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# The correlation of CBCT analysis derived bone density parameters with primary implant stability – a clinical study

## Korelacija vrednosti gustine kosti dobijene pomoću kompjuterizovane tomografije konusnim zrakom i primarne stabilnosti implantata – klinička studija

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**Abstract**

**Background/Aim.** There are numerous studies on the usefulness of computed tomography (CT) in the assessment of the bone volume and morphology and on the relationship between CT and primary implant stability. But there is the scarcity of data about the correlation between bone density and the value of primary implant stability. The aim of this study was to examine the correlation of cone beam CT (CBCT) analysis derived bone density with primary stability value. **Methods.** Clinical prospective experimental study was conducted on 38 healthy patients missing one tooth in the lateral region. It was planned to install Bredent Blue Sky Narrow self-taping dental implants with dimensions 3.5 × 10 mm. During preoperative preparation, a CBCT scan was performed on Planmeca apparatus, followed by preimplantation measurements and planning in the CBCT apparatus software (Romexis). The mean value of the average bone density was automatically generated and expressed in Hounsfield units (HU). Upon implant placement, we performed measurements of the primary implant stability using Osstell apparatus. **Results.** Of the 38 patients included in the study, there were 68.4% male patients and 31.6% female patients. The arithmetic mean of the measured bone density of all subjects in the study amounted to 536.2 HU. The arithmetic mean of dental implant primary stability for all subjects in the study was 68.7 ISQ. There was a statistically significant strong positive connection between HU and ISQ ($r = 0.744$, $p < 0.001$). Higher HU values were connected to higher ISQ values. In the multivariate linear regression model, statistically significant predictors of higher ISQ values: males ($B = 4.669$; $p = 0.047$) and higher HU values ($B = 0.032$; $p < 0.001$). **Conclusion.** In our clinical study, there was a statistically significant strong positive correlation between the bone density expressed in HU units, measured in the software of the CBCT device and the primary stability of dental implants expressed in ISQ units.

**Key words:**
**bone, density; tomography, computed, cone beam; implants, dental; treatment, outcome.**

**Apstrakt**

**Uvod/Cilj.** Postoje mnogobrojne studije o korisnosti kompjuterizovane tomografije (KT) u proceni volumena i morfologije kosti, kao i o odnosu između KT i primarne stabilnosti implantata. Međutim, malo je podataka o povezanosti gustine kosti i vrednosti primarne stabilnosti implantata. Cilj studije bio je da se ispita povezanost gustine kosti dobijene putem KT konusnim zrakom i vrednosti primarne stabilnosti. **Metode.** Klinička prospektivna eksperimantalna studija je obavljena kod 38 zdravih pacijenata sa nedostatkom jednog zuba u bočnoj regiji. Planirana je ugradnja samourezujućih *Bredent Blue Sky Narrow* dentalnih implantata dimenzija 3,5 × 10 mm. U preoperativnoj pripremi urađen je snimak KT konusnim zrakom na aparatu Planmeca, a zatim su u softveru aparata za KT konusnim zrakom (Romexis) izvršena preimplantološka merenja i planiranja. Srednja vrednost prosečne gustine kosti je automatski dobijena i izražena u Hounsfield jedinicama (HU). Nakon postavljanja implantata izvršili smo merenja primarne stabilnosti implantata pomoću Osstell aparata. **Rezultati.** Od 38 pacijenata uključenih u studiju, 68,4% je bilo muškog, a 31,6% ženskog pola. Aritmetička sredina izmerene gustine kosti svih ispitanika u istraživanju iznosila je 536,2 HU. Aritmetička sredina primarne stabilnosti dentalnih implantata svih ispitanika u istraživanju iznosila je 68,7 ISQ. Utvrđena je statistički značajna jaka pozitivna povezanost HU

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i ISQ ($r$ = 0,744, $p$ < 0,001). Više vrednosti HU bile su povezane sa višim vrednostima ISQ. U modelu multivarijantne linearne regresije statistički značajni prediktori viših vrednosti ISQ bili su: muški pol (B = 4,669; $p$ = 0,047) i više vrednosti HU (B = 0,032; $p$ < 0,001). **Zaključak.** U našoj kliničkoj studiji smo pokazali da postoji statistički značajna jaka pozitivna povezanost između gustine kosti izražene HU jedinicama, izmerene u softveru aparata za KT konusnim zrakom i primarne stabilnosti dentalnih implantata izraženih u ISQ jedinicama.

**Ključne reči:**
**kost, gustina; tomografija, kompjuterizovana, konusna; implantati, stomatološki; lečenje, ishod.**

## Introduction

Dental implants are used widely and routinely to treat partial or total edentulism [1]. The success of implant therapy depends on a number of factors that may be related to the patient as well as to implant placement procedures. Osseointegration is directly related to implant therapy. Primary implant stability can be used to estimate and predict the success of osseointegration [2–4]. Resonance Frequency Analysis (RFA) method, using Ostell Mentor apparatus, enables clinical measurement of implant stability and the monitoring of biological tissue response and osseointegration over time. The measured resonant frequency amplitude, i.e. the registered vibration generated by the pre-energized implant-mounted smartpeg magnet, is shown numerically and graphically on the analyzer, and its maximum represents the implant stability quantified through implant stability quotient (ISQ) units i.e. implant stability coefficient whose values can range from 0 to 100. The higher the ISQ, the more stable the implant [5].

The most significant factors affecting the primary implant stability are: implant design, surgical technique, bone quality and quantity [6].

Implant macro design plays an essential role in achieving adequate primary stability. Macro design entails implant type and thread design, as well as depth, width, density, angle and thread shape. The difference in primary stability between self-tapping implants, characterized by sharp thread edges and non-self-taping implants, whose threads have a rounded profile [7], as well as implants with parallel walls [8], is particularly noteworthy.

Bone density plays an important role in the success of implant therapy [9]. For this reason, evaluation of bone tissue density stands as an integral part of pre-implant clinical and radiographic examination. The introduction of cone beam computer tomography (CBCT) represents a significant progress in the use of computed tomography [10].

Unlike the classifications based on the subjective assessment of the given criteria according to Misch [11], and Lekholm and Zarb [12], Norton and Gamble [13] proposed bone density classification based on computed tomography (CT) images using interactive software, where bone quality data at the future implant site are obtained based on objective and quantitative result expressed in Hounsfield units (HU). HU unit represents a qualitative radiolucency measure of different tissues at CT. HU scale ranges from – 1,000 (air), 0 (water) to + 1,000 (bone), where the value of this unit depends on the tissue density through which the X-rays pass.

Clinical studies showed higher survival rate for dental implants placed in the mandible [14–16]. The available literature shows studies with a lower survival rate for implants placed in the maxilla [17, 18]. A higher failure rate was recorded in immediate implants placement in maxilla [19]. It is believed that a deviation in survival rates of implants located in the maxilla and mandible results from the bone condition around the implant. It is obvious that, compared to the maxilla, the bone in mandible around the implant has a better volume and quality [20].

Some studies have shown that in lower bone density, type 3 and type 4 according to Lekholm and Zarb bone classification, using self-tapping implants in combination with modified implant bed preparation can achieve superior primary stability compared to classical surgical technique with non-self-tapping implants [20].

In literature, there are numerous studies on the usefulness of CT in terms of the assessment of the bone volume and morphology [21–23] as well as several clinical studies on the relationship between CT values and primary implant stability [24, 25]. However, there have not been a sufficient number of clinical studies attempting to determine the correlation between bone density and the value of primary implant stability [26–29].

The aim of this study was to examine the correlation of CBCT analysis derived bone density with the primary stability value.

## Methods

This study was approved by the Institutional Review Board of the Public Health Institution, Clinical Center of Podgorica, Montenegro (No. 0301-4536/1) and written consents were obtained from all subjects. Clinical prospective experimental study was conducted on 38 healthy patients missing one tooth in the lateral region without defects and augmentation, indicated for implant placement under favorable conditions.

The study inclusion criteria were: missing one tooth in the premolar region and/or molar region of the upper and lower jaw, height of the alveolar ridge ≥ 11 mm and width 6 ≤ mm, the remaining teeth repaired together with a signed statement of consent for the procedure as well as completed and signed questionnaire about the patient's health.

The study exclusion criteria were: health conditions contraindicated for the execution of a surgical procedure, pronounced alveolar ridge atrophy, presence of parafunctions and poor oral hygiene.

In all 38 patients missing one tooth, who met the requested criteria, it was planned to install Bredent Blue Sky Narrow self-taping dental implants with dimensions 3.5 × 10 mm. During the preoperative preparation, a CBCT scan was performed on Planmeca apparatus, followed by pre-implantation measurements and planning in the CBCT apparatus software (Romexis).

The above mentioned CBCT apparatus software enables the volume of bone tissue density to be analyzed at the site of a virtually positioned implant. The bone volume limits for analyzing bone density surrounding the virtually positioned implant are set to include 1 mm of bone around the implant. After setting the bone volume limits for analysis, the mean value of the average bone volume is automatically generated and expressed in HU (Figure 1).

The implants were mechanically placed with a torque of 35 N/cm$^2$ (Figure 2). Upon implant placement, we performed measurements of the primary implant stability using Osstell apparatus. There was the following procedure with Osstell apparatus: appropriate Smartpeg is placed on the implant, in this case type 49 and tightened manually. The Osstell mentor probe is placed with Smartpeg in 4 positions (buccal, oral, mesial and distal) and the primary stability mean value is calculated (Figure 3).

*Statistical analysis*

For the analysis of primary data we used descriptive statistical methods, methods for testing statistical hypotheses, methods for examining correlation and methods for examining the relationship between the outcome and potential predictors. Depending on the type of variables, the descriptive data are displayed as n (%) and as mean ± standard deviation (SD) or median (range). The *t*-test was used to test the statistical hypothesis. To test the correlation between two variables, the Pearson linear correlation coefficient was used. The

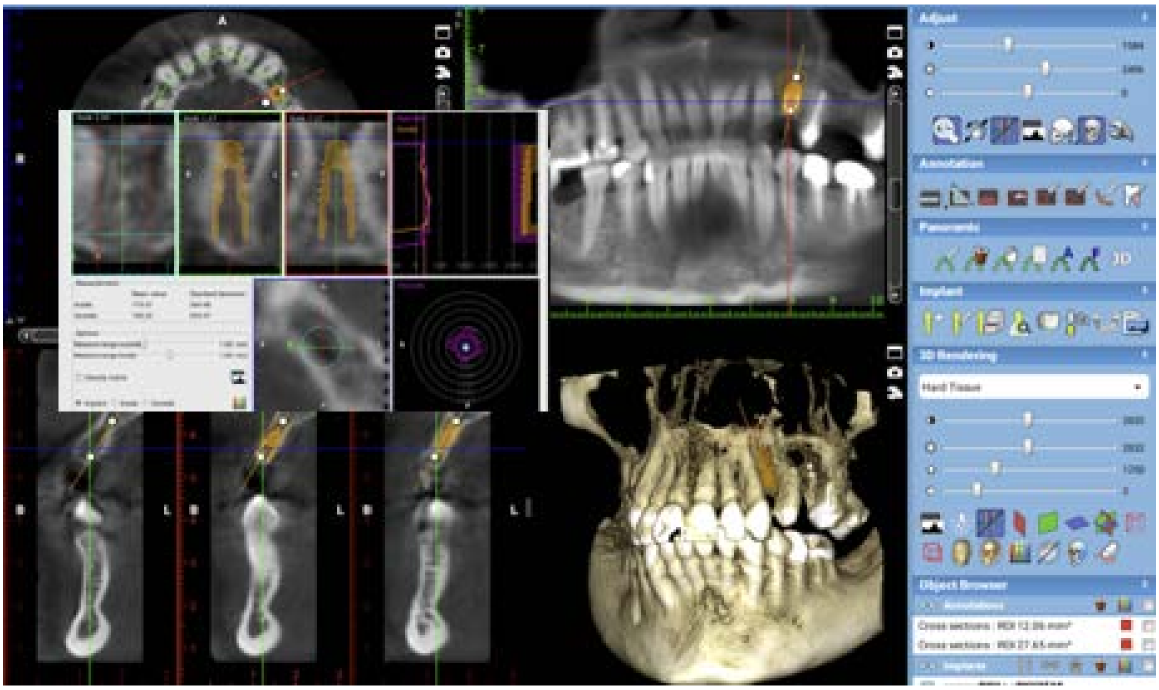


**Fig. 1 – Virtual implant placement planning and bone density measurement.**

**Fig. 2 – Implant site preparation.**

**Fig. 3 – Primary stability measurement by Ostell mentor.**

linear regression was used to investigate the relationship between ISQ and potential predictors. Statistical hypotheses were tested at a statistical significance level of 0.05. The obtained data were statistically processed to obtain a correlation between the mean value of the bone density and the value of primary stability of the placed implants.

## Results

Of 38 patients included in the study, there were 68.4% male patients and 31.6% female patients. A total of 19 implants were placed in the lateral mandible region and 19 in the lateral maxilla region (Table 1).

**Table 1**

**Distribution of subjects by gender and implantation jaw**

| Gender | Mandible | Maxilla | Total |
|---|---|---|---|
| Male | 15 (78.9) | 11 (57.9) | 26 (68.4) |
| Female | 4 (21.1) | 8 (42.1) | 12 (31.6) |
| Total | 19 (100.0) | 19 (100.0) | 38 (100.0) |

**All values are expressed as numbers (percentages).**

The average age of all subjects in the study was 44.6 ± 6.8 years. The youngest subject was 33 years old and the oldest 57 years. A total of 81.6% of subjects were under 50 years of age and 18.4% of patients were over 50 years old (Table 2).

**Table 2**

**Distribution of subjects by age and bone density**

| Age (years) | n | Bone density (HU) | |
|---|---|---|---|
| ≤ 50 | 31 | 555.1 ± 159.7 | 526.3 (350.5–944.7) |
| > 50 | 7 | 452.3 ± 105.4 | 443.2 (337.6–594.4) |

**Values are expressed as mean ± standard deviation and median (minimum–maximum).**

The arithmetic mean of the measured bone density of all subjects in the study amounted to 536.2 HU [95% confidence interval (CI): 485.1–587.2] (Figure 4).

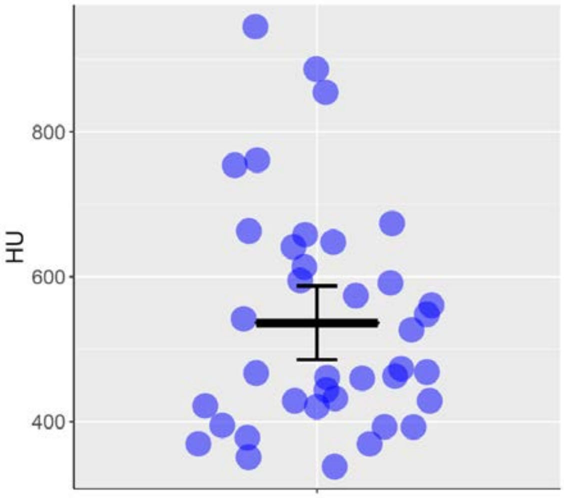


**Fig. 4 – Hounsfield unit (HU) values in research subjects.**

The arithmetic mean and standard deviation of bone density in the mandible was 642.6 ± 146.8 HU, while in maxilla it was 429.8 ± 64.3 HU, which was a statistically significant difference ($t$ = 5.789; $p$ <0.001). Significantly higher HU values were recorded in the mandible (Table 3).

**Table 3**

**Jaw bone density of research subjects**

| Implantation jaw | n | Bone density (HU) | |
|---|---|---|---|
| Mandible | 19 | 642.6 ± 146.8 | 640.7 (420.1–944.7) |
| Maxilla | 19 | 429.8 ± 64.3 | 428.4 (337.6–591.0) |

**Values are expressed as mean ± standard deviation and median (minimum–maximum).**
**HU – Hounsfield units.**

The arithmetic mean of dental implant primary stability for all subjects in the study was 68.7 ISQ (95% CI 65.8–71.5) (Figure 5).

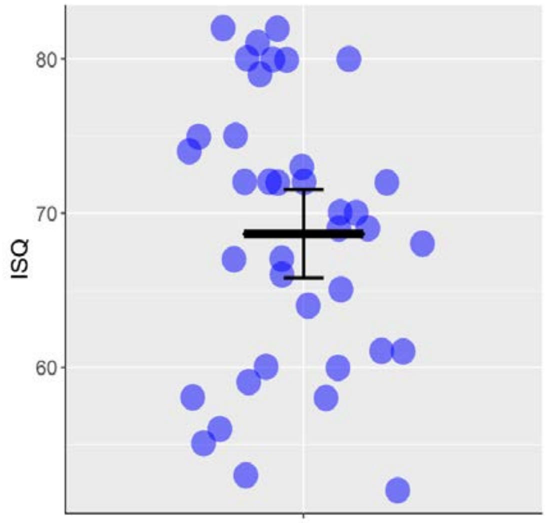


**Fig. 5 – Implant stability quotient (ISQ) values.**

The arithmetic mean and standard deviation of the dental implants primary stability in the mandible amounted to 73.2 ± 8.1 ISQ, while in maxilla it was 64.2 ± 7.0 ISQ, which ws a statistically significant difference ($t$ = 3.673; $p$ = 0.001). Significantly higher ISQ values were found in the mandible (Table 4).

**Table 4**

**Jaw bone implant stability quotient (ISQ) of research subjects**

| Parameter | n | Implant stability quotient | |
|---|---|---|---|
| Mandible | 19 | 73.2.6 ± 8.1 | 73.0 (53.0–82.0) |
| Maxilla | 19 | 64.2 ± 7.0 | 64.0 (52.0–75.0) |

**Values are expressed as mean ± standard deviation and median (minimum–maximum).**

There was a statistically significant strong positive connection between HU and ISQ ($r$ = 0.744, $p$ < 0.001). Higher HU values were connected to higher ISQ values (Figure 6).

The model of multivariate linear regression with ISQ as a dependent variable included those predictors that were statistically significant in the model of univariate linear regression at a significance level of 0.05.

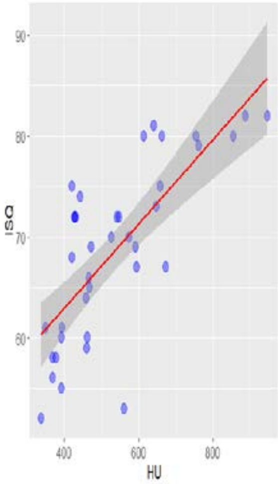


**Fig. 6 – Bone density (HU) and implant primary stability (ISQ) ratio.**

The model contains 4 predictors listed in Table 5. The entire model (with all predictors) was statistically significant ($p < 0.001$). The model explains 63% of the variance of the dependent variable. There was no multicollinearity between predictors.

**Table 5**

**Multivariate linear regression with ISQ as a dependent variable**

| Independent variables | Univariate linear regression | | Multivariate linear regression | |
|---|---|---|---|---|
| | B | *p* | B | *p* |
| Jaw (lower *vs* upper) | 9.000 | 0.001 | 0.138 | 0.959 |
| Gender (male *vs* female) | 10.096 | < 0.001 | 4.669 | 0.047 |
| Age (up to 50 *vs* over 50) | 7.811 | 0.031 | 3.782 | 0.141 |
| Hounsfield units | 0.042 | < 0.001 | 0.032 | 0.001 |

In the multivariate linear regression model, statistically significant predictors of higher ISQ values were: males (B = 4.669; $p = 0.047$) and higher HU values (B = 0.032; $p < 0.001$) (Figure 7).

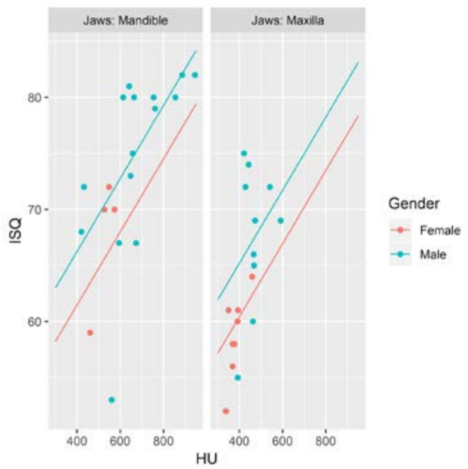


**Fig. 7 – Predictors to implant stability quotient (ISQ) ratio.**

**Discussion**

To analyze bone density in this study, we used software analysis based on CBCT imaging.

According to the Norton and Gamble classification, the software-measured bone density at the implant site which is above + 850 HU corresponds to Q1 bone quality according to Lekholm and Zarb and is typical for mandible anterior region. Bone density between +500 and + 850 HU corresponds to Q2 and Q3 bone quality in the posterior mandible and anterior maxilla, while the bone density from 0 to 500 corresponds to Q4 bone quality in the posterior maxilla [30].

Bone density obtained by software analysis in our study of the posterior maxilla was 429.8 HU, which corresponds to Q4 bone quality, and in the posterior mandible region it was 642.6 HU, which corresponds to Q2 and Q3 bone quality which is expected in these regions according to literature.

Several studies have reached similar or slightly higher results of the average bone density in maxilla and mandible compared to our research. Since our research was performed in lateral regions, we believe that this slightly greater bone density found in studies of these authors results from the frontal jaw regions or greater differences in the distribution of subjects' genders [31–35].

The average value of bone density in lateral regions of both jaws, measured in 38 subjects was 536.16 HU. Our results are similar to the results obtained in a clinical study where the arithmetic mean of the average bone density in the posterior regions of maxilla and mandible was 568.5 HU [31].

According to a similar clinical study conducted on a sample of 108 subjects, the mean bone density in the posterior maxilla was 459 HU and in the posterior mandible it was 669 HU. As it was the case in our study, a significant statistical correlation between bone density expressed in HU units and primary implant stability was observed. These authors conclude that bone density values from preoperative CT examination may provide an objective assessment of bone quality, and significant correlations between bone density and implant stability parameters may help clinicians to predict primary stability before implant insertion [27].

In our study, we used a noninvasive resonance frequency analysis (RFA) with Ostell device to measure the primary stability of dental implants. The measurement was performed immediately after the placing of implants, and the average primary implant stability immediately after the implantation was 68.7 ISQ. The average value in the mandible was 73 ISQ, while in the maxilla it was 64 ISQ.

Predictors that were statistically significant in the model of univariate linear regression were included in our research as a model of multivariate linear regression with ISQ as a dependent variable. In the multivariate linear regression model, statistically significant predictors of higher ISQ values were male gender and higher HU values.

In the clinical study, primary stability measured immediately after the implantation in the posterior mandible was 65 ISQ, while in the posterior maxilla it was 60 ISQ [32].

In the clinical study, the average primary stability value in maxilla was 72 ISQ, while in mandible it was 75.8 ISQ [31].

According to a clinical study conducted on 125 patients with type II bone, self-tapping implants showed greater primary stability with 73 ISQ, in type III bone the self-tapping implants recorded ISQ of 74, and for type IV bone, the implant value was 66 ISQ [8].

In the literature, different results of the primary implant stability of numerous clinical studies can be explained by various factors that affect the stability of implants. Different design of implants was used as well as various placement techniques and different toothless regions with different quality and quantity of bone.

The most important factors affecting the primary implant stability are: implant design, surgical technique, bone quality and quantity [6].

## Conclusion

We showed that there was a statistically significant strong positive correlation between the bone density expressed in HU units measured in the software of the CBCT device and the primary stability of dental implants expressed in ISQ units. Higher HU values were related to higher ISQ values.

## Conflict of interest

None of the authors had any conflict of interest for this study.

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