Biomechanical Aspects of Primary Implant Stability: A Human Cadaver Study

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ABSTRACT

Background: The quality of bone is an important factor in the successful implant treatment, and it is evident that higher implant failure is more likely in poor quality of bone. The primary stability of oral implants related to resistance to micromotion during healing is influenced by bone quality, surgical technique, and implant design.

Purposes: The aims of this biomechanical study were to explore the effect of bone quality on initial intraosseous stability of implants, and to determine the correlations between the bone quality and implant stability parameters.

Materials and Methods: Twenty-four implants (Neoss Ltd., Mölnlycke, Sweden) were placed into anterior and posterior regions of three human cadaver mandibles. The bone densities of implant recipient sites were preoperatively determined using computerized tomography (CT) in Hounsfield unit (HU). The maximum insertion torque values were recorded, and primary implant stability measurements were noninvasively performed by means of resonance frequency analysis (RFA).

Results: The bone density values ranged from −267 HU to 553 HU. It was found that mean bone density, insertion torque, and RFA values were 113 ± 270 HU, 41.9 ± 5 Ncm, and 70 ± 7 implant stability quotient (ISQ), respectively. Statistically significant correlations were found between bone density and insertion torque values ($r = 0.690$, $p < .001$); bone density and ISQ values ($r = 0.557$, $p < .05$); and insertion torque and ISQ values ($r = 0.853$, $p < .001$).

Conclusion: CT is a useful tool to assess bone quantity and quality in implant recipient sites, and bone density has a prevailing effect on implant stability at placement.

KEY WORDS: bone density, CT, human cadaver, implants, implant stability, insertion torque, resonance frequency analysis

Clinical success of dental implants is influenced by both the quantity and quality of available bone as they vary from site to site and from patient to patient.[1] Clinical studies showed higher survival rates for implants placed in the anterior region of the mandible with good bone quality and quantity.[2–5] Therefore, an accurate evaluation of bone structure might be necessary prior to implant placement.

Several bone classification systems have already been introduced.[6,7] Lekholm and Zarb[6] classified bone density radiographically into four types, based on the amount of cortical bone versus trabecular bone. Misch[7] related bone density to the clinical hardness of the bone as subjectively perceived during drilling prior to implant placement.

Computerized tomography (CT) is an established method for acquiring bone images before oral implant surgery.[8] It was also used for objective quantification of trabecular and cancellous bone mineral densities, and direct density measurements, expressed in Hounsfield units (HU).[9–11]

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An insufficient primary stability causes poor healing related to the early loss of the implant.[12] The main two factors affecting implant stability are the location and the stiffness of the implant in the surrounding tissue. The stiffness can be considered in three ways: (1) the stiffness of the implant components themselves associated with the geometry and material composition; (2) the stiffness of the implant–bone interface; and (3) the stiffness of the bone itself associated with the trabecular/cortical bone ratio and bone density.[13]

Noninvasive clinical test methods (insertion torque, vibration methods) and invasive research test methods (removal torque) are available for implant stability measurements.[14] The insertion torque method recording the torque during implant placement provides valuable information on the local bone quality.[15] Another quantitative noninvasive clinical method for implant stability is the resonance frequency analysis (RFA) technique.[16]

Few studies have reported on the use of CT in relation to oral implants,[17,18] and the relation between bone density recordings and initial implant stability.[19,20] However, only one clinical study[21] searching the correlations between the bone density and the insertion torque, and the implant stability values is available in the literature.

The objectives of this study were to evaluate (1) the variations in bone quality in implant recipient sites using HU density recordings from CT and (2) torque resistance during implant placement and RFA immediately after implant placement and to explore possible correlations among all three parameters. In addition, the bone density, insertion torque, and RFA values were compared between anterior region and posterior region.

MATERIALS AND METHODS

Cadavers

For this study, three completely edentulous mandibles of formalin-fixed human heads of subjects who had donated their bodies for scientific research to the Department of Anatomy, Faculty of Medicine, University of Hacettepe, Turkey, were selected. No detailed systemic and/or dental history is available. The mandibles were screened fastidiously and gently retrieved from skulls. All soft tissues were carefully cleaned from the mandibles.

Figure 1 Preparation of implant sockets.

Implant Placement

Twenty-four titanium screwed-type Neoss™ implants (Neoss AB, Mölnlycke, Sweden) were used in the present study. This self-tapping implant had an altered rough surface and double thread design.

All implants were inserted by one author (I.T.) according to the manufacturer's instructions by using a final twist drill of 3.4 mm diameter. A screw tap was utilized for each implant socket preparation (Figure 1). No countersink preparation was made, and all implants were placed using an OsseoSet™ motor (Nobel Biocare AB, Göteborg, Sweden). The implants were inserted into central, canine, second premolar, and second molar teeth positions in both sides, thus, each mandible received eight implants. The distribution of implants included 12 anterior sites (central and canine positions) and 12 posterior sites (second premolar and second molar positions).

Acquisition of CT Images

CT machine (Siemens AR-SP 40, Munich, Germany) was used for preoperative evaluation of each mandible. Gutta-perchas of 1 mm thickness producing radiopaque view were attached to the mandibles to determine implant recipient sites before CT scan (Figure 2). The rectangular implant-receiving area of each implant placed was plotted on the sagittal images with a tool included to the CT machine,[21] and the mean bone density of the implant area including 1 mm surrounding bone was measured using a provided software (Siemens Somaris/4, Erlanger, Germany) with the CT machine

Figure 2 Human cadaver mandible with gutta-perchas determining implant recipient areas prior to computerized tomography scan.

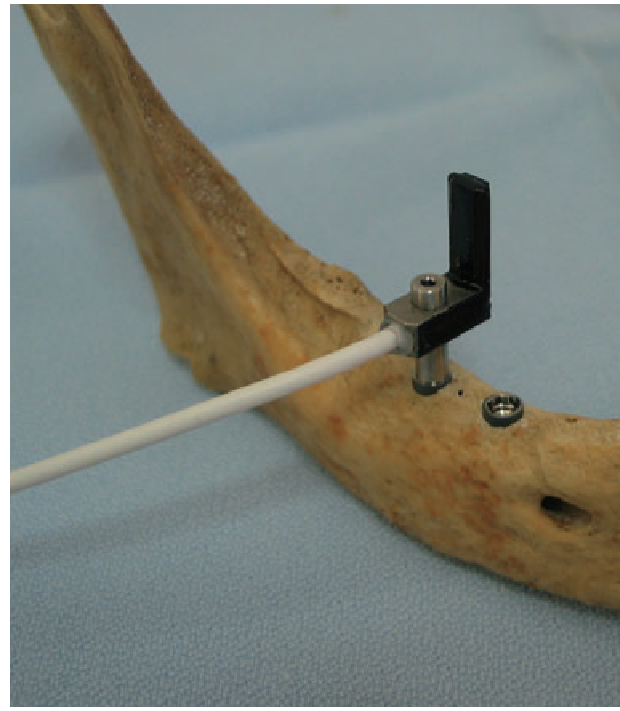

Figure 4 Resonance frequency measurement of the implant immediately after placement.

(Figure 3). The bone density measurements were given in HU. High HU values mean high bone density, whereas low HU values mean low bone density.

Insertion Torque Measurements

The final peak insertion torque of each implant was recorded with the OsseoSet motor. The motor was set to 30 Ncm and then gradually increased to 35, 40, 45, and 50 Ncm until the implant was fully seated.

Implant Stability Measurements

Following implant insertion, primary stability was evaluated with RFA (Ostell™, Integration Diagnostics AB, Göteborg, Sweden) (Figure 4). This method involves the use of an L-shaped transducer designed as a simple offset cantilever beam. The transducer was screwed manually to each implant orthoradially with the upright part on the oral side and vibrated with a sine wave. RFA values are derived from the stiffness (N/µm) of the implant/bone system and the calibration parameters of the transducer. High implant stability quotient (ISQ)

A B

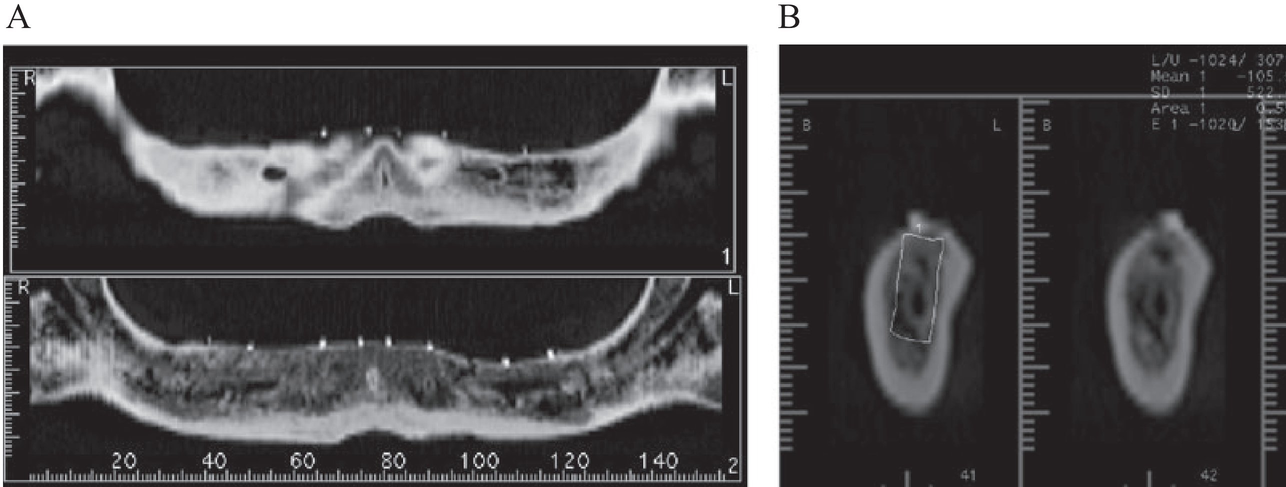

Figure 3 Frontal (A) and sagittal computerized tomography views with bone density measurement (B) of the mandible.

value indicates high stability, whereas low value indicates a low implant stability.

Statistical Analysis

General analysis of the raw data was performed with SPSS statistical software (SPSS Inc., Chicago, IL, USA). Differences in bone density, insertion torque, and ISQ values between anterior and posterior regions were evaluated using nonparametric Mann-Whitney test. Spearman's test was utilized to evaluate the correlations among bone density, insertion torque, and implant stability values at implant placement. Differences were considered significant when p values less than 0.05 were observed.

RESULTS

The mean bone density, insertion torque, and RFA values of all implants were 113 ± 270 HU, 41.9 ± 5 Ncm, and 70 ± 7 ISQ, respectively. Statistically significant correlations were found between bone density and insertion torque values ($r = 0.690$, $p < .001$), bone density and RFA values ($r = 0.557$, $p < .05$), and insertion torque and RFA values ($r = 0.853$, $p < .001$) (Figure 5).

Statistically significant differences in the mean bone density of the implant sites were observed between the anterior and the posterior regions of the mandibles ($p < .05$, Mann-Whitney). In addition, when compared to the posterior region, higher insertion torque ($p < .05$) and RFA values ($p < .05$) were observed in the anterior region (Table 1).

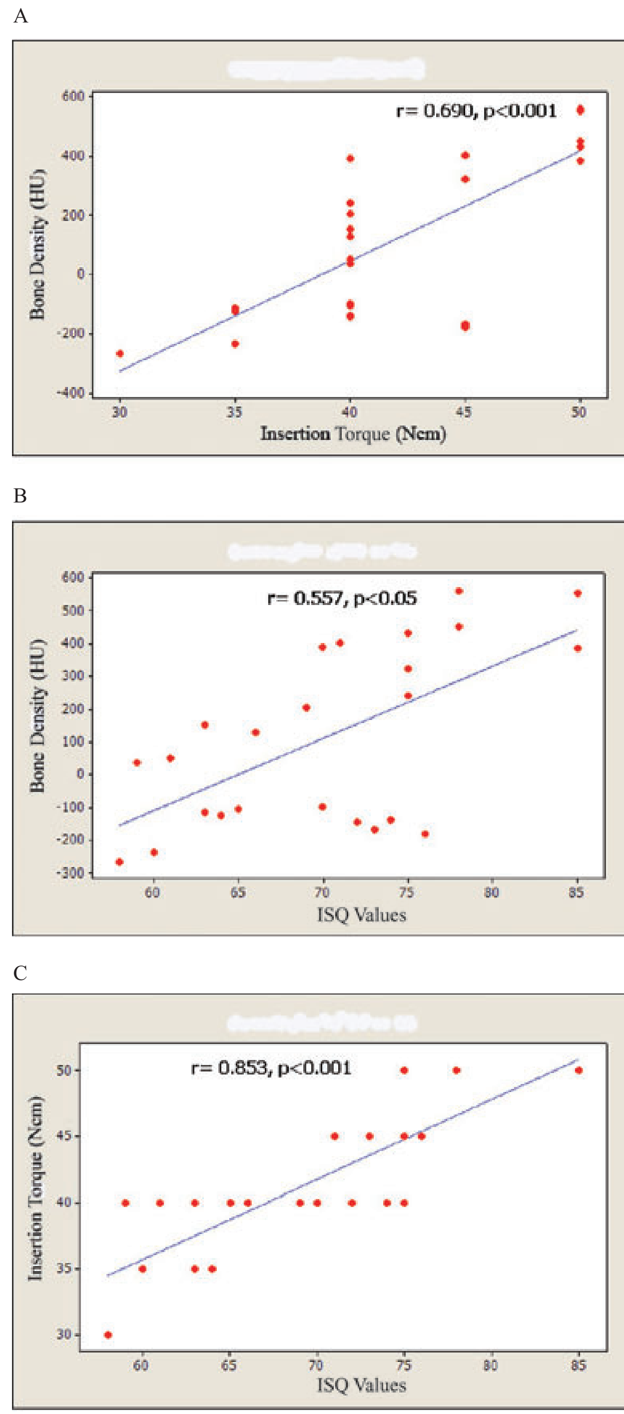

Figure 5 Scatter plots of bone density versus insertion torque (A), bone density versus implant stability quotient (ISQ) values (B), and insertion torque versus ISQ values (C).

DISCUSSION

The successful results of any implant procedure require a series of patient-related and procedure-dependent parameters. The volume and quality of the bone, which determine the type of surgical procedure, and the type of the implant are associated with the success of dental implant surgery.[22] The human postmortem mandibles used in this study were good representations of an actual clinical situation where degree of variance in bone quality would have had a significant biomechanical impact on treatment planning and prognosis. Although the cadavers were suitable for assessment of initial stability,[23] the results achieved in human cadavers may not be completely relevant for clinical situations.[13]

Owing to mechanical feature of bone is an important factor in the successful osseointegration, several classification methods were suggested for assessing bone quality.[6,7,24] Lekholm and Zarb[6] suggested a bone classification based on macrostructure where morphology and distribution of cortical and trabecular bone determine the quality, while Misch[7] described density-related macrostructure bone classification in which subjective tactile sense in drilling establishes the quality of bone

TABLE 1 Results from Measurements (Mean ± SD)

Implant Locations	Bone Density (HU)	Insertion Torque (Ncm)	Resonance Frequency Analysis (ISQ)
Anterior region	191 ± 279	44.2 ± 4	73.5 ± 3
Posterior region	36 ± 249	39.5 ± 6	66.8 ± 9

HU = Hounsfield unit; ISQ = implant stability quotient.

density. Friberg and colleagues[24] suggested a cutting resistance procedure providing a composite value for mechanical characteristics in predicting bone quality for initial stability. However, these classifications and procedures for assessing bone have some limitations as mechanical competence in terms of mass, structure, and material is not well addressed. An image-based bone density classification utilizing gray scale values through CT has lately been proposed.[10]

It is well known that primary stability of implants depends on surgical techniques applied, bone density, and implant design.[14] Primary implant stability has a principal role in successful osseointegration.[12] Maintenance of low implant micromovement, especially in early healing periods, presents importance in promotion of direct bone ingrowth to implant surface.[25] Therefore, achievement of optimum primary implant stability during surgical placement is cardinal. Regardless of implant design and surgical technique, bone quality has a clear influence on primary implant stability. Insertion torque, ISQ, and periotest values are widely used for primary implant stability measurements.[15,16,26] However, periotest values are not sensitive enough to determine implant stability, while recent studies confirmed the reliability of ISQ values in implant stability.[18,21]

When oral implants are placed with a two-stage surgical technique, good and predictable outcomes are well documented.[27] Recent studies regarding immediate/early loading protocols have shown promising results.[28] A relatively new challenge with oral implants is the paradigm shifts in loading protocols because of increased patient/clinician expectations to shorten the treatment time. Limiting micromovement to certain levels is vital in achieving osseointegration especially when peri-implant bone interface is subjected to mechanobiologic stimulation by immediate/early loading protocols. In this regard, the type and magnitude of loading may influence the ongoing healing process, and in some cases, this may cause demineralization of the bone–implant interface, loss of stability, and eventually implant failure.[29] Therefore, when immediate/early loading is taken into consideration, accuracy in predicting initial implant stability has become more critical.

The findings in the present study are comparable with those in the previous reports regarding human cadavers.[9,18,20,30,31] A 72-year-old male cadaver had been used in a study by Fanuscu and Chang.[30] They reported the bone density values ranged from 51 to 529 HU in the mandible, and from 186 to 389 HU in the maxilla. Shahlaie and colleagues[9] reported the bone density from nine human cadaver values varied between 18 and 1, 265 HU with a mean of 457 HU. The mean bone density recorded in the present study was lower than those reported previously.[9,30] This difference might come from the distribution of the sites, the variations in the age, and the gender of patients.

In addition, it was determined that there were significant correlations between bone density and insertion torque values, bone density and ISQ values, and insertion torque and ISQ values, which concurred the previous reports with different types of implants.[18,20,31] The study by Homolka and colleagues[18] included 25 Brånemark® Mk III implants, and they reported strong correlations between bone mineral density values from CT and insertion torque values. Beer and colleagues[20] also found similar findings with the same type of 45 implants placed in eight human cadaver mandibles. Akca and colleagues[31] observed significant correlation between insertion torque and ISQ values for Straumann and Astra Tech implants placed into edentulous maxilla and mandible of a human cadaver.

A clinical study by Alsaadi and colleagues[15] included a total of 761 Brånemark TiUnite™ implants placed in 298 patients, but RFA values using an Osstell™ Mentor instrument were recorded from only 136 implants. They found significant correlation between placement torque and RFA values for these 136 implants, and also between bone quality determined by Lekholm and Zarb index and placement torque for 719 implants, which are in agreement with the present data.

Under the limitations of this human cadaver study, the following conclusions can be drawn:

1. Bone density certainly influences implant stability at placement, thus predicting that initial implant stability is possible using CT scans prior to implant placement.
2. Both RFA and insertion torque measurements are effective methods to assess implant stability and provide valuable information about implant stability.

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