Influence of Defect Depth on Resonance Frequency Analysis and Insertion Torque Values for Implants Placed in Fresh Extraction Sockets: A Human Cadaver Study

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ABSTRACT

Background: Clinical studies show promising outcomes with implants inserted at the time of extraction. However, this often results in an initial bone defect at the marginal region which preferably should heal for an optimal function. Therefore, monitoring of these implants is vital.

Purposes: The aims of this study were to determine the initial stability of implants placed into fresh extraction sockets, and to explore the correlations between the peri-implant bone levels and implant stability parameters.

Materials and Methods: Six human cadaver mandibles including all natural teeth were selected for this study. All natural teeth were gently extracted, and 84 implants were immediately placed into fresh extraction sockets with five different implant depths. The maximum insertion torque values were recorded, and primary implant stability measurements were performed by means of resonance frequency analysis (RFA). The vertical distance between implant/abutment junction and the first bone–implant contact was recorded using a periodontal probe.

Results: It was found that the insertion torque and RFA were 28.9 ± 7 Ncm and 65.6 ± 9 implant stability quotient (ISQ), respectively, for 420 measurements from all 84 implants. Statistically significant correlation was found between insertion torque and ISQ values ($r = 0.86$; $p < .001$) for all implants. Both insertion torque and ISQ values dramatically decreased when the amount of peri-implant vertical bone defect increased.

Conclusion: The results of this study demonstrated a linear relationship between peri-implant vertical bone defect depth and RFA value. It is proposed that the RFA method is sensitive to detect changes of the marginal bone level and may be used to monitor healing of peri-implant bone defects.

KEY WORDS: human cadaver, implants, insertion torque, resonance frequency analysis, tooth extraction

Several clinical studies have demonstrated good clinical outcomes for implants placed in fresh extraction socket sites.[1–3] The implant placement at the time of tooth extraction has several advantages: a reduction in the overall treatment time with fewer surgical procedures and a lower rate of morbidity, a lowering in treatment cost, and prevention of initial bone loss.[4,5]

The placement of dental implants directly into extraction sockets also presents specific challenges because of the geometric discrepancy between the

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extraction socket and the implant design,[3,6] and thus firm initial implant stability is probably more difficult to achieve in this situation. One of the most crucial factors for uneventful bone tissue differentiation around immediately loaded implants is a stiff bone-implant interface, allowing low implant micromovement in bone.[7] When considering immediate loading for immediately placed implants, the mechanical properties of the interface are of utmost importance because an initial bone defect at the marginal region always occurs,[8,9] and this bone defect increases the crown/implant ratio and theoretically leads to higher bending movements on the implant. Therefore, immediate loading for immediately placed implants has frequently been considered for splinted implants.[10,11]

The resonance frequency analysis (RFA) technique measures implant stability as a function of stiffness of the bone/implant complex. The measured resonance frequency (RF) (in Hz) of a transducer which is attached to the implant is transformed to an implant stability quotient (ISQ) value. Implant stability is typically measured in the range from 45 to 85 ISQ. Initial implant stability is in great part determined by the bone density at the site.[12] However, the RFA technique is also sensitive to the effective implant length above the bone crest. This means that when the distance from the transducer to the first bone contact increases, the RF and ISQ value decrease in a linear fashion.[13] This suggests that the technique may be sensitive to monitor healing of peri-implant defects. Insertion torque measurements have been demonstrated to provide valuable information about bone density at the implant site and to some extent about implant stability.[14–16]

The aims of this study were to explore the initial intraosseous stability of implants immediately placed into fresh extraction sockets and the correlation between peri-implant bone levels and implant stability parameters.

MATERIALS AND METHODS

Cadavers, Implants, and Surgical Procedures

This study was undertaken in six formalin-fixed human heads of subjects who had bequeathed their bodies for scientific research to the Department of Anatomy, Faculty of Medicine, University of Ankara and Hacettepe. The human cadaver mandibles with all natural teeth have been obtained from men, and no further systemic and/or dental history is available. Six mandibles with all natural teeth were screened meticulously and gently dearticulated from skulls. All soft tissues were cleaned from the mandibles (Figure 1). All natural teeth have been carefully extracted, preserving the alveolar bones (Figure 2). Six mandibles with minimum alveolar bone height and width necessary to insert 4 × 11 mm dental implants were supplied.

Figure 1 Human cadaver mandible with all natural teeth after cleaning of all soft tissues.

Figure 2 Human cadaver mandible following the extraction of all teeth.

Eighty-four titanium screwed-type Neoss™ implants (Neoss AB, Mölnlycke, Sweden) were used for this study. The diameter and length of the implants used in this study were 4.0 and 11 mm, respectively. The implant has a "biomodal" surface presenting a coarse level of surface roughness. The implant has thread-cutting and thread-forming features to facilitate firm stability in all bone qualities. The implant is "double threaded" and is designed with a positive tolerance to achieve compression and increase stability in poor bone quality.

All implants were inserted according to the manufacturer's instructions. The application of all implants was carried out by one prosthodontist for standardization. Round burs, 2.2, 3.0, and 3.4 mm–diameter twist drills were used for each implant socket preparation. All implants were placed using an implant inserter (Neoss AB) with an OsseoSet™ motor (Nobel Biocare AB, Göteborg, Sweden). The implants were immediately inserted into the fresh extraction sockets of each tooth, meaning each mandible received 14 implants.

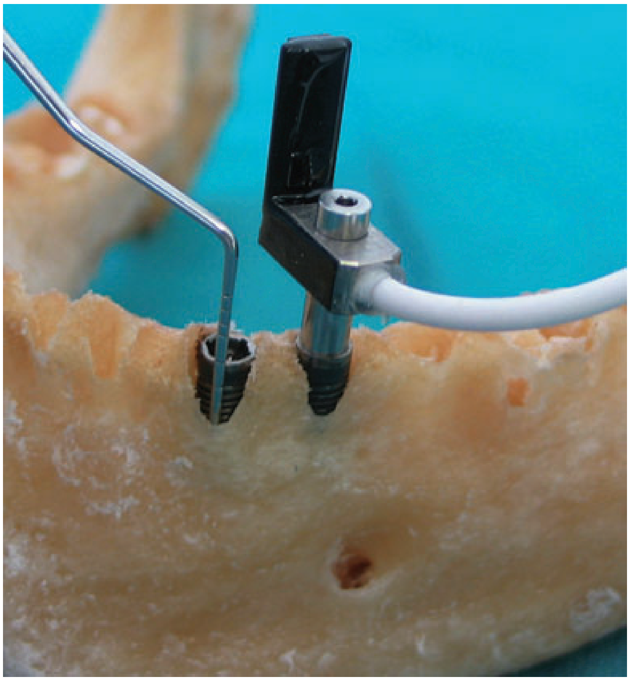

Figure 3 Peri-implant vertical bone defect measurement and resonance frequency measurement of the implant immediately after placement.

Experimental Parameters

Insertion Torque Measurements. The final insertion torque value of each implant was recorded with the OsseoSet motor, which was developed to insert the implant into the bone socket with a well-controlled insertion torque. It can only apply limited amount of torque in order to avoid mechanical overload of the equipment or bone tissue. The final insertion torque values of the implants were recorded in 20, 25, 30, 32, 35, 40, 45, and 50 Ncm.

Peri-Implant Bone Defects. The vertical defect depths from the implant/abutment junction to the first bone–implant contact at four sites (mesial, buccal, distal, lingual) were measured using a standardized Michigan O periodontal probe with Williams markings (Hu-Friedy, Chicago, IL, USA) after implant placement (Figure 3). Then, the average of the four values was determined for each implant. Special care was given to strict parallelism between the probe and the long axis of the implant. Each implant was placed into the socket with five different vertical defect depths, which were 1 ± 0.1, 2 ± 0.2, 3 ± 0.2, 4 ± 0.3, and 5 ± 0.3 mm. Therefore, each implant provided five different insertion torque and ISQ values from one fresh extraction socket, thus a total of 420 insertion torque and 420 ISQ values were obtained from 84 implants.

Implant Stability Measurements. The RFA method by means of the Osstell™ instrument (Integration Diagnostics AB, Göteborg, Sweden) was used to determine the rigidity of the implant-bone continuum immediately after implant placement. This noninvasive vibration method includes the use of an L-shaped transducer designed as a simple offset cantilever beam. The transducer including two piezoceramic elements was screwed to each implant orthoradially with the upright part on the oral side (see Figure 3). RF values are recorded in a quantitative unit called ISQ on a scale from 1 to 100. ISQ values are derived from the stiffness (N/µm) of the implant/bone system and the calibration parameters of the transducer. A high ISQ value indicates high stability, whereas a low value indicates a low implant stability.

Statistical Analysis

SPSS statistical software (SPSS, Inc., Chicago, IL, USA) was used for all statistical analyses. The means of insertion torque and ISQ values from five different peri-implant vertical bone defect depths were compared by Mann-Whitney test. Spearman test was used to explore the correlation between insertion torque and implant

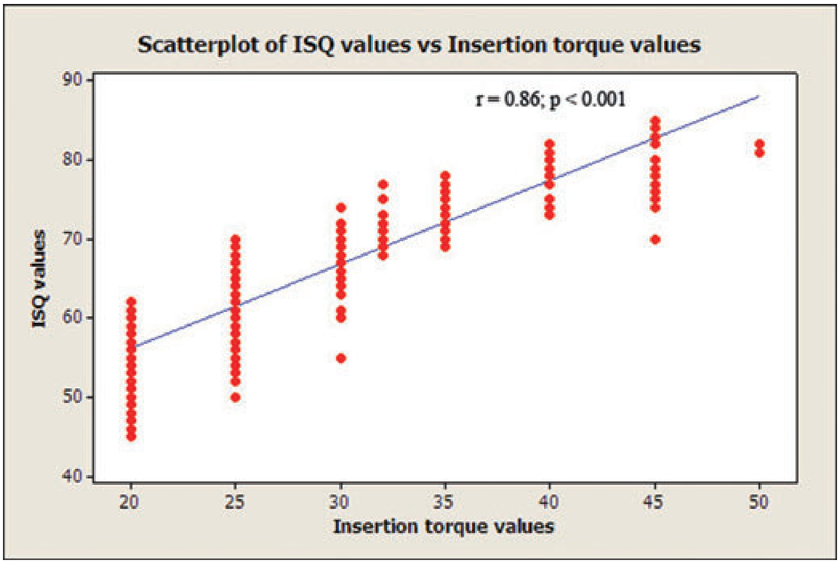

Figure 4 For 420 insertion torque and implant stability quotient (ISQ) values from all 84 implants, correlation between Ncm and ISQ values.

stability values at implant placement. Differences were considered significant when p values less than .05 were observed.

RESULTS

A total of 84 implants were inserted into six human cadaver mandibles for this study. The means of 420 insertion torque and RFA values from all 84 implants were 28.9 ± 7 Ncm and 65.6 ± 9 ISQ, respectively, which indicated a statistically significant correlation ($r = 0.86$; $p < .001$) (Figure 4).

When the peri-implant vertical bone defect depths were increased in each millimeter, the mean insertion torque and ISQ values significantly decreased, and the statistical differences between groups were given in Figures 5 and 6.

The implant positions have been considered as six anterior sites (central, lateral, and canine positions), and eight posterior sites (premolar and molar positions) for each mandible. When compared to the posterior region of the mandibles, higher insertion torque and ISQ values were observed in the anterior region for each millimeter ($p < .001$) (Table 1).

DISCUSSION

The present study indicated a linear relation between the depth of the peri-implant defects and ISQ values. This demonstrates that the technique is sensitive to detect marginal bone defects at implants placed in fresh extraction sockets. A decrease of about 2.7 ISQ/mm was seen, which corresponds well to the information obtained from the manufacturer. According to them (Osstell AB, Göteborg, Sweden), a change of about 3 ISQ/mm should be expected if implants are placed in the same bone density. The present cadaver study also showed a linear relation between insertion torque and depth of the marginal bone defects, which is more difficult to explain. However, the most likely explanation is the design of the Neoss implant, which has a positive tolerance and thus behaves as a tapered implant. Because of the increased

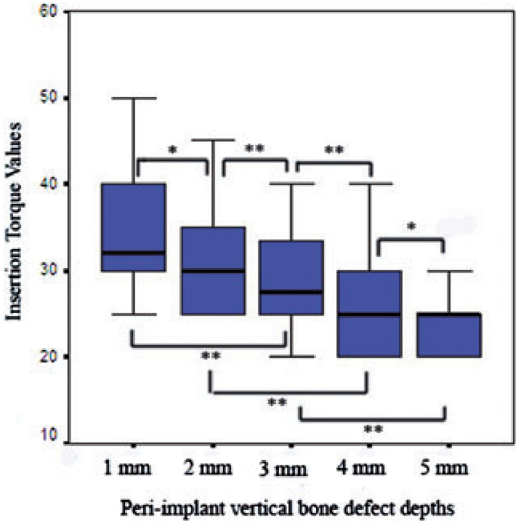

Figure 5 Mean insertion torque values and statistical differences when peri-implant vertical bone defect depths were increased (*$p < .05$; **$p < .001$).

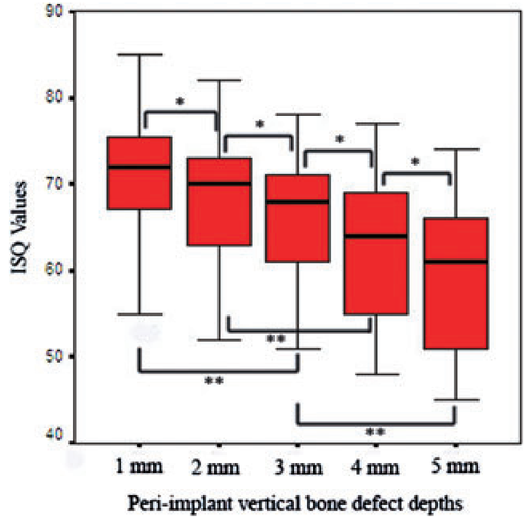

Figure 6 Mean implant stability quotient (ISQ) values and statistical differences when peri-implant vertical bone defect depths were increased (**p* < .05; ***p* < .001).

diameter of the implant from apical to coronal direction, an increased resistance is experienced during insertion.[17] A graph displaying insertion torque against time shows therefore a continuous increase of insertion torque.[18] Consequently, implants in shallow defects are placed with a greater proportion of the body in bone than implants placed in deeper defects and will show insertion torque values.

The present study also showed higher ISQ and insertion torque values in anterior than in posterior sites. A previous clinical study using parallel-walled implants showed no differences between posterior and anterior sites neither in the mandible nor in the maxilla.[12] However, they used wider implants in posterior regions which per se showed firmer stability than narrower implants, which could have influenced the mean values for posterior sites. In this study, implants were placed in fresh extraction sockets, and the lower values for the posterior sites may reflect differences of the socket sizes and the possibility to engage marginal cortical bone.

Primary implant stability, which is mainly associated with surgical techniques used, bone quality and quantity, and implant design, has a vital role in successful osseointegration.[19,20] Maintenance of low implant micromovement, especially in early healing periods, presents importance in promotion of direct bone ingrowth to implant surface.[21] Therefore, achievement of optimum primary implant stability during surgical placement is principal. Insertion torque, ISQ, and periotest values are widely used for primary implant stability measurements.[22,23] However, periotest values are not sensitive enough to provide sufficient information about bone-implant interface,[24] and recent studies confirmed the reliability of ISQ values in implant stability.[3] With a two-stage surgical technique, good and predictable outcomes of dental implants have been reported,[25] and recent studies regarding immediate/early loading protocols have also shown encouraging outcomes.[7,26,27] The latest challenge with dental implants is the immediate/early loading protocols for implants immediately placed into fresh extraction sockets, which has been preferred by some clinicians to achieve more esthetic outcomes.[4,28] However, limiting micromovement to certain levels is vital in achieving osseointegration especially when peri-implant bone interface is subjected to mechano-biologic stimulation by immediate/early loading protocols,[2,4,28] and in some cases, this may cause demineralization of the bone-implant interface, and eventually implant failure.[29] Therefore, when immediate/early loading is taken into consideration for implants immediately placed into fresh extraction sockets, both accuracy in predicting initial implant stability and monitoring of implants during healing are more crucial. The present study

TABLE 1 Mean Implant Stability Quotient (ISQ) and Insertion Torque Values (Ncm) According to the Implant Regions

	Peri-Implant Vertical Bone Defect Depths (mm)									
	1		2		3		4		5	
	ISQ	Ncm	ISQ	Ncm	ISQ	Ncm	ISQ	Ncm	ISQ	Ncm
Anterior region	76.2 ± 5	40.7 ± 7	73.9 ± 5	36.9 ± 6	71.1 ± 5	32.4 ± 5	67.9 ± 6	29.5 ± 4	65.4 ± 6	26.9 ± 4
Posterior region	66.8 ± 6	30.2 ± 4	64.6 ± 7	28.3 ± 4	62.3 ± 7	25.5 ± 4	58.9 ± 7	22.5 ± 3	55.9 ± 7	21.6 ± 3

When compared to the posterior region, higher ISQ and insertion torque values were found in the anterior region ($p < 0.001$) for each millimeter.

indicated that firm initial stability was achieved for all implants, because differences in vertical defect height could explain the differences in ISQ values. A difference of about 10 ISQ was observed between posterior and anterior sites, which is explained by differences of bone density because of the different sizes of the extraction sockets. It may be advisable to use wide implants in posterior regions in order to compensate for defect size and engage as much cortical bone as possible.

So far, only few studies have involved correlations between insertion torque and ISQ values, and peri-implant vertical bone defects and ISQ values with different types of implants.[30–33] Lachmann and colleagues[30] compared the performance of damping capacity assessment to RFA in the assessment of peri-implant bone loss in an in vitro study. Brånemark® and Frialit 2® implants were polymerized into acrylic blocks, and then the acrylic material around the implants representing peri-implant bone loss was removed in millimeter increments to the same extent on all four implants in each of the resin blocks. They have concluded that the Periotest® and Osstell instruments are both suitable to detect a decrease in implant stability as indicated by peri-implant bone loss. While measurement accuracy shows on a clinical level only minor differences between both methods, the RFA may detect bone loss somewhat earlier because the corresponding thresholds to define discrimination in millimeter increments of bone loss are lower.

Sennerby and colleagues[31] aimed to evaluate bone tissue and associated implant stability alterations that occurred during induction and resolution of peri-implantitis using RFA, radiography, and histology. Twenty-four implants were placed in the mandibles of four dogs, and experimental peri-implantitis was induced for 3 months. Then, the animals were treated with antibiotics and surgical therapy and were followed for another 6 months. The RF values at all implant sites markedly decreased during the phase of ligature-induced peri-implantitis, while those values increased during the healing phase, meaning a linear relationship between marginal bone level and RF value.

One of the aims of the clinical study by Turkyilmaz and colleagues[32] was to evaluate possible correlations between bone density, insertion torque, and RF values. Their study included 85 patients treated with 158 Brånemark System TiUnite™ Mk III implants, but RFA measurements were performed for only 70 implants. The average bone density, insertion torque, and RFA values were 849 ± 240 HU, 40.9 ± 6 Ncm, and 73.2 ± 6 ISQ for 70 implants, respectively, which indicated significant correlations between the bone density and insertion torque values, bone density and RFA values, and insertion torque and RFA values. They also reported higher insertion torque and ISQ values for the implants placed in the anterior regions, which is confirmed by the present study. This finding can be explained by higher bone density in the interior region of the mandibles. Alsaadi and colleagues[33] also studied the correlations between subjective bone quality assessment and implant stability. Their study included a total of 761 Brånemark TiUnite implants placed in 298 patients, but RFA measurements using Osstell Mentor instrument were taken from only 136 implants. They found a significant correlation between placement torque and RFA values for these 136 implants.

The results of this study demonstrated a linear relationship between peri-implant vertical bone defect depth and RFA value. It is proposed that the RFA method is sensitive to detect changes of the marginal bone level and may be used to monitor healing of peri-implant bone defects.

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