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Original Article

Evaluation of bone density by cone-beam computed tomography and its relationship with primary stability of dental implants

Sina Haghanifar[1], Ali Malekzadeh Shafaroudi[2], Pegah Nasiri[2], Mostafa Mirzaie Amin[3], Javad Mehrani Sabet[4,5]

[1]Department of Oral and Maxillofacial Radiology, Faculty of Dentistry, Babol University of Medical Sciences, Babol, [2]Dental student, Student Research Committee, Faculty of Dentistry, Mazandaran University of Medical Sciences, [4]Assistant professor, Department of Periodontics, Faculty of Dentistry, Mazandaran University of Medical Sciences, [5]Department of Tissue Engineering and Regenerative Medicine, School of Advanced Technologies in Medicine, Mazandaran University of Medical Sciences, Sari, [3]General Dentist, Iran

ABSTRACT

Background: One of the critical factors determining the success of dental implants is primary stability. This study aimed to determine the density of jawbones in the implant candidate sites via cone-beam computed tomography (CBCT) and its correlation with the values obtained from resonance frequency analysis during surgery.

Materials and Methods: In this descriptive-analytic study seventeen implant sites requiring implant placement were selected. Impressions were sent to the laboratory to construct a surgical guide via the stereolithographic method. An electronic surgery was performed on the chosen implant sites according to each patient's CBCT information entered into the Kaveh surgical guide software. The bone density of the target areas was calculated using the gray value (voxel value). After preparing the final osteotomy, an implant was installed in the area according to the manufacture's recommendation. The relevant Osstell® SmartPeg was selected and installed on the implant body to determine the primary stability. Kolmogorov–Smirnov test and the correlation pearson correlation statistical test. used for statistical analyze. *P* value amounts < 0.05 was considered significant.

Results: The mean and standard deviation of the gray scale in this study were 563.7 ± 218.8 and 65.3 ± 7.7 implant stability quotient (ISQ) respectively. The correlation between gray scale and ISQ was evaluated by the Pearson correlation test, and the results indicated a strong correlation between the two variables.

Conclusion: The voxel value and primary stability had a normal distribution and strong correlation. In other words, the gray scale determined by CBCT imaging techniques at the proposed implant site could be used to assess the bone density before the surgery.

Key Words: Cone-beam computed tomography, dental implant, implant stability, resonance frequency analysis

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Address for correspondence: Dr. Javad Mehrani Sabet, Department of Periodontics, Faculty of Dentistry, Mazandaran University of Medical Sciences, Sari, Iran. E-mail: dr.J.Mehrani.S@gmail.com, j.mehrani@mazums.ac.ir

INTRODUCTION

Dental implants are among the most viable treatment options to provide the esthetic and function for the missing teeth.[1] Implant-based dental restorations are among the most successful treatments, and their

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long-term success is predictable.[2] A dental implant is a titanium alloplastic material surgically placed in the jawbone as a prosthetic base. Following the implant placement in the bone, a micromechanical connection is established between the body of the implant and the living bone, which is called osseointegration.[3] The success or failure of dental implants depends on the quality of the bone contact surface and the ability of the implant to transfer forces from the implant to the bone and provides initial stability.[4] Once the implant is placed in the bone, its initial stability is defined, which depends on the quality of the bone, the geometry of the implant, and the surgical procedure. If there is no looseness, the implant will have initial stability.[5] Therefore, primary implant stability is one of the critical factors for achieving osseointegration, and it is a prerequisite for immediate implant treatments.[6] Various methods have been proposed in studies to assess the initial stability of dental implants. Still, the prominent insertion torque (IT) and resonance frequency analysis (RFA) methods are used during implant insertion.[7]

The IT method examines the extent to which the bone is attached to the implant. One of the disadvantages of this technique is the possibility of being destructive due to the entry of unnecessary forces into the body of the implant being stowed and the lack of grading on the quantity and quality of the staging process. This method is characterized by the presence or absence of osseointegration.[8] RFA is a simple and noninvasive method to measure the stability of an implant at different time intervals. However, the IT method can only be used for implant placement during surgery. RFA measures the hardness and flexibility of the bone–implant complex.[9] The unit of measurement in this technique is called implant stability quotient (ISQ), which, if the recorded number ranges between 57 and 82 (average 69), it indicates the success of the implant, and a score <50 indicates a high risk for implant failure.[10]

Various studies have examined the relationship between implant density and RFA/IT values and the relationship between IT and RFA.[9-11]

After performing clinical examinations for a patient who is a candidate for dental implant treatment, the quantity and the quality of the bone at the implant sites must be assessed by radiographic examinations. Computed tomography (CT) scan is one of the most common radiographic techniques used to evaluate bone quality and quantity before performing surgery.[12] Determining the bone density or the quality based on the Hounsfield unit is one of the most important advantages of using this technique which is proportional to the degree of X-ray attenuation by the tissue, and it is shown by gray scale (voxel value). However, one of the most important disadvantages of CT scans in assessing those areas requiring an implant is the high dose of radiation imposed on the patient.[13] With the advent of cone-beam CT (CBCT), higher quality images with lower radiation doses can be produced. However, due to technical reasons such as calibration problems with various CBCT devices, the final results are not reliable.[14] This study aimed to investigate the density of jawbones at implant candidate sites using the Ondemand three-dimensional (3D) dental CBCT device and its relationship with the values obtained by the RFA method after inserting the implant in the jaw bone.

MATERIALS AND METHODS

In this descriptive-analytic study, 17 implant treatment sites were selected from a total of 3 patients (including one male and two females). The mean age of the patients was 48.6 3 ± 3.45. The inclusion criteria for entering the study included healthy individuals aged between 30 and 50 and those requiring implant treatments in the maxillary and mandibular areas. Conditions including a systemic bone disease such as osteoporosis, osteomalacia, Paget's disease, bone tumors, and systemic diseases that could weaken the immune system such as diabetes, blood diseases, and a history of antibiotic therapy in the last 6 months were determined as exclusion criteria in this study.

All patients were informed of how the study was performed, and they participated in the study after obtaining informed consent. After conducting clinical examinations of qualified patients, an impression was taken to fabricate a surgical guide via a stereolithographic printer as one of the fastest prototyping methods for each patient [Figure 1]. In the meantime, patients were referred to an oral and maxillofacial radiology center to obtain CBCT images of implant treatment areas. All CBCTs were obtained using Cranex 3D (Soredex/Helsinki/Finland) with a field of view of 8 × 6, high-resolution mode and by using Ondemand 3D Dental Software. Afterward, the information related to each patient's CBCT images and the images related to digital scanning of the

casts were uploaded into the Kaveh surgical guide software (Iran). In the next step, by assembling the patient's CBCT images and scanning the patient's cast, 3D models of implant treatment candidate areas were prepared using Kaveh surgical guide software.

Electronic surgical placement of implants was performed in the selected areas in the 3D model in the Kaveh surgical guide software platform. Prosthetic reconstruction of implants was performed and the final file of the implant placement site was sent to the virtual implant site for bone density assessment. In the software platform, the bone density at the area of each implant site was calculated by Ondemand 3D dental software, and the relevant numbers were recorded for each implant site.

One hour before the operation, each patient was given 2 g of amoxicillin and appropriate analgesia on the day of surgery. To produce anesthesia in those areas requiring implant surgery, a 4% articaine anesthetic carpule with epinephrine 1/100,000 (Septanest®, Septodont Inc., France) was used. After anesthesia, the crestal incision was made on the toothless ridge, followed by vertical incisions.

The flaps were then reflected by a periosteal elevator. Afterward, the surgical guide was placed on the toothless ridge. The initial osteotomy was performed to place the implant using a pilot drill. After completing the drilling process to the final diameter of the implants according to the manufacture' guidelines, the implants with the optimum predetermined dimeters were placed at their desired location. Finally, the surgical guide was removed.

The implants used were purchased from SIC (SICace®, Invent AG Inc., Switzerland), two of which were 3.4 mm in diameter, 12 of the others were 4 mm in diameter, and three had a diameter of 4.5 mm. All implants, except one of them having a 9.5 mm length, had a length of 11.5 mm.

Next, the SmartPeg of the Osstell® device was selected according to the diameter of the implant used and was installed on the body of the implant. Upon activating, the Osstell® piezoelectric device recorded the received frequency values in the form of numbers between 0 and 100 according to the ISQ unit, by creating a vibration in the body of the SmartPeg connected to the implants and recording the amount of response received from the body of the implant. The SmartPeg was then removed from the implant body. Depending on the situation, a cover screw or healing abutment was installed on the implant body, and the area was sutured using a Vicryl 4-0 suture (coated Vicryl®, Ethicon Inc. USA). The normality of the distribution in gray scale and ISQ was examined by the statistical test one-sample Kolmogorov–Smirnov test and the correlation between gray scale and ISQ was evaluated by Pearson correlation statistical test.

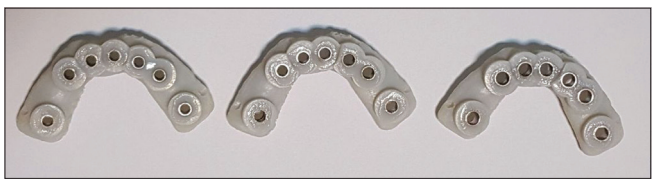

Figure 1: Surgical guide printed by a stereolithography printer.

Home instructions were given to the patients, and the sutures were removed 2 weeks later. After giving a 3–5 months healing period, the prosthetic phase of the treatment was undertaken.

RESULTS

In three patients, 17 implants were placed [Figures 2 and 3]. In the first patient, all implants were placed in the maxilla, and in the other two patients, the implants were placed in the mandible. The location of each implant in all patients was shown separately in the respective tables. The results showed that the initial stability values of the implant and bone density varied from patient to patient in different implant areas. For example, the initial stability of the implant in the first patient was 70, which was in the right canine area of the maxilla and the bone density was 528.8. The values of the gray scale and ISQ were reported separately for each patient and the implant site in Tables 1-3.

Table 1: The first patient (male) initial implant values in terms of ISQ and bone density values in terms of Hu

Implanted area	Primary stability (ISQ)	Bone density
Right maxillary first molar	53	233.9
Right maxillary second premolar	67	621
Right maxillary first premolar	59	385
Right maxillary canine	70	528.8
Right maxillary lateral	66	743.3
Left maxillary first molar	50	226
Left maxillary first premolar	61	431.5
Left maxillary canine	57	346.5
Left maxillary lateral	68.5	501.2

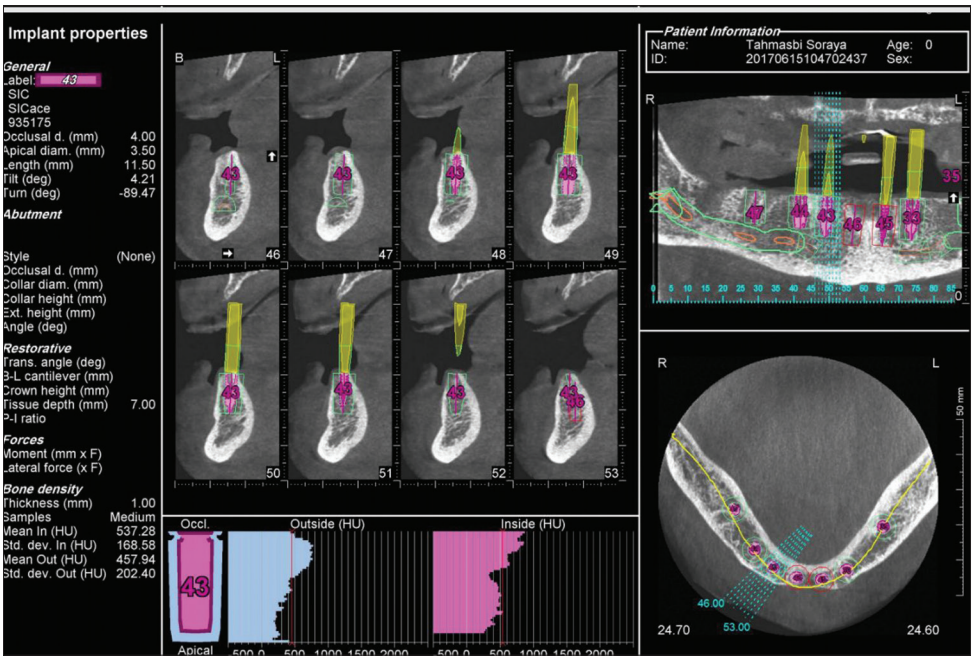

Figure 2: Radiographic view of the areas intended for implant placement and the grayscale value of the bone.

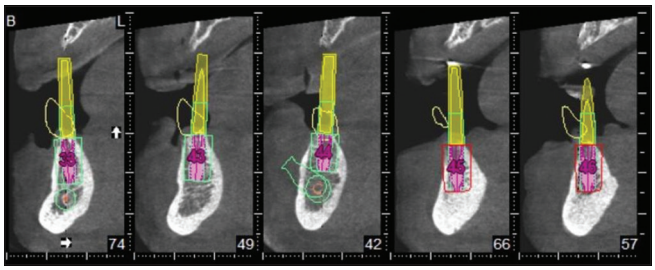

Figure 3: Sagittal view of the implant placement areas and the grayscale value of the bone.

The normality of the distribution in gray scale and ISQ was examined by the statistical test one-sample Kolmogorov–Smirnov test. This test showed that the distribution of both was normal (P = 0.849 and 0.625, respectively).

Based on mean and standard deviation results, gray scale and ISQ were measured 563.7 ± 218.8 and 65.3 ± 7.7, respectively. The results are also shown in Table 4.

The correlation between gray scale and ISQ was evaluated by Pearson correlation statistical test. The results showed a strong correlation between the two variables, and the correlation coefficient was 0.811 (P < 0.0001), of which 66.3% of ISQ changes can be predicted with grayscale values.

DISCUSSION

Primary successful stability is necessary for optimum osseointegration. Many factors, including bone density, implant geometry, surgical techniques, and the overall health conditions of the patient, can affect the primary stability and survival rates of dental implants.[15] The present study showed that the two variables, gray scale and ISQ, had a normal distribution and were strongly correlated [Figure 4]. Formerly, CT scans were used to evaluate preimplant surgery.[12] This technique had some advantages and disadvantages. The most important advantage of using this technique was determining the density or the quality of the bone based on the gray scale.[13] Mikić *et al*. also showed that the bone density in HU units assessed with CBCT was significantly associated with primary implant stability in ISQ units, consistent with the present study results.[16]

RFA is a simple, noninvasive intraoral procedure for measuring the stability of implants at different times and examining the implant interface.[9] Until 1996, several studies have shown that RFA analysis helped obtain objective implant stability.[17] However, there is inadequate evidence that Osstell® ISQ is reliable in measurement. Reliability is measured by the meanings of repeatability concepts (several attempts with one converter led to one result) and reproducibility (several converters on a single implant provide the same data). Several studies have reported similar approximate results of the average bone density in maxilla and mandible compared to the present study.

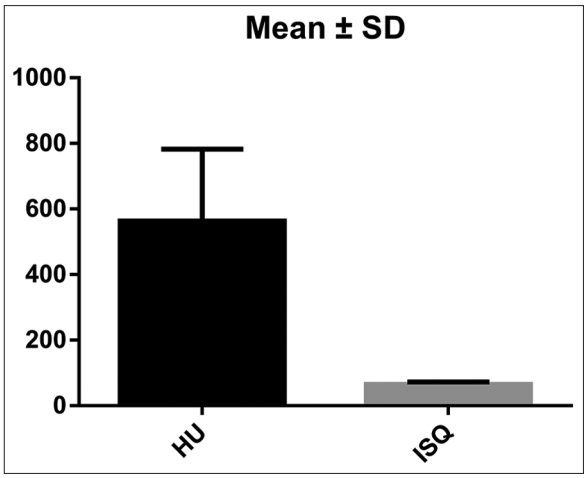

Figure 4: Mean ± standard deviation of gray scale (bone density) and implant stability quotient.

Salem *et al*. showed that at the beginning of implant placement, ISQ and grayscale values were 67.5 ± 5.8 and 683.48 ± 78.63, respectively, both of which are higher than the numbers reported in the present study. The authors also stated a positive relationship between grayscale and ISQ values, consistent with the present study results.[18] Herrero-Climent *et al*. examined the validity of the Osstell® device in determining the stability values of dental implants. Measurements were performed three times in a row using SmartPeg. They found that the stability of the implant at the third measurement had a statistically significant difference. The RFA system Osstell® ISQ is a repeatable and reliable method for determining the values of implant stability.[19]

In the present study, the RFA method was also used to evaluate the initial stability of the implant. According to the present study results, the ISQ scores were higher in the mandible than in the maxilla. This could be due to higher bone density rates in the mandible, resulting in better primary stability of implants placed in the mandible than the maxilla. Consistent with the findings of the present study, other clinical studies have concluded that dental implants have better primary stability and higher durability when placed in the mandible than the maxilla.[15] The primary stability of dental implants was significantly related to the thickness of the cortical bone. The maxillary bones mainly consist of a thick layer of trabecular bone covered with a thin superficial cortical bone, while the cortical bone is bulkier in the mandible.[20] Some studies report that ISQ values reduce in the case of crestal bone loss. Therefore, obtaining preapical radiographs seems to be necessary to evaluate more

Table 2: The second patient (female) initial implant values in terms of ISQ and bone density values in terms of Hu

Implanted area	Primary stability (ISQ)	Bone density
Left mandibular canine	71	548.9
Left mandibular lateral	66	708.6
Left mandibular second premolar	77	712.6
Right mandibular canine	66	457.9
Right mandibular lateral	60	395.4
Right mandibular second premolar	70	526.4
Midline of mandible	73	702

Table 3: The third patient (female) initial implant values in terms of ISQ and bone density values in terms of Hu

Implanted area	Primary stability (ISQ)	Bone density
Left mandibular first premolar	76	713

Table 4: Mean and standard deviation of grayscale and ISQ

Variables	Mean	Std. Deviation	N
HU	563/7	218/8	17
ISQ	65/3	7/7	17

accurate results.[21] In addition to bone density, surgical procedures, ITs, and various implant surface parameters also play an essential role in primary implant stability; several studies have suggested different techniques to increase primary stability and prevent resorption in the preimplant bone.[22,23] Therefore, low bone densities can be compensated by other factors to gain maximum implant primary stability. The benefit of the RFA technique is examining the state of the surrounding bone tissue of the implant at any stage of the treatment procedure. ISQ values could indicate a long-term prognosis of implants as implants with low ISQ levels after the primary healing period are more likely to fail.

CONCLUSION

The present study results showed that the two variables, gray scale and the initial stability of the implant, had a normal distribution, and there is a significant correlation between these two variables. The correlation coefficient was 0.811, of which 66.3% of the ISQ changes are predictable with grayscale values. Due to the limitations of the present study and the high correlation between the grayscale values

measured with ISQ, the Cranex 3D CBCT device could help assess bone density before implant surgery.

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Conflicts of interest
The authors of this manuscript declare that they have no conflicts of interest, real or perceived, financial or nonfinancial in this article.

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