Cumhuriyet Dental Journal, 28(1): 29-35, 2025
DOI: https://doi.org/10.7126/cumudj.1450913

Cumhuriyet Dental Journal

| cdj.cumhuriyet.edu.tr | Founded: 1998 Available online, ISSN: 1302-5805 Publisher: Sivas Cumhuriyet Üniversitesi

Evaluation of Early Changes in Periimplantal Alveolar Bone Micromarchitecture During Immediate Implantation Using Fractal Analysis: A Retrospective Study

Turan Emre Kuzu[1,a,*], Fatma Akkoca[2,b], Cem A. Gürgan[3,c]

[1] *Erciyes University, Faculty of Dentistry, Department of Periodontology, Kayseri-Turkiye.*
[2] *Nuh Naci Yazgan University, Faculty of Dentistry, Department of Periodontology, Kayseri-Turkiye.*
[3] *Dokuz Eylul University, Faculty of Dentistry, Department of Oral and Maxillofacial Radiology, Izmir-Turkiye.*
**Corresponding author*

Research Article

History

Received: 13/03/2024
Accepted: 12/03/2025

ABSTRACT

Objectives: The aim of our study was to evaluate the effect of immediate implantation on the peri-implant bone using fractal analysis.

Materials and Methods: Orthophotomographs of the participants just before the immediate implantation (T0) and the first (T1) and fourth months (T2) after the immediate implantation were used for fractal dimension analysis. In the radiographs, "Regions of Interest" (ROI) with dimensions of 33 × 33 pixels were determined (ROI-1: mesial-coronal, ROI-2: mesial-apical, ROI-3: distal-apical, ROI 4: distal-coronal, ROI average).

Results: The fractal dimension analyzes at T0, T1, T2 times in the research; It was found that there was a significant decrease in ROI1, ROI-4, ROI average measurements between T1-T0 ($p< 0.05$), and T2-T1 ($p < 0.05$), no significant difference in measurements between T0 -T2 ($p > 0.05$). No significant differences were found in the ROI-2 and ROI-3 measurements at any time ($p >0.05$). Gender, jaw subgroups: ROI1, ROI-4, and ROI average, while a significant difference ($p < 0.05$) was observed between T0- T1, T1–T2 values, no significant difference was found in the measurements between T0-T2 ($p >0.05$). No significant differences were found in the ROI-2 and ROI-3 measurements for all subgroups and evaluation times ($p >0.05$). When gender and jaw type subgroups were evaluated within themselves, it was observed that there was no statistically significant difference ($p > 0.05$).

Conclusion: Within the limits of our study, we can state that immediate implantation preserves the fractal dimension in the peri-implant bone.

Key words: Dental Implant; Fractal; Panoramic Radiography.

İmmediat Implantasyon Sırasında Periimplantal Alveoler Kemik Mikro Mimarisindeki Erken Değişikliklerin Fraktal Analiz Yöntemiyle Değerlendirilmesi: Retrospektif Bir Çalışma

Araştırma Makalesi

Süreç

Geliş: 29/12/2023
Kabul: 19/02/2025

ÖZ

Amaç: Çalışmamızın amacı immediat implantasyonun peri-implant kemik üzerindeki etkisini fraktal analiz yöntemiyle değerlendirmektir.

Gereç ve Yöntem: Çalışmada Fraktal boyut analizi için katılımcılardan immediyat implantasyondan hemen önceki (T0) ve immediyat implantasyondan sonraki birinci (T1) ve dördüncü ayda (T2) alınan ortopantomografik filmler kullanıldı. İlgili radyografilerde 33×33 piksel boyutlarında "İlgi Alanları" (ROI) belirlendi (ROI-1: mesial-koronal, ROI-2: mesial-apikal, ROI-3: distal-apikal, ROI -4: distal-koronal, ROI ortalama).

Bulgular: Araştırmada T0, T1, T2 zamanlarında yapılan fraktal boyut analizlerine bakıldığında T0-T1 ve T1-T2 arasında ROI1, ROI-4, ROI ortalama ölçümlerinde istatistiksel olarak anlamlı bir azalma olduğu, ($p< 0,05$), T0 -T2 ölçümlerinde anlamlı fark olmadığı belirlendi. ($p >0,05$). ROI-2 ve ROI-3 ölçümlerinde T0, T1, T2 dönemlerinde anlamlı farklılık bulunmadı ($p >0,05$). Cinsiyet, çene alt gruplarında ROI1, ROI-4 ve ROI ortalamaları, T0-T1 ve T1–T2 değerleri arasında anlamlı fark gözlenirken ($p<0,05$), T0-T2 arasındaki ölçümlerde anlamlı fark bulunamadı ($p>0,05$). Tüm alt gruplar (Cinsiyet, çene) ve değerlendirme süreleri (T0, T1, T2) için ROI-2 ve ROI-3 ölçümlerinde anlamlı farklılık bulunmadı ($p>0,05$). Cinsiyet ve çene tipi alt grupları kendi içinde değerlendirildiğinde istatistiksel olarak anlamlı bir fark olmadığı görüldü ($p>0,05$).

Sonuç: Çalışmamızın sınırları dahilinde immediat implantasyonun peri-implant kemikteki fraktal boyutu koruduğunu söyleyebiliriz.

Anahtar Kelimeler: Diş İmplantı; Fraktal; Panoramik Radyografi

[a] *turanemrekuzu@erciyes.edu.tr* *https://orcid.org/0000-0002-9478-1578*
[a] *cagurgan@yahoo.com* *https://orcid.org/0000-0003-0811-008X*
[b] *fatmaakkoca92@gmail.com* *https://orcid.org/ 0000-0002-4522-656X*

How to Cite: Kuzu TE, Akkoca F, Gürgan CA. (2025) Evaluation of Early Changes in Periimplantal Alveolar Bone Micromarchitecture During Immediate Implantation Using Fractal Analysis: A Retrospective Study, Cumhuriyet Dental Journal, 28(1): 29-35.

Introduction

Dental implants are a suitable treatment option for replacing missing teeth. There are different protocols in the clinic when implants are placed instead of the extracted teeth. These are as follows: Type 1 placement: This is the protocol of placing an implant into the extraction socket simultaneously with the tooth extraction. (immediate implantation), Type 2 placement: This protocol involves implant placement after soft tissue healing after tooth extraction. (4-8 weeks), Type 3 placement: This is a protocol for implant placement after soft tissue healing following tooth extraction and bone formation in the extraction socket at a level that can be determined clinically and radiologically. (12-16 weeks), Type 4 placement: The protocol for implant placement after both the soft tissue and alveolar bone completely healed after tooth extraction (+16 weeks).[1]

Mandelbrot stated that objects do not always conform to standard geometric shapes; however, when looking at their microarchitecture, their irregularities have a certain ratio, known as the fractal dimension of the object. It has been determined that alveolar bone also has a certain fractal dimension.[2,3] Although there have been studies examining the fractal dimension of the peri-implant alveolar bone, there is still a lack of research on the short-term microarchitectural changes in the peri-implant alveolar bone.[4]

The aim of our study was to evaluate the effect of immediate implantation on peri-implant bone using fractal analysis.

Our hypothesis:

H0: Implants placed in the extraction socket with the immediate implantation protocol have no effect on preserving the fractal dimension of the peri-implant alveolar bone.

H1: Implants placed in the extraction socket with the immediate implantation protocol preserve the fractal dimension of the peri-implant alveolar bone.

Materials and Methods

Our study was conducted with the approval of Nuh Naci Yazgan University, Non-invasive Ethics Committee (number 2023/003-00). Our research group consisted of patients who underwent immediate implantation at the Faculty of Dentistry,Nuh Naci Yazgan University in 2022.

Collection of Data

All orthopantomographs (OPG) (KaVO OP 3D Pro, PaloDEx Group Oy, Tuusula, Finland) were obtained using the same X-ray device with the following parameters (66–75 kVp, 10–14 mA, and 16 s.) OPGs of the patients participating in the study before immediate implantation (T0), at the the first month (T1), and at the fourth month (T2) after immediate implantation were collected from the Faculty PACS system for fractal dimension analysis.

Fractal dimension analysis

In the OPGs included in the study, "Regions of Interest" (ROI) with dimensions of 33×33 pixels were selected from the alveolar bone, specifically from the areas closest to the teeth and implants, while avoiding adjacent anatomical structures (ROI-1: mesial-coronal, ROI-2: mesial-apical, ROI-3: distal-apical, ROI 4: distal-coronal. For ROI-1 and ROI-4, 1 mm apical to the alveolar crest was defined as the coronal starting point, whereas for ROI-2 and ROI-3, the bottom of the implant/root apex was determined as the border (Figure 2). The average of the data obtained from all ROIs for each implant was recorded as the mean ROI value for that implant. Fractal dimension analysis of the images was performed using ImageJ version1.3 software (National Institutes of Health, Bethesda, MD, USA, http://imagej.nih.gov/ij/download.html) using the relevant ROIs at different times by an expert oral radiologist and periodontologist. The final research data consisted of the average fractal dimension values calculated independently by both Observers.[5]

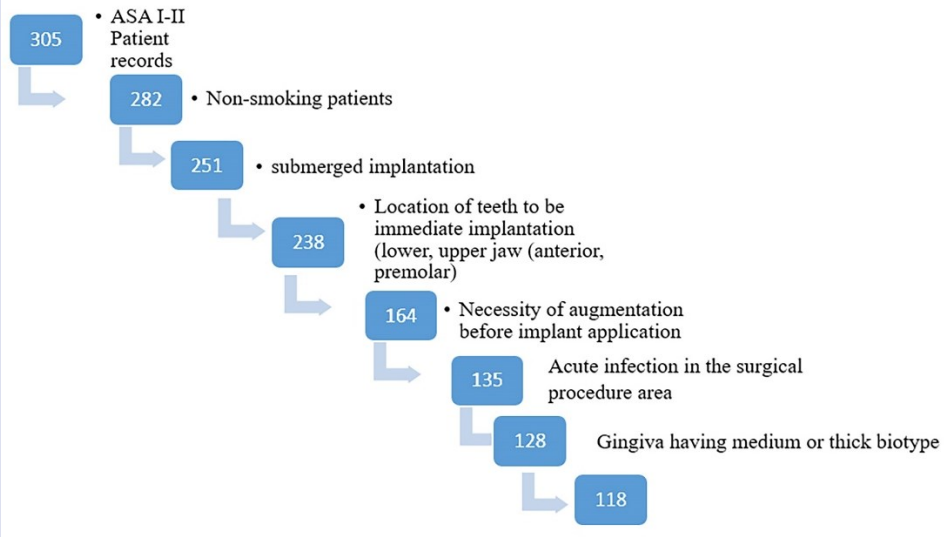

Figure 1:Assesment of the research group

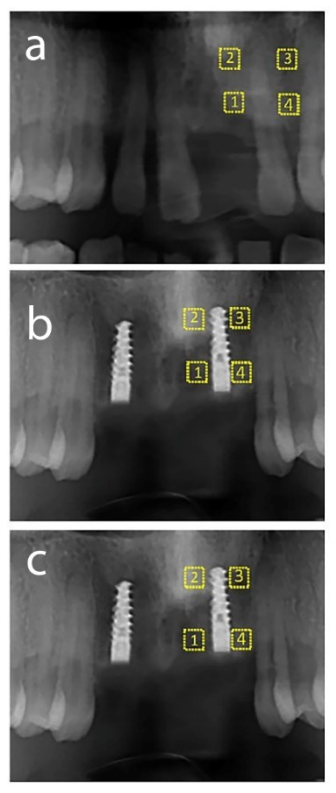

Figure 2: ROIs selected from periodontal and periimplantal areas: A:preop, B: post op 1. month, C: post-op 4. month. ((mesial-coronal (ROI1), mesial-apical (ROI-2), distal-apical (ROI-3), distal-coronal: (ROI 4))

Figure 3: Fractal analysis steps: a- Saving and copying ROI images in 8-bit format after cropping, b- Images were duplicated and Gaussian filter (Sigma 35 pixels) applied. c- Applying 'subtraction' process to the image. d-128 gray values were added to each pixel and the threshold value was determined as 128. e- Converting the resulting image into binary format. f- Erosion application to images g- Dilation application h- Image reversal i- Skeletonization of the resulting image

Statistical Analysis

The sample size was determined using the G Power 3.1.9 program, resulting in 111 participants, with an effect size of 0.3, α=0.05, and a power of 0.95. Analyses were performed using SPSS 21.0. Normal distribution of the data was determined using the Shapiro-Wilk test and Q-Q plots. The Mann-Whitney U test was used to compare nonparametric data for the independent variables. Friedman test and Wilcoxon signed-rank test were applied for the dependent variables. The agreement between observers was investigated using Spearman's correlation test. Statistical significance was set at $p < 0.05$.

Results

In this study, 118 implants from 75 patients were included. Descriptive statistical analyses were performed for all the 118 implants (Table 1). According to the fractal dimension analysis at T0, T1, and T2, a significant decrease was observed in T1 values for ROI1, ROI-4, and ROI average measurements compared to T0 ($p<0.05$). However, there was a significant increase in T2 measurements compared to T1 ($p<0.05$), with no significant difference between T0 and T2 ($p > 0.05$). No significant differences were found in the ROI-2 and ROI-3 measurements at all evaluation times ($p > 0.05$) (Table 2). Gender, and jaw subgroups, while a significant difference ($p < 0.05$) was observed between T0 and T1 and T1–T2 values in ROI1, ROI-4 and ROI Average measurements, no significant difference was found between T0 and T2 across all subgroups ($p > 0.05$) (Table 3,4) For all subgroups and no significant difference was found in ROI-2 and ROI-3 measurements. ($p > 0.05$) It was observed that there was no statistically significant difference when gender and jaw subgroups were compared as intra groups. ($p>0.05$) According to Spearman correlation analysis, a strong

correlation was observed between the two observers. (r=0.719, P=0.002)

Table 1: Descriptive statistical analysis

		n	Median ±SS
Gender	Female	58	45.564 ±9.59
	Male	60	47.261 ±12.65
Jaws	Maxilla	63	46.621 ±10.56
	Mandibula	55	46.541 ±11.48
Location of teeth	Anterior	56	43.654 ±7.64
	Premolar	62	49.548 ±9.83

Table.2 Evaluation of fractal dimension analyzes of the study groups at T0, T1 and T2 times

	T0	T1	T2	
ROIs	Median (Q1-Q3)	Median (Q1-Q3)	Median (Q1-Q3)	p
ROI 1	1.423^{a*} (1.351-1.345)	1.304^{b} (1.262-1.431)	1.391^{a} (1.326-1.438)	<0.05
ROI 2	1.405 (1.318-1.453)	1.322 (1.246-1.373)	1.388 (1.364-1.438)	>0.05
ROI 3	1.438 (1.382-1.295)	1.271 (1.223-1.296)	1.397 (1.341-1.438)	>0.05
ROI 4	1.409 ^{c} (1.253-1.429)	1.302^{d} (1.171-1.327)	1.400 ^{c} (1.320-1.421)	<0.05
ROI Mean	1.406^{e} (1.325-1.431)	1.289^{f} (1.241-1.345)	1.402^{e} (1.356-1.417)	<0.05

Table.3 Evaluation of fractal dimension values according to gender at T0-T1-T2 times

ROIs	Gender	n	T0	T1	T2	P
			Median (Q1-Q3)	Median (Q1-Q3)	Median (Q1-Q3)	<0.05
ROI 1	Female	58	1.419 *^{a} (1.303-1.453)	1.385 ^{b} (1.218-1.395)	1.402 ^{a} (1.319-1.438)	<0.05
	Male	60	1.439 ^{c} (1.377-1.468)	1.372 ^{d} (1.316-1.385)	1.405^{c} (1.361-1.438)	>0.05
ROI 2	Female	58	1.401 1.288-1.407	1.367 (1.226-1.373)	1.390 (1.285-1.479)	>0.05
	Male	60	1.408 (1.380-1.453)	1.389 (1.247-1.403)	1.401 (1.393-1.453)	>0.05
ROI 3	Female	58	1.390 (1.208-1.418)	1.376 (1.140-1.336)	1.374 (1.285-1.424)	>0.05
	Male	60	1.393 (1.307-1.447)	1.375 (1.235-1.359)	1.382 (1.354-1.408)	<0.05
ROI 4	Female	58	1.411 ^{e} (1.204-1.415)	1.372 ^{f} (1.126-1.387)	1.393 ^{e} (1.273-1.408)	<0.05
	Male	60	1.409 ^{k} (1.289-1.438)	1.383 ^{l} (1.205-1.385)	1.395 ^{k} (1.364-1.442)	<0.05
ROI Mean	Female	58	1.383 ^{m} (1.300-1.418)	1.323 ^{n} (1.222-1.338)	1.400 ^{m} (1.253-1.410)	<0.05
	Male	60	1.421 ^{o} (1.340-1,431)	1.343 ^{r} (1.260-1.345)	1.405^{o} (1.128-1.483)	<0.05

n: Number of samples Min (minimum) Max (maximum), Q1 (first quarter, Q3 (third quarter) *Different uppercase letters indicate statistically significant differences.

Table.4 Evaluation of fractal dimension values according to jaws at T0-T1-T2 times

ROIs	Jaws		T0	T1	T2	
		n	Median (Q1-Q3)	Median (Q1-Q3)	Median (Q1-Q3)	p
ROI 1	Maxilla	63	1.419a (1.360-1.466)	1.326 b (1.272-1.731)	1.364 a (1.320-1.438)	**<0.05**
	Mandibula	55	1.428 c (1.350-1.447)	1.320 d (1.205-1.351)	1.409 c (1.316-1.438)	**<0.05**
ROI 2	Maxilla	63	1.393 (1.316-1.453)	1.302 (1.244-1.273)	1.393 (1.333-1.438)	>0.05
	Mandibula	55	1.408 (1.320-1.445)	1.338 (1.206-1.359)	1.364 (1.280-1.409)	>0.05
ROI 3	Maxilla	63	1.390 1.295-1.438	1,292 (1.224-1.351)	1.409 (1.341-1.438)	>0.05
	Mandibula	55	1.364 (1.295-1.438)	1.296 (1.140-1.336)	1.408 (1.270-1.408)	>0.05
ROI 4	Maxilla	63	1.409 e (1.253-1.429)	1.302 f (1.172-1.345)	1,409e 1.316-1.438	**<0.05**
	Mandibula	55	1,409 k (1.284-1.409)	1.296 l (1.126-1.317)	1.409 k (1.270-1.400)	**<0.05**
ROI Mean	Maxilla	63	1.404 m (1,316-1,431)	1.302 n (1.249-1.345)	1.406 m (1.353-1.416)	**<0.05**
	Mandibula	55	1.416 o (1.322-1.429)	1.302r (1.220-1.330)	1.400 o (1.248-1.408)	**<0.05**

n: Number of samples Min (minimum) Max (maximum), Q1 (first quarter, Q3 (third quarter) *Different uppercase letters indicate statistically significant differences.

Discussion

In our study, we examined the effects of immediate implantation on the fractal dimension of the alveolar bone in both the entire study group (regardless of gender and jaw) and in the groups divided into subgroups according to gender and jaw A decrease in T1 measurements compared to T0 was observed in coronal and average ROIs (ROI1, ROI-4, ROI average). However, T2 measurements showed an increase. Following this increase, the difference between T0 and T2 became statistically insignificant. There were no differences between the periods in the apical ROIs (ROI-2 and ROI-3).

To prevent bias, the average fractal dimension of each patient was calculated and used as the patient's representative fractal dimension for statistical analysis. These results are compatible/consistent with those of our study. In analyses based on the number of patients, the power of the test was 0.85.

Studies on the fractal dimension of the alveolar crest have shown that periodontal disease, post-extraction changes, and systemic diseases cause a decrease in fractal dimension.[6] When reviewing studies that evaluates changes in alveolar bone after implantation using by fractal dimension analysis, Soylu *et al.* They determined that after implant placement, there was an initial decrease in fractal dimension during the osseointegration process, followed by an increase with osseointegration. However, the fractal dimension did not return to pre-implant surgery levels.[7] In a study conducted by Sansare *et al.,* implants were applied using the two-stage Branemark protocol, and it was determined that fractal dimension increased with osseointegration.

Mishra et al. and Kato et al. examined the fractal dimension and implantation relationships in their systematic reviews.[3,8] In this review, only one study on immediate implantation was found and it was determined that this study was a case series consisting of only three implants Studies of immediate implantation after tooth extraction. Studies on immediate implantation after tooth extraction highlight several advantages, including a reduction in the number of surgical procedures and overall treatment time, ideal implant orientation, protection of the numbered extraction area, and more aesthetically favorable results in soft tissue.[6] Moreover, recent systematic reviews have observed that there is no difference in implant survival between type 1 implant placement and a delayed approach.[7,8] In studies investigating immediate implantation, treatment success has been associated with factors such as buccal bone thickness[9], buccal gap size[10] whether the implant was applied without or with a flap implant diameter and apico-coronal bucco-lingual position of the implant use of bone grafts.[11] Also it has been determined that it depends on factors such as biotype / use of connective tissue graft and use of temporary restorations.[12]

It can be thought that the decrease in coronal ROI values in the T1 period observed in our study was due to the gap between the implant and the vestibular wall of extraction socket and in the coronal peri-implant area or changes in the vestibule bone plate. Carlson et al. stated that a gap distance of 1.5 mm is the limit, and that healing will occur in larger intervals with fibrous tissue.[13] Tarnow

et al. reported that there is no threshold value for gap width and that the use of grafts in this region will not affect implant osseointegration but will be effective in peri-implant soft tissue recession and loss of buccolingual thickness/contour of the alveolar crest.[14] Caneva et al. stated that 1 mm is the threshold for vestibular bone thickness in the and that a thickness of less than 1 mm is important for peri-implant bone resorption/apposition.[10] In our study, we restored the gaps in 110 implants (93.2%) with xenografts and resorbable collagen membranes, and the implants were submerged 1 mm apical to the coronal alveolar bone edge. In this respect, we believe that the post-implantation procedures performed in our study contributed to preserving the coronal bone microarchitecture.

Osseointegration in dental implants depends on patient-related factors, such as bone metabolism, which differs between male and female genes in terms of bone-regulating hormones.[15] August *et al.*[6] demonstrated that estrogen deficiency and the resulting bone changes may be risk factors for intraosseous implant failure. Chen et al. reported that implant stability quotient (ISQ) values were lower in women compared to men; however, the difference was not statistically significant.[17] In our study, we included ASA-I and II patient groups. With a minor modification, we excluded smokers from these groups. Patients with ASA-I and ASA-II generally have good systemic conditions. The results of this study show that the sustainability of success in immediate implantation is speculative when the characteristics of the patient groups are different.

Our study had certain limitations. First, we determined implant osseointegration in our patients using a single parameter. RFA measurements could be used as an additional parameter. Although RFA was not measured in this study, reverse torque values were observed to be > 30 N both on the day of implant placement and at the 4th month. These measurements were determined as a second parameter, in addition to radiographic imaging, providing osseointegration and implant stability. Second, the study only included patients with ASAI-II. What the results will be on a larger study groups remains speculative.

Although cone beam computed tomography (CBCT), as a radiographic imaging method, provides more detailed information about alveolar bone in implantology, Lee et al. in his study, stated that fractal analysis OPG is still used more often than CBCT.[18] At the same time, it should not be forgotten that implant-related artifacts in CBCT may still pose an obstacle in evaluating the alveolar bone.

Conclusions

Within the limits of our study, immediate implantation preserved the fractal dimension and microarchitecture of the peri-implant bone. Further studies with larger study groups are needed to reach broader and more comprehensive conclusions.

References

1. Chrcanovic BR, Martins MD, Wennerberg A. Immediate placement of implants into infected sites: a systematic review. Clin Implant Dent Relat Res 2015;17 Suppl 1:e1-e16.
2. BB. M, Freeman. The fractal geometry of nature. 2 nd ed: W.H Freeman New York 1983.
3. Mishra S, Kumar M, Mishra L, Mohanty R, Nayak R, et al. Fractal Dimension as a Tool for Assessment of Dental Implant Stability-A Scoping Review. J Clin Med 2022;11.
4. Ozturk K, Kis HC. Peri-implant bone microstructural analysis and comparison of resonance frequency analysis before prosthetic placement: a retrospective study. Clin Oral Investig 2022;26:4967-4975.
5. White SC, Rudolph DJ. Alterations of the trabecular pattern of the jaws in patients with osteoporosis. Oral Surg Oral Med Oral Pathol Oral Radiol Endod 1999;88:628- 635.
6. Chen ST, Buser D. Clinical and esthetic outcomes of implants placed in postextraction sites. Int J Oral Maxillofac Implants 2009;24 Suppl:186-217.
7. Lang NP, Pun L, Lau KY, Li KY, Wong MC. A systematic review on survival and success rates of implants placed immediately into fresh extraction sockets after at least 1 year. Clin Oral Implants Res 2012;23 Suppl 5:39-66.
8. Esposito M, Grusovin MG, Polyzos IP, Felice P, Worthington HV. Timing of implant placement after tooth extraction: immediate, immediate-delayed or delayed implants? A Cochrane systematic review. Eur J Oral Implantol 2010;3:189-205.
9. Araújo MG, Sukekava F, Wennström JL, Lindhe J. Tissue modeling following implant placement in fresh extraction sockets. Clin Oral Implants Res 2006;17:615-624.
10. Caneva M, Salata LA, de Souza SS, Bressan E, Botticelli D, et al. Hard tissue formation adjacent to implants of various size and configuration immediately placed into extraction sockets: an experimental study in dogs. Clin Oral Implants Res 2010;21:885-890.
11. Blanco J, Nuñez V, Aracil L, Muñoz F, Ramos I. Ridge alterations following immediate implant placement in the dog: flap versus flapless surgery. J Clin Periodontol 2008;35:640-648.
12. Caneva M, Botticelli D, Viganò P, Morelli F, Rea M, et al. Connective tissue grafts in conjunction with implants installed immediately into extraction sockets. An experimental study in dogs. Clin Oral Implants Res 2013;24:50-56.
13. Carlsson L, Röstlund T, Albrektsson B, Albrektsson T. Implant fixation improved by close fit. Cylindrical implant-bone interface studied in rabbits. Acta Orthop Scand 1988;59:272-275.
14. Chu SJ, Salama MA, Garber DA, Salama H, Sarnachiaro GO, et al. Flapless Postextraction Socket Implant Placement, Part 2: The Effects of Bone Grafting and Provisional Restoration on Peri-implant Soft Tissue Height and Thickness- A Retrospective Study. Int J Periodontics Restorative Dent 2015;35:803-809.
15. Guido Mangano F, Ghertasi Oskouei S, Paz A, Mangano N, Mangano C. Low serum vitamin D and early dental implant failure: Is there a connection? A retrospectclinical study on 1740 implants placed in 885 patients. J Dent Res Dent Clin Dent Prospects 2018;12:174-182.
16. August M, Chung K, Chang Y, Glowacki J. Influence of estrogen status on endosseous implant osseointegration. J Oral Maxillofac Surg 2001;59:1285-9; discussion 90-91.

17. Chen MH, Lyons K, Tawse-Smith A, Ma S. Resonance Frequency Analysis in Assessing Implant Stability: A Retrospective Analysis. Int J Prosthodont 2019;32:317-326.

18. Lee DH, Ku Y, Rhyu IC, Hong JU, Lee CW, 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.