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Original Article

Association between Bone Density Values, Primary Stability and Histomorphometric Analysis of Dental Implant Osteotomy Sites on the Upper Jaw

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Abstract

Introduction: Sufficient bone volume, as well as the bone quality characteristics are necessary prerequisites to ensure optimal mechanical stability of the implants and subsequent osseointegration.

Aim: The aim of the present study was to assess the correlation between bone density values obtained by cone-beam computed tomography (CBCT), the primary stability of dental implants and the histomorphometric analysis of bone quality.

Materials and methods: Following tooth extraction, socket preservation with frieze-dried bone allograft or protein-rich fibrin (PRF) was performed on 30 patients with 30 maxillary teeth in the region from second premolar to second premolar. Four months after the procedure, CBCT was used to assess the bone density (Hounsfield units) in the area of extraction. Thirty bone samples were harvested from implant sites using a trephine drill. They were analyzed with Image J software. Immediately after placing the implant, the implant stability quotient was measured using the Osstell Idx device.

Results: The results revealed significant correlations between bone density and primary stability along the vestibulo-oral ($r=0.392$, $p=0.032$) and mesiodistal axes ($r=0.407$, $p=0.026$). Bone density also correlated strongly with the percentage of newly formed bone ($r=0.776$, $p<0.001$).

Conclusion: Bone quality, in terms of bone density measured in CBCT and new bone formation are correlated to the primary stability of the dental implants and vice versa.

Keywords

bone density, dental implants, primary stability, osseointegration, histomorphometric analysis

INTRODUCTION

The clinical success of dental implants is dependent upon the bone quality and bone volume as well as the surgical technique used in implant placement.[1] Several bone classifications have been used to assess bone quality. Lekholm and Zarb divided bone into four types based on the amount of cortical and trabecular bone. Misch[2] classified bone into 5 types based on Hounsfield units[3] using computed tomography. CT is a well-established method for evaluation of bone quality and quantification of bone density expressed in HU.[4] According to some studies, there is a strong correlation between grey values in CBCT and Hounsfield units in multislice CT.[5-7] The advantages of CBCT include high resolution, lower radiation dose and reduced costs.[8,9]

The most biologically reliable system for bone structure evaluation is histomoprhometric examination of bone biopsies, but it is not routinely applied in clinical practice.[10] The long-term success of dental implants is highly dependent upon the degree of osseointegration in sufficient and healthy bone.[11,12] In the present clinical study, implant placement was performed 4 months after a socket preservation procedure with PRF as a sole grafting material or frieze-dried bone allograft (BoneAlbumin^{TM}, OrthoSera Dental, Hungary). There is a large variability reported in literature in the amount of newly formed bone, residual graft material and connective tissue using different bone substitutes and socket preservation techniques.[13]

Primary implant stability is one of the most important factors influencing implant survival rates. Implant stability is a combination of both mechanical and biological stability. The mechanical stability is defined as the result of bone tissue compression during implantation, which is crucial for the undisturbed healing and osseointegration.[14,15] The biological stability results from the formation of new bone cells on the implant surface during the osseointegration process.[16] Hence, implant stability is associated with the quality and quantity of local bone.[16,17] A variety of noninvasive methods have been proposed to evaluate implant stability, including Periotest (Bensheim, Germany)[18], insertion torque (IT)[19] measurement and resonance frequency analysis (RFA) with Osstell (Osstell – Integration Diagnostics, Sweden). In 1996. Meredith et al.[20] developed Osstell (Integration Diagnostic Ltd., Goteborgsvagen, Sweden). The implant stability quotient (ISQ) is produced by the Osstell device through resonance frequency analysis on a scale from 1 to 100. The higher the ISQ value, the higher the stability. Implant stability is measured in two directions – vestibulo-oral and mesio-distal. Measurement of implant stability with RFA is a reliable, noninvasive method which can be used at any time after implant placement.[21]

AIM

The purpose of the current study is assessing whether there is a correlation between bone density, the primary implant stability and the histomorphometric analysis. The association between the aforementioned parameters is important considering preoperative planning and expectations regarding implant success rate.

MATERIALS AND METHODS

The Ethics Committee of Medical University, Plovdiv, Bulgaria, approved the present study (ethic code: P-2230/26.04.2018). The patients were enrolled after informed consent was obtained, and the protocol conformed to the ethical guidelines of the 1975 Declaration of Helsinki.

Patient selection and evaluation

Thirty patients, with one extraction socket each, all on the upper jaw, were included and treated in the oral surgery department of the Faculty of Dental Medicine in Plovdiv, Bulgaria. All patients were consulted with the need for rehabilitation with oral implants. The inclusion criteria included: presence of tooth with indication for extraction, presence of adjacent teeth, >18 years of age, ASA (Physical Status Classification System, American Society of Anesthesiologist) I (normal healthy patient) or II (patient with mild systemic disease), and good oral hygiene. The exclusion criteria included: ASA III or IV patients, uncontrolled diabetes, smokers (>than 10 cigarettes/day), use of immunosuppressant medication, use of anticoagulants, adjacent tooth extractions, or a diffuse infectious process next to the site to be intervened. All patients received tapered endosseous dental implants at the maxillary area (AB Dental Implants, Ashdod, Israel). Surgical procedures were performed according to the manufacturer's instructions.

Radiographic examination on CBCTs

Two consecutive CBCTs were obtained – one immediately after the socket preservation procedure and another one 4 months after. All of the CBCT scans were performed at the Faculty of Dental Medicine in Plovdiv. All CBCT assessments were performed using the same CBCT system (Planmeca Romexis Viewer 4.4.3, Planmeca, Helsinki, Finland). Measurements were performed independently by two investigators in all three planes – axial, sagittal and coronal, and the mean final HU values were determined **(Fig. 1)**

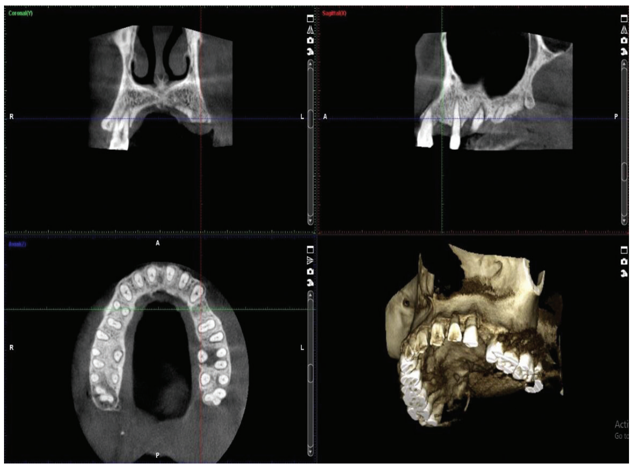


Figure 1. Measurement of HU units in the three planes - coronal, sagittal and axial plane.

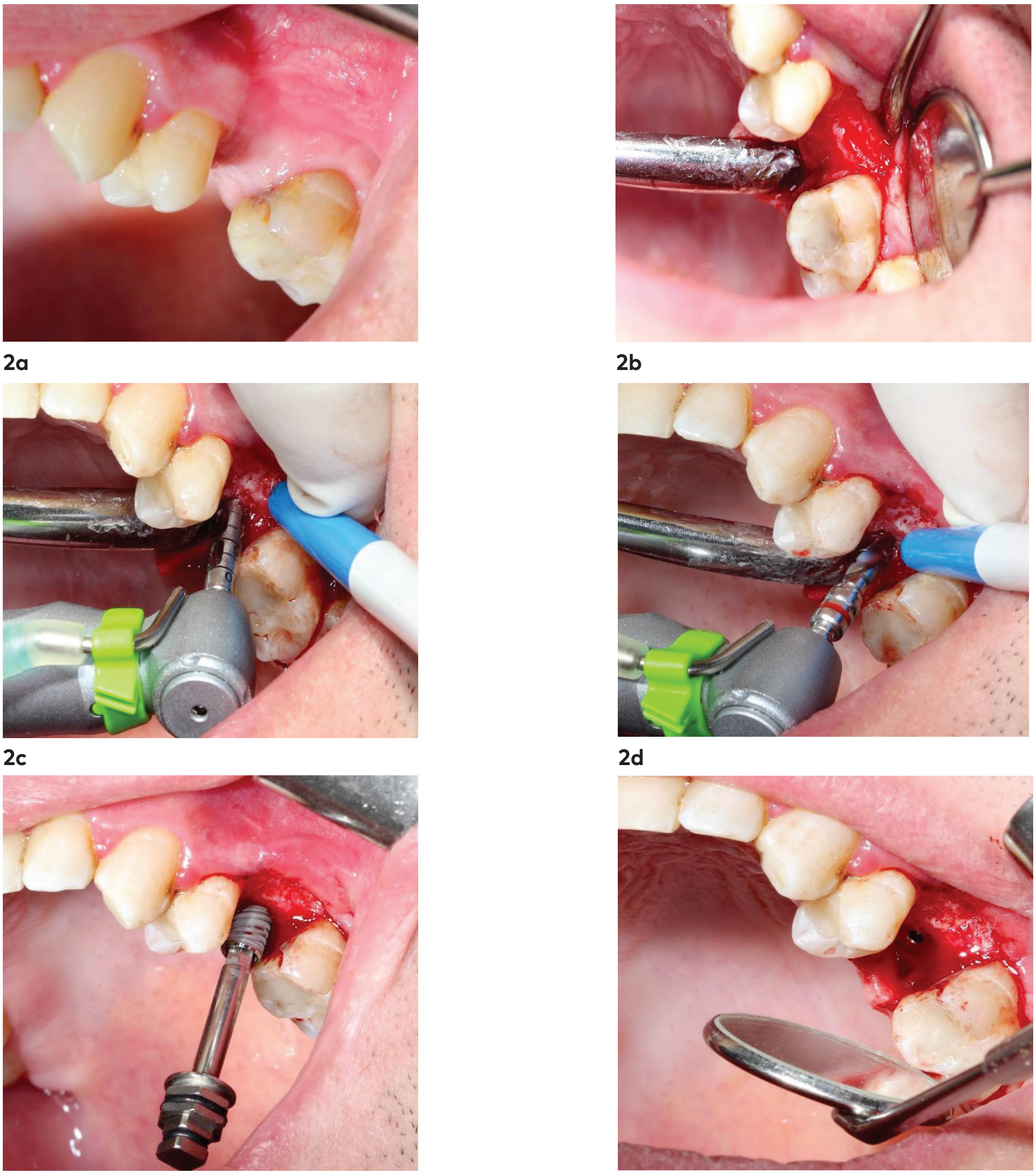
Calculations and measurements were performed independently from two researchers at all three levels.

Surgical procedure

Four months before implant placement, patients were randomly allocated (by the flip of a coin) into three groups of ten patients each. The first group of patients received socket preservation with frieze-dried bone allograft (BoneAlbumin™, OrthoSera Dental, Hungary), the second group was treated with socket preservation with PRF as a sole grafting material. The remaining ten patients were included in the control group (without socket preservation).

After a healing period of 4 months, a surgical procedure involving placement of dental implant was performed on each patient **(Fig. 2a)**. A total of 30 implants (conical dental implants – I5, A.B. Dental Corporate, Ashdod, Israel) were placed on 30 patients.

Following administration of local anesthesia, an incision was performed on the alveolar crest. On the buccal side two releasing incisions extended beyond the mucogingival junction were made at the mesial and distal papilla of the adjacent teeth. A full-thickness mucoperiosteal flap was elevated on both buccal and lingual sides **(Fig. 2b)**. A 2.5 mm trephine burr was used as a pilot drill for the preparation of the implant bed **(Fig. 2c)**. The diameter of the trephi-



2a 2b 2c 2d 2e 2f

Figure 2. a) clinical picture of soft tissues 4 months after socket preservation; b) clinical picture of bone 4 months after socket preservation; c) bone harvesting with trephine drill; d) osteotomy for implant placement; e) implant placement; f) placed dental implant.

ne burr was smaller than the final drill used in the surgical implant protocol. In this way, it was possible to place the implants with the correct primary stability **(Figs. 2d, 2e)**. A healing cap was placed **(Fig. 2f)** and the flap was sutured with 4-0 suture. The patients were prescribed amoxicillin – 1000 mg every 8 hour for 5 days and anti-inflammatory drugs for 3 days (nimesulide 100 mg every 12 hours). The sutures were removed after 10 days.

Resonance frequency analysis

In order to measure the primary stability of the dental implants, resonance frequency analysis (RFA) was performed using Osstell IDx (Osstell IDx, Gothenburg, Sweden). A cylindrical magnetic peg (SmartPeg) was screwed to the implant and measurements were performed in two directions – vestibulo-oral and mesio-distal direction **(Figs 3a, 3b)**.

3a

3b

Figure 3. a) SmartPeg connected to the dental implant and measurement of primary stability of the dental implant; b) Osstell Idx device

Histologic processing and histomorphometrical evaluation

The bone biopsies were fixed in 10% neutral buffered formalin **(Fig. 4)**. Each specimen was examined for vital bone, connective tissue and residual bone/other fractions under

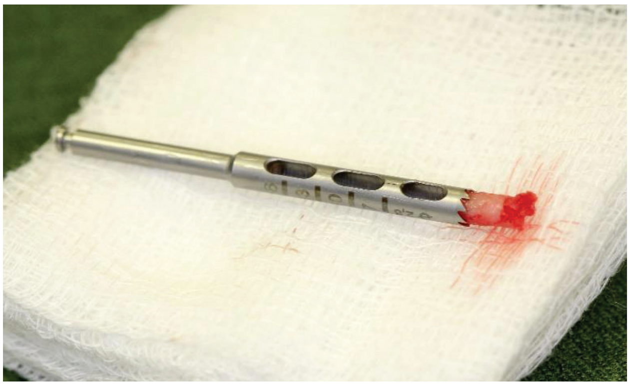


Figure 4. Bone biopsy in the trephine drill.

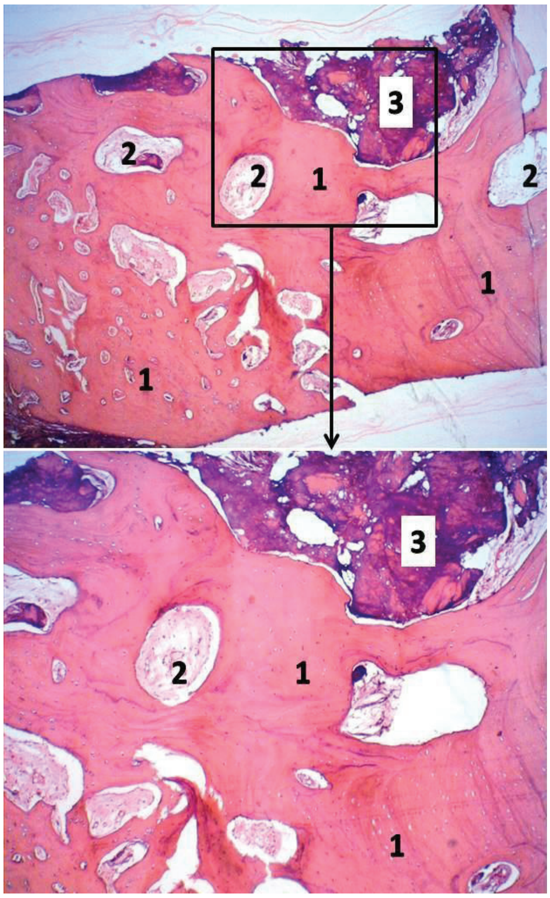
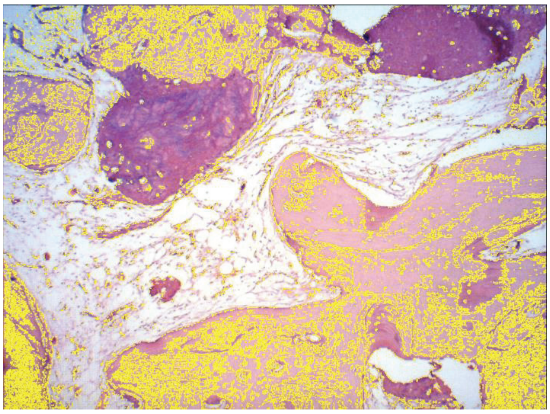
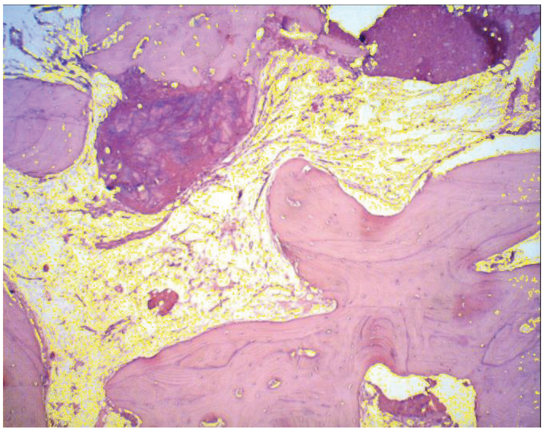


Figure 5. Digital image of section of freeze-dried bone allograft specimen: 1. Vital bone formation; 2. Connective tissue; 3. Residual bone particles.

×20 minimal magnification. The material was dehydrated and enlightened with xylene. Bone fragments are incorporated into a paraffin block, cut on a rotational basis into multiple sections (3-4 microns) and stained with Hematoxylin-Eosin for light microscopic observations **(Fig. 5)**. Digital images were imported into image analysis software (ImageJ) to calculate the percentage of newly formed bone, connective tissue, and residual bone graft particles **(Fig. 6)**.



6a



6b

Figure 6. Imported images in Image J: a) newly formed bone marked in yellow b) connective tissue marked in yellow.

Statistical analysis

The demographic data is presented as mean ± SD, raw frequencies and percentages. Age comparisons between the two sexes were performed by an independent samples t-test. The parameters of interest – bone density, primary stability and newly formed bone were measured on continuous scales and were normally distributed according to Kolmogorov-Smirnov's test with $p > 0.05$. This allowed the use of Pearson correlation analysis to examine the relationships between them and linear regression to identify significant predictors of the percentage of newly formed bone. The results were interpreted as significant at $p < 0.05$. The statistical analyses were performed using the IBM SPSS software program, version 25 (2017).

RESULTS

The study involved 30 patients who underwent tooth extraction and socket preservation and were scheduled for dental implant placement four months after the extraction. The patients' age ranged from 18 to 68 years (mean age, 41±15 years). Of these, 16 were women (53.3%) and 14 were men (46.7%). The female patients had a mean age of 44.44±12.82 years and the male patients – 37±16.77 years. The age difference was not significant, p =0.184.

The relationship between bone density (HU), primary stability, including vestibulo-oral (VO) and mesio-distal (MD) and newly formed bone four month after tooth extraction was examined using Pearson r correlations. The results are summarized in **Table 1** below.

We found significant correlations between bone density and primary stability along the vestibulo-oral ($r = 0.392$, $p = 0.032$) and mesio-distal axes ($r = 0.407$, $p = 0.026$). Bone density also correlated highly with the percentage of newly formed bone ($r = 0.776$, $p < 0.001$). These correlations are illustrated in **Fig. 7**.

The primary stability along the vestibulo-oral axis correlated significantly with the primary stabilities along the

Table 1. Correlations between bone density, primary stability, and newly formed bone

Parameters		HU	VO	MD	% Newly formed bone
HU	Pearson Correlation		0.392	0.407	0.776
	Sig. (2-tailed)	-	0.032 *	0.026*	0.000**
	N		30	30	30
VO	Pearson Correlation	0.392		0.734	0.395
	Sig. (2-tailed)	0.032*	-	0.000**	0.031*
	N	30		30	30
MD	Pearson Correlation	0.407	0.734		0.335
	Sig. (2-tailed)	0.026*	0.000**	-	0.071
	N	30	30		30

HU: bone density, VO: vestibulo-oral, MD: mesio-distal, ** Significant at the 0.05 level, ** Significant at the 0.01 level mesio-distal axis ($r = 0.734$, $p < 0.001$) and with the percentage of newly formed bone ($r = 0.395$, $p = 0.031$) **(Fig. 8)**.

The predictive role of the three parameters, bone density, vestibulo-oral and mesio-distal primary stabilities, for the formation of new bone was examined through a linear regression analysis, where the % of newly formed bone served as the dependent variable. The results showed that bone density was the sole significant predictor for the % of newly formed bone, accounting for 79.2% of the result ($R2 = 0.792$, B-coefficient 0.53, $p = 0.001$). There was a significant correlation between bone densities and primary stabilities in both of the directions.

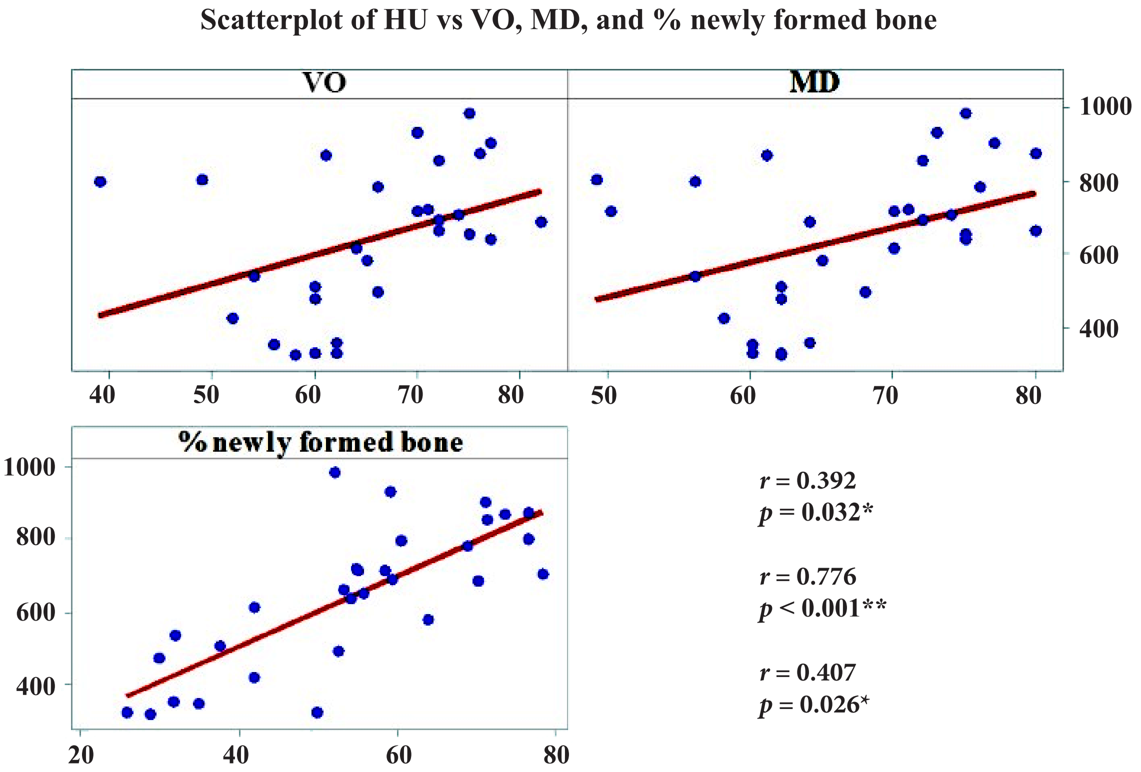


Figure 7. Significant correlations between bone densities and primary stabilities and newly formed bone.
HU: bone density, VO: vestibulo-oral, MD: mesio-distal, ** Significant at the 0.05 level, ** Significant at the 0.01 level

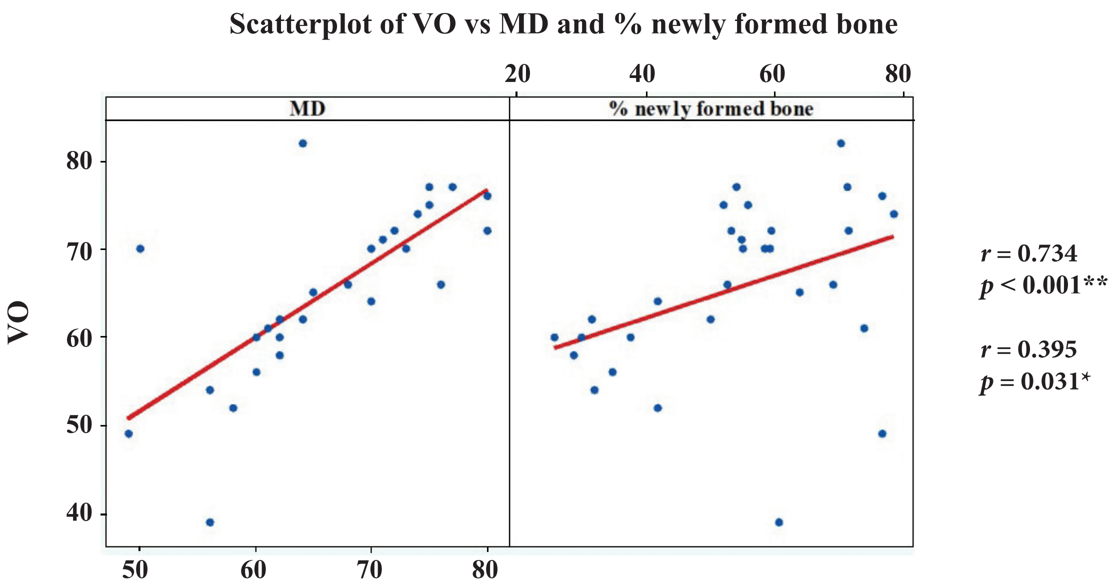


Figure 8. Significant correlations between primary stabilities and newly formed bone.
VO: vestibulo-oral, MD: mesio-distal, ** Significant at the 0.05 level, ** Significant at the 0.01 level

DISCUSSION

Successful implant treatment is considered to be dependent on the quality and the quantity of available bone. The predictable osseointegration of dental implants depends on their placement within bone with adequate internal structure.[22] Lekholm and Zarb[23] assessed bone quality by dividing bone density radiographically into four types. Although well-established, this method lacks objectivity and reproducibility. Schwartz et al.[24] introduced the concept of using computed tomography scans (CT) for pre-operative assessment of patients undergoing implant placement. Bone density can be assessed in Hounsfield units (HU)[3] on CT (Computed tomography) or CBCT (Cone-beam computed tomography). Misch[2] classified bone density into 5 types based on Hounsfield units on computed tomography (CT). When compared to CT, CBCT has a variety of advantages, including high resolution, lower radiation dose and reduced costs. Nonetheless this method has some disadvantages such as: scattered radiation, limited dynamic range of the X-ray area detectors, and density values without a linear correlation to bone density.[4] Therefore, there has not been established a method for objective assessment of bone quality.

The quantity of vital bone and connective tissue can also affect the different types of internal bone structure. In order to assess these parameters a bone biopsy is needed. It is performed by using a trephine burr at the place of the future implant. The first reported use of trephine drill for bone sampling in implant dentistry was in 1995 by Klinge et al.[25] This procedure is considered as a "gold standard" method for assessment of bone microstructure.[10,26,27] It is not performed on a regular basis because of the challenge and lack of bone weight and height in most of the cases and because it is time consuming. In 1992, Sennerby et al. suggested that the amount of cortical bone that implant passed is one of the most important factors in optimal implant stability.[28] In the study of Rokn et al.[27] it is concluded that tactile sense of the surgeon can exhibit the histologic properties of the bone, hence the practitioner is able to estimate the healing prognosis of the bone in implant placement. One of the purposes of our study was to determine whether there is a correlation between bone density in HU and bone quality, represented as the quality of vital bone formation at the implant bed. The results of this study reveal that bone density correlated highly with the percentage of newly formed bone, $r = 0.776$, $p < 0.001$.

In the presented clinical study four months before implant placement the post extraction sockets were filled with frieze dried bone allograft or PRF as a sole grafting material. The third group in our research was the control group, in which no grafting material was used for socket preservation. The extent of bone quality changes depends largely on the duration of healing in addition to the rate of absorption of the bone replacement material and its ability to promote the formation of new bone.[29] The presence of residual bone graft material often interferes with the normal healing process as well as with the diagnosis of preclinical results.[13] Decreased bone density caused by the presence of residual particles may negatively affect the ability to obtain primary stability. This situation may occur in cases where the remaining particles are encapsulated in connective tissue.[29]

Implant stability is one of the most important factors regarding the success and survival of dental implants. Previous research reveals that implant micromotion is responsible for the failure of osseointegration and it should not exceed 50-100 mm.[30,31] Primary implant stability is defined as the mechanical engagement of the dental implant in the bone. Hence, it is influenced by the quality and quantity of the surrounding bone. Previous studies have investigated the relationship between bone density and primary implant stability and have revealed variable correlations.[32-34] In a clinical study by Turkyilmaz et al.[34] a strong correlation between bone density and ISQ values was found. Herekar et al.[35] proposed a scoring index according to which the primary stability was 77.35 in D2 bone, 70.55 in D3 bone, and 60 in D4 bone. According to the research of Barikani et al.[36] ISQ values for implant placements in D1 bone were significantly higher than those for implants placed in D3 bone. According to Farre-Pages et al.[37] there is a significant correlation between bone density according to Lekholm-Zarb classification and ISQ value. In another study by Friberg et al.[38] the authors found a significant relation between bone density and primary and secondary implant stability.

The present study focused on the association between bone density, vital bone formation and primary stability of the dental implants. The results confirm the relationship between primary stability and bone density. We found a strong correlation between primary stability and vital bone formation ($r = 0.395$, $p = 0.031$). Bone density also correlated highly with the percentage of newly formed bone ($r = 0.776$, $p < 0.001$).

CONCLUSION

The results of our study suggest that bone quality, in terms of bone density measured in CBCT and new bone formation data, derived from bone biopsy are correlated to the primary stability of the dental implants and vice versa. The presence of high implant stability, together with adequate bone density and predominant quality of vital bone at the implant insertion area are crucial factors to obtain and maintain osseointegration.

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Взаимосвязь между значениями плотности кости, первичной стабильностью и гистоморфометрическим анализом участков остеотомии для размещения дентальных имплантатов на верхней челюсти

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Резюме

Введение: Достаточный объём кости, а также характеристики качества кости являются необходимыми предпосылками для обеспечения оптимальной механической стабильности имплантатов и последующей остеоинтеграции.

Цель: Целью настоящего исследования было установить корреляцию между значениями плотности кости, полученными с помощью конической лучевой компьютерной томографии (КЛКТ), первичной стабильностью дентальных имплантатов и гистоморфометрическим анализом качества кости.

Материалы и методы: После удаления зубов лунка корня зуба была сохранена с помощью замороженного высушенного костного заменителя аллотрансплантата или богатого белком фибрина (ББФ) у 3 пациентов с 30 верхнечелюстными зубами в области от второго премоляра до второго премоляра. Через четыре месяца после процедуры была использована КЛКТ для измерения плотности кости (число КТ) в области экстракции. Тридцать образцов кости были взяты из мест имплантации с помощью трепанационной турбины. Их анализировали с помощью программного обеспечения Image J. Сразу после установки имплантата коэффициент стабильности имплантата измерили с помощью устройства Osstell Idx.

Результаты: Результаты показали значительную корреляцию между плотностью кости и первичной стабильностью по вестибулоральной ($r=0.392$, $p=0.032$) и мезиодистальной осям ($r=0.407$, $p= 0.026$). Плотность кости также сильно коррелировала с процентом новообразованной кости ($r=0.776$, $p<0.001$).

Заключение: Качество кости с точки зрения плотности кости, измеряемой с помощью КЛКТ, и образования новой кости коррелируют с первичной стабильностью зубных имплантатов и наоборот.

Ключевые слова

плотность кости, зубные имплантаты, первичная стабильность, остеоинтеграция, гистоморфометрический анализ