whole object when viewed from different scales. The other feature is a varying of a determined scale. In addition, when the analyzed region is narrowed or expanded, it resembles the entire shape at every scale size [5]. If any part of the object resembles the original, the general shape of the self-similar object does not change. Fractal analysis is a non-invasive method that quantitatively measures complicated patterned geometric designs present all through the image [6,7]. While a decrease in the fractal dimension (FD) value indicates a simpler structure, an increase is observed in case of a more complex patterned structure [8]. There are many approaches to estimate FD, however, the most preferred is the box counting method and is suitable for two-part figure analysis.

There are studies reporting that differences in the trabecular morphology of the alveolar bone in disease and health status can be defined with this procedure [9]. However, there are a bounded number of research in the literature supporting the use of FA to reinforce the radiographic diagnosis of periodontal disease. Periapical films have been adopted by many researchers

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Main Points;

- No statistically significant difference was found in terms of fractal analysis (FA) between artificially created three-walled alveolar bone defects and defect-free areas in human skulls.

- Artificial defects that cannot fully replicate natural defects, the superposition of intact bone walls in two-dimensional radiographs, and the fact that the experiment was self-controlled may have affected the outcomes.

- There may be some standardization problems of the FA method, such as different imaging procedures, methodological differences in FA stages, individual differences, ROI size and location.

- Although the FA method is non-invasive, quantitative and safe, it has difficulties in clinical practice in terms of performing the procedure steps and ensuring standardization.

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due to their clarity and high detail in determining the status of bone defects occurring in periodontal disease [10]. It is the most utilized radiography technique as an easy, practical and economic imaging method used in limited areas for any dental reason.

In the studies carried out, measurements of the trabecular structure of the alveolar bone surrounding the teeth were made, and the applicability of these measurements in certain areas of dentistry was discussed. According to current developments, these areas are; it includes the diagnosis of osteoporosis with dental radiographs, the effects of diabetes on the jaws, the effects of orthodontic therapy on the bone, follow-up of implant osseointegration, follow-up of periapical lesions, and evaluation of the diagnosis and follow-up of periodontitis [9].

The goal of this in vitro study is to examine the periapical radiographs of artificially created periodontal defect areas in human skull bones using the FA method, to compare them with healthy alveolar bone regions and to investigate possible bone structure differences.

MATERIALS AND METHODS

This in vitro study includes areas of intact alveolar bone with and without periodontal defects of molar teeth of human skull mandible bones. (Ethical approval: Health Sciences Ethics Committee, Ankara Yıldırım Beyazıt University, Date and no: 08.12.2022-19/1229). Alveolar bone fragments consisting of 24 teeth without metal restorations, fillings, pins or wires were included in the study. Furcation and intrabony defects were artificially created in the mandible bones with teeth. Elevated speed rotating diamond burs were applied for this process. The apex of the bony margins of each defect was accepted as the reference point. Then, periapical X-ray images of alveolar bone regions containing teeth with bone defects were taken using the parallel technique. Fractal analysis was performed on periapical x-ray images from areas containing healthy and defective trabecular bone.

Creation of Bifurcation Defects
About 2-4 mm of cortical and trabecular bone was removed from the bifurcation area of the mandibular molar teeth. Thus, gaps were prepared in the form of class 2 furcation defects (n:12).

Creation of Intrabony Defects
Vertical bone defects with three walls were readied mesially

or distally (2 mm bucco-lingual, 5 mm depth and 2 mm wide, approximately) from the interdental septum to the root of the mandibular molar tooth (n:12).

Image Acquisition

Alveolar bone areas with periodontal defects were coated with double layers of pink wax to simulate soft tissue before imaging. The X-ray machine (Gendex Digital Systems, Hatfield, PA, USA) used for digital intraoral periapical radiographs (at 65 kVp and 7 mA) was a device with a size 2 photostimulated phosphor plate detector (GXPS-500 PSP, Gendex Digital Systems, Bensheim, Germany). Images were recorded in 32 bit color and 64 lm (high) pixel size. Ex vivo imaging was performed (0.25 s image exposure time and 40 cm focus receptor distance) using equipment of the paralleling technique with standardized rectangular collimation (Rinn Manufacturing Company, Elgin, IL, USA) [11].

Fractal Dimension Analysis

Fractal analyses were applied in a software (ImageJ v1.53for Windows; National Institute of Health, Bethesda, MD, USA). Region of interest (ROI) was drawn in a square shape from the regions with defects (bifurcation - intrabony) and healthy trabecular bone (interdental). The ROI drawn for each tooth was made reproducible and standardized by keeping its size and location the same (25 × 25 pixels; Figure 1A, 1B).

The box counting method was completed by following the steps below, as performed by White and Rudolph (Figure 2) [8]. The replicated 25 × 25 pixel ROI image was blurred by applying Gaussian blur (sigma = 35 pixels, Figures 2A and 2B). 128 shades of gray were added to each pixel of the blurred image (Figure 2D), which was subtracted from the original image (Figure 2C). To convert the image to a 2-color black and white image, it was first converted to 8-bit format by using the "Type" option and then the "Threshold" option. Here the outlines of the bone marrow could be distinguished from the trabecular structure (Figure 2E). Image noise was reduced with the "Erode" option (Figure 2F) and existing areas were made more distinct with the "Dilate" option (Figure 2G). The "Invert" option was used to reveal the outline of the trabecular bone, thus converting white areas to black and black areas to white. (Figure 2H). With the "Skeletonize" option, the outlines of the trabecular bone were determined and it was ready for FA (Figure 2 I). "Fractal box counting" in the "Analyze" tab was then applied to calculate the FD.

Statistical Analysis

Statistical analyzes were performed using SPSS (version 22.0, SPSS Inc., Chicago, IL, USA). Normal distribution of the data were analysed using Shapiro-Wilk test. Fractal dimensions of the healthy bone tissue with bifurcation defects, and with the intrabony defects were compared with student's t-test. The value of $p < 0.05$ was determined as the limit of statistical significance. Before the study, to determine the required minimum sample size; Error level (a) = 0.05, power (1-b) = 0.80, f = 0.25, estimated correlation between repeated measurements = 0.75 values were used as criteria. It was calculated that a total of 24 periodontal defects, including 12 furcation and 12 intrabony defects, would be sufficient (GPower 3.1 program).
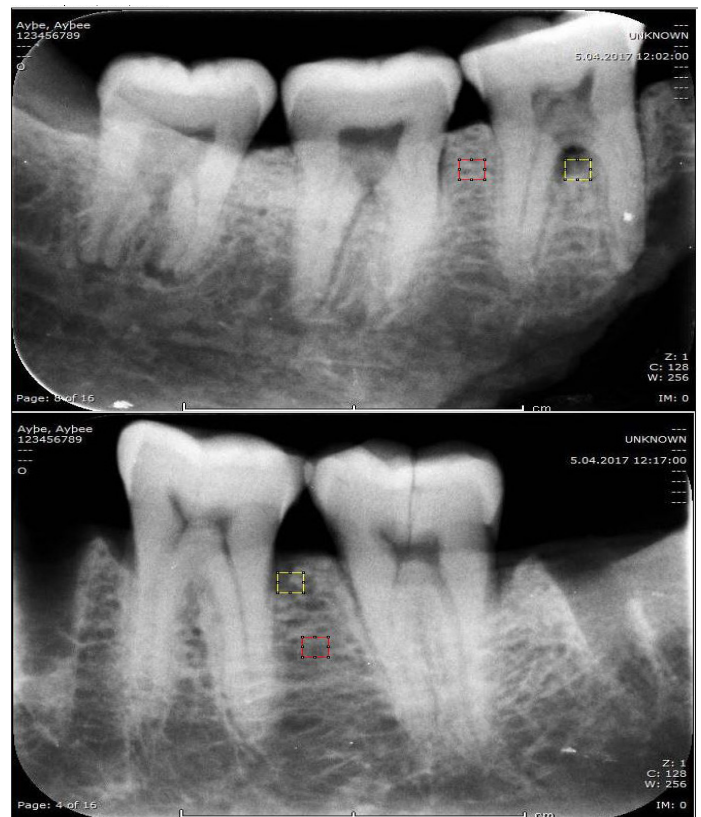
Figure 1. Square-shaped region of interest (ROI) drawn from bifurcation (Figure 1A) and intrabony defects (Figure 1B) and healthy interdental trabecular bone.
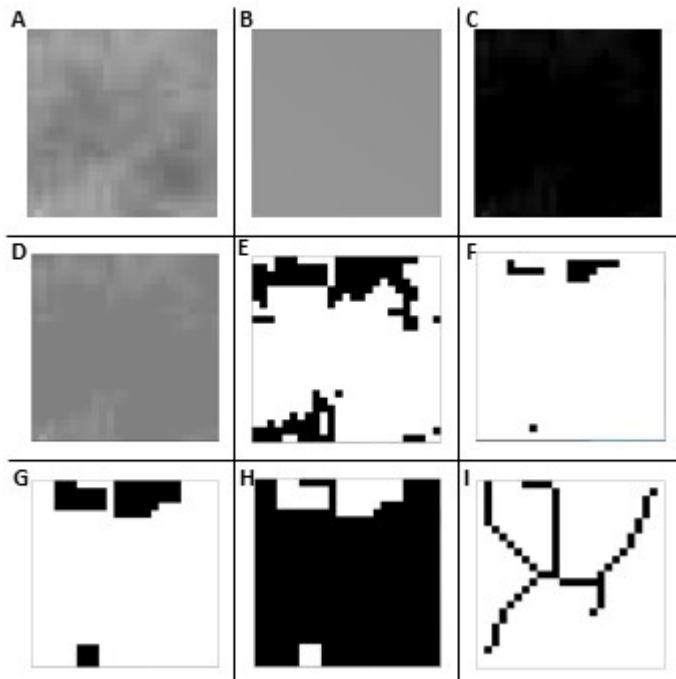
Figure 2. The box counting method was applied for fractal analysis. Blurred by applying Gaussian blur (sigma = 35 pixels, 2A and 2B). Subtracted from the original image (2C). Gray were added to each pixel (2D). Convert to black and white image, "Type" and "Threshold" (2E). Reduced image noise, "Erode" (2F). Made more distinct, "Dilate" (2G). Convert white areas to black and black areas to white, "Invert" (2H). Ready for FA, "Skeletonize" (2I). Calculate the fractal dimension, "Analyze".

RESULTS

The results were shown on table-1. No significant difference was found between the fractal values of healthy tissue and bifurcation defetcs (p> 0.05; t-test) and between the healthy tissue and intrabony defects (p> 0.05; t-test).

Table 1. Comparing the fractal dimension values of healthy bone tissue with the bifurcation defects and intrabony defects

	Mean±SD	n	t	p
Bifurcation defects	1.062±0.120	12	1.660	0.111
Healthy bone	0.979±0.125	12		
Intrabony defekt	1.082±0.083	12	1.300	0.207
Healthy bone	1.033±0.102	12		

DISCUSSION

Radiographic examination is a subjective evaluation that does not contain quantitative data [12]. Compared to immediate measurements at the time of surgery, intraoral radiographs measured nearly 1.4 mm less depth of bone defects around the teeth [13]; In this case, early stage bone defects may not be noticed in radiographic evaluation [14]. Fractal analysis has been frequently used in recent years to analyze bone and examine invisible details through various radiographic imaging methods [15–17]. In our study, we examined the healthy areas in the interdental region and the areas with periodontal defects using the FA method, and we could not detect any difference in-between the FD values.

In the first study to evaluate bone loss in periodontitis with FA using periapical radiographs, conventional radiographs were scanned and digitalized on a computer, and as a result, the FD values of the healthy group were found to be significantly higher than the periodontitis group [18]. Image losses occur due to the decrease in the gray value range of the radiographs digitized in this way, which affects the FD [3,19]. We can also state that our results are not similar because ROIs of different sizes were determined by the form and dimension of the interproximal bone in the study [18]. There are also studies stating that the location of the selected ROI from different areas of the jaws causes significant differences in FD values [20,21,22]. Updike et al., who selected the ROI from the apical region of the mandibular anterior teeth, showed that FA can be considered a diagnostic tool to distinguish between healthy and periodontitis subjects, but cannot determine the severity of periodontitis [23]. Our results may be different due to differences in ROI location or size. Similarly, Lin et al. reported that significant differences were observed in FD measurement of trabecular bone structure depending on the selected region [24].

In the study of Updike et al., significant difference in mean age between the healthy group and the periodontitis groups may have caused the difference in FD values. Belgin et al measured FD from digital periapical films and the measurements of the healthy group were found to be higher than the periodontitis group [14]. However, in the study, the mean age of the healthy group was statistically significantly lower than the periodontitis group, and this may have caused the difference in FD between the groups. Since our study was designed with self-control, individual factors were minimized and thus it was not affected by the age factor. While Ruttimann demonstrated in his in vitro

study that the calculated FD value of trabecular bone increased with the age variable [4], Amer et al. reported that the FD of trabecular bone had no relationship with age [25]. This indicates the possibility that a larger sample size could reveal a significant difference.

In the study of Cha et al., who used periapical radiographs, the FD values of the healthy group were found to be significantly higher than the values of the periodontitis group with furcation-involved defects [26]. However, while a significant difference was reported in the measurements in the furcation area, there was no significant difference in the measurements made from the top of the alveolar crest [26]. In our study, there was no significant difference between the FD values in the regions with in vitro created bone defects and the interdental regions without bone defects, but we think that the superposition due to the 3-wall nature of the defects we created and the fact that it was a self-controlled study affected our results.

While a significant difference was found in a study using periapical radiographs when measuring the FD of the trabecular bone of healthy and periodontitis groups [3], no significant difference was found in the study of Coşgunarslan et al. using CBCT images [27]. In another study comparing periapical and panoramic radiographs of the same patients, the authors reported that higher FD was calculated in periapical radiographs [28]. This suggests that differences in detail and resolution in imaging procedures may vary the outcomes in diseases with local bone loss. Periapical radiographs, which we preferred in this study, have better resolution and provide better detail, but their disadvantages are that they only allow imaging of a very limited area and the number of films to be taken increases when the full mouth is desired to be evaluated [29].

Based on the information in the literature that differences in image resolution may change FD values [14], the analysis of all images in our study was performed on the same computer and by the same physician. Radiographs with fillings, root canal treatment, lesions, bone fractures, or various artifacts in the relevant area that were likely to change our study results, and radiographs with no diagnostic value due to wrong positioning were excluded from the study. All films were taken with the same x-ray device, following the same irradiation parameters and the same positioning rules. In our study, digital periapical radiographs with the same format and high image quality were used.

The ROI we chose in our study was determined within the boundaries of trabecular bone, not including cortical bone, teeth or periodontal ligament space. According to a study on the selection of optimal teeth in determining periodontal bone loss, it was reported that measurements taken from the posterior regions of the mandible represent whole-mouth bone loss measurements [30]. In our study, we selected the ROI of the artificially created defects from the mesial, distal and furcation regions of the mandibular molar teeth and compared them with the ROI we selected from the interdetal areas of the teeth without any defects. Unlike some studies in the literature that similarly determined ROI from periapical films of the mandibular molar regions [3, 14], there is no significant difference in our study.

Although the existing dimensions and shapes of the interdental and interradicular bone to be analyzed are limiting in determining ROI dimensions, we preferred a square ROI of 25×25-pixels. Performing the ROI selection process manually may lead to individual errors and the inability to standardize the ROI location [31]. It is not possible to standardize by selecting ROI from exactly the equal location in each individual, which could give onto differences in measurements and is a limitation of this study. In a study in which lung cancer was evaluated using FA, it was reported that the main limitation of this method was the standardization problem [32]. Moreover, the artificially created defects in our study may not fully mimic real periodontal defects, and the defects created from samples may not fully replicate defects in living tissue.

We cannot make an evaluation in terms of gender, but since our study is self-controlled, we think that the gender variable does not affect our study. Additionally, there are studies that did not find a significant relationship between FD values and gender [23,14,20]. In the literature, many different studies investigating FA draw attention with contradictory results. For example, in a study where FD was calculated from periapical and panoramic X-rays of patients with a history of osteoporotic fracture, FD of patients in the osteoporosis group was found to be higher than the control group [28]. Contradictory results stand out in the literature regarding whether the FD of demineralized bone will increase [4,28,33] or decrease [34,35], as in osteoporosis. Geraets stated that there were conflicting results due to the image being obtained by different methods or the anatomical differences of the analized area [36]. Additionally, when performing FA, it should be remembered that all of the stages in the methodical series have an impact on the results. In fact,

mandibular dimension and structure, medical history, and individual differences in bone metabolism may be determinants that can affect the FD value [14].

CONCLUSION

There are many studies in the literature reporting that FA can be used in certain areas, that it produces contradictory results, or that it needs to be improved. There are difficulties in performing FA in clinical practice in terms of performing the process steps and ensuring standardization. Many factors such as patient selection, quality of the methods and different imaging methods, gender and age distributions, sample size, ROI size and location, anatomical variations and individual differences in ROI selection are likely to affect the results. It seems that the limitations of FA need to be improved, standardized, and performed in larger sample sizes.

REFERENCES

[1] Papapanou PN, Sanz M, Buduneli N, Dietrich T, Feres M, Fine DH, Flemmig TF, Garcia R, Giannobile WV, Graziani F, Greenwell H, Herrera D, Kao RT, Kebschull M, Kinane DF, Kirkwood KL, Kocher T, Kornman KS, Kumar PS, Loos BG, Machtei E, Meng H, Mombelli A, Needleman I, Offenbacher S, Seymour GJ, Teles R, Tonetti MS (2018) Periodontitis: Consensus report of workgroup 2 of the 2017 World Workshop on the Classification of Periodontal and Peri-Implant Diseases and Conditions. J Periodontol. 89 Suppl 1:S173-S182. https://doi.org/10.1111/jcpe.12946

[2] Özer N, Baksı Şen B (2021) Dental Radyografik Görüntülemede Üçüncü Boyut: Bir Literatür Güncellemesi. Atatürk Üniversitesi Diş Hekim Fakültesi Derg.14;31(4):652–661. https://doi.org/10.17567/ataunidfd.821983

[3] Sener E, Cinarcik S, Baksi BG (2015) Use of Fractal Analysis for the Discrimination of Trabecular Changes Between Individuals With Healthy Gingiva or Moderate Periodontitis. J Periodontol. 86(12):1364–1369. https://doi.org/10.1902/jop.2015.150004

[4] Ruttimann UE, Webber RL, Hazelrig JB (1992) Fractal dimension from radiographs of peridental alveolar bone: A possible diagnostic indicator of osteoporosis. Oral Surg Oral Med Oral Pathol. 74(1):98–110. https://doi.org/10.1016/0030-4220(92)90222-c

[5] Mandelbrot BB (1967) How long is the coast of Britain? Statistical self-similarity and fractional dimension. Science. 156(3775):636–638. https://doi.org/10.1126/science.156.3775.636

[6] Ruttimann UE, Ship JA (1990) The use of fractal geometry to quantitate bone structure from radiographs. J Dent Res. 69:287.

[7] Doyle MD, Rabin H, Suri JS (1991) Fractal analysis as a means for the quantification of intramandibular trabecular bone loss from dental radiographs. Biostereometric Technology and Applications. 1380:227–235. https://doi.org/10.1117/12.25125

[8] White SC, Rudolph DJ (1999) Alterations of the trabecular pattern of the jaws in patients with osteoporosis. Oral Surg Oral Med Oral Pathol Oral Radiol Endod. 88:628–635. https://doi.org/10.1016/s1079-2104(99)70097-1

[9] Kato CN, Barra SG, Tavares NP, Amaral TM, Brasileiro CB, Mesquita RA, Abreu LG (2020) Use of fractal analysis in dental images: a systematic review. Dentomaxillofac Radiol. 49(2):20180457. https://doi.org/10.1259/dmfr.20180457

[10] Eley BM, Cox SW (1998) Advances in periodontal diagnosis. 1. Traditional clinical methods of diagnosis. Br Dent J. 184(1):12-16. https://doi.org/10.1038/sj.bdj.4809529

[11] Tayman MA, Kamburoğlu K, Öztürk E, Küçük Ö (2020)

The accuracy of periapical radiography and cone beam computed tomography in measuring periodontal ligament space: Ex vivo comparative micro-CT study. Aust Endod J. 46(3):365-373. https://doi.org/10.1111/aej.12416

[12] Alan A (2008) Kronik Periodontitisli Bireylerde Konvansiyonel Periapikal Radyografi Ve Dijital Subtractıon Radyografi Veri Etkinliklerinin Karşılaştırılması.

[13] Zybutz M, Rapoport D, Laurell L, Persson GR (2000) Comparisons of clinical and radiographic measurements of inter-proximal vertical defects before and 1 year after surgical treatments. J Clin Periodontol. 27(3):179–186. https://doi.org/10.1034/j.1600-051x.2000.027003179.x

[14] Aktuna Belgin C, Serindere G (2020) Evaluation of trabecular bone changes in patients with periodontitis using fractal analysis: A periapical radiography study. J Periodontol. 91(7):933–937. https://doi.org/10.1002/JPER.19-0452

[15] Yaşar F, Akgünlü F (2014) The differences in panoramic mandibular indices and fractal dimension between patients with and without spinal osteoporosis. Dentomaxillofacial Radiol. 35(1):1–9. https://doi.org/10.1259/dmfr/97652136

[16] Prouteau S, Ducher G, Nanyan P, Lemineur G, Benhamou L, Courteix D (2004) Fractal analysis of bone texture: a screening tool for stress fracture risk? Eur J Clin Invest. 34(2):137–142. https://doi.org/10.1111/j.1365-2362.2004.01300.x

[17] Heo MS, Park KS, Lee SS, Choi SC, Koak JY, Heo SJ, Han CH, Kim JD (2002) Fractal analysis of mandibular bony healing after orthognathic surgery. Oral Surg Oral Med Oral Pathol Oral Radiol Endod. 94(6):763–767. https://doi.org/10.1067/moe.2002.128972

[18] Shrout MK, Roberson B, Potter BJ, Mailhot JM, Hildebolt CF (1998) A comparison of 2 patient populations using fractal analysis. J Periodontol. 69(1):9–13. https://doi.org/10.1902/jop.1998.69.1.9

[19] Parissis N, Kondylidou-Sidira A, Tsirlis A, Patias P (2005) Conventional radiographs vs digitized radiographs: image quality assessment. Dentomaxillofac Radiol. 34(6):353–356. https://doi.org/10.1259/dmfr/99611204

[20] Uğur Aydın Z, Ocak MG, Bayrak S, Göller Bulut D, Orhan K (2021) The effect of type 2 diabetes mellitus on changes in the fractal dimension of periapical lesion in teeth after root canal treatment: a fractal analysis study. Int Endod J. 73;54(2):181–189. https://doi.org/10.1111/iej.13409

[21] Hayek E, Aoun G, Geha H, Nasseh I (2020) Image-based Bone Density Classification Using Fractal Dimensions and Histological Analysis of Implant Recipient Site. Acta Inform medica. 28(4):272–277. https://doi.org/10.5455/aim.2020.28.272-277

[22] Shrout MK, Farley BA, Patt SM, Potter BJ, Hildebolt CF, Pilgram TK, Yokoyama-Crothers N, Dotson M, Hauser J, Cohen S, Kardaris E, Hanes P (1999) The effect of region of interest variations on morphologic operations data and gray-level values extracted from digitized dental radiographs. Oral Surg Oral Med Oral Pathol Oral Radiol Endod. 88(5):636–639. https://doi.org/10.1016/s1079-2104(99)70098-3

[23] Updike SX, Nowzari H (2008) Fractal analysis of dental radiographs to detect periodontitis-induced trabecular changes. J Periodontal Res. 43(6):658–664. https://doi.org/10.1111/j.1600-0765.2007.01056.x

[24] Lin JC, Amling M, Newitt DC, Selby K, Srivastav SK, Delling G, Genant HK, Majumdar S (1998) Heterogeneity of trabecular bone structure in the calcaneus using magnetic resonance imaging. Osteoporos Int. 8(1):16–24. https://doi.org/10.1007/s001980050043

[25] Amer ME, Heo MS, Brooks SL, Benavides E (2012) Anatomical variations of trabecular bone structure in intraoral radiographs using fractal and particles count analyses. Imaging Sci Dent. 42(1):5-12. https://doi.org/10.5624/isd.2012.42.1.5

[26] 26 Sang-Yun C, Won-Jeong H, Eun-Kyung K (2001) Usefulness of fractal analysis for the diagnosis of periodontitis. Imaging Sci Dent. 31(1):35–42.

[27] Coşgunarslan A, Aşantoğrol F, Canger EM, Medikoğlu EK, Soydan D (2019) Periodontitis ile ilişkili trabeküler kemik değişikliklerinin fraktal analiz ile incelenmesi. Selcuk Den J. 6:341-345.

[28] Bollen AM, Taguchi A, Hujoel PP, Hollender LG (2001) Fractal dimension on dental radiographs. Dentomaxillofacial Radiol. 30(5):270–275. https://doi.org/10.1038/sj.dmfr/4600630

[29] Molander B, Ahlqwist M GH (1995) Panoramic and restrictive intraoral radiography in comprehensive oral radiographic diagnosis. Eur J Oral Sci. 103(4):191–198. https://doi.org/10.1111/j.1600-0722.1995.tb00159.x

[30] Shrout MK, Hildebolt CF, Vannier MW, Province M, Vahey EP (1990) Periodontal disease morbidity quantification. I. Optimal selection of teeth for periodontal bone loss surveys. J Periodontol. 61(10):618–622. https://doi.org/10.1902/jop.1990.61.10.618

[31] Magat G, Ozcan Sener S (2019) Evaluation of trabecular pattern of mandible using fractal dimension, bone area fraction, and gray scale value: comparison of conebeam computed tomography and panoramic radiography. Oral Radiol. 35(1):35–42. https://doi.org/10.1007/s11282-018-0316-1

[32] Lennon FE, Cianci GC, Cipriani NA, Hensing TA, Zhang HJ, Chen CT, Murgu SD, Vokes EE, Vannier MW, Salgia R (2015) Lung cancer -a fractal viewpoint. Nat Rev Clin Oncol. 12(1):664. https://doi.org/10.1038/nrclinonc.2015.108

[33] Hua Y, Nackaerts O, Duyck J, Maes F, Jacobs R (2009) Bone quality assessment based on cone beam computed tomography imaging. Clin Oral Implants Res. 20(8):767–771. https://doi.org/10.1111/j.1600-0501.2008.01677.x

[34] Hwang JJ, Lee JH, Han SS, Kim YH, Jeong HG, Choi YJ, Park W (2017) Strut analysis for osteoporosis detection model using dental panoramic radiography. Dentomaxillofac Radiol. :20170006. https://doi.org/10.1259/dmfr.20170006

[35] Güngör E, Yildirim D, Çevik R (2016) Evaluation of osteoporosis in jaw bones using cone beam CT and dual-energy X-ray absorptiometry. J Oral Sci. 58:185–194. https://doi.org/10.2334/josnusd.15-0609

[36] Geraets WG van der SP (2000) Fractal properties of bone. Dentomaxillofac Radiol. 29:144–153. https://doi.org/10.1038/sj/dmfr/4600524