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IN VITRO STUDY OF FRACTAL ANALYSIS OF OSTEOTOMIES PERFORMED WITH DIFFERENT DESIGN IMPLANT DRILLS IN LOW DENSITY BONE BLOCKS

DÜŞÜK YOĞUNLUKLU KEMİK BLOKLARINDA FARKLI TASARIMA SAHİP İMPLANT FREZLERİ İLE GERÇEKLEŞTİRİLEN OSTEOTOMİLERİN FRAKTAL ANALİZLERİNİN VİTRO İNCELENMESİ

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ABSTRACT

Objective: Alternative osteotomy techniques were introduced instead of the traditional drilling procedures of dental implant placement. One of these techniques is bone densification through a special design of drills. To study the effect of densification burs on low bone quality in comparison with conventional drilling procedures, the trabecular bone changes will be determined quantitively using fractal analysis (FA).
Material and Methods: A control group (PKD) with the standard osteotomy burs and a test group (PV) with the osseodensification burs were used. In each group, 10 dental implants (4.2x10mm) were placed. A three dimensional (3D) image was obtained from the blocks on a Micro Computed Tomography (micro-CT) device. Fractal analysis was performed, and the results were analyzed by nonparametric tests ($p<0.05$).
Results: According to the results, the FA value of apical and lateral areas from the PV group (1.292, 1.251 respectively) were significantly higher than the control group ($p<0.01$). When apical and lateral FA values of the PV group were compared, the apical values were found to be significantly higher than the lateral ones ($p<0.01$).
Conclusion: In terms of fractal analysis, the bone densification effect of the burs in the PV group around the implants, compared to the PKD group, apical and lateral values, were found to be higher and have been found to provide better trabecular compression. FA may be useful for preoperative and non-invasive assessment of bone quality at implant sites.
Keywords: Osseodensification, fractal analysis, micro-CT, artificial bone block

ÖZ
Amaç: Dental implant cerrahisinde; osteotomi bölgelerindeki kemik partiküllerini dışarı çıkarma prensibi ile çalışan geleneksel yaklaşımlara ek olarak; partikülleri osteotomi alanında tutarak yoğunlaştırılmasını sağlayan frezleme teknikleri geliştirilmiştir. Bu çalışma ile, düşük kemik yoğunluğuna sahip yapay bloklar kullanılarak; iki farklı frez tasarımı ile oluşturulan osteotomilerde; trabeküler kemik değişikliklerinin kantitatif olarak belirlenmesinde fraktal analizin (FA) etkinliği araştırılmıştır.
Gereç ve Yöntem: Standart osteotomi frezleri ile bir kontrol grubu (PKD) osseodensifikasyon frezleri ile bir test grubu (PV) oluşturulmuştur. Osteotomiler 2x2x2cm ebatlarındaki yapay kemik bloklarında gerçekleştirilmiştir ve her gruba 10 adet dental implant (4,2x10mm) yerleştirilmiştir. Blokların, Mikro Bilgisayarlı Tomografi (mikro-BT) cihazında elde edilen kesitlerinin mezial ve lateral bölgelerinden ölçümler gerçekleştirilmiş, kutu sayma algoritması ile ImageJ programı kullanılarak FA yapılmıştır. Veriler varyans analizi ile değerlendirilmiştir ($p<0,05$).
Bulgular: Elde edilen bulgulara göre PV grubunda apikal ve lateral alanlarda FA değerleri (sırasıyla 1,292, 1,251), PKD grubuna göre (1,258, 1,233) istatistiksel olarak anlamlı bulunmuştur ($p<0,01$). PV grubunun apikal ve lateral FA değerleri karşılaştırıldığında ise apikal değerler laterale göre anlamlı derecede yüksek bulunmuştur ($p<0,01$).
Sonuçlar: Fraktal analiz değerleri açısından; osseodensifikasyon frezlerinin implant etrafındaki kemik yoğunlaştırma etkisi, geleneksel grubuna göre, hem apikalde hem de lateralde yüksek bulunmuş ve daha etkin trabeküler sıkıştırma sağladığı tespit edilmiştir. FA; implant bölgelerindeki kemik kalitesinin, preoprative ve noninvaziv değerlendirilmesinde, faydalı bir yöntem olarak düşünülmektedir.
Anahtar Kelimeler: Osseodensifikasyon, fraktal analiz, mikro-BT, yapay kemik bloğu

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INTRODUCTION

Nowadays, dental implant sockets are prepared by conventional burs. These burs are surrounded by flutes that cut through the bone with their tapered ends and accumulate hard tissues as the drill progresses through the bone (1). These bone chips are preserved as an autogenous bone graft that can be used to compensate for bone volume deficiencies that occur during implant surgery (2).

Although traditional osteotomies are obtained by drilling out the bone, some approaches attempt to increase primary stability in low-bone density by using a counterclockwise (CCW) applied drilling process that results in the densification of the osteotomy site wall by tapering the bur geometry and placing the flutes at different angles (3-6).

Another clinical approach recommended for low-bone density is an “undersize” drilling procedure (7). The main purpose of this modified preparation technique is to reduce the size of the final osteotomy compared to the implant diameter (8). Sahalabi et al., in their animal studies, investigate the effect of different osteotomy techniques on primary stability in trabecular bone; they concluded that undersize prepared osteotomies improved implant fixation according to the standard protocol (9).

50%-90% of trabecular bone has a high porosity and many fractal-like structures (10). There is a correlation between the fractal dimension and the complexity of the structure, which is expressed numerically with FA. For determining the interior trabecular structure of bone, the FA was used; this analysis was easy to use, non-invasive, and offers objective data (11).

FA is a mathematical technique used to evaluate the amount and complexity of bone structure (13). FA is a reliable method for evaluating the shape and structure of the alveolar bone as claimed by published studies (14, 21). Nevertheless, FA results are affected by the Region of Interest (ROI) selection parameters such as shape, size, and sample area (22). It was also noted that the inaccurate positive or negative results in the ROI area might result in differences in FA values (25). Additionally, FA is highly reliable to distinguish osteoporotic and non-osteoporotic cases (24). A decrease in FA values caused by a bone loss in osteoporotic patients was observed in some studies (12,13,22).

The box-counting method, which forms the basis of fractal analysis, is a method used to examine bone morphology. A scale with boxes is placed over the trabecular structure to be sized. Boxes containing trabecular bone are counted in grids created from boxes with sizes ranging from 2-64 pixels (13).

A high FA value indicates that the bone structure is more complex and the spaces in the bone are less, while a low FA value means that the bone has more lacuna (13-15).

In the determination of bone structure, there are also studies suggesting that the combined use of FA and CT is beneficial (16). In CT scans, it is possible to examine the internal structure of bone tissue and the internal adaptation of materials to surfaces without destroying them (33).

Bone microarchitecture can be studied in great detail with high-resolution micro-CT in laboratory environments (31,32). Micro-CT is a tool that provides 3D imaging at very high resolution on a small scale. It has been proposed as a standard imaging tool for many applications, such as tissue engineering, dentistry, and research on the mineral density of hard tissues and bone growth. The 3D trabecular architecture projects a roughly two-dimensional pattern on plain radiographs, and the FA can then be calculated on these projected patterns and used to describe the spatial arrangement of the trabecular bone (31). However, the high costs of micro-CT, the time required for scanning and reconstruction, computer expertise requirements, and lack of usage knowledge are disadvantages (17). Recent studies have shown a good correlation between micro-CT morphology and fractal dimension (18).

In our study, FA and micro-CT were used to determine the bone densification properties of Osseo densification burs in comparison to standard conventional milling techniques in D4 artificial bone blocks, which mimic trabecular bone in vitro and exhibit isotropic fractal properties.

MATERIALS and METHODS

Study group and sample size

A total of 20 implants were inserted into each of the manufactured artificial bone blocks that mimic D4 bone with two different drilling procedures. Considering similar studies, the sample size was determined by G Power analysis (G Power, Dusseldorf, Germany).

Osteotomy procedure, artificial bone block supply and implant placement

A control group (PKD) with standard osteotomy burs (Figure 1) was formed. A test group (PV) was formed with osteotomy burs displaying osseodensification (Figure 2). Standard burs (Implant Direct, CA, USA) in the normal protocol, undersize preparation (soft bone protocol), 800rpm, clockwise (1.6 mm pilot, 2.3 mm and 3.4 mm drills) and Densah burs (Versah, Jackson, MI, USA) in osseodensification protocol, 800rpm, counterclockwise (2.0 mm pilot, 2.3 mm and 3.3 mm multi-channel burs) were applied. 10 implants (4.2 mmx10 mm) were placed in each group (Table 1).

ASTM standard and F-1839 reference artificial polyurethane blocks (Pacific Research Laboratories Inc, WA, USA) were preferred to represent D4 bone, mimicking trabecular bone. Homogeneous bone blocks produced from cellular rigid polyurethane foam offer an alternative test environment similar to human cancellous bone (35). The blocks were divided into homogeneous pieces 2x2x2 cm in size.

After the appropriate osteotomy areas were created in the artificial bone blocks with the drilling procedures, the placement of the implants was carried out. A total of 20 dental implants (4.2x10 mm) were manufactured from polyetheretherketone (PEEK) material (Uysal Medical, Istanbul, TURKEY) to obtain a clear measurement of bone-implant contacts in high-resolution computed tomography imaging (Figure 3).

Micro-CT imaging and fractal analysis of digital images

The trabecular bone around dental implants has been evaluated utilizing FA on cone-beam computed tomography (CBCT) images. The sections were examined with Micro CT imaging through an X-ray tube of 90–150 kVA, a filter and collimator, a computer-controlled electric motor, a CCD camera for converting X-ray image data, and an image intensifier apparatus. Ultra-high-resolution images were obtained with artificial bone blocks placed on a rotating platform with an X-ray tube (17). Consequently, the cross-section of the implant surrounded by bone was obtained for all 20 implants.

For each implant, the middle slice of the implant illustrating its center was extracted from the CBCT radiograph. Measurements were made on two areas determined from the mesial and lateral regions of this section. The first ROI was assigned by creating a rectangular box along the whole lateral (16x64 pixel) part of the implant length and the second ROI was a square box apical (32x32 pixel) part of the implant, involving the bone intimately surrounding the implant without any threads included, which may distort the results.

Figure 1: Standard osteotomy Bur Kit

All the radiographic samples were inserted into ImageJ software (National Institutes of Health, Bethesda, MD; http://rsb.info.nih.gov/nih-image) for evaluation. The box-counting FA was computed using an algorithm featured in ImageJ as described in a previous study (19). In this procedure, several grids of reduced size (box size) were placed on the ROI and the number of boxes containing pixels was counted for each grid (12). The sections were subjected to various image processes and a skeletonized image was obtained (Figure 4). The mean gray level, trabecular area, perimeter, and the number of terminal points were measured from the transformed image.

Statistical analysis

All analyses were performed using a custom software program (SPSS 11.5.0, SPSS, Chicago, IL, USA). A Bartlett test was per-

Figure 2: Osseodensification Bur Kit

Table 1: Experimental design and drill protocols

		1.DRILL (Pilot drill)	2. DRILL	3.DRILL (Soft bone protocol)	IMPLANT (Diameter)
Control group (PKD)	**Standard Osteotomy Burs** (Undersize Preparation) (Implant Direct)	1.7mm	2.3/2.0mmD	3.4/2.8mmD	4.2mm X 10mm
		Clockwise	Clockwise	Clockwise	
Test group (PV)	**Densah Burs** (Versah)	1.7mm	2.3 Apical: 1.8 mmD Coronal: 2.8 mmD	3.3 Apical: 2.8 mmD Coronal: 3.8mmD	4.2mm X 10mm
		Clockwise	Counter-Clockwise	Counter-Clockwise	

PKD: Control group, PV: Test group

Figure 3: PEEK implant and artificial bone block with d4 bone characteristics

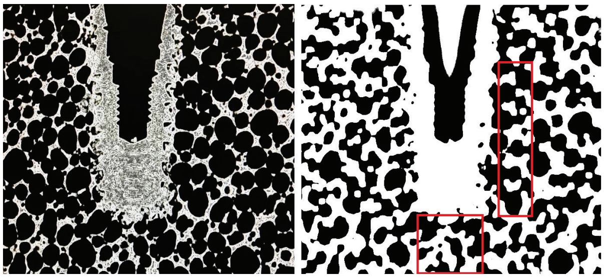

Figure 4: Image processing steps of micro-CT slices and region of interest (ROI) selection for fractal analysis

formed to check the suitability of the data set for analysis. A one-way ANOVA test was performed to determine whether there was a significant difference in the comparisons between the groups. The P value was accepted as 0.05. Tukey's multiple comparison test was used for pairwise comparisons.

RESULTS

As a result of the Anova test, a statistically significant difference was found between all groups (p<0.01) (Figure 5). In binary comparisons, the groups with a significant relationship are as follows: PKD apical and PKD lateral (p<0.01); PKD apical and PV apical (p<0.01); PKD lateral and PV apical (p<0.01); PKD lateral and PV lateral (p<0.01); PV apikal and PV lateral (p<0.01). However, no significant relationship was found between PKD apical and PV lateral (p=0.0004).

According to the results, apical and lateral ROI (1.292 and 1.251, respectively) taken from the PV group were found to be statistically significant and higher in terms of FA values (1.258, 1.233) compared to the control group (p<0.01).

The highest fractal analysis value was observed at the apical part of the osteotomy PV made with the osseodensification bur (1.292). The lowest fractal analysis value was found in the

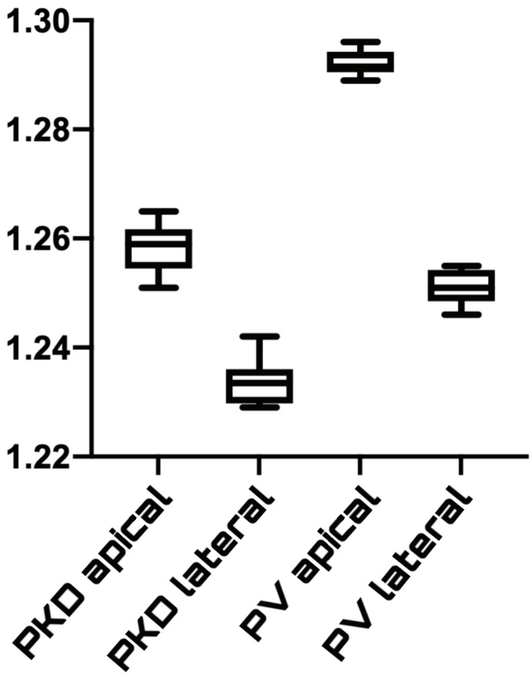

Figure 5: Box-whisker pilot plot showing median, min, max values between groups in terms of FA value PKD: Control group, PV: Test group

lateral ROI of the osteotomy PKD performed with the conventional bur (1.233).

Comparing the apical FA values of the PV and PKD groups, bone condensation in the apical part of the peri-implant bone by osseodensification bur showed a significantly higher value than the conventional technique (p<0.01).

Comparing the lateral FA values of the PV and PKD groups, bone condensation in the lateral part of the peri-implant bone by osseodensification bur showed a significantly higher value than the conventional technique (p<0.01).

In terms of fractal analysis, the bone densification effect of the burs in the PV group around the peri implant bone, compared to the PKD group, showed higher values both apically and laterally, and has been found to provide better trabecular compression in bone.

DISCUSSION

In this study, FA was used to evaluate the bone pattern surrounding the peek implants placed inside polyurethane blocks following two different osteotomy protocols.

The homogeneity and the horizontal isotropic pattern and the vertical anisotropic fractal pattern of the bone substitute blocks used in the present study make the results and evaluation more accurate regarding the FA values compared with other human or animal experimental models; this makes it possible to measure the fractal analysis independent from the locational differences of natural human bone (mandible, maxilla and/or frontal and posterior areas), and various negative factors that cannot be standardized due to physiological diversity that are encountered during bone growth or turnover period (15). In addition, the location of the trabecula in space changed under the effect of functional forces and loading, which negatively affect FA (25).

It is thought that osseodensification positively affects the implant primary stability in the apical area, thus making bone augmentation redundant in individuals with low bone density. Compared to conventional techniques, osseodensification increases the bone volume percentage surrounding the implants placed in a low-density bone (5).

In a similar study, 20 clockwise (control) and counterclockwise (test) osteotomy areas were prepared on polyurethane blocks like type iv bone microstructure, and tomography and Image J software were used to evaluate and measure the bone density. Compared to clockwise bur usage, counter-clockwise bur usage was densified and altered the microstructure of apical areas in the osteotomy site (p=0.026). But the researchers noted that it was due to the direction the bur was used in rather than the design of the osseodensification bur (29).

Delgado-Ruiz et al. revealed in their animal study that clockwise bur usage increased the bone density in lateral walls and caused higher bone density in the apical area as inspected by CT imaging (30). Their findings are consistent with the present study in terms of bone density in the apical, with disparate ranges attributed to the viscoelastic nature of polyurethane blocks used in the present study.

Due to Densah's osseodensification bur having bone density requirement in both lateral and apical aspects, the ROIs chosen to be analyzed in our study were determined to have a standard pixel size of 32x32 in apical and 16x64 in lateral. Our findings confirmed that Densah burs resulted in an increase in bone density, as already found in previous studies (3,4,5). In a human prospective study by Zeytinoğlu et al., 3 different ROIs of non-standard sizes from different areas (mesial, distal, and apical) were determined to evaluate the changes in surrounding trabecular bones in 198 implants. The results of their fractal analysis are consistent with our findings (apical:1.202; mesial:1.224) (27).

Based on studies that indicate that fractal analysis might be applied to CBCT images in order to estimate bone quality (16, 22). Corpas et al. evaluated the peri-implant bone tissue using fractal analysis on conventional intraoral, CBCT, and histological images after 3 months following the implant replacement. While the bone mass measurements are correlated in all methods, it was noted that the FA method cannot detect any histological changes, so it was correlated not with histological results but with bone density. No significant correlations were detected between fractal analysis on CBCT, intra-oral radiography, and histology (34).

Lee et al. concluded that osteointegration was successful due to the increase in the fractal dimension of the bone surrounding the implant and noted that the result of their analysis revealed a correlation between bone density and FA values (23).

Sansare et al. applied preoperative and post-osseointegration fractal analyses on ROIs determined from the apical area of the 50 implants. There was an increase in bone microstructure and significantly higher post-operative FA values were observed compared to pre-operative values (26).

Due to the low-density bone protocol, an undersized osteotomy was preferred in our study and micro-CT imaging was performed for the evaluation of the fractal analysis of the bone substitute block. Similarly, in another study that performed fractal analysis on the immediate implant with standard burs and undersized preparations, a circular ROI (10.7 mm2) around each implant was chosen for post-operative CBCT imaging. The researchers performed two FA measurements, one on the day of operation and another six months later, and indicated that undersized preparation might have a positive effect on bone healing, due to a 3% increase in the FA value measured after 6 months compared to the pre-operative value (28).

The increase in fractal dimension in both conventional and CBCT radiography compared to previous studies indicates a higher amount of bone mineralization (13, 18). As a result, the increasing bone structure measured by fractal analysis seems consistent with the significant increase in the quality of the bone surrounding the implant.

CONCLUSIONS

In terms of fractal analysis, in the bone densification effect of the burs in the PV group around the implants, compared to the PKD group, apical and lateral values were found to be higher, and this has been found to provide better trabecular compression. Fractal analysis (FA) may be useful for preoperative and non-invasive assessment of bone quality at artificial bone blocks.

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