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Original Research Article

Correlation Between Preoperative Bone Quality and Primer Stability For Mandibular Posterior Implants

Mandibulada Posterior Bölgeye Uygulanan İmplantlarda Preoperatif Kemik Kalitesi ve Primer Stabilite Arasındaki Korelasyon

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ABSTRACT

Aim: This study aimed to investigate preoperative bone quality obtained from the Hounsfield unit and fractal analysis scores in cone beam computed tomography (CBCT) sections and compare this value with primer stability derived from resonance frequency analysis scores soon after placement of implants in the mandibular posterior region.

Materials and Method: A total of 36 implant regions were examined retrospectively. Primary outcome variables include the Hounsfield unit, fractal analysis, and resonance frequency analysis scores soon after implant placement. Hounsfield unit and fractal analysis scores were calculated on the preoperative CBCT.

Results: The mean Hounsfield unit, fractal analysis and resonance frequency analysis scores of all implants were 76.44, 0.65 and 67.44, respectively. No statistically significant correlation was found between the Hounsfield unit, fractal analysis and resonance frequency analysis scores (p>0.05). Resonance frequency analysis scores (p=0.002) and Hounsfield unit scores (p=0.050) were significantly superior in males. Age was found to be related to resonance frequency analysis scores (r=0.445, p=0.007).

Conclusion: The preoperative bone quality of alveolar bone measured from cone beam computed tomography by Hounsfield unit or fractal analysis may be insufficient to determine initial implant stability. Further studies are needed to investigate parameters related to the prediction of implant stability.

Keywords: Bone quality; Cone-beam computed tomography; Dental implants; Fractal analysis; Hounsfield unit; Resonance frequency analysis

ÖZET

Amaç: Bu çalışmada mandibulada arka bölgeye uygulanmış implant bölgelerinde preoperatif konik ışınlı bilgisayarlı tomografi (KIBT) kesitlerinden elde edilmiş Hounsfield ünit ve Fraktal analiz skorlarının preoperatif kemik kalitesi anlamında değerlendirilmesi ve bu skorların implant yerleşiminden hemen sonra belirlenen rezonans frekans analizi değerleri ile karşılaştırılması amaçlanmaktadır.

Gereç ve Yöntem: Toplamda 36 implant bölgesi retrospektif olarak değerlendirilmiştir. Temel sonuç değişkenleri Hounsfield ünit, fraktal analiz ve rezonans frekans analizi skorları olarak belirlenmiştir. Hounsfield ünit ve fraktal analiz skorları preoperatif KIBT kesitleri üzerinde hesaplanmıştır.

Bulgular: Ortalama Hounsfield ünit, fraktal analiz ve rezonans frekans analizi skorları sırasıyla; 76.44, 0.65 and 67.44 olarak belirlenmiştir. Hounsfield ünit, fraktal analiz ve rezonans frekans analizi skorları arasında anlamlı istatistiksel kolerasyon saptanmamıştır. (p>0.05). Rezonans frekans analizi (p=0.002) ve Hounsfield ünit (p=0.050) skorları erkeklerde anlamlı düzeyde yüksek belirlenmiştir. Yaş, rezonans frekans analizi skorları ile ilişkili olarak belirlenmiştir (r=0.445, p=0.007).

Sonuç: Konik ışınlı bilgisayarlı tomografi üzerinde Hounsfield ünit veya fraktal analiz aracılığıyla ölçülen alveolar kemik bölgesindeki preoperatif kemik kalitesi değerlendirmesi başlangıç implant stabilitesinin belirlenmesinde yeterli bir parametre olmayabilir. İmplant stabilitesinin tahminine yönelik ilişkili parametrelerin değerlendirildiği ileri çalışmalara gereksinim vardır.

Anahtar Kelimeler: Dental implant; Fraktal analiz; Hounsfield ünit; Kemik kalitesi; Konik ışınlı bilgisayarlı tomografi; Rezonans frekans analizi

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INTRODUCTION

Recent advancements in material sciences and surgical techniques have revolutionized dental implant therapy, leading to enhanced functional and aesthetic outcomes. This treatment modality has evolved into a well-established procedure for individuals across various age groups, offering a reliable solution for replacing missing teeth.[1,2]

As the number of dental implants being inserted continues to rise, ensuring the success of the treatment becomes paramount. The quantity and quality of the bone tissue surrounding the implant play a crucial role in determining the long-term success of the procedure.[3,4] Implants placed in bones with inadequate quality were associated with higher failure rates.[4] Studies have shown a significant relationship between primary/secondary implant stability and bone density.[5-7] Therefore, evaluating the preoperative bone density/quality is vital in planning treatment decisions and estimating survival success.

Several classification systems have been introduced for assessing bone quality and density in the literature.[8,9] In 1985, Leckholm and Zarb proposed classifying bone density into four types based on the radiographic evaluation of cortical and trabecular bone.[8,10] In 1988, Misch proposed four categories (D1-D4) based on the mechanical properties of bone structure.[9,11] However, these techniques were based on subjective evaluations. With the advancements in dental radiology, the emergence of cone beam computed tomography (CBCT) technology has gained widespread popularity, revolutionizing the field. This technology has allowed dental professionals to conduct thorough preoperative assessments of bone structures with remarkable precision. Alongside these remarkable advancements, numerous distinguished studies emphasized the utility of CBCT in evaluating bone quality, particularly in terms of bone density, employing various methods such as the Hounsfield unit (Hu) and density value evaluation.[6,12,13] The inclusion of bone density measurements through preoperative CBCT scans can prove highly advantageous, especially when there are concerns regarding the suitability of the bone for successful implant placement.[12]

In recent years, fractal analysis (FA) emerged as another valuable tool for assessing bone quality.[14-17] This numerical technique is specifically designed to evaluate irregular and complex structures, providing quantitative outcomes in the form of a fractal dimension (FD). Within the field of dentistry, FA has been employed primarily to assess the bone structure and patterns of the jaws using dental radiographs.[14] Fractal analysis enables the examination of the microarchitecture of trabecular bone through the numerical expression of the FD, which serves as a scale of image complexity.[17] It has been reported that FD can be used as an adjunct to conventional methods for estimating implant stability.[18]

Primary stability of implants is generally considered a crucial factor for achieving successful osteointegration.[5,6,13] Several techniques have been developed to evaluate implant stability, including implant stability tests, insertion torque tests, reverse torque tests, and resonance frequency analysis.[13] Among these techniques, resonance frequency analysis (RFA) is a well-defined method for assessing implant stability.[6,7,12,13] This method involves connecting a metal rod to the implant through a screw connection instrument. The implant stability quotient (ISQ), which ranges from 1 to 100, is used to quantify implant stability, with higher ISQ values indicating greater stability.[19]

However, there is an ongoing debate regarding the correlation between bone density measurements around implant sites in three-dimensional reconstructions of CBCT, FA, and the assessment of implant stability using RFA. To date, limited data exists comparing preoperative Hu and FA scores obtained from CBCT with implant stability in terms of RFA. Therefore, the present study aimed to compare preoperative bone density scores obtained through Hu and FA with primary stability scores obtained from RFA of implants in the mandibular posterior region.

MATERIALS AND METHOD

Study design

This study was approved by the University of Health Sciences/Gülhane Scientific Research Ethics Committee (registration number 2022/226). Fourteen patients (four male and ten female; age range, 32-70 years; mean age, 52.6 years) who received dental implants at the mandibular molar or premolar region at the Department of Oral and Maxillofacial Surgery,

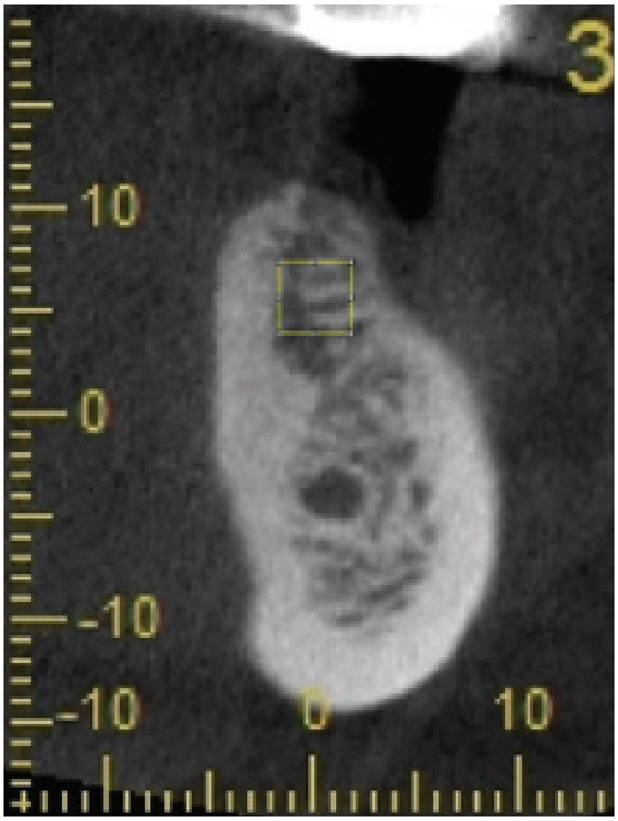

Figure 1. Selection of Region of interest (ROI) for fractal analysis.

Gülhane Faculty of Dentistry, Ankara, Türkiye between 2020-2022 included in the study. A total of 36 implant regions inserted by the same implant system (Oxy PS Line, Oxy Dental İmplant System, Colico, LC, Italy) were analyzed retrospectively. Patients' informed consent regarding using their data for scientific purposes was obtained. Patients with systemic diseases, metabolic bone disorders, osteopenia, destructive lesions in the mandibular region, cancer treatment history and who had undergone augmentation procedures before or simultaneously after implant placement were excluded from the study. All surgical procedures were performed by the same implant system.

All patients' preoperative CBCT examinations were performed using 3D Accuitomo 170 CBCT (3D Accuitomo; J Morita Mfg. Corp., Kyoto, Japan) device. The exposure parameters were set at 90 kV, 5 mA, 0.08 mm voxel size, 140 x100 mm field of view.

The appropriate implant area was chosen using cross-sectional images with 1-mm slice intervals and 1-mm slice thickness (iDixel 2.0/One Data Viewer/ One Volume Viewer; J Morita Mfg. Corp.). To ensure precision, the section positioned at the centre of the targeted region, where the implant will be situated, was specifically selected for a comprehensive assessment of bone quality. A region of interest (ROI) was defined and positioned below the uppermost point of the alveolar crest and conured to have a width of 14 pixels and a height of 14 pixels (Figure 1).

For FA, ImageJ software (National Institutes of Health, Bethesda, MD) was used for processing and analyzing all images with the box-counting method introduced by White and Rudolf.[20] (Figure 2). Hu was calculated using the "histogram" tool of the ImageJ software.

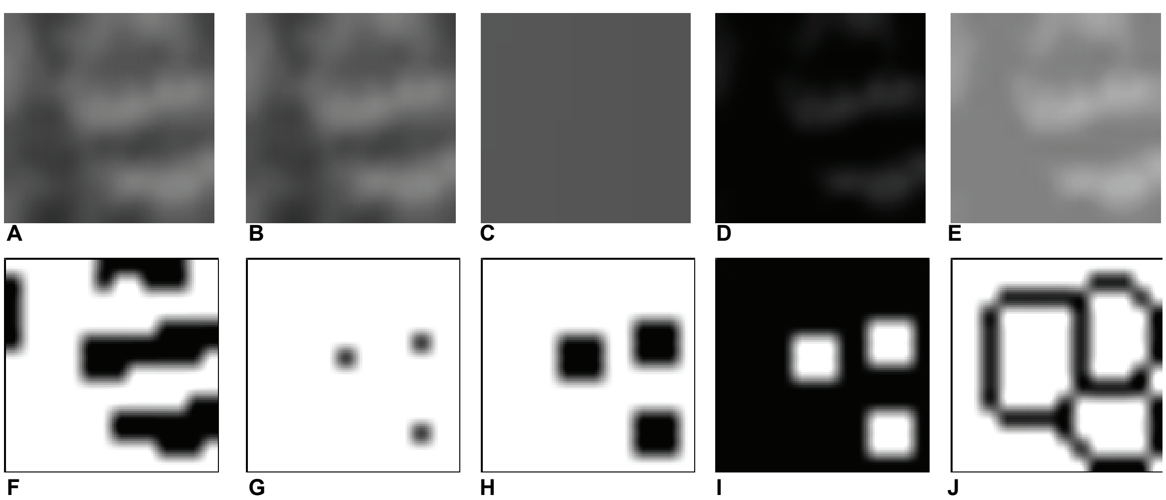

Figure 2. Stages of fractal dimension analysis.
A, The selected ROI from cross sectional images was cropped and **B,** duplicated. **C,** Gaussian blur filter (σ=35 pixels) was applied on duplicated image**. D,** The blurred image was subtracted from the original image. **E,** Addition of a gray value of 128 to each pixel location. **F,** Binarization **G,** Erosio**n H,** Dilatation **I,** Inversion **J,** The skeletonized image was used for fractal analysis.

All radiographical assessments were done by the same maxillofacial radiologist (EYK).

RFA were measured using an Osstell ISQ (Ostell AB, Göteborg, Sweden) and recorded immediately after implant placement. Smartpegs were inserted into the implants, and the RFA value was measured four times in four directions. Results were averaged and recorded as implant stability quotients (ISQ).[21]

Statistical analysis

Data was analyzed by IBM SPSS Statistics ver. 25 (IBM Corporation, Armonk, NY, US) software. The Shapiro-Wilk test was used to investigate whether the assumption of normal distribution was met. Descriptive statistics were displayed as mean ± SD or numbers (n) and percentage (%). The degree of associations between continuous variables was calculated via Spearman's rank-order correlation coefficient. The mean differences between gender groups were compared with the Student's t-test. To determine the best predictor(s), which mainly affected the resonance frequency analysis scores, was evaluated by multiple linear regression analyses. Coefficients of regression, 95% confidence intervals and t-statistics for each independent variable were also calculated.

RESULTS

A total of 36 implant regions in 14 patients were assessed, [mean age, 52.6; female, 10 (71.4%)]. The mean Hu, FA and RFA scores of all implants were 76.44, 0.65 and 67.44, respectively. Descriptive statistics for the measuring variables are presented in Table 1.

No statistically significant correlation was found among age, Hu (r=-0.230, p=0.177), and FA scores (r=-0.161, p=0.349). While there was a statistically significant positive correlation between age and RFA score (r=0.445, p=0.007) (Table 2).

No statistically significant correlation was found between the Hu, FD and RFA scores (p>0.05). In Table 3, whether there was a statistically significant change in the measuring parameters according to gender was summarized. According to the results, the mean Hu levels of males were statistically significantly higher than females (p=0.050). There was no statistically significant change in FA scores according to gender (p=0.962); however, the RFA scores of women were statistically significantly lower than men (p=0.002).

Table 1. Descriptive statistics for the measuring variables.

	Mean	**Std. Deviation**	**Minimum**	**Maximum**
Hu	76.44	18.24	41.21	114.21
FA score	0.65	0.23	0.10	1.04
RFA score	67.44	13.84	22.00	85.00

Table 2. Correlation coefficients and significance levels of the measured parameters.

	Hu mean	FA score	RFA score
Age			
Coefficient of correlation	-0.230	-0.161	0.445
p-value †	0.177	0.349	0.007
Hu mean			
Coefficient of correlation		-0.113	-0.052
p-value †		0.511	0.765
FA score			
Coefficient of correlation			-0.094
p-value †			0.587

† Spearman's rank-order correlation analysis, N/A: Not applicable.

Table 3. The comparisons between gender groups in terms of clinical measurement

	Male	Female	p-value †
Hu	86.7±15.8	73.0±17.9	0.050
FA score	0.64±0.27	0.65±0.22	0.962
RFA score	79.1±3.4	63.5±13.8	0.002

Data were shown as mean ± SD, † Student's t test.

Table 4. Determining the best predictor(s) which effect on the RFA scores

	Coefficient of Regression (B)	95% Confidence interval for B	t statistics	p-value
Model 1				
Age	-0.119	-0.600 – 0.362	-0.504	0.617
Female factor	-18.990	-30.676 – -7.303	-3.310	0.002
Hu mean	-0.172	-0.438 – 0.093	-1.322	0.196
Model 2				
Age	-0.002	-0.460 – 0.455	-0.011	0.991
Female factor	-15.571	-26.265 – -4.878	-2.966	0.006
FA score	-1.504	-20.718 – 17.709	-0.159	0.874
Model 3				
Age	-0.142	-0.637 – 0.354	-0.583	0.564
Female factor	-19.412	-31.374 – -7.451	-3.310	0.002
Hu mean	-0.190	-0.467 – 0.088	-1.392	0.174
FA score	-4.868	-24.460 – 14.725	-0.507	0.616

Evaluation of all possible factors thought to be effective in the change in RFA scores analyzed by multivariate linear regression analyses and results were summarized in Table 4. Gender was an independent factor in predicting the change in RFA scores according to all three models in which age and gender were compared with Hu mean, FA scores and Hu mean and FA scores, respectively. For all three models, RFA scores were lower in females independently of other factors (p values p=0.002, p=0.006, p=0.002, respectively).

DISCUSSION

This study aimed to investigate preoperative bone density obtained from the Hu and FA scores in CBCT sections and compare this value with primer stability derived from RFA scores soon after placement of implants in the mandibular posterior region. We hypothesized that higher bone density scores were related to better primer stability. However, no statistically significant correlation was found between the Hu, FA and RFA scores (p>0.05). Additionally, in this study, gender was found to be related to RFA and Hu scores. A comparison of other variables showed no statistically significant relationship.

Bone quality and implant stability were examined in several studies.[6,21,22] It has been reported that bone density obtained by CBCT images significantly collaborated with primary stability evaluated by implant stability meter device and insertion torque.[22] Ivanova *et al*.[5] showed that bone density values in CBCT scans as HU values and vital new bone formation evaluated histologically were related to primary and secondary implant stability. Similarly, Salimov *et al*.[21] and Isoda *et al*.[13] reported that preoperative bone density values obtained by CBCT scans could be a beneficial tool for predicting implant stability. Farre-Pages *et al*.[6] showed that bone density values obtained by preoperative CBCT scans in Hu value were related to Lekholm & Zarb classification in terms of resistance to drilling during implant surgery and primary implant stability measured by RFA in ISQ values. They concluded that HU can be beneficial as a diagnostic tool to predict implant stability. Kim *et al*.[19] evaluated the correlations between bone density obtained by CT-derived Hounsfiled units and primary implant stability parameters measured with insertion torques and RFA in the posterior maxilla. They reported that CT-derived HU is significantly related to the parameters of primary stability. In the present study, the mean Hounsfield unit score for implant regions was found to be 76.44 and Hounsfield unit scores were found to be significantly superior in males, p=0.050. No statistically significant correlation was found between the HU mean, FA and RFA scores (p>0.05).

Several studies have shown FA as an accurate and effective method for evaluating bone density.[16] One of the key advantages of FA in dentistry is the ease of accessibility, and it can be readily implemented in clinical practice. Moreover, it is independent of the variables such as projection geometry and radiodensity that ensure reliable and consistent results.[23] By employing FA, clinicians can obtain objective, repeatable, and precise numerical information about the trabecular structure of bone. Distinguished studies have reported several radiographic methods can be beneficial for the evaluation of the quality of bone in terms of bone density by FA.[15,24-26] A systematic review that evaluated the utilization of fractal dimension in dental radiographs to investigate implant stability showed that most studies used intraoral periapical radiographs and orthopantomograms.[18] Currently, there is no consensus about the gold standard of different radiological techniques. Hayek *et al*.[24] evaluated the correlation between fractal dimension obtained from digital periapical radiographs with bone specimens harvested from implant recipient sites and implant stability obtained by RFA. They concluded that there was a correlation between the fractal dimension and implant stability quotient/bone density. They underscored the FA assessed on periapical radiographs can offer predictable information for bone density. Similar to that result, another study that aimed to compare the bone density of surgically harvested bone specimens at implant recipient sites in the posterior region of jaw bones based on histological analysis using SEM to bone density obtained by fractal analysis based on intra-oral radiographs showed a correlation between fractal dimension scores and bone core specimens density's values.[16] Soylu *et al*.[27] evaluated the effectiveness of fractal analysis obtained by panoramic films on determining osteointegration of dental implants in mandibular molar/premolar region soon after, 1 and 2 months after surgery and before surgery. They stated FA as a promising, reliable method for predicting osteointegration around implants. Öztürk&Kış[28] reported that fractal analysis calculated by panoramic films could be used as a non-invasive method for evaluating microstructural analysis of peri-implant bone before prosthetic placement where access to devices for ISQ measurement is not available.

The investigation of FD based on CBCT is promising in the field of implantology owing to the 3-dimensional image of internal bone structure. However, only a few studies used CBCT to compare fractal analysis scores to implant stability.[18,29] To our knowledge, there has been no study on this date that compares preoperative HU and fractal dimension of recipient implant sites obtained by CBCT to implant stability based on RFA soon after implant placement. This study aimed to investigate preoperative bone density obtained from the Hounsfield units and fractal analysis scores in cone beam computed tomography sections and compare this value with primer stability derived from resonance frequency analysis score soon after placement of implants in the mandibular posterior region. In the present study, the mean fractal analysis scores for implant regions were found to be 0.64, which was not collareted to HU and RFA (p>0.05). Gender and age were not related to fractal analysis.

It was reported that the use of panoramic radiographs for evaluating trabecular structure was superior owing to higher image resolution than CBCT.17 However, Magat *et al*.[30] reported that digital panoramic radiographs and reconstructed panoramic CBCT are beneficial for evaluating trabecular bone regions with similar image quality. Additionally, they highlighted that CBCT could obtain more precise FD values due to avoiding the superimposition of cortical bone on trabecular bone. On the other hand, radiation dose, lower image resolution, and expenses of machines were stated as the limitations of CBCT. Gaalaas *et al*.[26] used fractal analysis to evaluate several types of bone regions by CBCT scans. They reported that fractal values could detect differences in the trabecular bone morphology in the different parts of the jaw and can be used to analyze trabecular bone using CBCT images.

This study has some limitations. Besides the trabecular structure of alveolar bone, it has been shown that the width of alveolar ridges may also contribute to primary implant stability.[7] In this study, the characteristic of the recipient's bone, such as the width of the alveolar ridge, was not evaluated. Secondly, only preoperative FD scores were evaluated in the scope of the methodology. However, it has been reported that the healing of bone can also be evaluated in the initial healing period following implant placement. Zeytinoglu *et al.*[15] evaluated the changes in FD from peri-implant alveolar bone regions in panoramic radiographs at six months and one year after prosthodontic loading and stated that trabecular bone around successful implants shows lower FD values six months after prosthodontic loading and displays a stable microstructure at one year of follow up. Soylu *et al.*[27] compared the fractal dimensions around dental implants in mandibular molar/premolar region soon after, 1 and 2 months after surgery and before surgery and reported that fractal analysis is an efficacious and non-invasive tool for predicting osteointegration. Lastly, due to the study's retrospective nature, total number of included implants was low.

CONCLUSIONS

The preoperative bone density of alveolar bone measured from cone beam computed tomography by Hu and FA scores may be insufficient to determine initial implant stability. Further studies with larger sample sizes are needed to investigate parameters related to the prediction of implant stability.

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